Excel HSC

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PHYSICS

Your Step by Step Guide to HSC Success

Revised in 2004
for the updated course

HSC

NEVILLE WARREN

Core + 3 Options

Excel
HSC
PHYSICS

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nts
e has been taken in the preparation of this study guide, but please check with your teacher or the NSW Board of Studies
the exact requirements of the course you are studying as they can change from year to year.

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Preface

Excel HSC Physics has been written to satisfy the Higher School Certificate course for the New South Wales 2 Unit Physics syllabus implemented in 2000 for initial examination in 2001, as part of the *New HSC*.

SYLLABUS AIMS

The syllabus aims to provide students with experiences that will contribute to their development in the areas of:

- *Knowledge and Understanding*
- *Skills*
- *Values and attitudes.*

Knowledge and Understanding

This encompasses:

- the history of physics
- the nature and practice of physics
- applications and uses of physics
- the implications of physics for society and the environment
- current issues, research and developments in physics
- kinematics and dynamics
- energy
- waves
- fields
- matter.

Skills

Practical experiences are designed to develop student competence in:

- planning investigations
- conducting investigations
- understanding and communicating information
- developing scientific thinking and problem solving techniques
- working individually and in teams.

A minimum of 80 hours of practical work is required (including 35 hours in the HSC course).

Values and attitudes

Students are encouraged to think positively about themselves, others, physics and the environment and learning as a life-long process.

COURSE STRUCTURE

The course is divided into a *Preliminary Course* (of 120 hours duration) and an *HSC Course* (also 120 hours). Each course is divided into *modules*.

The *Preliminary Course* consists of the following compulsory *core* modules:

- *The World Communicates*
- *Electrical Energy in the Home*
- *Moving About*
- *The Cosmic Engine.*

The *HSC Course* consists of three core and five option modules (of which *three* are provided in this book). Students are to complete all of the core modules and *one* option module.

The *Core* topics (90 hours) are:

- *Space*
- *Motors and Generators*
- *From Ideas to Implementation.*

Option topics (30 hours) include:

- *Medical Science*
- *Astrophysics*
- *Quanta to Quarks*

I wish to thank my editor May McCool and my publisher Vivienne Petris Joannou for their assistance in bringing this book to fruition.

I dedicate this book to Robyn, Kylie and Michelle.

N.G. Warren June 2000

This edition contains all amendments resulting from syllabus changes implemented by the Board of Studies in November 2002. Web sites have been updated and additional ones added.

N.G. Warren August 2003

How to Use This Book

The structure of this book is indicated by the various heading styles. You should read what each one means and this will assist you in using the book in the most efficient manner.

SECTION

Each chapter is divided into *sections*. Each section corresponds to a syllabus organiser—what I refer to as a **Big Idea**. This allows the chapter to be divided into suitable size 'chunks'.

OUTCOMES:

Each chapter begins with a list of student *outcomes*. These are taken directly from the *NSW Board of Studies Syllabus*. In your study, you should continually refer to these lists to ascertain whether you have completed and understood all of the syllabus requirements.

Students learn to:

These outcomes refer to knowledge and understanding—the *content* of the course.

Students:

In addition to the knowledge outcomes, the outcomes in *italics* represent the *practical skills* required by the syllabus. These are a mandatory part of the course. Students must ensure that they engage actively in practical experiences at school. These include:

- hands-on laboratory experiments using digital technology
- research using a variety of sources such as print, the Internet and digital technologies
- computer simulations
- using and analysing secondary data.

CONTEXTUAL OUTLINE

At the beginning of Section One of each chapter there is a *contextual outline*. This sets the context in which the module should be considered.

Important concepts *and formulas are put inside boxes to highlight them.*

EXAMPLE

Each chapter also contains sample questions used to reinforce particular concepts in the text. Check as you go through the chapter to see that you understand them. If not, read the relevant paragraphs again.

EXTENSION

Optional extension material is provided. This can be omitted if desired. It is used to expand on some of the concepts to improve understanding.

A line indicates the completion of this extension work as follows:

1st Investigation

Various examples of first-hand investigations are provided to assist you in mastering the practical skills. They cannot and should not replace the work you do in class.

In addition to actual 'hands-on' experiments there are a number of web sites indicated[1] where 'virtual experiments' and simulations can be conducted. If you have access to a computer it would be a good idea to try many of these, as they are a good way of consolidating the ideas and skills of each module. *(NB: These sites were operational at the time of writing this text. Because of the dynamic nature of the World Wide Web, it cannot be guaranteed that they will not be deleted or changed.)*

---

[1] They are indicated as a footnote like this one. Type in the web address (URL) on your browser and it will take you to the required site.

Some excellent Virtual Laboratory sites are:

http://physicsweb.org/TIPTOP/VLAB/

http://www.walter-fendt.de/ph11e/

http://www.phy.ntnu.edu.tw/java/index.html#

http://webphysics.ph.msstate.edu/javamirror/

http://www.explorescience.com/

http://jersey.uoregon.edu/vlab

Each of these *Virtual Laboratories* contains a number of *Java Applets* (that is, small applications that can be run within another program) for a range of topics. All you need to do is type the URL in your browser to bring up a list of simulations. Well worth visiting although the quality of the simulations vary considerably both between sites and within the same site. The 'best' of these simulations are placed in the text as a footnote where relevant.

Other useful non-interactive web sites are also indicated in the text as footnotes.

Secondary Source Investigation

Various examples of information that can be found from secondary sources are shown. However, you are encouraged to look for different sources yourselves. They are examples only of material that you might find.

Some suitable web sites are indicated as footnotes in the text to assist you in your searches. Two excellent sites that explain the workings of many devices are found at http://www.howstuffworks.com and the hyperphysics site from the University of Georgia at http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

An excellent general resource is the *Encyclopaedia Britannica*. It can now be found on the World Wide Web at http://www.britannica.com. Remember to use books as well as the web in your investigations!

SUMMARY

At the end of each chapter there is a summary of the key points and a list of key words. You should read these and check that you can elaborate on each one of them.

QUESTIONS ON ...

Lastly there is a series of questions to assist in revising and testing your knowledge and understanding of each section. A test at the end of each chapter examines your knowledge and understanding of the entire topic. Sample answers and worked solutions are provided to these questions. Any student who can correctly answer these questions can feel confident in their knowledge and understanding of the topic content. Two practice examinations with worked solutions are also included covering all the topics of this book.

GENERAL WEB SITES

In addition to the web sites mentioned in the previous sections, there are a number of other very useful sites, some of which were prepared for the introduction of the *New HSC*. These include: http://science.uniserve.edu.au/school/curric/stage6/phys/ a site prepared by the University of Sydney with links to sites for all of the Preliminary and HSC topics.

http://www.phys.unsw.edu.au/hsc/ is the University of NSW's equivalent site.

http://www.newhsc.schools.nsw.edu.au is a site prepared to assist teachers with the implementation of the *New HSC* but could prove useful to students. It has sample teaching programs with links to a range of web sites suitable for each topic.

Two additional sites that bring together a range of excellent physics resources are the *PhysicsWeb* at http://physicsweb.org and the hyperphysics series at http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html Well worth a visit for the keen student although the level of information may be too high for some.

No guarantee can be given that these sites will not be deleted or moved in the future.

EXAM PREPARATION

To be fully prepared for the examination you must ensure that you follow an effective program of study and revision.

1 The *'secret of success'* in the HSC is consistency in study and revision. Study regularly—15 minutes of study each weeknight is far better than 2 hours once a week. Constant review also ensures that you keep up to date with the work in class. In physics, as in many other subjects, you cannot understand a concept unless you have mastered the earlier concepts and ideas. Each night, read through the work from that day's lesson and make brief notes of important concepts, terms, equations... Some students prefer to do this using mind maps, others use different coloured pens. Use what works best for you! Check that you understand the work. If not, refer to the relevant section in this book. Remember to also use your teacher to help you clarify your understanding.

2 Regularly check the module *outcomes* to ensure you have covered the required material. Remember the practical skills outcomes.

3 Success is also dependent on you being familiar with the HSC-style questions. While this may prove more difficult in the first few years of the *New HSC*, nevertheless many of the questions will be similar to those of previous years. Copies of past papers can be downloaded from the *NSW Board of Studies* web site www.boardofstudies.nsw.edu.au. Practise answering these questions. See also *Excel HSC Physics Sample Examinations* by this author for a number of sample papers based on the 2001 Specimen Paper.

4 Using the Board of Studies web site you can obtain copies of *Physics Examination Reports*. From these you can find the common mistakes and misunderstandings of students. Learn from these!

5 It needs to be stressed that in addition to the *Knowledge and Understanding* outcomes the examination will test *Skills*. You must actively participate in practical lessons and learn the required skills. Ensure that you complete the practical work and hand it in for assessment when required to do so.

Chapter One

Space

SECTION 1: GRAVITY

BIG IDEA:

The Earth has a gravitational field that exerts a force on objects both on it and around it.

OUTCOMES:

Students learn to:

1 Define weight as the force on an object due to a gravitational field.

2 Explain that a change in gravitational potential energy is related to work done.

3 Define gravitational potential energy as the work done to move an object from a very large distance away to a point in a gravitational field $E_p = -G\frac{m_1 m_2}{r}$

Students:

1 *Perform an investigation, and gather information to determine a value for acceleration due to gravity using pendulum motion, or computer assisted technology and identify reasons for possible variations from the value* $9.8\ m.s^{-2}$

2 *Gather secondary information to predict the value of acceleration due to gravity on other planets.*

3 *Analyse information using the expression* $\vec{F} = m\vec{g}$ *to determine the weight force for a body on Earth and for the same body on other planets.*

CONTEXTUAL OUTLINE

On 4 October 1957 the world stood in awe as the first artificial satellite, *Sputnik 1*, was launched by the Soviet Union. Four months later on 31 January 1958 the United States launched its first satellite.

Manned space flight began on 12 April 1961, when the Russian cosmonaut Yuri Gagarin blasted into orbit. Although his flight lasted only 108 minutes it represented an important milestone in humankind's progress.

Concerns about the ability of the Earth to maintain its human population in the face of pollution, global warming and the ever-increasing number of inhabitants have some people speculating about the prospect of humans living in space in giant *space stations*.

This topic looks at the physics behind human exploration of space and the technology required, including putting an object into orbit, maintaining the orbit and allowing for safe return to Earth. It concludes with a look at Einstein's *theory of special relativity* and its implications for deep space travel in terms of our understanding of space and time.

We begin this topic with a look at gravity—a force integral to the study of space.

NEWTON'S LAW OF UNIVERSAL GRAVITATION

As we saw in the Preliminary Course *The Cosmic Engine*, gravity is a force that acts between any two (or more) objects in the universe. Isaac Newton showed that:

> ***The* gravitational force of attraction** *between any two objects of mass m_1 and m_2 whose centres are separated by a distance r is proportional to the product of their masses and inversely proportional to the square of their separation.*

Mathematically this is written as:

$$\boxed{F = G\frac{m_1 m_2}{r^2}}$$

where G is the *universal gravitational constant*. Its value is 6.67×10^{-11} N.m^2.kg^{-2}.

THE GRAVITATIONAL FIELD

Surrounding any object with mass is a *gravitational field*. This is a 'region of influence' in which another mass would experience a force due to the presence of the first mass.

We saw in *The Cosmic Engine* that the gravitational field, g, of a mass m at a distance r from the mass is given by:

$$\boxed{g = \frac{Gm}{r^2}}$$

This shows that the gravitational field strength is determined by the mass of the object producing the field and the distance from it. The gravitational field of the Earth decreases as the square of the distance from the centre of mass.

The direction of the Earth's field is towards the centre of the Earth (locally we say that the field acts 'down').

EXAMPLE 1

Determine the gravitational field strength (g) on t surface of the Earth given that the average radiu the Earth (R) is 6380 km and the mass of the Ea (M_E) is 5.983×10^{24} kg.

SOLUTION

$$g = \frac{GM_E}{R^2}$$

$$= \frac{6.67\times10^{-11}\times5.983\times10^{24}}{(6380\times10^3)^2}\text{ N.kg}^{-1}$$

$$= 9.804\text{ N.kg}^{-1}\text{ (or m.s}^{-2}\text{)}$$

This value varies slightly at different points on t Earth due to the variation in radius (the Earth is no perfect sphere).

EXAMPLE 2

Determine the acceleration due to gravity (g) at a altitude of 150 km above the surface of the Earth.

SOLUTION

$$g = \frac{GM_E}{R^2}$$

$$= \frac{6.67\times10^{-11}\times5.983\times10^{24}}{(6380\times10^3+150\times10^3)^2}\text{ N.kg}^{-1}$$

$$= 9.36\text{ N.kg}^{-1}\text{ (or m.s}^{-2}\text{)}$$

It is obvious that gravity decreases with distan from the Earth.

EXAMPLE 3

Determine the acceleration due to gravity on th surface of the moon given that the mass of the moo $M_m = 7.36 \times 10^{22}$ kg and its radius R is 1740 km.

SOLUTION

$$g = \frac{GM_m}{R^2}$$

$$= \frac{6.67\times10^{-11}\times7.36\times10^{22}}{(1740\times10^3)^2}\text{ m.s}^{-2}$$

$$= 1.62\text{ m.s}^{-2}$$

Secondary Source Investigation

Acceleration Due to Gravity on Other Planets

Table 1.1 shows the masses and radii of the planets expressed as a multiple of the mass and radius of the Earth respectively. The approximate acceleration due to gravity on these planets is shown and has been calculated as follows:

We have $g = \dfrac{GM}{r^2}$ and so:

$$\frac{g_{planet}}{g_{earth}} = \frac{\dfrac{GM_{planet}}{r^2_{planet}}}{\dfrac{GM_{earth}}{r^2_{earth}}}$$

$$= \left(\frac{M_{planet}}{M_{earth}}\right)\times\left(\frac{r_{earth}}{r_{planet}}\right)^2$$

Hence:

$$g_{planet} = \left(\frac{M_{planet}}{M_{earth}}\right)\times\left(\frac{r_{earth}}{r_{planet}}\right)^2 \times g_{earth}$$

Table 1.1 Approximate acceleration due to gravity of the planets

Planet	Mass (M_E)	Radius (r_E)	g(m.s^{-2})
Mercury	0.06	0.38	3.7
Venus	0.82	0.95	8.9
Earth	1.00	1.00	9.8
Mars	0.11	0.53	3.8
Jupiter	318	11.2	25..5
Saturn	95	9.4	10.8
Uranus	14.5	3.98	8.8
Neptune	17.2	3.88	11.8
Pluto	0.002	0.18	0.6

WEIGHT

Weight is a force. In particular:

> *The* **weight** *of an object is the force of gravity acting on it.*

Mathematically:

$$\boxed{\vec{W} = m\vec{g}}$$

where $\vec{W}$ is the weight in newtons (N), m is the mass in kilograms (kg) and $\vec{g}$ can be either:

1 the *acceleration due to gravity* (= 9.8 m.s^{-2} at the Earth's surface); or
2 the *gravitational field strength* (= 9.8 N.kg^{-1} at the Earth's surface).

Extension

Weighing the Earth

Once G was known, it was possible to calculate the mass of the Earth. It follows that the force of attraction of a body on the Earth's surface given by the law of universal gravitation must also equal the weight of the object. Hence:

$$mg = G\frac{mM}{r^2}$$

$$M = \frac{r^2 g}{G}$$

where M is the Earth's mass, r is its radius and g is the acceleration due to gravity.

All quantities on the right-hand side of the equation are known so M can be calculated. It is equal to 5.983×10^{24} kg.

EXAMPLE 4

What is the weight of an object on the moon if its weight on the Earth is 1500 N?

SOLUTION

The mass of the object is constant and is independent of its location. Weight, on the other hand varies with location.

The mass of the object is found from:

$$W = mg$$
$$m = \frac{W}{g}$$
$$= \frac{1500}{9.8}\text{kg}$$
$$= 153.1\text{ kg}$$

Hence the weight on the moon (where g = 1.62 m.s^{-2} as calculated in the previous example) is found from:

$$W = mg$$
$$= 153.1 \times 1.62\text{ N}$$
$$= 248\text{ N}$$

1st Investigation: Finding *g* from a Pendulum[1]

A student performed the following experiment to determine g.

Theory: The period of oscillation (T) of a simple pendulum of length l is given by the formula $T = 2\pi\sqrt{\frac{l}{g}}$ where g is the acceleration due to gravity. (NB: This is true for angles of up to ~10° from the vertical.)

Aim: To find the value of g by measuring the period of a pendulum of known length.

Method: A mass was tied to the end of a piece string and attached to a horizontal support as sho in Figure 1.1.

The length of the pendulum was measured from point of support to the centre of the mass. The m was pulled to the side so that the string made angle of <10° to the vertical and was released. T time for 10 oscillations (complete to and fro motio was recorded. The length was varied and the proce was repeated. The results are recorded in Table with the calculated values of g also shown.

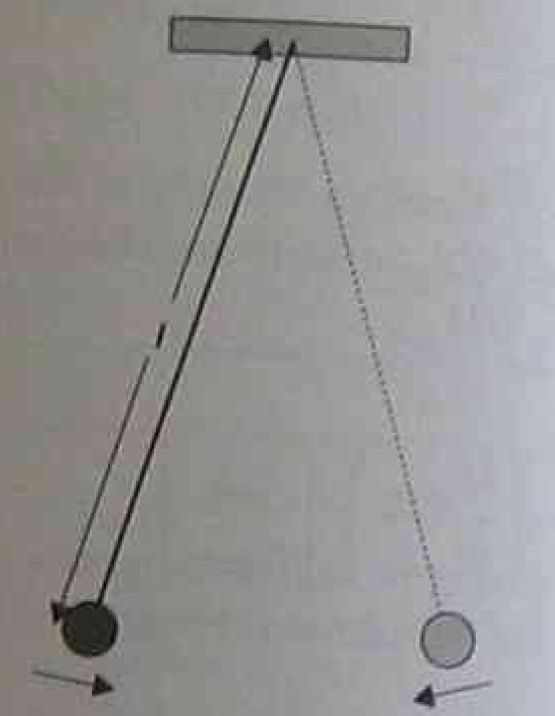

Figure 1. 1 Simple pendulum

Results:

Table 1. 2 Pendulum data

Length (l) (± 0.005 m)	Time for 10 oscillations (s)	Period T (s)	g (m.s^{-2})
1.00	20.08	2.008	9.79
0.80	17.90	1.790	9.86
0.60	15.64	1.564	9.68
0.40	12.58	1.258	9.98

The average value of g is found to be 9.83 m.s^{-2}

Conclusion: The acceleration due to gravity found using a simple pendulum to be $g = 9.8 \pm 0$ m.s^{-2}. (This includes all values between 9.6 10.0 m.s^{-2})

---

[1] http://www.phy.ntnu.edu.tw/java/pendulum30/pendulum Simple pendulum simulation that allows the above experiment to be done as a virtual experiment. To stop the swing, place the cursor on the circle where the pendulum is attached, depress the left mouse button and hold it down.

WORK

When a force is applied to an object and the object moves, we say *work* has been done on the object.

Work *(W) is the product of the force (F) and the displacement (s) in the direction of the force.*

$$W = Fs$$

Work is only done in the scientific sense when the point of application of the force moves.

When work is done on an object there is a corresponding change in the *kinetic* and/or *potential* energy of the object.

GRAVITATIONAL POTENTIAL ENERGY

As we lift an object from the ground to a height above the ground we do work on it. This work is stored in the object as *gravitational potential energy*. For an object of mass m at a height h above the Earth's surface the gravitational potential energy E_p is given by:

$$E_p = mgh$$

This equation is valid only when the object is near the Earth's surface. For objects such as satellites, which are high above the Earth's surface, an alternative expression is used to calculate the gravitational potential energy.

The **gravitational potential energy** *is a measure of the work done in moving an object from infinity to a point in the field.*

The general expression for the gravitational potential energy of an object of mass m at a distance r *from the centre of the Earth* (or other planet) is given by:

$$E_p = -G\frac{mM_E}{r}$$

where M_E is the mass of the Earth (or other planet). Although we can define the zero of potential to be wherever we like, it is mathematically convenient to *define* the zero of potential energy at an infinite distance from the centre of the Earth!

It follows that to move an object away from the Earth we must do work on it. If, after this work is done the potential energy is zero (by definition) then it must be negative when near the Earth. Such a system is called a *bound* system.

The *change* in the potential energy of a body as it moves from one point to another is the same, regardless of the choice of reference level and it is only the *difference* in potential energy that is significant.

Change in Gravitational Potential Energy Near the Earth

The change in gravitational potential energy of a mass m_1 when its distance from the Earth's centre increases from r_A to r_B is given by:

$$\Delta E_p = -G\frac{mM_E}{r_B} - \left(-G\frac{mM_E}{r_A}\right)$$
$$= GmM_E\left(\frac{1}{r_A} - \frac{1}{r_B}\right)$$

EXAMPLE 5

What is the change in gravitational potential energy for a satellite of mass 100 kg raised to a height of 300 km above the Earth's surface?

SOLUTION

$$\Delta E_p = GmM_E\left(\frac{1}{6380\times10^3} - \frac{1}{(6380+300)\times10^3}\right)$$
$$= 6.67\times10^{-11}\times100\times5.983\times10^{24}\times7\times10^{-9}\text{ J}$$
$$= 2.81\times10^8\text{ J}$$

(This compares with 2.90 x 10^8 J found from the more familiar potential energy equation $E_p = mgh$.)

The gravitational attraction of the Earth is the major obstacle to space flight. In the next section we will look at how gravity can be overcome so that craft can leave the Earth and go into orbit.

SECTION 2: SPACE LAUNCH AND RETURN

BIG IDEA:

Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth.

OUTCOMES:

Students learn to:

1 Describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components.

2 Describe Galileo's analysis of projectile motion.

3 Explain the concept of escape velocity in terms of the:

- gravitational constant
- mass and radius of the planet.

4 Outline Newton's concept of escape velocity.

5 Analyse the forces involved in uniform circular motion for a range of objects, including satellites orbiting the Earth.

6 Identify why the term 'g-forces' is used to explain the forces acting on an astronaut during launch.

7 Discuss the effect of the Earth's orbital motion and its rotational motion on the launch of a rocket.

8 Analyse the changing acceleration of a rocket during launch in terms of the:

- Law of Conservation of Momentum
- forces experienced by astronauts.

9 Compare qualitatively low Earth and geostationary orbits.

10 Define the term orbital velocity and the quantitative and qualitative relationship between orbital velocity, the gravitational constant, the mass of the satellite and the radius of the orbit using Kepler's Law of Periods.

11 Account for the orbital decay of satellites in low Earth orbit.

12 Discuss issues associated with safe re-entry into the Earth's atmosphere and landing on the Earth's surface.

13 Identify that there is an optimum angle for safe re-entry for a manned spacecraft into the Earth's atmosphere and the consequences of failing to achieve this angle.

Students:

1 Solve problems and analyse information to calculate the actual velocity of a projectile from its horizontal and vertical components using:

$v = u + at$

$v_x = u_x$

$v_y^2 = u_y^2 + 2a_y\Delta y$

$\Delta y = u_y t + \frac{1}{2}a_y t^2$

2 *Perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range, time of flight of a projectile, for a range of situations by using simulations, data loggers and computer analysis.*

3 *Identify data sources, gather, analyse and present information on the contribution of one of the following to the development of space exploration: Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill or von Braun.*

4 *Solve problems and analyse information to calculate centripetal force acting on a satellite undergoing uniform circular motion about the Earth using* $F = \frac{mv^2}{r}$

5 *Solve problems and analyse information using* $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$

Physics Stage 6 Syllabus Outcomes © Board of Studies NSW, 1999 (Amended 2000, 2001, 2002, 2003)

PROJECTILE MOTION

Any object thrown through the air is a projectile. Examples include a golf ball after it has been hit with the club, artillery shells fired from guns, arrows fired from bows, cricket balls hit or thrown, footballs kicked or passed…

> *Any moving object that moves only under the force of gravity is a* **projectile**.

Although at first glance projectile motion appears quite complicated, it turns out that it can be analysed in terms of two simple motions studied already—*constant velocity* motion and *constant acceleration*.

Experimentally it is found that if two objects of the same or different mass are released from the same height and allowed to fall straight down, they reach the ground at the same time. (Galileo discovered this over two hundred years ago.) This neglects the effects of air resistance.

Similarly two objects, one falling straight down and the other projected horizontally from the same height, also reach the ground at the same time as indicated in Figure 1.2. This shows that *the horizontal motion has no effect on the vertical motion*—they are independent of each other.

The reason for this 'unexpected' result is that gravity is the only force acting on the objects and this always acts towards the centre of the Earth.

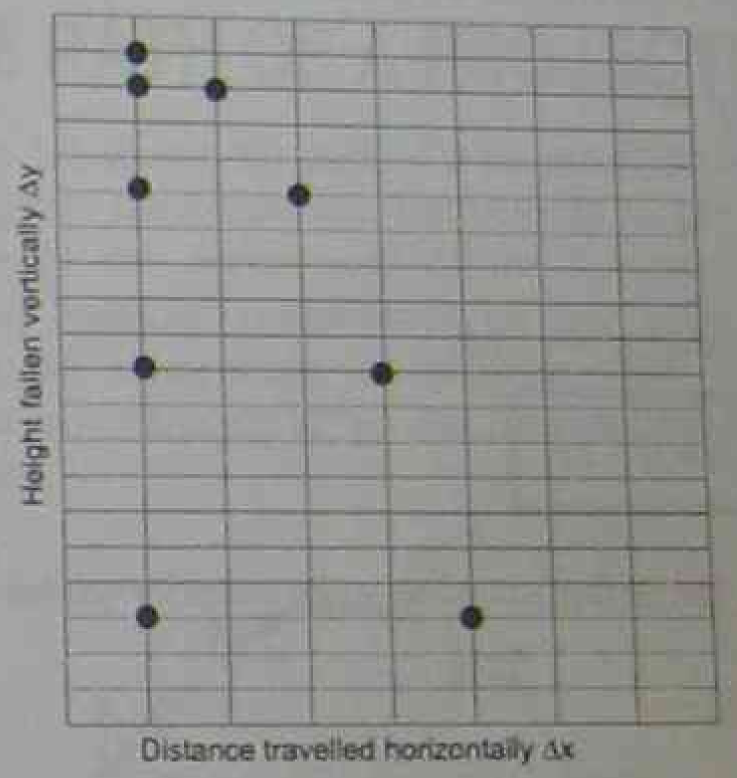

Figure 1. 2 Projectile motion. An object moving horizontally falls at the same rate as an object falling straight down.

> **Projectile motion** *can be analysed by realising that:*
>
> *1 the horizontal motion is* **constant velocity** *motion; and*
>
> *2 the vertical motion is* **constant acceleration** *(with acceleration of g).*

EQUATIONS OF UNIFORMLY ACCELERATED MOTION

Before we can investigate projectile motion further, we need to investigate the equations of uniformly accelerated motion.

Conventions

As we first saw in the Preliminary Topic *Moving About*, the following symbols are commonly used to represent the quantities given:

$\vec{v}$ – final velocity

$\vec{u}$ – initial velocity

$\vec{a}$ – acceleration

t – time

$\vec{s}$ – displacement

From our definition of acceleration and using the above conventions we have:

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$$
$$= \frac{\vec{v} - \vec{u}}{t}$$

Rearranging we find:

$$\boxed{\vec{v} = \vec{u} + \vec{a}t}$$

From the definition of average velocity we have:

$$\vec{v}_{av} = \frac{\vec{s}}{t}$$

So it follows that:

$$\vec{s} = \vec{v}_{av} \times t$$
$$= \left(\frac{\vec{v} + \vec{u}}{2}\right) \times t$$
$$= \left(\frac{\vec{u} + \vec{a}t + \vec{u}}{2}\right) \times t$$

Therefore:

$$\boxed{\vec{s} = \vec{u}t + \tfrac{1}{2}\vec{a}t^2}$$

Note that the statement $\vec{v}_{av} = \left(\frac{\vec{v} + \vec{u}}{2}\right)$ is true only for constant acceleration.

From the first equation, squaring both sides we find:

$$v^2 = u^2 + 2aut + a^2t^2$$
$$= u^2 + 2a(ut + \tfrac{1}{2}at^2)$$
$$= u^2 + 2as$$

Therefore:

$$\boxed{v^2 = u^2 + 2as}$$

Note that this last equation does not have vec signs. Although velocity is a vector, velocity squa is a scalar (since it is always positive). Also, product of acceleration and displacement is a scal

Problem Solving

In solving problems using the equations of moti the following steps should be employed:

1 Write down what data are known and wh needs to be found. (This is very helpful choosing which of the three equations to use.)

2 Take the initial direction of movement as bei positive.

3 All quantities whose direction is opposite to th of the initial velocity are negative.

4 Substitute the given data into the equation a solve. Add the correct unit to the answer.

EXAMPLE 6

An object starts from rest with an acceleration 5 m.s^{-2}. Find:

(a) the velocity and displacement after 10 s;

(b) the deceleration needed to bring the body to r in the next 5 s.

SOLUTION

(a) Data: $u = 0$ m.s^{-1}

$v = ?$ m.s^{-1}

$a = 5$ m.s^{-2}

$t = 10$ s

$s = ?$ m

$$v = u + at$$
$$= 0 + (5 \text{ x } 10)$$
$$= 50 \text{ m.s}^{-1}$$

$$s = ut + \tfrac{1}{2}at^2$$
$$= (0 \times 10) + (½ \times 5 \text{ x } 10^2) \text{ m}$$
$$= 250 \text{ m}$$

(b) Data: $v = 0$ when brought to rest

$u = 50$ m.s^{-1}

$a = ?$ m.s^{-2}

$t = 5$ s

$$v = u + at$$
$$0 = 50 + (a \times 5)$$
$$a = -10 \text{ m.s}^{-2}$$

The negative sign shows that the acceleration is in the opposite direction to the initial motion.

EXAMPLE 7

A body is projected vertically upwards with an initial velocity of 50 m.s^{-1}. Find:

(a) velocity after 2 s;

(b) maximum height it reaches;

(c) velocity with which it returns to Earth.

Note: The acceleration due to gravity always acts down and is of magnitude 9.8 m.s^{-2}.

SOLUTION

(a) Data: $u = 50$ m.s^{-1}

$v = ?$ m.s^{-1}

$t = 2$ s

$a = -9.8$ m.s^{-2}

$$v = u + at$$
$$= 50 + (-9.8 \times 2) \text{ m.s}^{-1}$$
$$= 50 - 19.6 \text{ m.s}^{-1}$$
$$= 30.4 \text{ m.s}^{-1}$$

(b) Data: $v = 0$ at maximum height

$a = -9.8$ m.s^{-2}

$u = 50$ m.s^{-1}

$s = ?$ m

$$v^2 = u^2 + 2as$$
$$0 = 50^2 + (2 \text{ x} -9.8 \text{ x } s)$$
$$19.6s = 2500$$
$$s = 127.6 \text{ m}$$

(c) Data: $s = 0$ when returns to Earth

$u = 50$ m.s^{-1}

$v = ?$

$a = -9.8$ m.s^{-2}

$$v^2 = u^2 + 2as$$
$$= 50^2 + (2 \text{ x} -9.8 \text{ x } 0) \text{ m.s}^{-1}$$
$$v = \pm\ 50 \text{ m.s}^{-1}$$

The only solution consistent with the data is $v = -50$ m.s^{-1}, since the direction of motion has to be opposite to the initial direction.

THE PATH OF A PROJECTILE

Figure 1.3 shows the path of a projectile thrown at an angle to the horizontal. The velocity at any point is simply the *vector sum* of the horizontal and vertical velocity components at that point. The horizontal component is constant; the vertical component changes at g, the acceleration due to gravity.

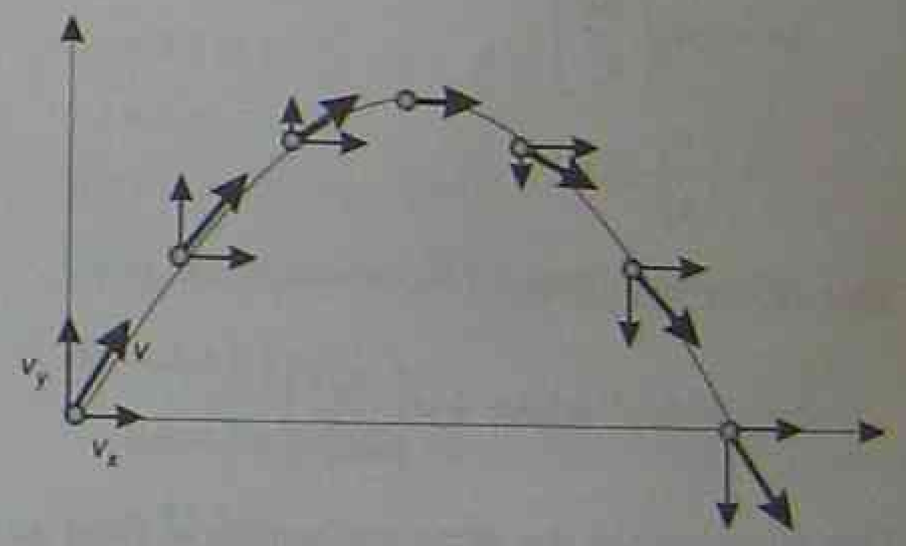

Figure 1. 3 The path of a projectile is simply the vector sum of its components

Trajectories

We are now in a position to be able to analyse projectile motion mathematically. Figure 1.4 represents a projectile thrown horizontally with speed v_x. Because of the independence of the vertical and horizontal components of the motion, *the vector sum of these motions describes the motion of the projectile*. Consequently:

1 *Horizontally*—constant velocity

that is, $\Delta x = u_x t$ (1)

2 *Vertically*—constant acceleration

that is, $\Delta y = \frac{1}{2} a_g t^2$ (2)

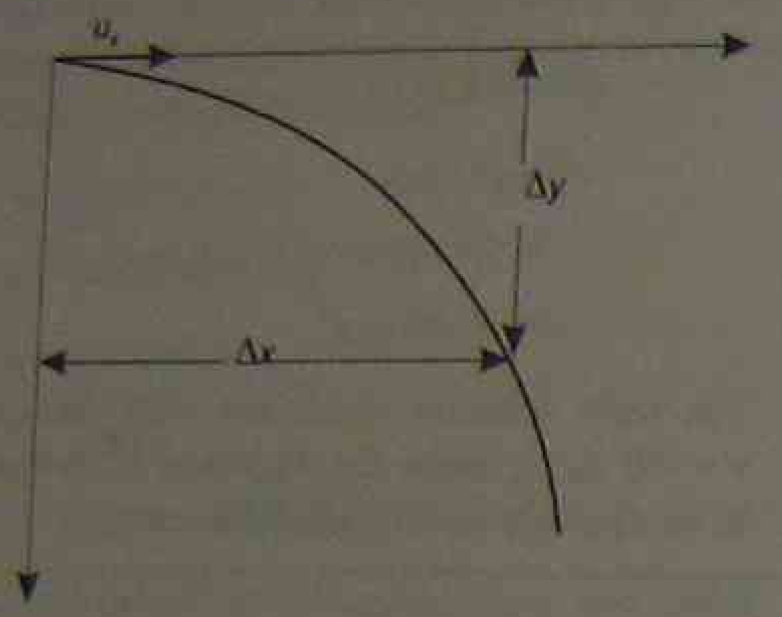

Figure 1. 4 The trajectory of a projectile fired horizontally

From equation (1) we get:

$$t = \frac{\Delta x}{u_x} \quad (3)$$

Combining equation (2) and (3) we get:

$$\Delta y = \tfrac{1}{2} a_g \left(\frac{\Delta x}{u_x} \right)^2$$

$$= \tfrac{1}{2} \frac{a_g}{u_x^2} (\Delta x)^2$$

This can be written as:

$$\Delta y = k(\Delta x)^2 \text{ where } k = \left(\frac{a_g}{2u_x^2} \right)$$

This equation has the same mathematical form as a *parabola*. It follows therefore that:

> *The path followed by a projectile—its* **trajectory**—*is a parabola.*

Air resistance means that in real life this is not fully correct. We will continue, however, for simplicity, to neglect air resistance in our analysis[2].

EXAMPLE 8

A search party travelling horizontally in a pla 50 m.s^{-1} approaches a group of lost hikers. purpose of the flight is to drop a supply of food specially designed package to the hikers wi using a parachute. If the plane cannot descend be a height of 100 m for safety reasons, what horizo distance in front of the hikers must the pilot rel the package to come as close as possible to the party?

SOLUTION:

The falling package is in effect a projectile. distance that the package must be released in fro the hikers is determined by the horizontal speed the package (and hence the plane), and the tim takes to drop the 100 m.

The latter is determined by considering the verti motion of the package, that is:

$$\Delta y = u_y t + \tfrac{1}{2} a_g t^2$$

$$100 = 0 + \tfrac{1}{2} 9.8 t^2$$

ie. $t = 4.5$ s

Hence the distance in front of the hikers which the package must be released is given

$$\Delta x = u_x t$$

$$= 50 \text{ x } 4.5 \text{ m}$$

$$= 225 \text{ m}$$

EXAMPLE 9

An object is projected at an angle of 30° to horizontal at a velocity of 50 m.s^{-1}. Taking acceleration due to gravity as 10 m.s^{-2}, calculate:

(a) the maximum height reached

(b) the range of the projectile.

SOLUTION:

(a) Rather than substitute into the maximum heig and range formulae we will start from fi principles, that is, because the horizontal vertical motions are independent, we c consider the motion as two components at ri angles to each other:

The vertical component of the velocity is given by:

$$u_y = u \sin \theta$$

$$= 50 \sin 30$$

$$= 25 \text{ m.s}^{-1}$$

At the top of its motion $v_y = 0$ and we also have:

$$u_y = 25 \text{ m.s}^{-1}$$

$$a_g = -10 \text{ m.s}^{-1}$$

$$\Delta y = ?$$

$$v_y^2 = u_y^2 + 2a_g \Delta y$$

$$0 = 25^2 + (2 \text{ x} - 10 \text{ x} \Delta y)$$

$$20 \Delta y = 625$$

$$\Delta y = 31.25 \text{ m}$$

(b) The time to reach the top is found from:

$$v_y = u_y + at$$

$$0 = 25 + -10t$$

$$t = 2.5 \text{ s}$$

The time of flight therefore = 5.0 s

The horizontal component of velocity (which with the time of flight determines the range) is given by:

$$u_x = u \cos \theta$$

$$= 50 \cos 30$$

$$= 43.3 \text{ m.s}^{-1}$$

The range is given by:

$$\Delta x = u_x t$$

$$= 43.3 \text{ x } 5 \text{ m}$$

$$= 216.5 \text{ m}$$

EXAMPLE 10

A rock is thrown horizontally out to sea from the top of a vertical cliff face with an initial velocity of 20 m.s^{-1} as shown in Figure 1.5. It is seen to reach the water after 3.0 s. Find:

(a) the height of the cliff

(b) the horizontal distance out from the cliff base that the stone hits

(c) the velocity just before it hits the water.

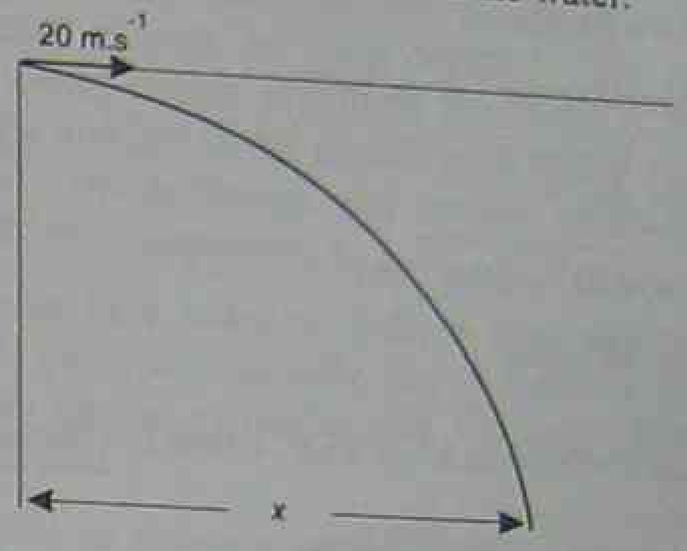

Figure 1. 5

SOLUTION:

(a) Since the initial velocity is horizontal, the vertical component of velocity is zero. Our data is therefore:

$$u_y = 0$$

$$a_g = 9.8 \text{ m.s}^{-1}$$

$$t = 3 \text{ s}$$

$$\Delta y = ?$$

Using the equations of kinematics we have:

$$\Delta y = u_y t + \tfrac{1}{2} a_g t^2$$

$$= 0 + \tfrac{1}{2} \text{ x } 9.8 \text{ x } 3^2 \text{ m}$$

$$= 44.1 \text{ m}$$

(b) The distance out from the cliff face the rock hits is found from:

$$\Delta x = u_x t$$

$$= 20 \times 3 \text{ m}$$

$$= 60 \text{ m}$$

(c) The velocity just before the rock hits is *the vector sum of the horizontal and vertical velocities* at this time.

Horizontally:

$v_x = u_x = 20$ m.s^{-1} (since the horizontal velocity is constant).

Vertically:

---

[2] http://www.phy.ntnu.edu.tw/~hwang/projectile/projectile.html Projectile motion simulation

http://www.explorescience.com/activities/Activity_page.cfm?ActivityID=32 The classic 'shoot the monkey' simulation.

$$\begin{aligned} v_y &= u_y + at \\ &= 0 + 9.8 \times 3\,\text{m.s}^{-1} \\ &= 29.4\,\text{m.s}^{-1} \end{aligned}$$

From Figure 1.6 we have:

$$\begin{aligned} v &= \sqrt{v_x^2 + v_y^2} \\ &= \sqrt{20^2 + 29.4^2}\ \text{m.s}^{-1} \\ &= 35.6\,\text{m.s}^{-1} \end{aligned}$$

Thus $\vec{v} = 35.6\,\text{m.s}^{-1}$ at 55.8° below the horizontal.

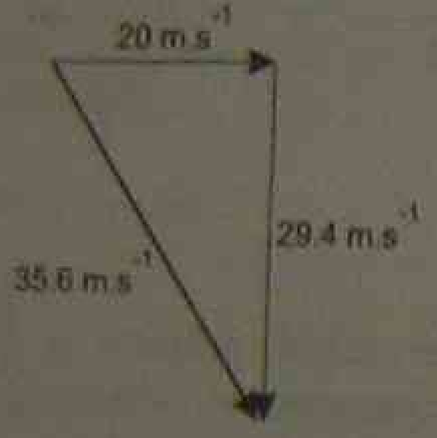

Figure 1. 6

EXAMPLE 11

A stone is projected out from the top of a high cliff. It leaves at 15 m.s^{-1} at 30° to the horizontal as shown in Figure 1.7. Find:

(a) the velocity of the stone after 2.0 s.

(b) the displacement of the stone at this time.

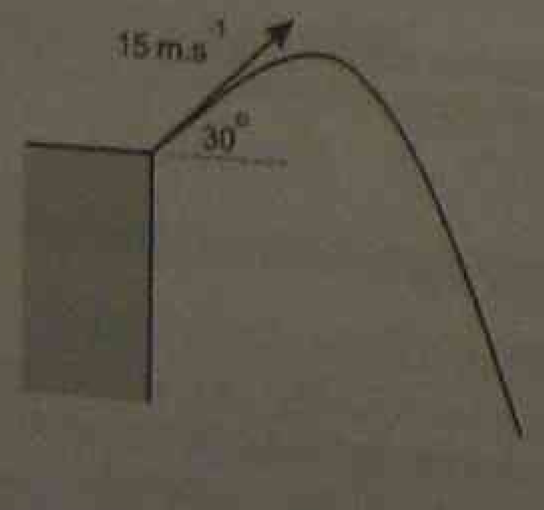

Figure 1. 7

SOLUTION:

Remember, *the motion of a projectile is simply the sum of its two components.*

(a) Horizontally—constant velocity

$$u_x = u\cos\theta = 15\cos 30 = 13.0\,\text{m.s}^{-1}$$

Vertically—constant acceleration (with up the positive direction)

$$\begin{aligned} v_y &= u_y + at \\ &= v\sin\theta + at \\ &= 15\sin 30 + (-9.8) \times 2 \\ &= -12.1\,\text{m.s}^{-1} \end{aligned}$$

This indicates the stone is travelling down after

From Figure 1.8 we have:

$$\begin{aligned} v &= \sqrt{v_x^2 + v_y^2} \\ &= \sqrt{13.0^2 + (-12.1)^2} \\ &= 17.8\,\text{m.s}^{-1} \end{aligned}$$

Also from Figure 1.8 we can see that:

$$\tan\theta = \frac{12.1}{13.0}$$

ie. $\theta = 43^0$

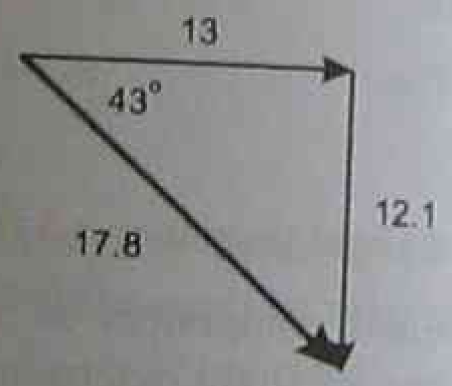

Figure 1. 8

That is, after 2.0 s the stone is travelling at m.s^{-1} at 43° below the horizontal.

(b) Horizontally:

$$\Delta x = u_x t = 15\cos 30 \times 2 = 26.0\,\text{m}$$

Vertically:

$$\begin{aligned} \Delta y &= u_y t + \tfrac{1}{2} a_g t^2 \\ &= (15\sin 30 \times 2) + \tfrac{1}{2}(-9.8) \times 2^2 \\ &= -4.6\,\text{m} \end{aligned}$$

(This indicates that the stone is 4.6 m vertic below the point of projection after 2.0 s)

Figure 1. 9

From Figure 1.9 we have:

$$\begin{aligned} s &= \sqrt{x^2 + y^2} \\ &= \sqrt{26^2 + (-4.6)^2} \\ &= 26.4\,\text{m} \end{aligned}$$

Also, we have from Figure 1.9:

$$\tan\theta = \frac{4.6}{26} \Rightarrow \theta = 10.0^{o}$$

The displacement after 2.0 s is 26.4 m at 10° below the horizontal.

GALILEO'S ANALYSIS OF PROJECTILE MOTION

Contrary to his predecessors, Galileo (1564–1642) emphasised the importance of mathematics in understanding natural phenomena and the need for experimentation.

In 1638 Galileo published the *Dialogues Concerning Two New Sciences*. In it he deduced the parabolic shape of the trajectory of a projectile, using a similar method to that we used on p.9. This made the analysis much easier since the properties of the parabola were known since the times of the ancient Greeks.

Prior to Galileo the general view of the day was that a projectile would follow a path like that represented in Figure 1.10.

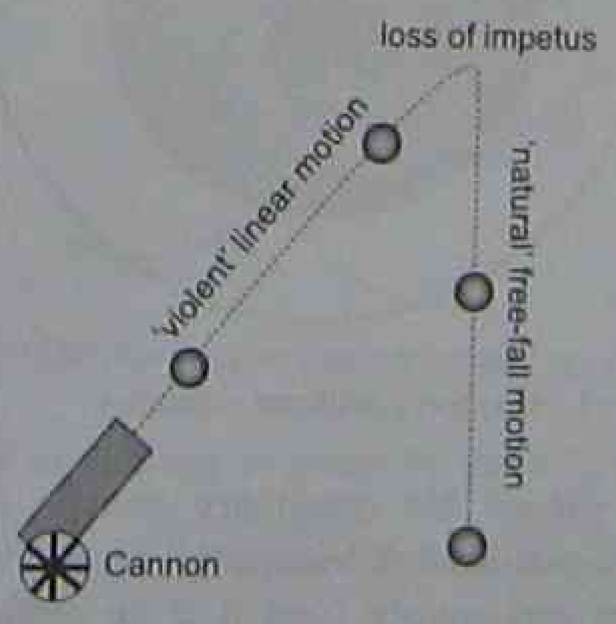

Figure 1. 10 Projectile motion as viewed in Galileo's day based on the ideas of Aristotle

This followed the views of Aristotle (~330 BC) whose teachings had been accepted without question for hundreds of years. Aristotle and his followers taught that a thrown object such as a spear would fall straight down when it left the thrower's hand except that its initial motion would create a vacuum and air rushing to fill this vacuum would provide an 'impetus' to push the spear forward. The spear's path would follow a straight line until it lost its impetus and fell to the ground in so-called 'natural' motion. The horizontal and vertical motions were thought to be sequential.

It seems hard today to believe that this is what people thought—one only has to throw a stone to another person to realize that the stone follows a curved path.

Contrary to Aristotle's view, Galileo reasoned that the motion of a projectile had two distinct motions; a vertical accelerated motion (where the displacement is proportional to the square of the travel time) and a constant velocity horizontal motion. *These motions occurred simultaneously.*

Using an inclined plane[3] Galileo was able to show the independence of these two motions and that they combined to produce a parabolic path for a projectile.

ESCAPE VELOCITY

If an object is projected upward with a large enough velocity it can escape the gravitational pull of the Earth (or other planet) and go into space. The necessary velocity to leave the Earth (or other planet) is called the **escape velocity**.

What factors determine this velocity?

Extension

Suppose an object of mass m is projected vertically upward from the Earth's surface (mass of M_E and radius R_E) with an initial velocity u. The initial

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[3] In Galileo's day there were not the accurate timing devices that are available to us. By rolling balls down inclined planes Galileo was able to 'dilute' the motion enabling reasonably accurate time measurements to be taken. In this way he was able to show that for a uniformly accelerated object the distance was proportional to the travel time squared.

mechanical energy, that is, kinetic and potential energy (see p.5) is given by:

$$E_{k} + E_{p} = \frac{1}{2}mu^2 - G\frac{M_E m}{R_E}$$

Let us assume that the initial speed is just enough so that the object reaches infinity with zero velocity. The value of the initial velocity for which this occurs is the escape velocity v_e.

When the object is at infinity the mechanical energy is zero (the kinetic energy is zero since the velocity is zero and the potential energy is zero because this is where we selected the zero of potential energy).

Hence $\frac{1}{2}mv_e^2 - G\frac{M_E m}{R_E} = 0$ which leads to:

$$v_e = \sqrt{\frac{2GM_E}{R_E}}$$

It can be seen from the equation above that the escape velocity depends on the gravitational constant, the mass and the radius of the planet.

By substituting into the equation it is found that the escape velocity from the Earth is ~11.2 km.s^{-1}. Since the mass of the object is not in the equation it follows that the escape velocity is the same for all objects (be they gas molecules or spacecraft)!

Table 1.3 shows the escape velocities for the planets and the Moon.

Table 1. 3 Escape velocities for the planets and the Moon

Planet	v_e (km.s^{-1})
Mercury	4.3
Venus	10.3
Earth	11.2
(Moon)	2.3
Mars	5.0
Jupiter	60
Saturn	36
Uranus	22
Neptune	24
Pluto	1.1

The lower the escape velocity the less likely it is th the planet has an atmosphere. Mercury for exampl would have lost its atmosphere over time as th escape velocity is relatively low and gas molecul would have speeds exceeding this value.

NEWTON AND ESCAPE VELOCITY

Isaac Newton in his *Principia Mathematica* fr proposed the idea of artificial satellites of the Eart Figure 1.11 is an adaptation of a diagram from h book[4]. He considered how a projectile could b launched horizontally from the top of a hig mountain so that it would not fall to Earth.

As the launch velocity was increased, the distanc that the object would travel before hitting the Ear would increase (*A* and *B*) until such a time that th velocity would be sufficient to put the object in orbit around the Earth (*C*). At this speed th curvature of the Earth exactly matches the curvatu of the projectile.

A higher velocity would lead to the object escapi from the Earth.

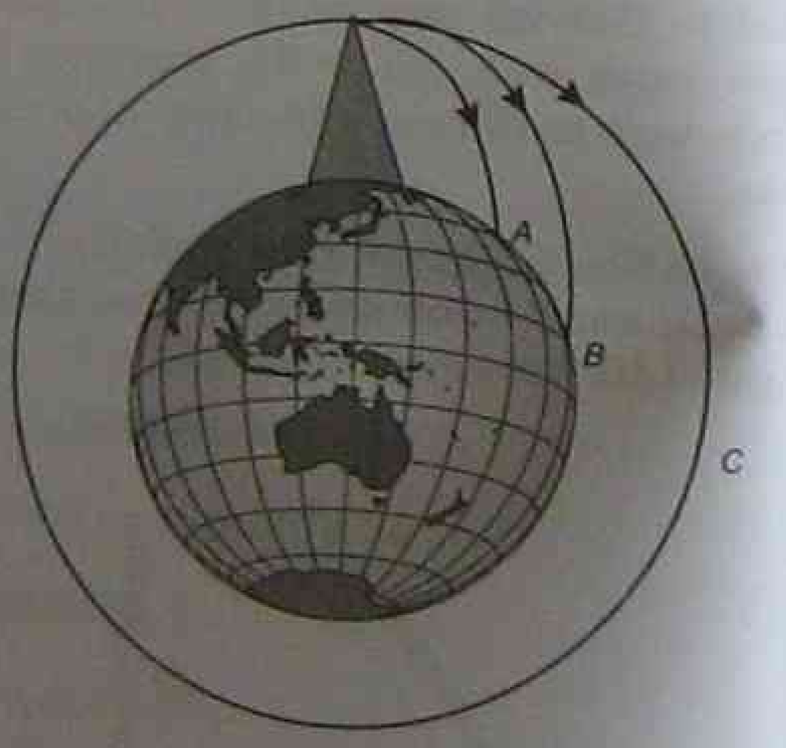

Figure 1. 11 Newton's artificial satellites

Newton placed his imaginary cannon on a hig mountain and fired it horizontally because he knew that if he had simply fired it at an angle from th Earth's surface it would *always* crash back to Earth

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[4] http://www.phys.virginia.edu/classes/109N/more_stuff/Applets/ne wt/newtmtn.html Applet simulating Newton's cannon fo projectile motion.

It would attempt to follow an ellipse, but the focus of that ellipse would lie within the Earth and so the cannonball would return and crash!

To understand how objects such as satellites can go into circular orbits, we must first look at the forces involved in circular motion.

CIRCULAR MOTION

Circular motion is a very a common two-dimensional motion. It is exhibited by various diverse systems including the moon revolving around the Earth (to a good approximation), wheels on moving cars and bicycles, particles in centrifuges, charged particles in cyclotrons (particle accelerators), cars travelling around corners...

To simplify this study we will concentrate on *uniform circular motion.*

> *The motion of an object in a circular path with constant speed is called* **uniform circular motion.**

Although the speed remains the same in uniform circular motion, it follows that an object travelling in a circular path must be *accelerating*, since the velocity (that is, the speed in a given *direction*) is continually changing. This is indicated by Figure 1.12 where $\vec{v}_1 \neq \vec{v}_2$ even though $v_1 = v_2$.

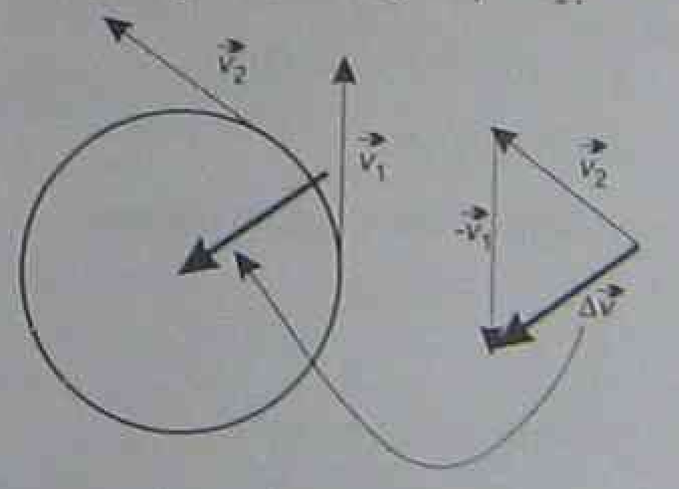

Figure 1. 12 Circular motion and centripetal acceleration

The change in velocity is given by $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$ and since $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$ it follows that the object is accelerating.

Centripetal Acceleration

As can be seen from Figure 1.12, when the change in velocity $\Delta\vec{v}$ is placed in the average position between $\vec{v}_1$ and $\vec{v}_2$, it is directed towards the *centre* of the circle. Thus, this is the direction of the *centripetal* (centre-seeking) acceleration.

> *When an object is moving with uniform circular motion, the acceleration (the* **centripetal acceleration***) is directed towards the centre of the circle.*

For an object moving in a circle of radius r with an *orbital velocity* of v, the centripetal acceleration a_c is given by:

$$\boxed{a_c = \frac{v^2}{r}}$$

Centripetal Force

From Newton's Second Law, $F = ma$, it follows that an object travelling in a circular path experiences a force. This force—the *centripetal force*—acts towards the centre of the circle.

For an object of mass m moving in a circle of radius r with an *orbital velocity* of v, the centripetal force F_c is given by:

$$\boxed{F_c = \frac{mv^2}{r}}$$

Table 1.4 illustrates some examples of circular motion and the source of the centripetal force.

Table 1. 4 Centripetal forces

Example of Centripetal force	Source of Centripetal force
Mass attached to a string and whirled in a horizontal circle	Tension in the string
Car travelling around a corner	Friction between the tyres and the road
Rider at bottom of curve on roller coaster	Reaction force of seat upwards on rider
Earth orbiting the Sun	Gravitational force between Earth and Sun
Satellite orbiting the Earth	Gravitational force between Earth and satellite

It is important to note that a centripetal force does not arise as a result of circular motion—circular motion is only possible if a centripetal force is present.

EXAMPLE 12

A car is travelling at constant speed around a circular track. The centre of mass of the car moves in a radius of 50 m. If the car's mass is 1500 kg and its speed is 30 m.s^{-1} calculate the resultant force acting on the car.

SOLUTION

$$F=\frac{mv^2}{r}=\frac{1500\times30^2}{50}=2.7\times10^4\ \text{N}$$

EXAMPLE 13

A car of mass 1500 kg goes over the crest of a hill, the surface of which is the arc of a vertical circle of radius 30 m. What is the maximum speed at which the car may travel and still be in contact with the road?

SOLUTION

If the car just maintains contact with the road then only the weight of the car provides the necessary centripetal force, that is:

$$mg=\frac{mv^2}{r}\text{, therefore}$$

$$v=\sqrt{gr}=\sqrt{9.8\times30}=17.1\ \text{m.s}^{-1}$$

EARTH ORBITS

A satellite can be put into Earth orbit by lifting it to a sufficient height (with rockets) and then giving it the required horizontal velocity so that it does not fall back to Earth (as predicted by Newton, p.14).

For the satellite to circle the Earth, the centripetal force required is provided by the gravitational attraction between the satellite and the Earth, that is:

$$F_c=\frac{mv^2}{r}=G\frac{mM_E}{r^2}$$

Hence the orbital speed is given by:

$$v=\sqrt{\frac{GM_E}{r}}$$

This equation shows that the orbital speed o satellite depends on the radius of the orbit and mass of the planet it is revolving about, bu independent of the mass of the satellite.

The speed is inversely proportional to the squ root of the radius. The smaller the radius, the fa the satellite must travel to stay in orbit at that radi

EXAMPLE 14

The Russian space station *Mir* was destroyed March 2001 when it burnt up in the Ear atmosphere following a controlled de-orbit. Prio that it moved in a circular orbit of altitude 390 for almost 15 years.

(a) Determine the orbital velocity required to ha kept *Mir* in a circular orbit at that altitude.

(b) Calculate the centripetal force required if M had a mass of 133 tonnes.

SOLUTION

(a) $$v=\sqrt{\frac{GM_E}{r}}$$

$$=\sqrt{\frac{6.67\times10^{-11}\times5.983\times10^{24}}{(6380+390)\times10^3}}\ \text{m.s}^{-1}$$

$$=7.678\times10^3\ \text{m.s}^{-1}$$

(b) The centripetal force is found from:

$$F_c=\frac{mv^2}{r}$$

$$=\frac{133000\times(7.678\times10^3)^2}{(6380+390)\times10^3}$$

$$=1.16\times10^6\ \text{N}$$

Orbital Speed and Period

The period (T) of an object in circular motion is t time for one complete revolution. In one revolu the object moves a distance equal to t circumference of a circle of radius r hence $v=\frac{2\pi r}{T}$

EXAMPLE 15

What was the period of the *Mir* space station in Example 14?

SOLUTION

$$v=\frac{2\pi r}{T}\Rightarrow T=\frac{2\pi r}{v}$$

$$T=\frac{2\pi\times(6380+390)\times10^3}{7.678\times10^3}\ \text{s}$$

$$=92.3\ \text{min}$$

It can be shown that a 'craft' in a low circular orbit of 150 km altitude requires a speed of 7.82 x 10^3 m.s^{-1} to maintain an orbit (Figure 1.13(a)). For speeds less than this the craft will fall back to Earth (following an elliptical orbit).

For speeds greater than this, the craft will move away from the Earth (Figure 1.13(b)) slowing down as it does until it eventually returns in an elliptical orbit. The greater the speed, the larger is the ellipse (Figure 1.13(c)).

If the speed is greater than or equal to the escape velocity, the craft will not return—the ellipse is infinite in size (Figure 1.13(d)).

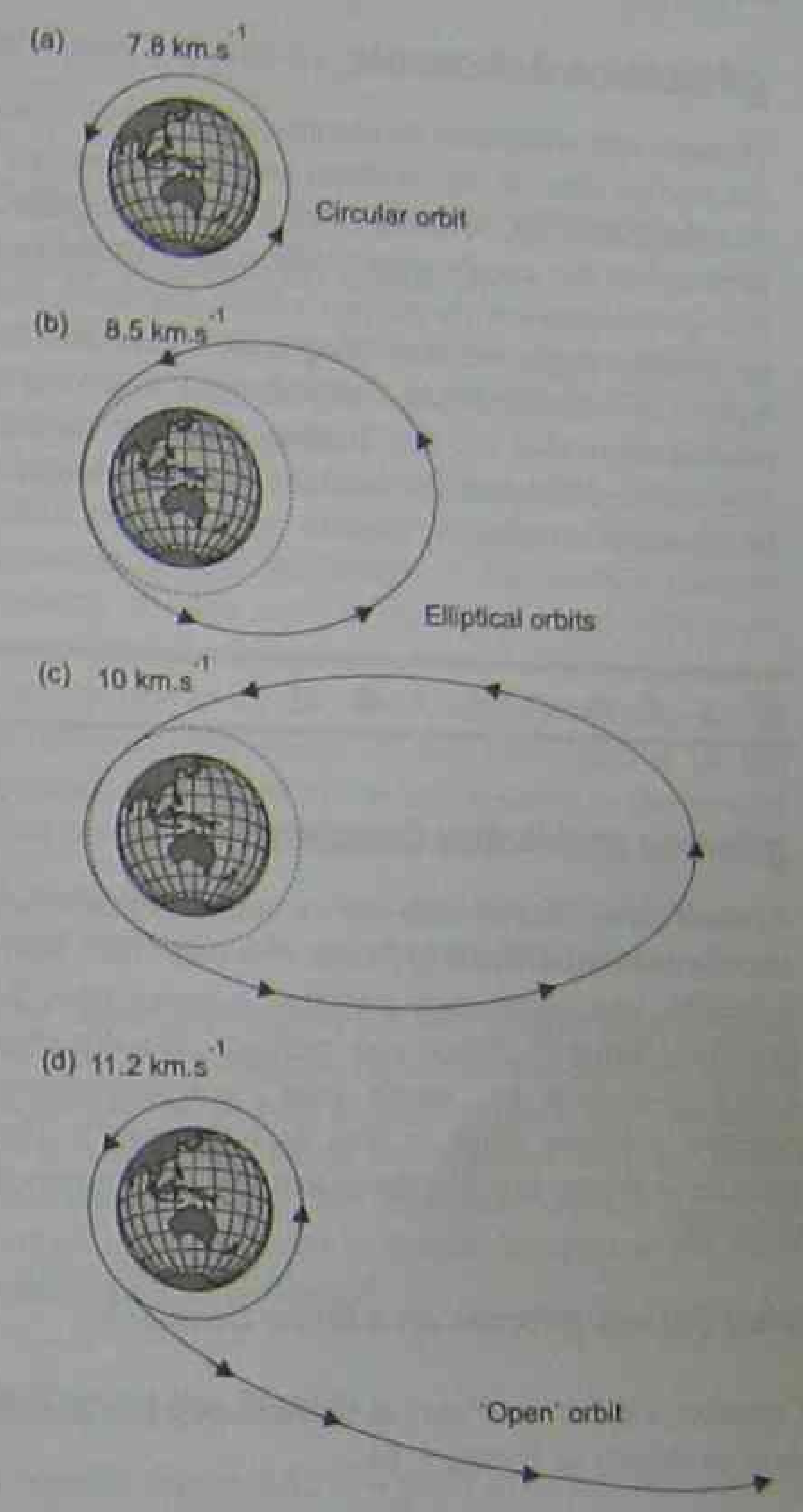

Figure 1. 13 Earth orbits

ACCELERATION AND THE HUMAN BODY

The human body is relatively unaffected by high speeds. For example, we experience no sensation of speed when travelling at a few hundred kilometres per hour in a jet airliner. Changes in speed, however, that is, accelerations, can and do affect the human body creating *'acceleration stress'*.

g-forces

Acceleration forces—g-forces—*are measured in units of gravitational acceleration g. For example, a force of 5g is equivalent to acceleration five times the acceleration due to gravity.*

If the accelerations are along the body's long axis (for example, the person is standing up and is accelerating vertically) then two distinct effects are possible.

1 If the acceleration is in the direction of the person's head they may experience a 'black out' as the blood rushes to their feet; or

2 If the acceleration is towards their feet, they make experience a 'red out' where the blood rushes to their head and retina (creating the red sensation in their eyes).

g-forces on Astronauts

Humans can withstand accelerations up to four times the normal (that is, 4g) without any undue concern[5]. Accelerations up to ~10g are tolerable for short times *when the acceleration is directed parallel to a line drawn between the person's front and back*, that is, at right angles to their long axis. These are the types of accelerations experienced by early astronauts at take-off and landing. For this reason, they reclined in specially moulded seats which direct the accelerations to their back.

Extension

g-forces and Roller Coasters[6]

Anyone who has ridden on a roller coaster has experienced significant *g-forces*. As you 'fall' from a height, you experience *negative g-forces* (that is, you feel 'lighter'). When you 'pull out' of a dip after a hill or follow an 'inside loop', you experience *positive g-forces* (that is, you feel 'heavier'). The positive *g-forces* are like those astronauts experience at lift-off.

What Causes g-forces on a Roller Coaster?

Consider a rider in a 'car' at the bottom of an inside loop as shown in Figure 1.14.

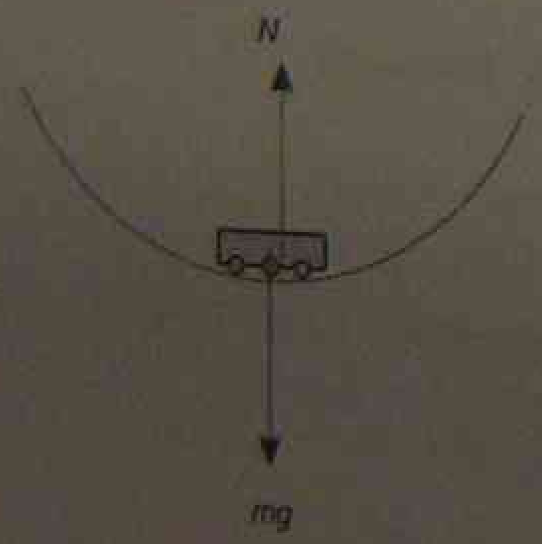

Figure 1.14 Forces on a rider on an 'inside loop'

The rider has two forces acting on them:

1 their normal weight (mg) acting down; an
2 the 'normal reaction force' (N) acting up. Th the push of the seat upwards on their bo (which, by Newton's Third Law, is equal t push of the rider on the seat).

Assume that the loop is part of a circle of radi As discussed earlier, a *centripetal force* is req for the rider to travel in a circle. This i difference between the normal force and the w force, that is:

$$N - mg = \frac{mv^2}{R}$$

$$N = mg + \frac{mv^2}{R}$$

The *g-forces* are found from the 'normal f divided by the weight. That is:

$$g \text{ felt by rider} = \frac{N}{mg}$$

$$= \frac{mg + \frac{mv^2}{R}}{mg}$$

$$= 1 + \frac{v^2}{gR}$$

It follows that the higher the speed v and the 'tig the loop (that is, the smaller the radius), the g will be the *g-forces*.

Most roller coasters keep the g-forces at less 5g.

The *Space Shuttle*[7]

The *Space Shuttle* has engines whose thrust c varied. They are 'throttled back' during the stages of ascent so that forces do not exceed (that is, accelerations of 3g). This is only abou third of the accelerations of earlier rockets allows non-flight specialists to venture into spac

Accelerations >10g are generally fatal (especiall any length of time). This determines the ma

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[5] http://www.hq.nasa.gov/office/pao/History/afspbio/part5-4.htm History of study into g-forces by NASA.

[6] http://www.kent.wednet.edu/staff/trobinso/physicspages/PhysOf9 9/Roller-Taylor/rollercoasters.htm and the physics of roller coasters

[7] http://www.seds.org/ssa/docs/Space.Shuttle/index.shtml O on the 'map' of the Space Shuttle and it tells you abo that component.

http://spaceflight.nasa.gov/shuttle/reference/ More good information on the Shuttle.

decelerations that astronauts can safely withstand on re-entry (see p.23).

LAUNCHING A ROCKET

Imagine the *Space Shuttle* sitting on the launch pad and facing skywards. The shuttle consists of three main components:

1 The winged *orbiter* that carries the crew and cargo;
2 An *external tank* containing fuel (liquid hydrogen) and an oxidiser (liquid oxygen) to power the orbiter's three main engines; and
3 Two large solid propellant *booster rockets* (fuelled with a mixture of aluminium powder, ammonium perchlorate powder and iron oxide catalyst bonded together with a polymer binder).

At lift off, the entire system has a mass of approximately 2.0 x 10^6 kg and the engines provide 31 x 10^6 N (31 MN) of thrust.

Momentum Conservation

The rocket engines generate thrust by burning fuel and expelling the resulting gases. Conservation of momentum means that as the gases move one way, the rocket moves the other. (Momentum before the burning is zero; hence momentum after is also zero. The gases carry momentum in one direction—'down'—and so the rocket carries an equal momentum in the opposite direction—'up'.)

As the fuel is consumed and the gases expelled, the mass of the system decreases. Since the acceleration is proportional to the thrust and inversely proportional to the mass (Newton's Second Law), as the mass decreases, the acceleration increases. Hence the forces on the astronauts increase.

After ~2 minutes the boosters are jettisoned (and are parachuted back to Earth for retrieval and reuse). When the propellants in the external tank are fully used, the tank is released and burns up in the Earth's atmosphere. By this time, the orbiter has reached approximately 99% of the speed required to place it in Earth orbit. Small rockets on the orbiter provide the additional thrust necessary to push the orbiter to the speed required to place it in orbit around the Earth.

Using the Earth's Rotation to Place the Space Shuttle into Earth Orbit

Launching the shuttle vertically and then tilting the trajectory so that the path is parallel to the Earth's surface when the correct orbital speed is reached, allows the shuttle to achieve Earth orbit. The tilting takes place in the easterly direction. This allows scientists to take advantage of the Earth's easterly velocity of ~464 m.s^{-1} at the equator and ~410 m.s^{-1} at the latitude of Cape Canaveral.[8] (This is similar to the situation in cricket where a fast bowler bowls to a batsman—the speed of the ball relative to the ground is the speed of the ball relative to the bowler *plus* the speed of the bowler relative to the ground.)

A westerly trajectory could be used but an additional ~600 m.s^{-1} would be required from the spacecraft.

The higher the latitude the less contribution is made by the Earth's rotation. Hence launch sites are placed as near to the equator as practicable. Cape Canaveral is at latitude 28° north; the Russian sites are above latitude 50° north; the European Space Agencies launch site at Kourou in South America is the most ideally sited at latitude 5°.

A Trip to the Moon

Consider Figure 1.15. To send a craft to the moon it is first put into a low circular Earth orbit (as just discussed, Figure 1.15(a)). Then, from a point on the opposite side to where it is planned to rendezvous with the moon, rockets are fired to put it into an elliptical orbit (Figure 1.15(b)). This *'injects'* the craft into the moon's orbit (Figure 1.15(c)).

The trajectory is designed so that the craft and the moon reach the same point in space at the same time. Rockets are then fired to put the craft into orbit around the moon or to land on it.

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[8] The horizontal component of the Earth's rotation is found from $v_{horizontal}$ = 464 cos (latitude)

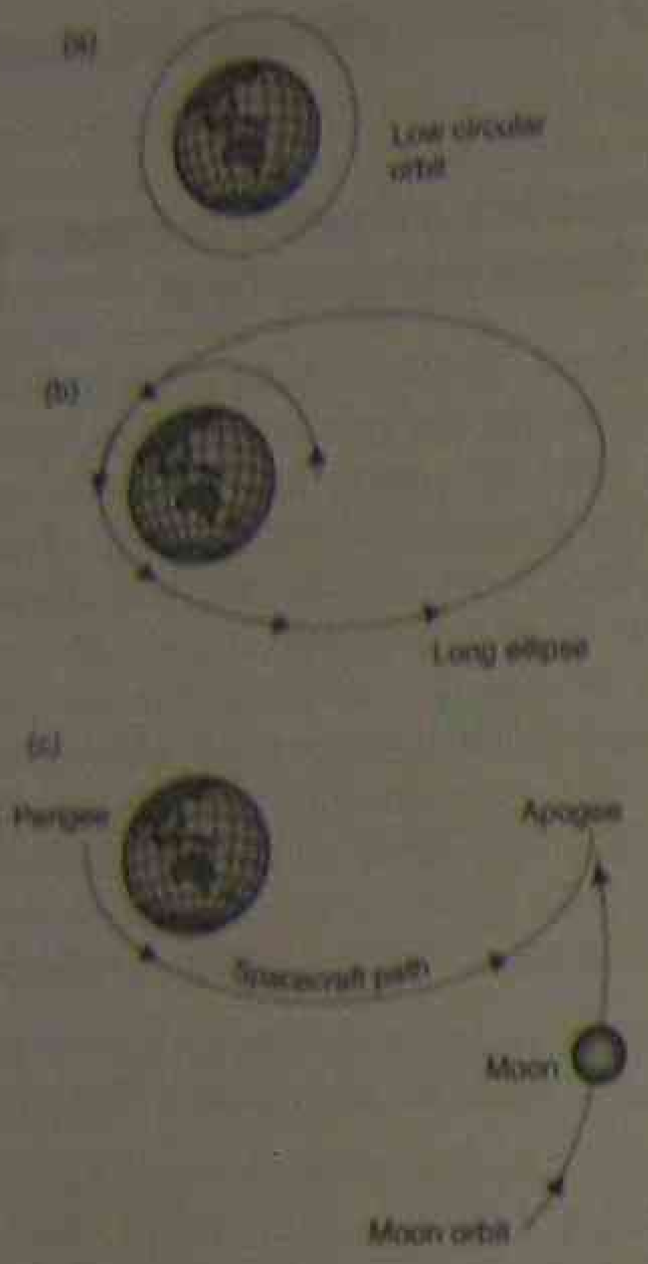

Figure 1.15 A trip to the moon

Extension

A Trip To The Planets (Interplanetary Spacecraft)

A similar process to that for the moon is used to send spacecraft to other planets (for example, Mars and Jupiter) except now we consider motion around the Sun.

Consider Figure 1.16. The Earth revolves around the Sun at a speed of ~30 km.s^{-1} as shown in Figure 1.16(a). If the speed of the craft is greater than the Earth's escape velocity, the craft will escape the Earth's pull. This can be relatively easily achieved by launching the craft in the direction of the Earth's motion (Figure 1.16(b)).

The craft will go into orbit *around the Sun* (just like any planet) so that Kepler's Law of Periods holds[9], that is, $\frac{r^3}{T^2}=\frac{GM}{4\pi^2}$ where T is in years and r is in astronomical units. By choosing the correct speed is possible to arrange for the craft to intercept t planet as in Figure 1.16(c).

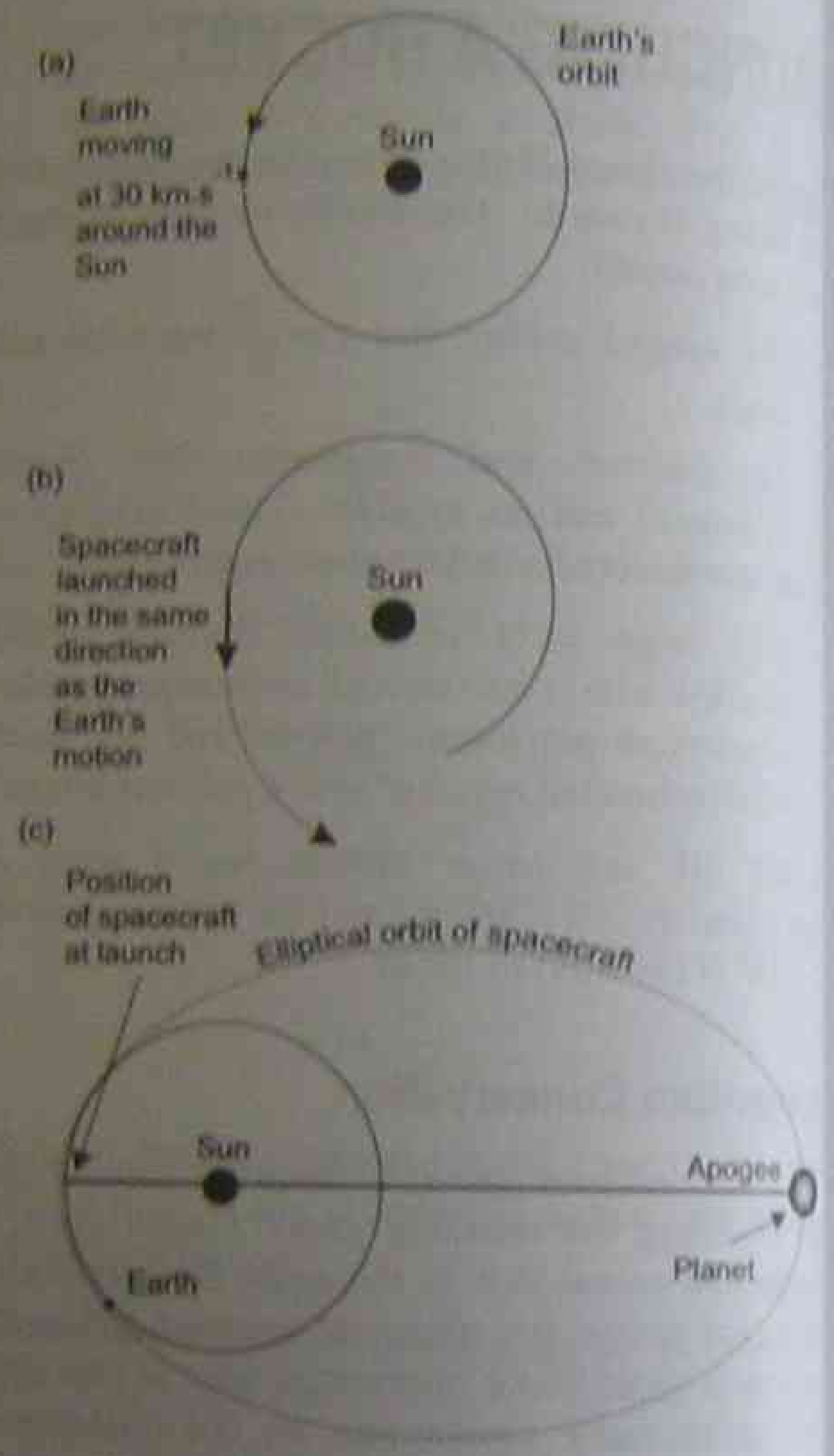

Figure 1.16 Interplanetary travel

It should be obvious that a space probe cannot b sent up at just any old time. To minimise th required velocity and travel time it is imperative th the Earth, Sun and planet (for example, Mars) be i the correct positions[10]. For Mars, this only happe every 780 days (~2 years). Hence Mar's probes c only be, at best, every two years and then there i only a small period of time in which launch will b successful. This is the *launch window*.

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[9] http://jersey.uoregon.edu/kepler/Kepler.html Java applet to simulate Kepler's Third Law.

[10] Orbits requiring minimum energy expenditure were first calculated in 1925 and are known as *Hohmann Transfer Orbits*. While energy requirements are minimised, the time requirements are not. In most cases a compromise trajectory is used.

To probe the inner planets (Mercury and Venus), the craft is fired in the opposite direction to the Earth's orbit around the Sun. This ensures that the craft will have an orbital velocity around the Sun of <30 km.s^{-1} and consequently cannot maintain the Earth orbit. As a result, the craft falls closer to the Sun, traversing an elliptical path.

LOW EARTH ORBITS

As we discussed previously (p.15), a satellite can be put into Earth orbit. The required orbital velocity depends on the radius of the orbit (and hence on the altitude above the Earth) as indicated in Table 1.5.

Table 1.5 Altitude versus orbital velocity

Altitude (km)	Orbital velocity (km.h^{-1})
200	29,000
1730	25,400
35,800	11,300

Satellites in low altitude orbits (altitudes ranging from ~300 km to ~800 km) are 'hidden' for part of their orbit round the Earth.

It is possible, however, to put a satellite in an orbit so that it is visible at all times from a point on the Earth. These are *geostationary* orbits.

GEOSTATIONARY (GEOSYNCHRONOUS) ORBIT

A **geosynchronous orbit** *is one in which the satellite has a period of 24 hours. If the orbit is in the equatorial plane, the satellite appears to stay above the same point on the Earth—such an orbit is said to be* **geostationary**.

Such geostationary orbits are essential to modern communications. By placing a satellite in a geostationary orbit, signals can be bounced off it to receiving stations in different parts of the world (see Figure 1.17).

Signal is sent from one place on the Earth and is 'bounced' to another point on the Earth. Both places can 'see' the satellite at the same time.

Figure 1.17 Communication with a geostationary satellite

EXAMPLE 16

At what altitude must a satellite be placed to be in a geostationary orbit?

SOLUTION

From the mathematical form of Kepler's Third Law we have:

$$\frac{r^3}{T^2}=\frac{GM}{4\pi^2}$$

$$r^3=\frac{GMT^2}{4\pi^2}$$

$$=\frac{6.67\times10^{-11}\times5.983\times10^{24}\times(24\times60\times60)}{4\pi^2}$$

$$=7.546\times10^{22}\text{ m}$$

$$r=4.23\times10^7\text{ m}=42\,300\text{ km}$$

Hence the altitude (that is, the distance above the Earth's surface) = 42,300 – 6,380 ~ 35,800 km

Comparing Low-Earth Orbits with Geostationary Orbits

As we have seen, geostationary orbits are essential to modern communication systems. There are, however, other uses of satellites that require that they be placed in low-earth orbit. Among these are the uses of satellites in spying missions by the military, surveying weather conditions, mapping ecological threats…

Geostationary satellites are placed in orbit ~35,800 km above the equator and have a period of 24 hours. Satellites placed in low-Earth orbit have a period less than 24 hours. If the orbit is *polar*, that is, the satellite orbits in a plane perpendicular to the plane of the equator and so passes over the poles of the Earth, then the orbit's orientation is fixed in space and the Earth rotates under the satellite (Figure 1.18). For example, if the period of a satellite is 6 hours then in one polar revolution its orbit will rotate 90° to the west, as the Earth rotates under the satellite. In a couple of days the whole Earth could be mapped.

Figure 1. 18 Polar orbits

ORBITAL DECAY

Low altitude orbiting objects such as satellites and discarded 'space junk' re-enter the Earth's atmosphere and generally burn up. The reason they re-enter is that although the atmosphere is very thin, nevertheless friction results in a loss of energy as heat, which causes it to move closer to the Earth where the atmosphere is thicker which causes more energy loss which … In 1979 the American space station *Skylab* crashed to Earth (with debris landing in the Indian Ocean and in Western Australia). It did so as a result of atmospheric drag that was exacerbated by sunspot activity.

Compared to low-Earth orbit satellites, geostationary satellites (see p.21) are so far above the Earth's atmosphere that frictional forces are negligible.

SAFE RE-ENTRY

Re-entry *is the return of a spacecraft into the Earth's atmosphere and subsequent descent to Earth.*

There are significant technical difficulties involv in safe re-entry, the most important being:

1 the heat generated as the spacecraft contacts t Earth's atmosphere; and

2 keeping the retarding-forces (*g*-forces) with safe limits for humans.

Heating Effects

The Earth's atmosphere provides *aerodynamic dr* on the spacecraft and as a result high temperatures are generated by friction with air molecules.

In early space exploration, including the *Mercury, Gemini* and *Apollo* missions, the blunt end of th nose cone was oriented to enter the atmosphere fir (see Figure 1.19). This followed the realisation th when a blunt end hits the atmosphere it sets up shock wave that carries away much of the heat. I addition, this end was covered with a *heat shi* made of *ablative* material that would burn up (and i this way prevent the spacecraft overheating).

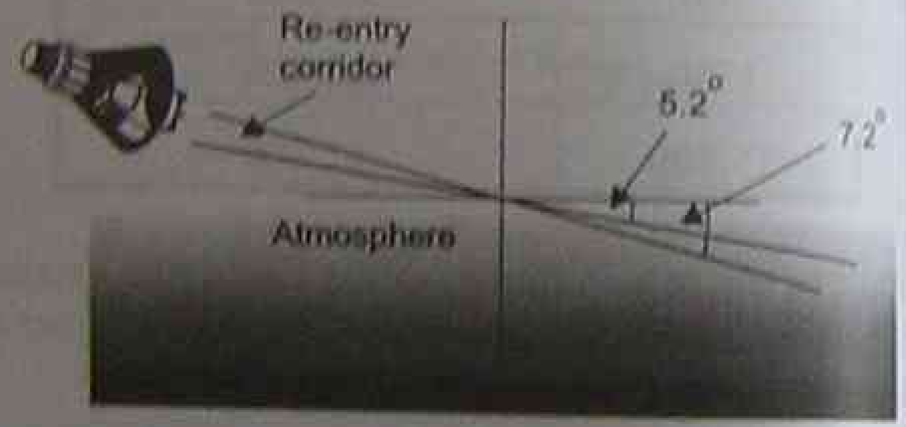

Figure 1. 19 Spacecraft re-entry into the Ear atmosphere

The *Space Shuttle*, on the other hand, uses four typ of material to limit the orbiter's temperature to abo 200° C.

1 Reinforced carbon-carbon composite to prote the nose cone and leading edges of the win where the temperature exceeds 1300°C.

2 20 000 reusable low-density silica tiles, mainl on the lower shuttle surfaces where th temperature approaches 750°C.

3 7000 reusable low temperature tiles on th upper wing and sides of the fuselage wher temperatures range from 400°C to 700°C.

4 A flexible reusable surface insulation applie directly to the payload bay doors, the fuselag sides and upper wing areas where th temperature does not exceed 400°C.

The shuttle also enters the atmosphere with its 'nose up' ensuring that the flat underbelly is presented to the air setting up a shock wave as for the nose cones of earlier missions.

g-forces

The angle of re-entry is critical: too shallow and the spacecraft will bounce off the atmosphere back into space; too steep and the *g*-forces will be too great for the crew to survive (and the temperatures generated with the atmosphere will be too high even for the refracting materials used).

The 'allowed' angle of re-entry for the *Mercury, Gemini* and *Apollo* missions was -6.2° ± 1° relative to the Earth's horizon. It can be shown that for angles of re-entry <5.2° the craft will 'skip' back into space and for angles >7.2° the *g*-forces will be too large.

It's a credit to space explorers and the teams on the ground that they can guide the craft into such a small *'re-entry window'*.

Deorbiting the Shuttle

The *Space Shuttle* is safely brought back to Earth with its occupants experiencing forces no greater that $3W$ as follows. First the shuttle is reoriented; the engines are fired in the direction of the orbiter's motion to slow it down. A second 'burn' points the nose forward and sets the nose with an attitude (angle) of ~40° to the atmosphere (see earlier). Approximately 30 minutes after the initial burn the shuttle reaches an altitude where the heating effects are significant, reaching a maximum ~20 minutes before landing. Four S-turn manoeuvres during the last 16 minutes before landing slow the shuttle down further (just like a skier). By now the atmosphere is dense enough to provide lift to the wings.

Seventeen seconds prior to landing the shuttle's glide path angle is changed from its current 22° to 1.5°. The landing gear is lowered 14 seconds before touchdown and the shuttle is brought in to land. A small parachute assists in bringing it to rest.

Ionisation Blackout

The high temperatures generated by re-entry result in ionisation of the atoms of the air. This prevents communication between the spacecraft and the ground. In the early *Apollo* flights this lasted for ~3 minutes; for the shuttle it lasts ~16 minutes.

Columbia Disaster

On 1 February 2003 the Space Shuttle *Columbia*, with seven astronauts aboard, disintegrated over Texas as it returned from a mission. At the time of writing (April 2003) the cause of the disaster was believed to be a long narrow slit on Columbia's left wing that may have let in scorching heat from the re-entry.

This gap may have been caused by a missing or broken seal on the leading edge of the wing believed to be where a piece of foam insulation hit during lift off some days earlier.

This tragedy illustrates both the technological advances made in sending people into orbit and the dangers inherent in such a mission.

Secondary Source Investigation

Rocketry[11]

Space exploration and travel relies on rockets to put the spacecraft into space.

Rocketry had its beginnings as far back as the thirteenth century when Chinese armies were reported to have used rockets in warfare. From China they spread to Europe and most of Asia. The use of rockets for fireworks remained however their prime use, although by the early 1800s rockets were being used to carry explosives in war. British troops used rockets against the United States in the War of 1812.

The modern study of rocketry had a number of important contributors, among these being Tsiolkovsky, Esnault-Pelterie, Goddard, Oberth and O'Neill. The German Wernher von Braun (later to take American citizenship) also made significant contributions to the development of sophisticated rockets.

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[11] http://spaceline.org/rockethistory.html History of rocketry site. http://www.ssi.org/body_obit.html for the life of Gerard O'Neill.

Konstantin Tsiolkovsky (1857—1935)

Modern rocketry theory began in 1903 when a Russian schoolteacher, Konstantin Tsiolkovsky published a scientific paper—*Investigations of Space by Means of Rockets*—which set out for the first time the correct theory of rocket power. Tsiolkovsky also was the first person to suggest the concepts of multi-stage rockets and liquid fuels and he developed wind tunnels to study aerodynamics. From the latter he developed advance designs for aeroplanes and for an all-metal *dirigible*.

Back in 1896 he commenced his work titled *Exploration of Cosmic Space by Means of Reactive Devices* which dealt with the problems of using rockets in space, the heating effects of air friction and fuel supply maintenance.

Tsiolkovsky also made important theoretical contributions to the explanation of the stratosphere and interplanetary flight.

Robert Esnault-Pelterie (1881—1957)

Frenchman, best known as an aviator pioneer (in 1907 he built the first all-metal monoplane), and for his interest in space exploration. The latter occupied his time from 1912—1930.

In 1912 he presented a paper (*Considerations of the Results of an Unlimited Lightening of Motors*) to the French Physics Society in which he gave one of the first scientific discussions of the inherent problems of space travel. He even speculated that nuclear energy would be needed for space travel.

In 1927 he gave a lecture to the French Astronomical Society subsequently published as *Rocket Explosion of the Very High Atmosphere and the Possibility of Interplanetary Travel*.

In 1930 he published his book *Astronautics* introducing that word to our vocabulary. In it he discussed the possibility of space travel and his work on high-altitude rocket flight including calculations of trajectories to the planets. A further edition in 1934 gave considerably more attention to space travel. By this time he had been convinced by the work of others that nuclear energy was not necessary; that chemical energy would suffice for trips to the moon. (In October 1931 Esnault-Pelterie lost 4 fingers in an accident using a rocket fuel mixture of liquid oxygen and tetranitromethane!)

Robert H. Goddard (1882—1945)

The American pioneer rocket scientist Robe Goddard (acknowledged as the 'father' of m rocketry), was the first person to prove that r would work in a vacuum and did not require push against' to provide propulsion.

In 1919 he published a treatise on *A Meth Reaching Extreme Altitudes* in which he propo rocket that could reach the moon. Goddard ana the energy yield and thrust per unit mass of va fuels (including liquid fuels) and developed a m motor that could use the liquid fuels petrol liquid oxygen.

Then in 1926, Goddard successfully launched first liquid-propellant rocket (all previous ro had used solid fuels). This reached an altitud 57 m and a speed of 97 km.h^{-1}. In 1929 he sen the first instrument-carrying rocket. God accumulated over 200 patents relating to rocket his career.

Largely unrecognised in his own lifetime, Godda work was utilised by German scientists in development of their wartime rockets.

Hermann Oberth (1894—1989)

The Austrian Hermann Oberth in 1923 publishe book titled *The Rocket into Interplanetary Spac* which he set out for the first time a mathema description of the conditions required for a rocke reach escape velocity. (This book was supplemente 1925 by one titled *The Possibility of Reach Celestial Bodies* in which Walter Hohmann prov the first detailed calculations of interplanetary orbits

Oberth also simulated weightlessness and in 1929 book *Ways to Spaceflight* predicted the developme electric propulsion and the ion motor.

Gerard O'Neill (1927—1992)

The American physicist Gerard O'Neill ma significant contributions to physics including hi energy particle physics and space exploration. In t former he invented the *colliding beam storage* r allowing investigations of subatomic particles (Option Topic *Quanta to Quarks*). In the latter he responsible for advocating the colonisation of spa

An enthusiastic university lecturer, in the late 6 (around the time of the *Apollo* missions) he ask his class to write a paper on human habitation

space. He was so taken by the enthusiasm of their responses that he wrote his own paper in 1974 on *The Colonisation of Space.*

In 1978 he published *The High Frontier* in which he suggested that space colonies might be the answer to many of the Earth's problems: overpopulation, pollution, the need for environmentally 'clean' energy … He designed a space colony placed in a kilometre-long cylinder positioned between the Earth and the moon.

In 1978 a working model of a *mass driver* was built. This device, invented by O'Neill, was to be used for cheap and efficient transfer of materials such as mineral ores from the low-gravity moon or an asteroid into orbit. This was done using electro-magnetic drive coils to provide the necessary force.

Wernher von Braun (1912—1977)

The Second World War provided the impetus to rapidly advance rocket science. The Germans under the leadership of Wernher von Braun developed the V-2 guided missile that rained death and destruction on London in the last months of the war. Victorious American forces captured many of these rockets and sent them back to America. In addition, almost the entire German rocket development team went to America at the war's end to continue their work. (Some German rocket scientists even 'found their way' to the Soviet Union.)

Within months of their arrival in America, von Braun's team were assembling, testing and supervising V-2 rocket launches for high altitude research. von Braun became an American citizen in 1955 and in 1958 headed the team that put America's first satellite, *Explorer I*, into space, some three months after the Soviets had put *Sputnik I* into space. von Braun continued to lead rocket development in America culminating in the *Saturn* series of rockets. The *Saturn V* rocket carried the first men to the Moon in 1969.

von Braun is also responsible for the idea of the space station and the space shuttle.

SECTION 3: THE SOLAR SYSTEM

BIG IDEA:

The Solar System is held together by gravity.

OUTCOMES:

Students learn to:

1 Define Newton's Law of Universal Gravitation $F = G\frac{m_1m_2}{d^2}$

2 Describe a gravitational field in the region surrounding a massive object in terms of its effects on masses in it.

3 Discuss the importance of Newton's Law of Universal Gravitation in understanding and calculating motion of satellites

4 Identify that a 'slingshot' effect is provided by planets for space probes.

Students:

1 *Present information and use available evidence to discuss the factors affecting the strength of gravitational force.*

2 *Solve problems and analyse information using* $F = G\frac{m_1m_2}{d^2}$

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NEWTON'S LAW OF UNIVERSAL GRAVITATION

As mentioned earlier (see p.1), Newton proposed that any two objects in the universe attract each other with a force given by $F = G\frac{m_1m_2}{d^2}$. Here F is the force, G is a constant called the '*universal gravitational constant*', m_1 and m_2 are the masses of the two objects and d is the separation of between the centres of the two objects.

Cavendish's Experiment

In 1798 Henry Cavendish first succeeded in determining the value of G. Its current accepted value is 6.67×10^{-11} N.m^2 kg^{-2}.

EXAMPLE 3

Two objects of mass 1 kg and 2 kg respectively separated by 0.5 m in air. What force acts betw the two masses?

SOLUTION

$$F = G\frac{m_1m_2}{d^2}$$
$$= \frac{6.67 \times 10^{-11} \times 1 \times 2}{0.5^2}\text{ N}$$
$$= 5.34 \times 10^{-10}\text{ N}$$

EXAMPLE 4

Two objects of mass m_1 and m_2 respectively are separated by a distance d. They exert a force F on each other. If the masses are halved and the distance tripled, what is the size of the new force?

SOLUTION

$$F = G\frac{m_1m_2}{d^2}$$
$$F' = G\frac{\frac{1}{2}m_1\frac{1}{2}m_2}{(3d)^2} = \frac{F}{36}$$

that is, the new force is $\frac{1}{36}$ of the original force.

Gravitational Field

In Chapter Two, *Electricity in the Home*, we were introduced to the concept of a *field* as a way of explaining so called '*action at a distance*', where two (or more) separated objects exert forces on each other without direct contact between them. Just as we use the *electric* field and the *magnetic* field to explain forces between charges and magnetic poles respectively, so too we can use the *gravitational field* to explain the forces between two (or more) objects with mass.

An object of mass m_1 for example produces a gravitational field in the space surrounding it. A second object of mass m_2 placed in the field will experience a force *due to the field*. Similarly m_2 produces a field that acts on m_1.

Gravitational fields, like electric and magnetic fields are *force fields*. Masses experience a force when placed in the gravitational field of another mass.

Just as we define an electric field as the force per unit charge, so too we *define the gravitational field as the force per unit mass.*

Field Mathematics

From the equation $F = G\frac{m_1m_2}{d^2}$, we define the gravitational field (g_1) due to mass m_1, as the ratio of the force acting on mass m_2 to the mass m_2. That is,

$$g_1 = \frac{F}{m_2} = \frac{G\frac{m_1m_2}{d^2}}{m_2} = G\frac{m_1}{d^2}.$$

By symmetry the gravitational field g_2 due to mass m_2 is given by $G\frac{m_2}{d^2}$.

It follows that the gravitational field of a mass m at a distance d from the mass is given by:

$$\boxed{g = G\frac{m}{d^2}}$$

EXAMPLE 5

Calculate the value of 'g' – the acceleration due to gravity – on Jupiter, given that its radius is 7.18×10^7 m and its mass is 1.88×10^{27} kg.

SOLUTION

We have:

$$g = \frac{Gm_J}{d^2}$$
$$= \frac{6.67 \times 10^{-11} \times 1.88 \times 10^{27}}{(7.18 \times 10^7)^2}$$
$$= 24.3\text{ m.s}^{-2}$$

At the Earth's surface, g is equal to 9.8 N.kg^{-1}, which is the same as 9.8 m.s^{-2} – the value of the *acceleration due to gravity*. (This explains why we can calculate the weight of a *stationary* object from $W=mg$.) The g refers to the strength of the field rather than to any acceleration of the mass.

Kepler's Law of Periods and Newton's Law of Universal Gravitation

Orbital velocity

Consider the motion of an object in a circular path (Figure 4.17) of radius r. In one revolution it moves a distance equal to the circumference of the circle, that is, $2\pi r$.

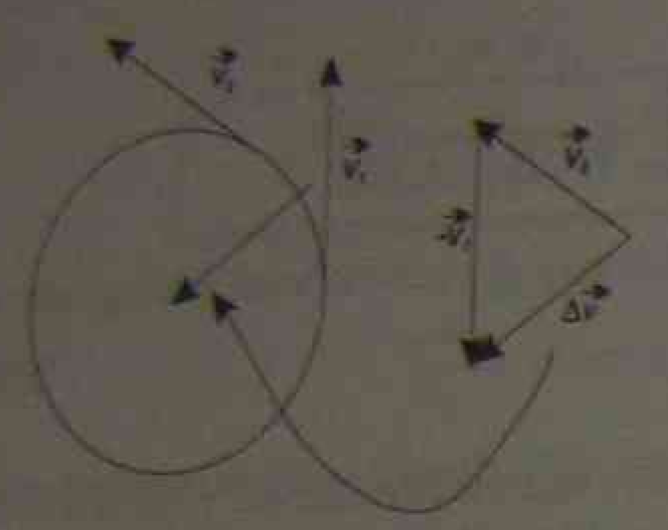

Figure 4. 1 Orbital velocity

The speed *v* with which it moves in a circle is called the *orbital speed* (or 'orbital velocity', although strictly speaking this continually changes as the direction of the object changes, as it moves around the circle). If the time to make one complete revolution is given by the *'period' T*, then the orbital speed *v* is given by:

$$\boxed{v=\frac{2\pi r}{T}}$$

Since the object's *velocity* is changing due to its continual change in direction, it follows that the object must be *accelerating*. (The object does not get faster, only its direction changes.) This requires a force, the *centripetal* (centre seeking) force. This force acts towards the centre of the circle and has magnitude given by $F=\frac{mv^2}{r}$.

For a planet revolving around the Sun in a circular orbit or radius *r*, the centripetal force is provided by the gravitational attraction between the planet and the Sun. If the mass of the planet is *m* and the mass of the Sun is *M*, then:

$$F=G\frac{Mm}{r^2}=\frac{mv^2}{r}$$

$$G\frac{Mm}{r^2}=\frac{m\left(\frac{2\pi r}{T}\right)^2}{r}$$

$$\frac{GM}{r^2}=\frac{4\pi^2 r}{T^2}$$

That is:

$$\boxed{\frac{r^3}{T^2}=\frac{GM}{4\pi^2}}$$

This last equation is Kepler's Law of Peri called Kepler's Third Law) which he derived from empirical data! We can see how necessary consequence of Newton's La Universal Gravitation!!!

EXAMPLE 6

Calculate the mass of Jupiter given that Io, one satellite moons, has a period of 1.53 x 10 moving in an approximately circular 4.20 x 10^8 m.

SOLUTION

Letting M_J and r be the mass of Jupiter distance between their centres respectively, we

$$\frac{r^3}{T^2}=\frac{GM_J}{4\pi^2}$$

Hence:

$$M_J=\frac{4\pi^2 r^3}{GT^2}$$

$$=\frac{4\pi^2 \text{ x } (4.20 \text{ x } 10^8)^3}{6.67 \text{ x } 10^{-11} \text{ x } (1.53 \text{ x } 10^5)^2}\text{ kg}$$

$$=1.87 \text{ x } 10^{27}\text{ kg}$$

NEWTON'S LAWS AND TH MOTION OF SATELLITES

As we saw in the Preliminary Course *The C Engine*, the motion of the planets around the S be described by the equation $\frac{r^3}{T^2}=\frac{GM}{4\pi^2}$ equation is found by comparing the force fr Law of Universal Gravitation with the force re to keep an object in circular motion. That is:

$$F_c=\frac{mv^2}{r}=\frac{GmM}{r^2}$$

$$v^2=\frac{GM}{r}=\left(\frac{2\pi r}{T}\right)^2$$

$$\frac{r^3}{T^2}=\frac{GM}{4\pi^2}$$

This equation represents the mathematical form of Kepler's Law of Periods

Kepler's Laws not only apply to planets and comets orbiting the Sun, but they also apply to satellites (both natural and artificial) and spacecraft orbiting planets. Kepler's Third Law can, for example be used to calculate the mass of a planet by determining the period and radius of a satellite of that planet.

EXAMPLE 17

Calculate the mass of Jupiter given that Io, one of its satellite moons, has a period of 1.53 x 10^5 s when moving in an approximately circular orbit of 4.20 x 10^8 m.

SOLUTION

Letting M_J and r be the mass of Jupiter and the distance between their centres respectively, we have:

$$\frac{r^3}{T^2}=\frac{GM_J}{4\pi^2}$$

Hence:

$$M_J=\frac{4\pi^2 r^3}{GT^2}$$

$$=\frac{4\pi^2 \text{ x } (4.20 \text{ x } 10^8)^3}{6.67\times 10^{-11}\times(1.53 \, x \, 10^5)^2}\text{ kg}$$

$$=1.87 \text{ x } 10^{27}\text{ kg}$$

Newton's Law of Universal Gravitation determines the motion of satellites, enabling scientists to calculate their position and velocity at any instant. It also controls the motion of spacecraft travelling through the solar system to other planets.

THE 'SLINGSHOT' EFFECT[12]

Many of today's space probes to distant planets such as Jupiter use a *gravitational 'slingshot' effect* (also known as a *gravity-assist trajectory*) that brings the probe close to other planets to increase the probe's velocity. In 1974, *Mariner* 10 was directed past Venus on its way to Mercury. The *Pioneer* and *Voyager* probes that went to the outer planets and became the first manmade objects to leave the Solar System also used this method.

How does this work? Why isn't the increase in speed of a probe as it approaches a planet cancelled out by the decrease as it recedes?

Consider a trip to Jupiter such as the *Galileo* probe launched in 1989 that involved a single fly-by of Venus and two of the Earth. As the probe approaches Venus (Figure 1.20(a)), it is accelerated by Venus' gravitational attraction, causing it to speed up relative to Venus. (By Newton's Third Law, Venus will also experience a force slowing it down. Its mass, however, is so much greater than that of the probe that the velocity decrease is imperceptible.)

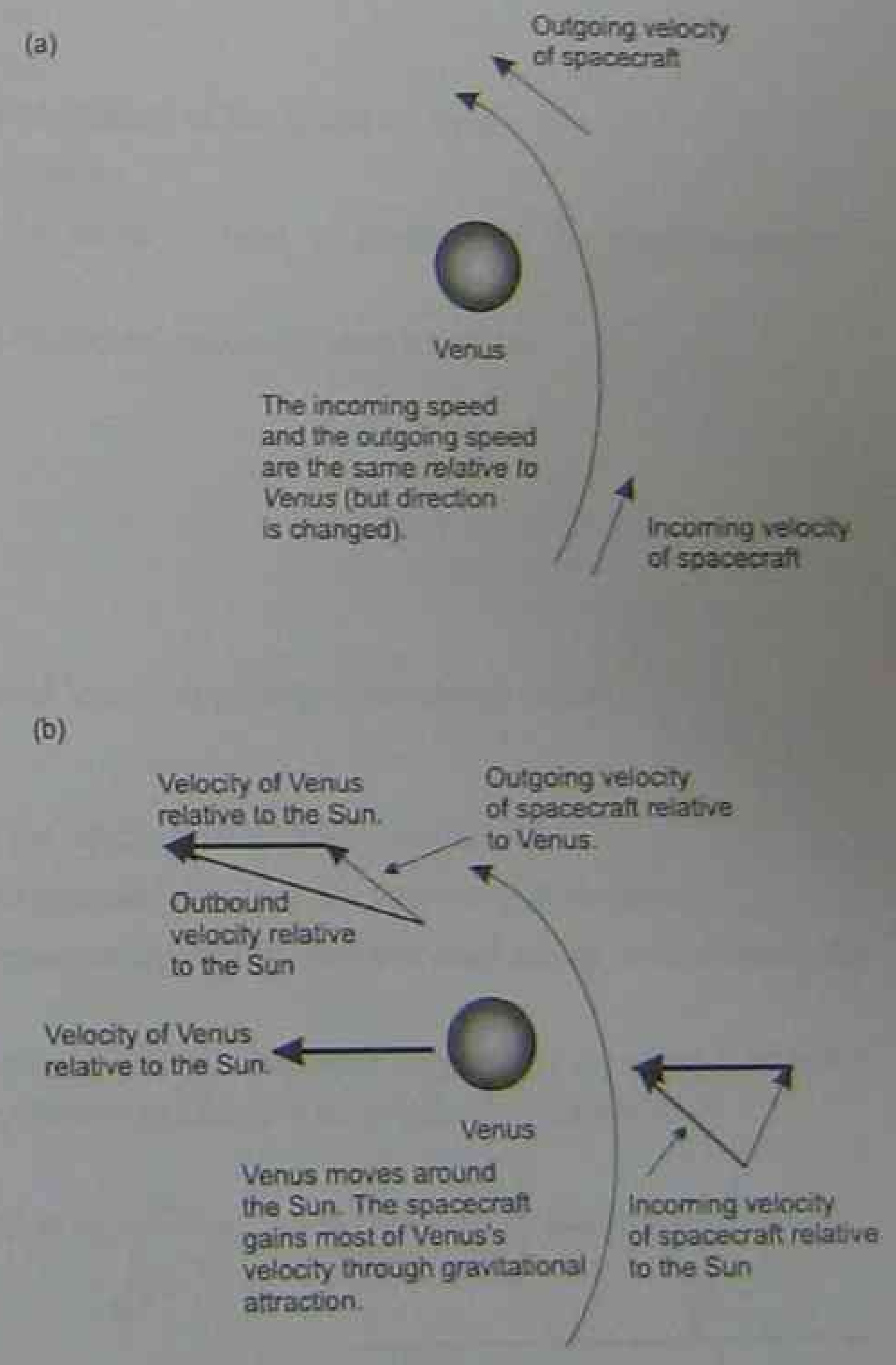

Figure 1. 20 The slingshot effect

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[12] http://www.sciam.com/askexpert/astronomy/astronomy10.html Experts from Scientific American answer questions about the slingshot effect.

As the probe passes Venus, its speed is reduced (relative to Venus)[13]. Relative to the Sun, however, its speed has increased (Figure 1.20(b)). The probe picks up *angular momentum*[14] from the planet (which loses an equal amount of angular momentum). Gravity allows the 'coupling' between the probe and planet to facilitate the transfer. For this reason, gravity-assist trajectories should more correctly be called *angular momentum-assist trajectories.*

---

[13] In fact, the speed of receding is the same as the speed of approach relative to Venus.

[14] Angular momentum is the momentum of a rotating object (= *mvr*) where *m* is the mass, *v* is the orbital velocity and *r* is the radius of the orbit.

SECTION 4: SPECIAL RELATIVITY

BIG IDEA:

Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light.

OUTCOMES:

Students learn to:

1 Outline the features of the aether model for the transmission of light.
2 Describe and evaluate the Michelson-Morley attempt to measure the relative velocity of the Earth through the aether.
3 Discuss the role of the Michelson-Morley experiment in making determinations about competing theories.
4 Outline the nature of inertial frames of reference.
5 Discuss the principle of relativity.
6 Describe the significance of Einstein's assumption of the constancy of the speed of light.
7 Identify that if *c* is constant then space and time become relative.
8 Discuss the concept that length standards are defined in terms of time in contrast to the original metre standard.
9 Explain qualitatively and quantitatively the consequence of special relativity in relation to:
    - the relativity of simultaneity
    - the equivalence between mass and energy
    - length contraction
    - time dilation
    - mass dilation.
10 Discuss the implications of mass increase, time dilation and length contraction for space travel.

Students:

1 *Gather and process information to interpret the results of the Michelson-Morley experiment.*
2 *Perform an investigation to help distinguish between non-inertial and inertial frames of reference.*
3 *Analyse and interpret some of Einstein's thought experiments involving mirrors and trains and discuss the relationship between thought and reality.*
4 *Analyse information to discuss the relationship between theory and the evidence supporting it, using Einstein's predictions based on relativity that were made many years before evidence was available to support it.*
5 *Solve problems and analyse information using:* $E = mc^2$, $m = \dfrac{m_0}{\sqrt{1-\dfrac{v^2}{c^2}}}$, $l = l_0\sqrt{\left(1-\dfrac{v^2}{c^2}\right)}$ and $t = \dfrac{t_0}{\sqrt{1-\dfrac{v^2}{c^2}}}$

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THE ETHER[15]

The ancient Greeks spoke of the Earth as being surrounded by water, the water by air and the air by *ether*. Beyond the ether was nothing.

The Frenchman René Descartes in the mid-seventeenth century was notable in popularising the concept of all-pervasive ether. Descartes believed that motion could be carried from one piece of matter to another only by contact with other matter. Because the planets were in motion, space could not be empty but must be full of an invisible substance, the 'ether' (or *'aether'* or *'luminiferous aether'*) that carries the motion. This ether was arranged in whirlpools or vortices. According to Descartes, an object is visible because the ether transmits a pressure from the object to the observer's eye.

The Englishman Robert Hooke in 1667 and the Dutchman Christiaan Huygens in 1678 proposed that luminous objects set up vibrations that were transmitted through the ether like sound waves through air (compression waves). Newton himself spoke of 'ether waves' even though he is commonly presented as a believer in a particle theory of light.

The Frenchman Augustin Fresnel is credited with being the real founder of the wave theory of light because he presented such convincing evidence for its wave nature. However, he too found it necessary to consider the ether to be the medium needed to propagate light.

The Ether's Properties

Before the work of Thomas Young and Fresnel it was assumed that the ether was a tenuous fluid (that is, thin in consistency)—why else had not the planets been brought to rest long ago? Young and Fresnel, however, had shown that light was not a longitudinal wave but was in fact a transverse wave. Transverse waves cannot travel through liquids or gases, and so the ether must be solid!

In 1845 George Stokes 'overcame' the apparent paradox by suggesting the ether acted somewhat like wax, which is rigid for rapidly changing forces but is fluid under the action of long continued forces.

The ether was supposed to permeate all matt evidenced by the transmission of light thr transparent materials.

The Ether Wind

Because the Earth was moving around the Su 30 km.s^{-1}, it was reasoned that an *'ether wind'* sh be blowing past the Earth (just like a car dr through still air).

The speed of sound in air is independent of velocity of the source (it depends only on properties of the medium through which i travelling). However, if a wind blows, the spee sound relative to a stationary observer would v Thus it was believed that the speed of light sh vary due to the presence of the 'ether wind'.

It was in an attempt to detect this difference t Michelson and Morley did their famous experime

MICHELSON-MORLEY EXPERIMENT[16]

In 1887 two United States scientists A.A. Michel and E.W. Morley attempted to measure the motio the Earth relative to the ether. They used phenomenon of the interference of light to mea minute distances.

Light was sent from a source (Figure 1.21) and s into two perpendicular beams by the *half-silv* mirror at *A*. (Half of the light was reflected and h was transmitted). These two beams are then refle back by the mirrors M_1 and M_2 and are recomb in the observer's eye. An interference pattern re from these two beams (the source *S* acts a coherent source).

The beam AM_1 travelled across the ether, whilst travelled with and against the ether. The times t this can be shown to be different (see exte following) and so introduce a phase diffe between the beams.

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[15] The 'ether' is also spelt 'aether'. Although the syllabus spells it this way (aether), the more common 'ether' will be used in this book.

[16] http://sim.jpl.nasa.gov/interferometry/michelson.html Michelson's interferometer and the ether debate.

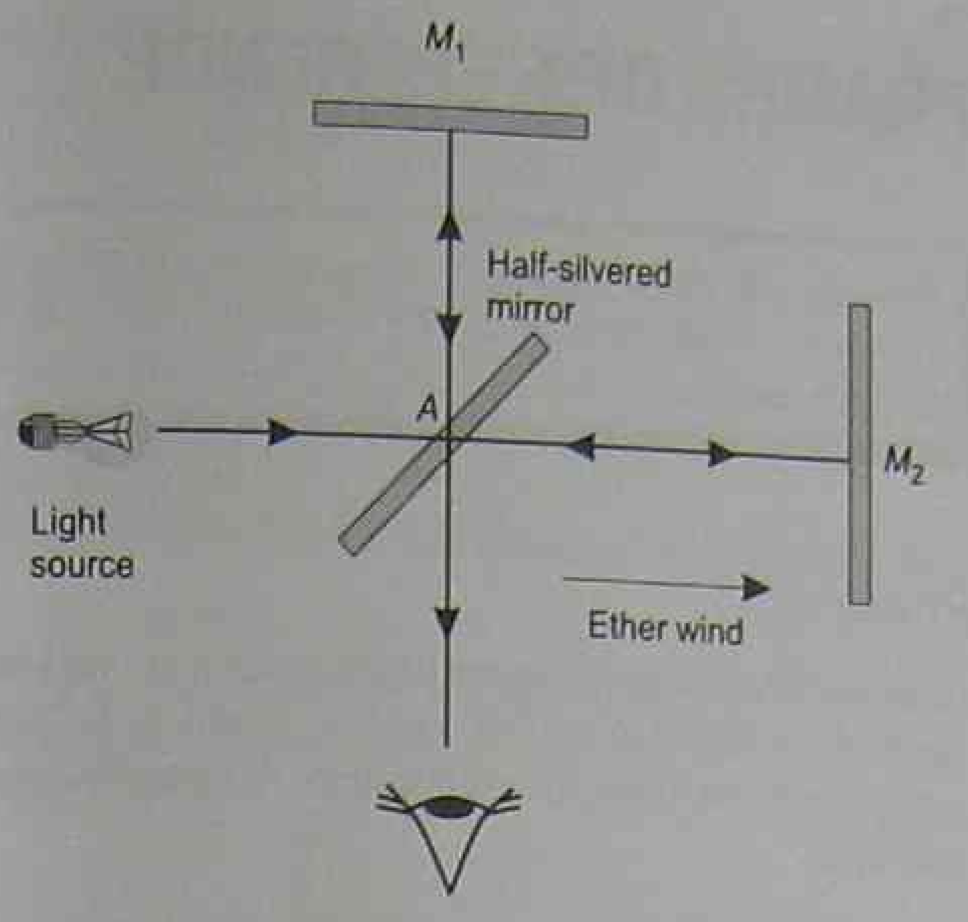


Figure 1. 21 Michelson-Morley experiment to detect the ether wind

When the entire apparatus was rotated through 90°, *a change in the interference pattern was expected* (since the rays AM_1 and AM_2 were now interchanged). None was observed even after the experiment was repeated at different times of the year and at different altitudes.

> *The result of the* **Michelson-Morley experiment** *was that no motion of the Earth relative to the ether was detectable.*

Extension

Ether Analogy

Consider a square raft *ABCD* being towed along in a non-flowing river with speed *v* relative to the riverbank as in Figure 1.22.

Swimmer 1 swims from *A* to *B* and back to *A*. Swimmer 2 swims *A* to *D* and back to *A*. Each swimmer can swim at speed *c* relative to the water. How do their times compare?

For swimmer 1:

When swimming from *A* to *B*, the swimmer's speed is *c* - *v* relative to the raft (and *c* + *v* when swimming from *B* to *A*). The time to swim from *A* to *B* and back to *A* is:

$$\begin{aligned} t_{ABA} &= t_{AB} + t_{BA} \\ &= \frac{l}{c-v} + \frac{l}{c+v} \\ &= \frac{l(c+v)+l(c-v)}{c^2-v^2} \\ &= \frac{2lc}{c^2-v^2} \\ &= \frac{\frac{2l}{c}}{1-\frac{v^2}{c^2}} \end{aligned}$$

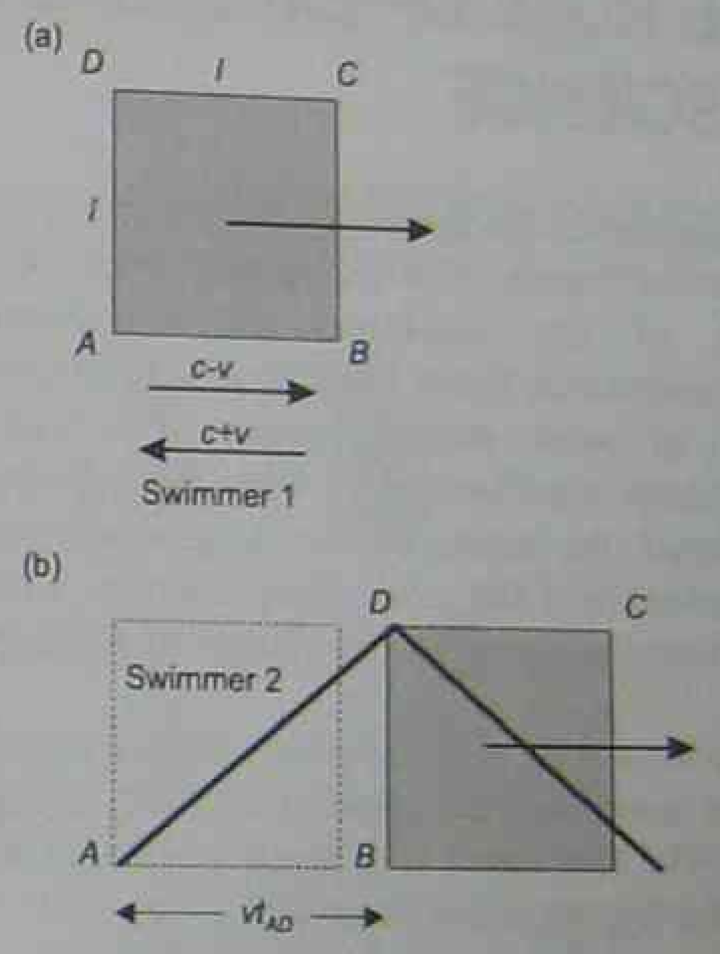


Figure 1. 22 Ether analogy

For swimmer 2, the shortest path to *D* will be along the diagonal (Figure 1.22(b)). In the time it takes to get to *D*, the raft moves a distance vt_{AD}.

$$\begin{aligned} c^2t_{AD}^2 &= l^2 + (vt_{AD})^2 \\ l^2 &= t_{AD}^2(c^2-v^2) \\ t_{AD} &= \frac{l}{\sqrt{c^2-v^2}} \\ &= \frac{\frac{l}{c}}{\sqrt{1-\frac{v^2}{c^2}}} \end{aligned}$$

The time to swim back to *A* will be the same (from symmetry) and so the total time of the swim will be:

$$t_{ADA} = \frac{\frac{2l}{c}}{\sqrt{1-\frac{v^2}{c^2}}}$$

It follows that $t_{ABA} \neq t_{ADA}$. If we replace the two swimmers with light rays and the motion of the raft through the water with the 'ether wind', we have the essence of the Michelson-Morley experiment.

THE ROLE OF EXPERIMENTS IN SCIENCE

As indicated in *The Scientific Method* in Appendix *A* of the Preliminary Course, science progresses as a result of the validation of hypotheses by experimentation. From a hypothesis, predictions are made of what should happen if a particular experiment is performed. If, when the experiment is performed, the results are not in agreement with the prediction (and the same thing happens when the experiment is repeated), the hypothesis is incorrect.

As we have seen, the Michelson-Morley experiment set out to measure the speed of the Earth through the ether. The fact that a null result was found showed the ether hypothesis to be invalid.

Although Michelson and Morley did their experiment in 1887 and Einstein proposed his theory in 1905, it is likely that Einstein did not know of the experiment, making no reference to it in his 1905 papers.

The Michelson-Morley experiment, however, provided supporting evidence for Einstein's theory allowing a choice to be made between two conflicting theories—one requiring an ether and one that did not.

To better understand the importance of the Michelson-Morley experiment, we need to look at the concept of *frames of reference*.

FRAMES OF REFERENCE

Frames of reference *are objects or coordi systems with respect to which we measurements.*

Position

In maths, the Cartesian coordinate system is use position is referred to the axes *x*, *y* and *z*. In experiments in class, the laboratory is your fra reference.

Velocity

An object *P* travels with *velocity v* with respe reference frame *S* (Figure 1.23). Another fra moves with velocity *u* relative to *S*. The velocity relative to *S'* is $\vec{v}'=\vec{v}-\vec{u}$. *Velocity thus dep upon the reference frame.*

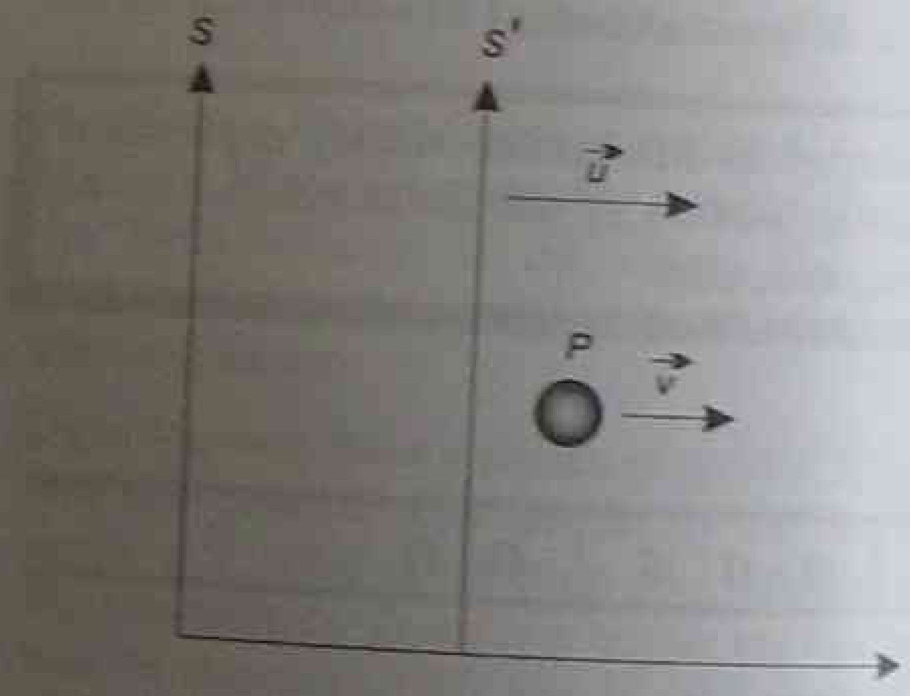


Figure 1.23 Frames of reference

Inertial Frames of Reference

An **inertial frame of reference** *is one that moving with constant velocity or is at rest (the tw conditions being indistinguishable, see Newton relativity).*

In such reference frames, Newton's Law of Ine holds.

No frame is any more correct than any other, but some are simpler. The *fixed stars* are often taken as the best example of an inertial frame.

Non-inertial Frames of reference

A **non-inertial frame of reference** *is one that is accelerating.*

In such frames observers have to postulate the existence of 'forces' to maintain the validity of Newton's Laws. These are pseudo (fictitious) or *inertial forces*.[17]

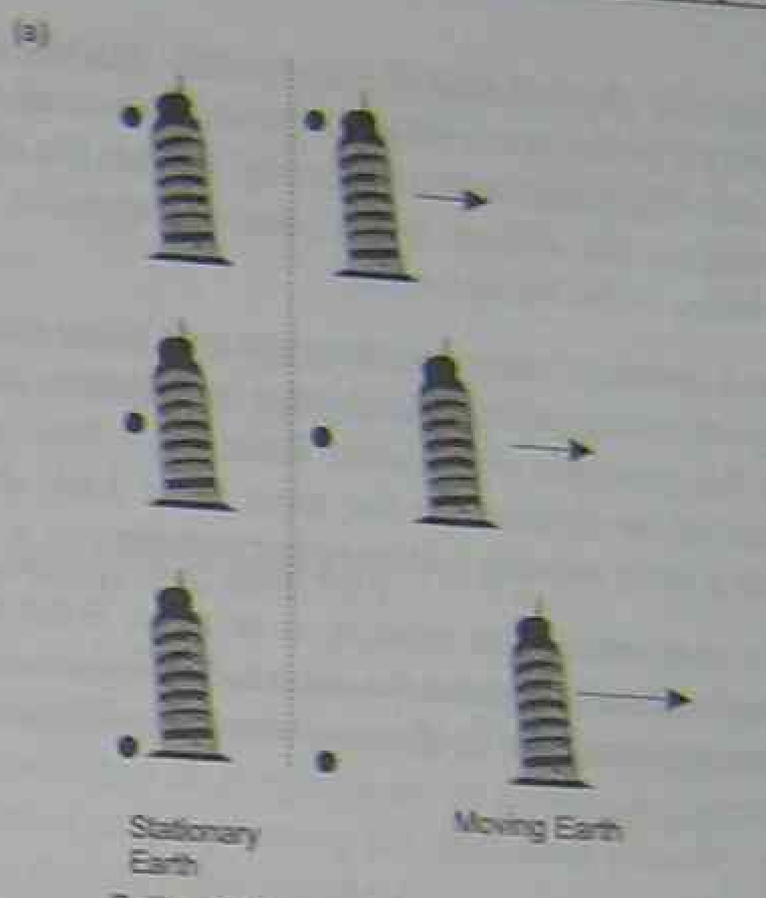
RELATIVITY

Galilean Relativity

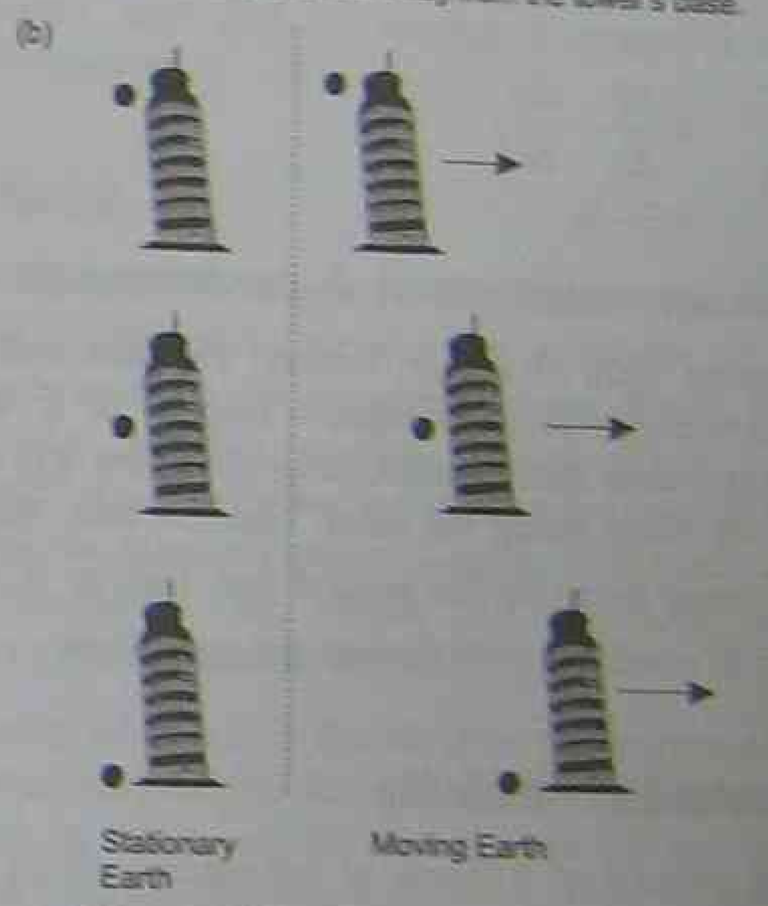
Relativity did not have its beginnings with Einstein, but goes back much further in time to Galileo and Newton.

The study of motion as we know it began with Galileo. This study necessarily involves the concepts of space and time. The view that motion must be relative, that is, it involves displacement of objects relative to some reference system—had its beginnings with Galileo.

Galileo's analysis of projectile motion led him to consider *reference frames*. As we have seen, this is what all measurements are compared to. For example, the desks and walls of the laboratory is your common frame of reference. Galileo was a strong advocate of the *heliocentric* model of the universe which has the Sun at the centre and all the planets revolving around it. This was in opposition to the *geocentric* ('Earth centred') model current in his day. Galileo's opponents believed that if the Earth moved, then a stone dropped from a tower would be 'left behind' and fall away from the tower's base as in Figure 1.24(a). This did not happen (Figure 1.24(b)), and so Galileo's critics said this showed the Earth did not move about the Sun!



Galileo's critics argued that if the Earth moved, a stone dropped from the top of the tower would be left behind and land away from the tower's base.



Galileo argued that the stone and tower have the same horizontal velocity and so would fall near the base. An observer could not tell from the stone's motion whether the Earth moved or not.

Figure 1. 24 Galileo and frames of reference

Galileo proposed that the reason the stone did not fall behind was that it shared the Earth's motion. He said the tower and the stone had the same horizontal velocity and because of the independence of the vertical and horizontal motions, the stone would fall close to the base (as actually occurred). Galileo said that looking at the stone could not tell an observer whether the Earth moved or not.

In 1642 he even devised an experiment where an object was dropped from the 'crows nest' of a sailing

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[17] Centrifugal force is an inertial force. A weightless observer in orbit around the Earth postulates an outwards force to counteract the force of gravity.

ship. He showed that the object fell straight down *relative to the mast*, whether the ship was stationary or moving with constant velocity! (When the ship is moving, the object traces out a parabolic path relative to the background.)

As a result of these experiments and other *thought experiments*, Galileo stated what has become known as the principle of Galilean Relativity—that is, *the laws of mechanics are the same for a body at rest and a body moving with constant velocity.*

We saw earlier that velocity is relative. What about acceleration? Suppose the object *P* in Figure 1.23 is now undergoing a uniform acceleration. We have:

$$\vec{v}' = \vec{v} - \vec{u}$$

Then:

$$\begin{aligned} \vec{a}' &= \frac{\Delta\vec{v}'}{\Delta t} = \frac{\Delta(\vec{v}-\vec{u})}{\Delta t} \\ &= \frac{\Delta\vec{v}}{\Delta t} - \frac{\Delta\vec{u}}{\Delta t} \\ &= \vec{a} - 0 \end{aligned}$$

since for constant velocity $\vec{u}$, the change is zero.

Newton took this idea further. He said that two observers travelling at relative velocity of $\vec{u}$ would see the same acceleration. Both observers will agree on the mass being the same[18] and so both will see the same *form* for the second law, that is: $\vec{F} = m\vec{a}$ and $\vec{F}' = m\vec{a}'$ so *both frames are equivalent.*

Newtonian Relativity

The concept of a frame of reference took on more importance with the work of Newton. Since observers in inertial frames will get the same results for experiments based on Newton's Second Law, Newton extended this to become a more general statement.

> **Newtonian relativity** *states that 'it is impossible to do any mechanical experiment, wholly within an inertial frame of reference, that can tell you whether the frame is at rest or moving with constant velocity'.*

Absolute motion

In his *Principia Mathematica* Newton defines absolute motion as *'the translation of a body from one absolute place to another'*, without expanding on what he meant by absolute place.

Similarly he defined absolute time as *'absolute true and mathematical time, of itself, and from its own nature flows equally without regard to anything external'*. Time was regarded as being independent of space.

Newton was aware that motion was relative but believed that ultimately there was a *fixed frame of reference* to which all other motions could be compared—this frame was the ether. But as we have seen (p.32), all attempts to measure the motion of the Earth through the ether proved futile.

Attempts to Explain the Negative Result of the Michelson-Morley Experiment

To preserve the idea of the ether as an absolute frame of reference a number of proposals were put forward to account for the negative result (also called a null result) of the Michelson-Morley experiment.

1 It was suggested that the Earth 'carried the ether along' with it so that there was no relative motion. Other observations (for example, the aberration of light), however, showed this to be incorrect.

2 Hendrik Lorentz in Holland and George Fitzgerald in Ireland proposed that the length of the apparatus used by Michelson and Morley *contracted in the direction of motion*. (While this 'explained' the negative result, it was simply an *ad hoc* assumption with no physical basis.) Lorentz and Fitzgerald reached this conclusion as a result of their studies of Maxwell's equations of electromagnetism viewed from different frames of reference.

Poincaré's Relativity

The investigations of Lorentz were restricted to electromagnetism and light, and it was a bold step to extend it to ordinary dynamics. But in 1904 Henri Poincaré introduced the 'Principle of Relativity' namely:

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[18] This is true for speed much less than the speed of light (see later).

> *The* **laws of physics** *are the same for a 'fixed' observer as for an observer who has a uniform motion of translation relative to him.*

This extended Newtonian-Galilean relativity to include the laws of electromagnetism (as well as the laws of mechanics).

In 1905 Einstein proposed a whole new theory of dynamics—the theory of *Special Relativity* (this theory is restricted to inertial frames of reference and neglects gravity[19]).

THE SPECIAL THEORY OF RELATIVITY[20]

In 1905 Albert Einstein proposed that:

> **The speed of light is constant** *and is independent of the speed of the source or the observer.*

This premise explained the 'negative' result of the Michelson-Morley experiment and showed that the *ether concept was not needed.*

As a consequence of this *'law of light'* it can be shown that there is no such thing as an absolute frame of reference[21]. All inertial reference frames are equivalent. That is, *all motion is relative.*

Einstein's Theory of Special Relativity represents one of the greatest changes in scientific thought since the time of Newton. It presents many apparently impossible conclusions—conclusions that appear to defy common sense. Einstein, however, described common sense as a *'deposit of prejudice laid down in the mind prior to the age of eighteen'.*

Because the effects of 'Einsteinian' relativity become obvious only at speeds approaching the speed of light, we are generally unaware of effects such as *length contraction, mass dilation* and *time dilation.*

To understand how these effects come about we have to review what we mean by measurement.

MEASUREMENT

> **Measurement** *is the process of comparing some quantity such as length, mass or time to a selected standard and expressing the measured quantity as some factor of that standard.*

It follows then that *all measured quantities are relative quantities.*

The Metre

The standard of length is the metre. This was originally defined to be one ten millionth of the distance between the equator and the North Pole along the meridian passing through Paris. This 'distance' was marked on a platinum-iridium bar and became the *standard metre*. Copies were made and sent throughout the world. All distances were *compared* to this standard.

Following advances in the accurate measurement of light wavelengths, this definition was changed to one defined in terms of the *wavelength* of the light emitted from the element krypton-86 when excited in a discharge tube.

Since 1960, our standard of distance has been defined in terms of *time* and velocity as follows:

> *The* **metre** *is the distance travelled by light in a vacuum in the fraction 1/299 792 458 of a second.*

Strange as it may seem, *our current standard of length is defined in terms of time.*

The emphasis on the processes of measurement became vital with relativity (and quantum mechanics). Our reality is what we *measure* it to be. Reality and observation cannot be separated. Remember this as we proceed.

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[19] Gravity is included in Einstein's General Theory of Relativity.

[20] http://math.ucr.edu/home/baez/relativity.html Relativity on the World Wide Web. Consists of popular science sites, animated graphics and tutorial sites. Another excellent site that gives a nice 'simple' explanation of Special Relativity is found at http://howstuffworks.com/relativity.htm

[21] That was supposed to be the role of the ether but it did not even do that task, so there was no point in having it!

Measuring Length

It is a simple matter to measure the length, say, of a stationary object. But what if the object being measured is moving? To measure the length of a moving object, such as a train passing a station, it is necessary to mark points on the station directly opposite the front and back of the train *simultaneously*. It is then a simple matter to measure the distance on the station between the points and so measure the length of the moving train.

This example of the measurement of a moving object depends for its accuracy on all observers agreeing as to the *simultaneity* of marking the front and back of the train. But will they?

SIMULTANEITY AND THE VELOCITY OF LIGHT

Galileo made an attempt to measure the velocity of light by using lanterns flashing between mountaintops. All he could conclude from his crude experiment was that the speed of light was extremely fast.

In 1676 the Dutchman Christiaan Huygens, using observations of the satellites of Jupiter made by the Danish astronomer Ole Roemer, calculated the speed of light to be 2 x 10^8 m.s^{-1}. Since then many experiments have yielded the value of $c = 3 \times 10^8$ m.s^{-1}. Although this speed is very fast, it is not infinite and hence must be taken into account when dealing with simultaneity.

Two events at *A* and *B* separated by a distance *l* will be simultaneous if the observer at *A* in Figure 1.25 records an event at *A* occurring at time *t*, and that from *B* occurring at time *t+l/c*. (Alternatively we can define two events *A* and *B* as simultaneous in a particular frame of reference, if light from these events arrives simultaneously at the mid-point between *A* and *B*.)

Figure 1.25 Simultaneous events

A GEDANKEN (THOUGHT EXPERIMENT)[22]

Assume two Einsteinian spaceships are through space with relative velocity *v* parallel other. Further assume that observers *O* and the middle of their respective spaceships highly charged points *A* and *A'* and *B* and directly opposite each other at some instant 1.26(a)).

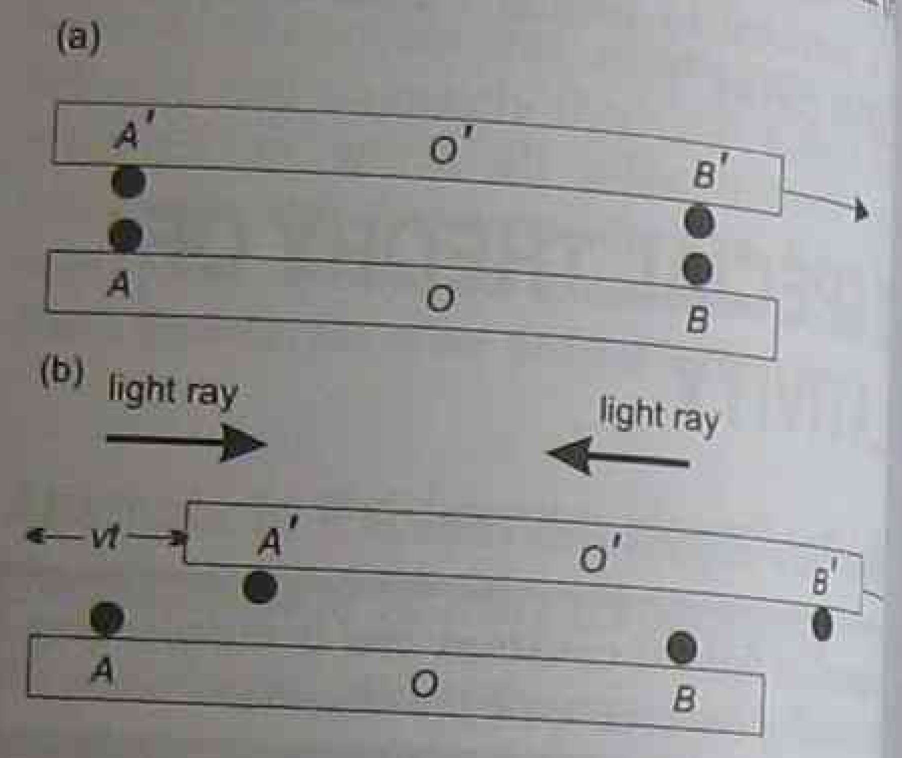

Figure 1. 26 Einsteinian spaceships

Now assume that sparks jump between *A* and *B* and *B'* so that the flashes are simultaneous Will the events also be simultaneous for *O'*?

As shown in Figure 1.26(b), in the finite time spacecraft would have moved relative to each *O* sees *O'* approaching the light from *B'* (still and receding from the light from *A'*, and hence concludes that the events are not simultaneous

Conversely if the events were simultaneous then *O'* would conclude that the events were simultaneous for *O*.

> *Observers in relative motion will disagree simultaneity of events separated in space. known as the* **relativity of simultaneity**.

From our discussion on the measurements of objects and simultaneity, it should be clear lengths of moving objects depend upon the reference from which they are measured!

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[22] A thought experiment is an experiment that is 'all mind'. Einstein used such thought experiments to his Theory of

IMPLICATIONS OF SPECIAL RELATIVITY

Consider a spacecraft moving at a speed of *c/2* (that is, half the speed of light) towards another planet. An astronaut in the spacecraft now flashes a light beam in the direction of the motion of the spacecraft. What is the speed of the light relative to the planet? Prior to Einstein we would have said 3*c*/2 but now we know it is *c*. How can this happen?

To measure speed we need to measure distance and time. If *c* remains constant, then it follows that distance (length) and time must change! *Space and time are relative concepts. So too is mass.*

Length Contraction

> **Length contraction** *is where the length of a 'moving' rod appears to contract in the direction of motion relative to a 'stationary' observer.*

Lorentz-Fitzgerald Contraction Equation

$$\boxed{l = l_0\sqrt{\left(1-\frac{v^2}{c^2}\right)}}$$

where *l* is the moving length, l_0 is the 'rest' length (that is, the length as measured by an observer at rest with respect to the rod) and *v* is the speed of the rod.

(This was Lorentz's original 'explanation' for the negative result of the Michelson-Morley experiment, but now it has a physical basis.)

Consider Figure 1.27, which shows how a 'flying saucer' would appear to different observers, one at rest with respect to the saucer and one who is moving relative to the saucer. Note that the contraction is in the direction of motion only (resulting in a flying 'ellipse'!).

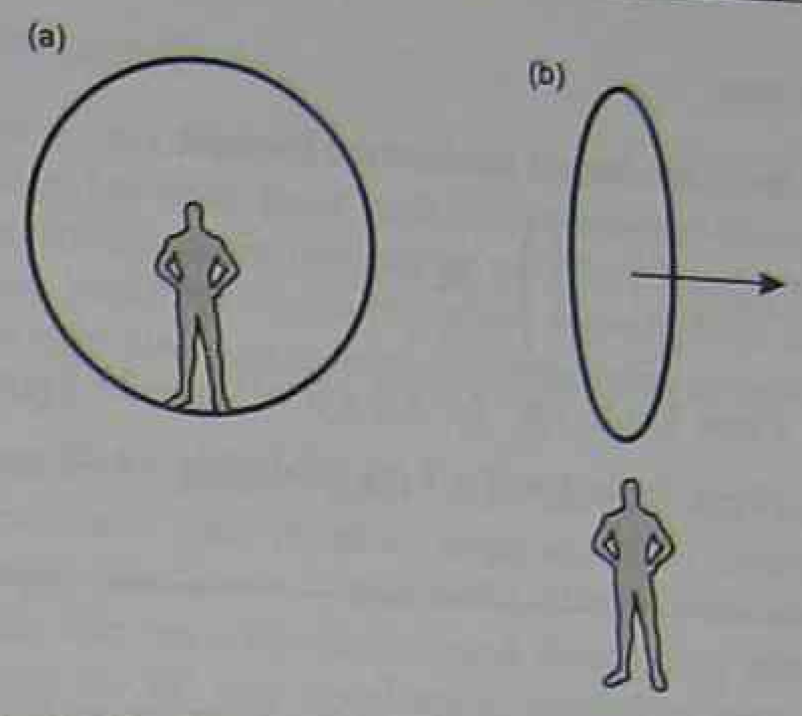

Figure 1. 27 Flying saucers

The factor $\sqrt{1-\frac{v^2}{c^2}}$ and its reciprocal $\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ are central to special relativity. Table 1.6 gives the values of these for a range of values of *v* (expressed as a fraction of the speed of light). We will refer back to this table in the examples to follow.

Table 1. 6

v	$\beta = \sqrt{1-\frac{v^2}{c^2}}$	$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
0.1*c*	0.995	1.005
0.5*c*	0.886	1.155
0.75*c*	0.661	1.512
0.9*c*	0.436	2.29
0.99*c*	0.141	7.08
0.999*c*	0.0447	22.37

EXAMPLE 18

A spacecraft moves away from the Earth. If an observer on the spacecraft measures some object to be 1.0 m long, what length does an observer on the Earth determine this object to be if:

(a) the spacecraft is moving at 0.1*c*?

(b) the spacecraft is moving at 0.999*c*?

SOLUTION

We have the length contraction formula:

$$l = l_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = \beta l_0$$

(a) From Table 1.6: $l = 1.0 \times 0.995$ m = 99.5 cm

(b) From Table 1.6: $l = 1.0 \times 0.0447$ m = 4.47 cm!

We can see that *according to the observer on Earth*, the object on the spacecraft has shrunk (in length).

Time dilation[23]

Time dilation *is where the time in a 'moving' frame appears to go slower relative to a 'stationary' observer.*

Time dilation equation:

$$\boxed{t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \gamma t_0}$$

where t is the observed time for a 'stationary' observer and t_0 is the time for an observer travelling in the frame and $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

t_0 is called the *proper time*. This is the time measured by an observer present at the same location as the events that indicate the start and end of an event.

How Do We Know that Time Dilates?

A number of experiments have been conducted that have conclusively proven time dilation actually happens. In one celebrated experiment, two extremely accurate atomic clocks were synchronised. One of the clocks was then flown around the world in a plane and the other clock remained on the ground. When they were brought back together and compared, the clock that had been in the plane lagged slightly behind the one left behind. Although the difference was very small, nevertheless it was measurable.

A second famous experiment involves a subatomic particle called a muon that is created in the upper atmosphere by cosmic rays. Muons are unstable and disintegrate in a lifetime of 2.2 μs (in their reference frame). In this time, they should not be able to reach the Earth's surface regardless of their enormous speed of ~0.999*c*. Regardless, they are found at the Earth's surface. Relative to observers on the Earth, their lifetime is dilated (= 22.37 x 2.2 = 49.2 μs), sufficient for them to reach the Earth.

Time dilation today, is a well-accepted scientific fact.

EXAMPLE 19

If one hour of time passes for the observer on the spacecraft, how much time passes (on the spacecraft) from the point of view of the observer on Earth, i the velocity of the spacecraft is:

(a) 0.5*c*?

(b) 0.9*c*?

SOLUTION

We have the time dilation formula:

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

(a) We have $t_o = 1$ h. From Table 1.6 we then have $t = 1.0 \times 1.154 = 1.154$ hours (that is, 69 mi 14 sec).

(c) From Table 1.6 we have: $t = 1.0 \times 2.2$ = 2.29 hours (that is, 137 min 24 sec).

The time, *as measured by the observer on the Earth* has been lengthened (dilated). (For an observer in the spacecraft, his clock works perfectly correctly; b sees the clocks on the Earth going slow!)

---

[23] http://www.walter-fendt.de/ph11e/timedilation.htm Physics applet that simulates time dilation.

Extension

Proof of Time Dilation (Another Gedanken)

Consider a simple light 'clock' as shown in Figure 1.28(a). The clock operates by bouncing a light beam from mirrors. The clock registers one click for one complete up and down motion. When viewed by an observer travelling with the clock, the light follows the path as indicated in Figure 1.28(a). From the point of view of an observer who sees the clock moving past at constant speed, the path is as in Figure 1.28(b). This path is longer than that in Figure 1.28(a) and since both observers agree on the speed of light, as being *c* then the outside observer must conclude that time lengthens!

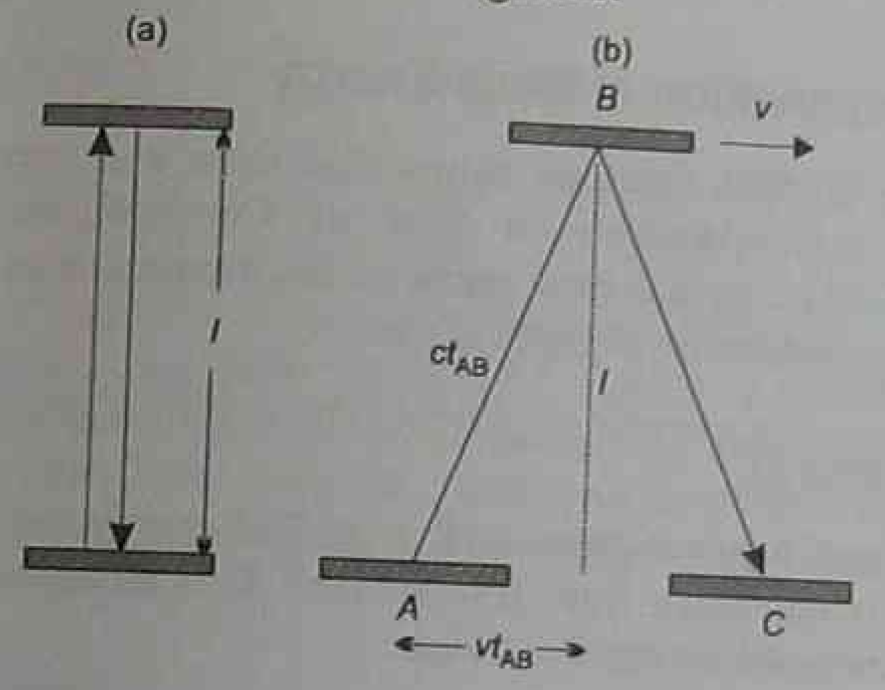

Figure 1. 28 Time dilation

Mathematically:

In Figure 1.28(a): $t_0 = \frac{2l}{c}$

In Figure 1.28(b): Pythagoras' Theorem gives:

$$(ct_{AB})^2 = (vt_{AB})^2 + l^2$$

$$t_{AB} = \frac{\frac{l}{c}}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$t_{ABA} = \frac{\frac{2l}{c}}{\sqrt{1-\frac{v^2}{c^2}}} = t$$

$$\therefore t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

'Biological Clocks'

Our simple 'light clock' seems to indicate that time dilates but what about 'real clocks' such as those that operate on quartz crystals or with gears and levers? How could they possibly slow down? What about our own biological clocks that determine growth and aging?

Special relativity states that *all moving clocks experience time dilation*, even our own biological clocks (see *Space Travel* p.43). If this were not the case, then we could determine a discrepancy between 'light clocks' and 'mechanical clocks' or own body clocks and so infer we were moving. This, however, violates the view that all inertial frames of reference are equivalent.

Mass dilation

Not only do length and time depend on an object's speed but so too does its mass.

The mass of a 'moving' object is greater than when it is 'stationary'. This effect is called **mass dilation.**

As an object's speed increases, the mass of the object changes as shown in Figure 1.29 according to the mass dilation formula below.

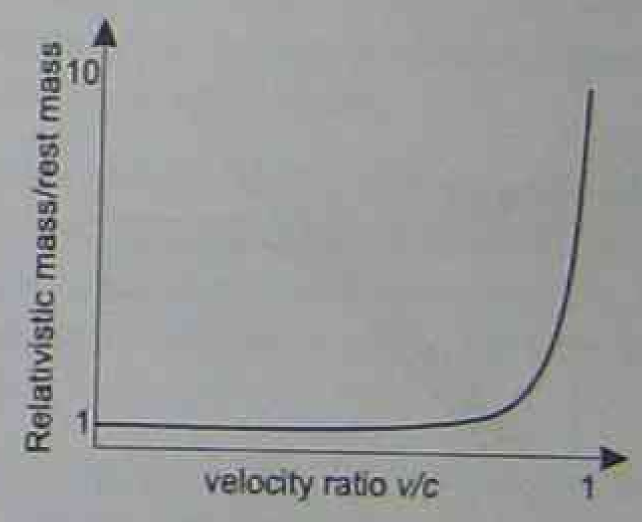

Figure 1. 29 Effect of increasing speed on mass

Mass dilation Equation:

$$\boxed{m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} = \gamma m_0}$$

where m is the mass for a 'moving' object and m_0 is the mass for that object when it is 'stationary'—the *rest mass*.

EXAMPLE 20

A 1 kg mass is accelerated to a speed of 0.75*c*. What is its mass as determined by a stationary observer?

SOLUTION

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} = \gamma m_0$$

and from Table 1.6 we find $\gamma = 1.512$ so relativistic mass = 1 x 1.512 = 1.512 kg

How do we know that mass must increase for a moving object relative to a stationary observer? Since c is the maximum speed in the universe then it follows that a steady force applied to an object cannot continue to accelerate the object indefinitely or else it would cause the object's speed to exceed c. This means the inertia, that is the resistance to acceleration of the object, must increase. But inertia is a measure of mass and so the mass increases causing the acceleration to get less and less so that the object never reaches c as indicated in Figure 1.30.

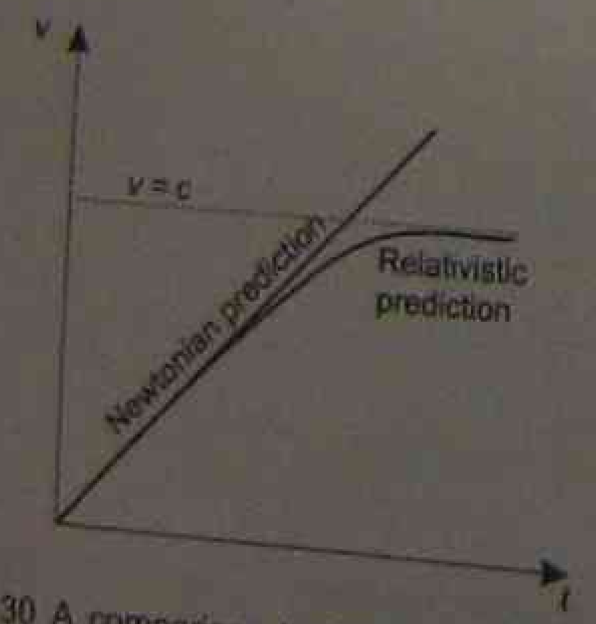

Figure 1. 30 A comparison between the Newtonian and Einsteinain predictions of the effect of increasing the speed on the mass

As with length and time, the mass measured by an observer travelling with the object is unchanged.

The question remains, where does this mass increase come from?

MASS-ENERGY

When we do work on an object we increase its kinetic energy ($E_k = \frac{1}{2}mv^2$). As the speed approaches c we still do work but he kinetic energy does not increase significantly. The work goes into increasing the object's mass according to Einstein's famous equation:

$$\boxed{E = mc^2}$$

where $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} = \gamma m_0$

Conservation of Mass-Energy

The Einstein equation shows that mass and energy are interchangeable—a Law of Conservation of Mass-Energy has now replaced the separate laws of mass and energy conservation.

EXAMPLE 21

1 kg of water requires 4.18 x 10^5 J of energy to raise its temperature from 0°C to 100° C. Calculate the corresponding mass increase.

SOLUTION

$$E = mc^2 \Rightarrow m = \frac{E}{c^2}$$

$$m = \frac{4.18\times10^5}{(3.0\times10^8)^2}$$

$$= 4.6\times10^{-12}\ \text{kg}$$

This example shows that the conversion of energy into mass (and mass into energy) can be ignored in physical changes. This is also true for chemical changes.

The conversion of mass into energy occurs in nuclear fission and fusion. In nuclear physics however, where particles can be accelerated to speeds close to the speed of light, the conversion of mass and energy cannot be ignored.

Because the amounts of energy for individual reactions is small when expressed in SI units (joules), a new unit of energy is used—the *electron volt*.

The Electron-Volt

One **electron-volt** (eV) *is the energy gained by an electron accelerated through a potential difference of one volt.*

It can be shown that:

1 eV = 1.602 x 10^{-19} J

1 keV = 1.602 x 10^{-16} J

1 MeV = 1.602 x 10^{-13} J

Since mass and energy are equivalent, physicists often give the mass of subatomic particles in energy units/c^2. For example, the mass of a proton is stated as:

$$m_p = 938/c^2$$

EXAMPLE 22

The mass of an electron and its antiparticle the positron are each 9.1 x 10^{-31} kg. In a collision between an electron and a positron the two particles are annihilated and two equal energy gamma rays are produced. Calculate the energy of the gamma rays.

SOLUTION

The energy of the gamma rays is found from:

$$E = mc^2$$

$$= 2\times9.1\times10^{-31}\times(3.0\times10^8)^2$$

$$= 1.638\times10^{-13}\ \text{J}$$

$$= \frac{1.638\times10^{-13}}{1.6\times10^{-16}}\ \text{keV}$$

$$= 1024\ \text{keV}$$

Hence each gamma ray has energy of 512 keV

SPACE TRAVEL AND RELATIVITY

Science fiction writers and film producers often have *time travel* as a theme where people can be transported into the future or back into the past. Is this possible, and if so what are the implications for space travel? Let us begin with a simple example.

EXAMPLE 23

Twins *Bib* and *Bub* are separated at birth. Bub is placed in a spacecraft that leaves Earth and travels at a speed of 0.75*c*. Bib remains on Earth. When Bib reaches his 80th birthday (in Earth years), how old does he determine his twin Bub to be?

SOLUTION

Since Bub is moving at 0.75*c* relative to Bib, then according to Bib (and using Table 1.6), Bub is now approximately 80 x 1.5 Earth years old (~120!), *as measured by Bib's clocks.*

Conversely, on his 80th birthday, Bub will determine that Bib is now ~120 years old (*by Bub's clocks*). Who is correct? They both are! This appears at first to be nonsense. It has to be remembered, however, that Bib and Bub are in different frames of reference and hence can differ in their answers. There is no reference frame that is any more correct than any other.

The Twin Paradox

The previous example leads us to one of the celebrated paradoxes of relativity—the *twin paradox.*

According to Bib, Bub will age more slowly. (For every 1.5 of Bib's years, only 1 year will pass for Bub.) But since all motion is relative, then according to Bub, Bib ages more slowly.

If Bib now returns to Earth, will he and Bub agree on who has aged the least? (Remember each thinks the other ages less. *Since they are back in the same reference frame they must agree* but they both can't be right.)

The paradox is resolved when we remember that the Special Theory of Relativity *applies in inertial frames of reference only*[24]. But Bub has left the Earth, accelerated to reach 0.75*c*, reversed direction to return to Earth and then decelerated to come to rest. Bub is therefore in a non-inertial frame of reference and so the rules do not apply to him.

---

[24] The General Theory of Relativity applies to non-inertial frames of reference.

How to be Younger Than Your Twin

The rules of special relativity, however, apply to Bib's observations. Bib sees Bub age slower[25]. At 0.75*c*, 1.5 of Bib's years pass for every one of Bub's years. Suppose that 60 years elapse (according to Bib) before Bub returns. Then Bub only ages by 60/1.5 = 40 years. Although born at the same time, Bub is now 20 years younger than Bib!

Time Travel

If Bub had travelled at 0.999*c*, he would have aged by 60/22.37 = 2.68 years. (Obviously the faster the velocity, the less time elapses.)

Time dilation suggests that it may be possible to travel in one lifetime to distant stars. *But there is a catch.* Suppose you wish to travel to a star 100 light years away at 0.999*c* relative to Earth. At this speed, slightly over 100 Earth years elapse as measured by an observer on the Earth. As measured by you in the spacecraft it takes only 100/22.37 = 4.47 years.

You could get to your destination but you could not go back to the era you left. Over 200 Earth years would elapse before you could return. Everyone you knew would be dead (unless by then we have found the answer to aging).

The relativity of time allows for space travel in to the future but not into the past.

Length Contraction

Relative to an observer on Earth, time for the astronauts on the spacecraft goes slower so the astronauts age less than their contemporaries back on Earth.

Relative to the astronauts, their destination is closer than would be determined by Earth-bound observers. Length contraction would occur (they see the planet or star approaching them) and so the astronauts would calculate less distance to travel. Remember, the astronauts see no time dilation—they age 'normally' as far as they are concerned.

Mass Dilation

The feasibility of space travel is not only affected b time dilation (and length contraction) but also b mass dilation. As the spacecraft speeds up, its ma increases so that if the thrust of the engines (or io drive, solar sail...) is constant, the acceleratio decreases. The thrust becomes less and less effecti in accelerating the spacecraft, limiting the speed th can be reached (even in the time-dilated lifetime o the crew).

---

[25] The Theory of General Relativity applied to Bub also shows Bub aging less than Bib.

SUMMARY

- Weight is the force on an object due to a gravitational field.
- The gravitational potential energy is a measure of the work done in moving an object from infinity to a point in the field.
- A projectile is any object moving under the influence of gravity only.
- Projectile motion is composed of a horizontal component with constant velocity and a vertical component with constant acceleration.
- The escape velocity is the velocity needed for an object to escape from the Earth (or other planet or moon). It depends on the radius and mass of the planet and the gravitational constant.
- The motion of an object in a circular path with constant speed is called *uniform circular motion* (UCM).
- For an object moving with UCM, the acceleration is directed towards the centre of the circle.
- *g*-forces are measured in units of the Earth's gravitational acceleration, *g*.
- A geostationary orbit is one in which the satellite has a period of 24 hours.
- 'Gravity-assist' trajectories are used to send space probes to distant planets.
- Safe re-entry to Earth is limited to a small 'window'. This ensures that the spacecraft does not 'bounce' off into space and the *g*-forces are not too high for the astronauts.
- The ether is the medium proposed prior to Einstein to transmit electromagnetic radiation.
- The Michelson-Morley experiment showed that the speed of the Earth relative to the ether could not be detected.
- An inertial frame of reference is one moving with constant velocity (or is at rest).
- Einstein proposed that the speed of light is constant and is independent of the speed of the source or observer.
- The principle of relativity is that the laws of physics are the same for all inertial observers.
- Two or more events that are simultaneous for one observer are not necessarily simultaneous for observers in different inertial frames of reference.
- The length of a moving rod appears to contract in the direction of motion relative to a stationary observer.
- Time in a moving frame appears to be slower relative to a stationary observer.
- The mass of a moving object increases in relation to a stationary observer.
- Mass and energy are different forms of the same entity.
- Relativity 'allows' for travel into the future but not into the past.

Key Terms:

centripetal acceleration
circular motion
escape velocity
ether
geostationary
g-forces
gravitational potential energy
gravity
length contraction
mass dilation
mass-energy
Michelson-Morley experiment
orbit
projectile motion
relativity
simultaneity
time dilation
trajectory
twin paradox
universal gravitation
weight

QUESTIONS AND PROBLEMS ON SPACE

Section 1: Gravity

The following data may be required to answer some of these questions.

Mass of Earth = 5.983×10^{24} kg

Radius of Earth = 6380 km

$G = 6.67 \times 10^{-11}$ N.m^2.kg^{-2}

1 Write the mathematical statement of Newton's Law of Universal Gravitation. Explain the meaning of each term.

2 Define the following terms:

(a) gravitational field

(b) weight

(c) gravitational potential energy.

3 Given that the radius of the Earth is 6380 km, find the acceleration due to gravity at a height of 1600 km above the Earth's surface.

4 On another planet the acceleration due to gravity is found to be 25 m.s^{-2}. Calculate the weight of an object on this planet if it weighs 80 N on Earth.

5 Calculate the change in gravitational potential energy for a satellite of mass 1000 kg put into a geostationary orbit, 35 800 km above the Earth's surface

Section 2: Space Launch and Return

1 Define the following terms:

(a) projectile motion

(b) trajectory

(c) horizontal component

(d) vertical component.

2 In projectile motion, the vertical and horizontal motions are independent of one another.

(a) Explain why they are independent.

(b) How is this information used in solving problems on projectiles?

3 A stone is projected horizontally out to sea fro the edge of a cliff 100 m high. Given that the stone is thrown with an initial speed of 10 m.s find:

(a) the time the stone takes to hit the water

(b) the distance from the cliff base at which th stone hits the water (assuming the cliff fa is vertical)

(c) the velocity at this instant (size and direction).

4 A projectile is fired with an initial velocity of 1000 m.s^{-1} at an angle of 30 degrees with the ground. Find:

(a) the maximum height reached by the projectile

(b) the time to reach the maximum height

(c) the range, that is, the horizontal displacement of the projectile.

5 A bomber, flying horizontally at 1000 m above the ground at 300 m.s^{-1}, drops a bomb to reac a target. Find:

(a) the horizontal distance at which the plane must release its bomb in front of the targe

(b) the angle at which the bomb strikes the ground.

6 Define the following terms:

(a) escape velocity

(b) *g*-forces.

7 The planet Mercury has a lower escape veloci than the Earth. Explain why this is so.

8 Compare the similarities, if any, which exist between Newton's concept of escape velocity and current methods for placing spacecraft int orbit around the Earth.

9 Explain how an object can have a constant speed but a changing velocity. Give an examp of where this occurs.

10 Define the following terms:

(a) orbital speed

(b) period

(c) centripetal acceleration.

11 How does the Earth's orbital and rotational motion affect the launch of a rocket?

12 One of the uses of the *Space Shuttle* is to plac communications satellites into orbit above the Earth. These satellites need to be placed in 'geostationary' orbits.

(a) Explain the meaning of a geostationary orbit.

(b) Calculate the period of such an orbit.

(c) What is the orbital speed of the satellite if it is placed at a height of 36 000 km above the Earth? (The radius of the Earth is 6380 km.)

(d) What is the centripetal acceleration of the satellite?

13 Explain why satellites in low Earth orbits eventually burn up.

14 Describe the issues affecting the safe re-entry of manned spacecraft returning to Earth.

Section 3: The Solar System

1 Define Newton's Law of Universal Gravitation.

2 Describe the meaning of a gravitational field.

3 Newton's Law of Universal Gravitation determines the motion of satellites and spacecraft. Explain.

4 So-called 'gravity-assist' ('slingshot') trajectories should more correctly be called 'angular momentum-assist' trajectories. Explain.

Section 4: Special Relativity

1 Define the following terms:

(a) the ether

(b) frames of reference

(c) the principle of relativity

(d) time dilation

(e) length contraction

(f) mass dilation

(g) mass-energy.

2 Describe the significance of the Michelson-Morley experiment.

3 *'The speed of light is the same for all observers in inertial frames of reference.'* Explain the significance of this statement.

4 Explain how it is possible for two events to be simultaneous for one observer and the same two events to not be simultaneous for a second observer.

5 An electron moving at 0.5c moves a distance of 1.0 m in the frame of reference of the laboratory. What distance does the electron move in the frame in which the electron is at rest?

6 A spaceship leaves the Earth to travel to a star 5 light years away. If it can travel at 0.6c, calculate how long the trip takes:

(a) as measured by observers on Earth.

(b) as measured by the crew.

7 An electron of rest mass 9.1×10^{-31} kg is travelling at a speed of 0.9c. Calculate its mass relative to a stationary observer.

8 What is a *Gedanken*?

9 Explain the significance of the 'twin paradox' in relativity.

TEST ON SPACE

Multiple Choice Questions

Choose the letter A, B, C or D that corresponds to the correct answer.

1 Two bodies of mass m_1 and m_2 whose centres are separated by a distance *d* attract each other with a gravitational force of *F*. If the mass of each body is doubled and their separation reduced to one-quarter of its original value, the new force of attraction is given by:

(A) *F*

(B) 16*F*

(C) 32*F*

(D) 64*F*

2 Table 1.7 shows the masses and radii of four imaginary planets expressed as ratios of the Earth's mass and radius.

Table 1. 7

Planet	Mass (x Earth's mass)	Radius (x Earth's radius)
W	4	3
X	2	4
Y	½	1
Z	½	½

An astronaut landing on the four planets would have the greatest weight on:

(A) W

(B) X

(C) Y

(D) Z.

3 A satellite of mass m travels with a speed v in a circular path of radius R (between centres) around a planet of mass M. The equation which best describes the motion of the satellite is:

(A) $\frac{mv^2}{R} = \frac{T^2}{R^3}$

(B) $\frac{mv^2}{R} = \frac{GM}{R^2}$

(C) $\frac{mv^2}{R} = \frac{GMm}{R^2}$

(D) $\frac{GMm}{R^2} = \frac{T^2}{R^3}$

4 In 1610 Galileo discovered four moons of Jupiter—Europa, Callisto, Io and Ganymede. Their periods are shown in Table 1.8.

Table 1. 8

Moon	Period (days)
Europa	3.6
Callisto	16.7
Io	1.8
Ganymede	7.2

On the basis of Kepler's Laws, the order of the moons from Jupiter starting with that closest to the planet is:

(A) Callisto, Ganymede, Europa, Io

(B) Io, Europa, Ganymede, Callisto

(C) Europa, Callisto, Io, Ganymede

(D) Io, Callisto, Europa, Ganymede.

5 In Newton's imaginary analysis of projectile motion, a cannon was used to fire a cannon ball horizontally from the top of a high mountain. Which of the graphs in Figure 1.31 best represents the horizontal velocity of the cannon ball against time if we neglect air resistance?

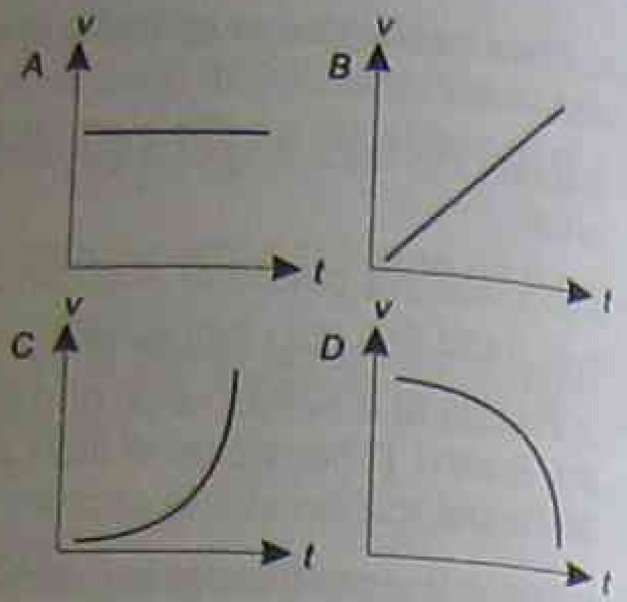

Figure 1. 31

6 As the *Space Shuttle* orbits the Earth in a circular orbit, it has:

(A) a constant velocity but a changing speed

(B) no resultant force acting on it

(C) a constant speed but a changing velocity

(D) a constant velocity and a constant acceleration.

7 As a rocket accelerates from the launch pad, the acceleration:

(A) increases as less fuel is burnt per second

(B) increases since the mass of the spacecraft and rockets decreases

(C) decreases due to air resistance

(D) decreases since less fuel is available.

8 A small 'window' exists for safe re-entry of spacecraft to Earth. This 'window' is determined by:

(A) the size of the spacecraft

(B) the landing site

(C) the hole in the ozone layer

(D) a compromise between generating too much heat and keeping within safe *g*-forces

9 The rocket pioneer who first suggested multi-stage rockets be used for space flight was:

(A) Tsiolkovsky

(B) Goddard

(C) Oberth

(D) von Braun.

10 According to Galilean-Newtonian relativity, all but one of the following statements is correct. Which is the incorrect statement?

(A) The laws of mechanics are the same for an observer at rest and one moving at a constant velocity relative to the first.

(B) The velocity of an observer A relative to another observer B is given by $\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$

(C) The length of a moving object depends upon the reference frame from which it is viewed.

(D) The speed of light c is relative to the ether.

11 The incorrect statement is:

(A) Galileo attempted to measure the speed of light but could only conclude it was extremely fast.

(B) All measured quantities are relative quantities.

(C) Newton regarded space and time as being dependent.

(D) The ether was believed to be the medium through which light could propagate.

12 For the Michelson-Morley experiment, which statement is incorrect?

(A) No motion of the Earth relative to the ether was detected.

(B) The speed of light depends on the motion of the observer through the ether.

(C) Interference methods were used to look for motion through the ether.

(D) No ether wind was detected.

13 If two separated events are simultaneous for an observer, then the same two events will:

(A) be simultaneous for all other observers

(B) not be simultaneous for an observer moving with constant velocity relative to the first observer

(C) be simultaneous only for observers in inertial frames of reference

(D) be simultaneous for a second observer only if the events are separated by a distance less than one light year.

14 An astronomer measures the speed of recession of a distant galaxy by means of its 'red shift' as 3c/4. Radio signals coming from the galaxy reach Earth at:

(A) c

(B) 3c/4

(C) c/4

(D) c/2.

15 A metre rule is seen by an observer stationary with respect to the rule, and by a second observer moving at a speed of c/2 relative to the rule. The second observer observes the rule to be:

(A) 1.0 m

(B) much more than 1.0 m

(C) slightly more than 1.0 m

(D) slightly less than 1.0 m.

SHORT ANSWER QUESTIONS

In keeping with the format of the HSC sample marks are given for each question.

Answer the following questions in approximately three lines of writing, calculation or diagram.

16 Given that the radius of the Earth is 6380 km, calculate the acceleration due to gravity at a height of 900 km above the Earth's surface. (2 marks) The following data may be required:

Mass of Earth = 5.983×10^{24} kg

$G = 6.67 \times 10^{-11}$ N.m^2.kg^{-2}

17 A ball rolls off a horizontal table with an initial velocity of 2.0 m.s^{-1}. If the table is 70 cm high, calculate how far out from the edge of the table the ball lands. (2 marks)

18 Briefly explain the physical principles that underlie the action of a rocket. (2 marks)

19 Astronauts experience '*g*-forces' when they are launched into space.

(a) What are *g*-forces? (1 mark)

(b) Identify the problems of having large *g*-forces acting on the astronauts. (2 marks)

20 All spacecraft rely on multi-stage rockets to get them free of the Earth. Explain why single-stage rockets are not sufficient. (2 marks)

21 The speed of a satellite orbiting the Earth in a circular orbit of radius R is given by $v^2 = \frac{GM_E}{R_E}$.

(a) Demonstrate how this equation can be derived. (3 marks)

(b) A geostationary communication satellite is placed in orbit at a height of 35,800 km above the Earth's surface. Calculate the orbital speed required to keep it in such a geostationary orbit. (2 marks)

22 Neptune has two satellites, Triton and Nereid. They have periods of 5.8 days and 360 days respectively. Calculate the ratios of their orbital radii. (2 marks)

23 Table 1.9 contains information about four of the planets. Use this data to demonstrate that Jupiter obeys Kepler's Law of Periods. (2 marks)

Table 1. 9

Planet	Period (years)	Average radius (AU)
Venus	0.615	0.7233
Earth	1	1
Jupiter	11.87	5.203
Saturn	29.46	9.539

24 Table 1.10 contains information about the planets Uranus and Pluto. Use this data to calculate the mass of Pluto. (2 marks)

Table 1. 10

Planet	Orbital Period (years)	Average distance from Sun (km)
Uranus	84.0	2.87×10^9
Pluto	248.4	5.91×10^9

25 Briefly describe the contribution to rocketry of one of the following pioneers:

(a) Tsiolkovsky

(b) Esnault-Pelterie

(c) Goddard

(d) Oberth. (3 marks)

26 (a) What was the purpose of the Michelson-Morley experiment? (1 mark)

(b) What role did the half-silvered mirror serve? (1 mark)

(c) Explain why an interferometer was used in the experiment. (1 mark)

(d) Recall the result of the experiment. (1 mark)

27 Explain the meaning of the phrase 'the relativity of simultaneity'. (3 marks)

28 Experiments prove that the speed of light is constant and is the same for all observers moving with constant velocity relative to each other. Give *three* consequences that result from this fact of nature. (3 marks)

29 By reference to a hypothetical 'light clock', describe why time is dilated (lengthened) for a moving observer when measured by a stationary observer. (3 marks)

30 An unidentified flying object (UFO) is observed by a stationary observer to be 10 m long and travelling at 0.4*c*.

(a) Calculate the length of the UFO as measured by the extraterrestrial pilot. (1 mark)

(b) Calculate how long an observer on Earth measures as having elapsed if the extraterrestrial pilot measures 1 hour of his time to have passed. (1 mark)

LONGER ANSWER QUESTIONS

Answer the following questions in approximately fi lines of writing, calculation or diagram.

31 A stone is projected with an elevation of 30 degrees out to sea from the edge of a vertic cliff 49 m high. Given that the stone is thrown with an initial speed of 29.4 $m.s^{-1}$, calculate:

(a) the time the stone takes to hit the water (1 mark)

(b) the distance from the cliff base at which the stone strikes the water (1 mark)

(c) the magnitude of the velocity at this instant (2 marks)

32 The satellite Phobos describes a nearly circular orbit of radius 9.7×10^6 m round the planet Mars with a period of 2.75×10^4 s. Given that $G = 6.67 \times 10^{-11}\ N.m^2.kg^{-2}$:

(a) Calculate the mass of Mars from this information. (2 marks)

(b) The period of revolution of the other Martia satellite, Demos, is 1.09×10^5 s. Calculate the radius of its orbit. (2 marks)

33 Describe the basic principles behind sending a spacecraft to the moon. (5 marks)

---

34 Figure 1.32 shows an *Apollo* spacecraft re-entering the Earth's atmosphere after completing its trip to the Moon.

(a) Briefly discuss why the 're-entry corridor' is restricted to 6.2 ± 1° to the horizontal. (4 marks)

(b) Describe how the Space Shuttle controls its re-entry. (3 marks)

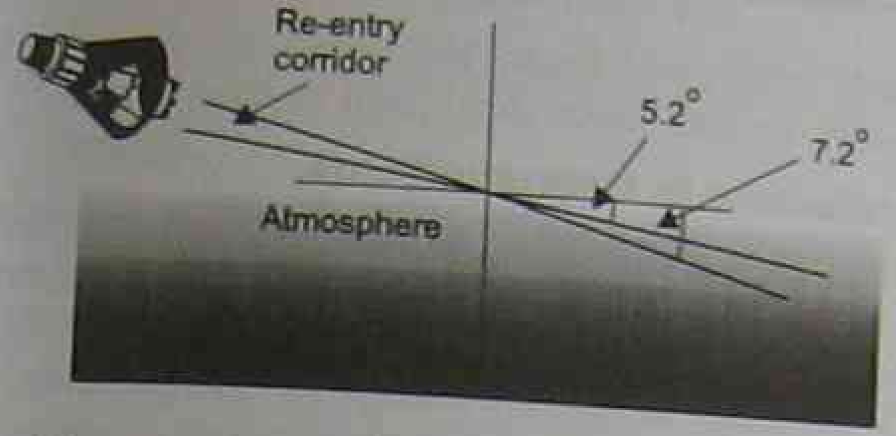

Figure 1. 32

35 This question refers to the Michelson-Morley experiment.

(a) Recall two reasons put forward prior to Einstein to 'explain' the negative results of the experiment. (2 marks)

(b) Describe how Einstein explained the result. (2 marks)

(c) Recall one implication that comes from Einstein's explanation and explain how this occurs. (2 marks)

36 This question refers to relativity.

(a) Define the meaning of the ether. (1 mark)

(b) Mu-mesons (muons) are elementary particles that come to Earth in cosmic ray showers. They disintegrate spontaneously after an average lifetime of 2.2×10^{-6} s (in their reference frame). Even allowing for their fast speed (0.999c), in this short lifetime they should not be able to travel more than 600 m. The muons, however, are created at the top of the atmosphere some 10 km up and reach the Earth's surface (where they are detected in laboratories). How can this be explained:

(i) in the reference frame of the muon? (1 mark)

(ii) in the Earth' reference frame? (1 mark)

37 A spaceship passes you at a speed of 0.80c.

(a) You measure its length to be 75 m. Calculate the length a member of the spaceships' crew would measure it to be. (2 marks)

(b) If a member of the crew held a 1 kg mass in his hand, what mass would an observer on the Earth say he was holding? (2 marks)

(c) If the spaceship were to travel to a star 100 light years away from Earth (as measured by an Earthbound observer) at this speed, calculate how far the ship's crew would determine the distance to the star to be. (2 marks)

38 Explain how, using the principles of relativity, it is theoretically possible for astronauts to visit 'nearby' stars in *their* lifetime but it is unlikely that any government would fund such a journey. (5 marks)

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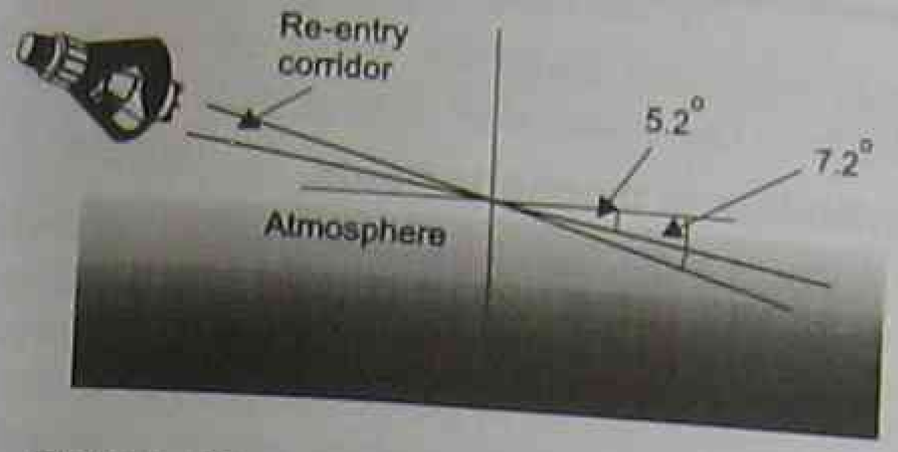

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Chapter Two

Motors and Generators

SECTION 1: THE MOTOR EFFECT

BIG IDEA:

Motors use the effect of forces on current-carrying conductors in magnetic fields.

OUTCOMES:

Students learn to:

1 Discuss the effect, on the magnitude of the force on a current-carrying conductor, of variations in:
  - the strength of the magnetic field in which it is located
  - the magnitude of the current in the conductor
  - the length of the conductor in the external magnetic field
  - the angle between the direction of the external magnetic field and the direction of the length of the conductor

2 Describe qualitatively and quantitatively the force between long parallel current-carrying conduct
$\frac{F}{l} = k\frac{I_1 I_2}{d}$

3 Define torque as the turning moment of a force using $\tau = Fp$

4 Describe the forces experienced by a current-carrying loop in a magnetic field and describe the net result
the forces.

5 Identify that the motor effect is due to the force acting on a current-carrying conductor in a magnetic field.

6 Describe the main features of a DC electric motor and the role of each feature.

7 Describe that the required magnetic fields in DC motors can be produced either by current-carrying coils
permanent magnets.

Students:

1 *Solve problems using* $\frac{F}{l} = k\frac{I_1 I_2}{d}$

2 *Perform a first-hand investigation to demonstrate the motor effect.*

3 *Solve problems and analyse information about the force on current-carrying conductors in magnetic fi*
using $F = BIl\sin\theta$

4 *Solve problems and analyse information about simple motors using* $\tau = nBIA\cos\theta$

5 *Identify data sources, gather and process information to qualitatively describe the application of the mo*
effect in the galvanometer and the loudspeaker.

Physics Stage 6 Syllabus Outcomes © Board of Studies NSW, 1999 (Amended 2000, 2001, 2002, 2003)

CONTEXTUAL OUTLINE

As we discussed in the Preliminary Course *Electricity in the Home*, electricity is the industrialised world's major energy source because:

1 it is relatively easy to produce from other energy sources;

2 it is relatively easy to distribute; and

3 it can be easily converted into other energy forms such as heat, light, sound and mechanical energy.

Electric motors convert electrical energy into mechanical energy. They are found in the home in various appliances such as washing machines, clothes dryers, refrigerators, vacuum cleaners, CD players… Some motors operate on direct current (DC) while others require alternating current (AC).

The opposite of an electric motor is a generator. This converts mechanical energy into electrical energy. This energy is transmitted at high voltages over power lines. Transformers change the voltage to appropriate values for household and industrial use. Generators produce AC, which has a number of advantages over DC.

In this chapter we will look at electric motors, generators and transformers and the transmission of electrical energy over the electricity grid.

First ✋ Investigation: Forces On Current-carrying Wires

The following is a report written by a student investigating the forces on current-carrying wires.

Aim: To investigate the motor effect.

Apparatus: Current balance, connecting wires, switch, rheostat, ammeter and power supply.

Theory: Since a current-carrying wire has an associated magnetic field, we might expect that such a wire would experience a force when placed in a magnetic field.

Method: A current balance (Figure 2.1) was assembled so that the 'U-shaped' loop was hanging vertically, resting on its knife-edges. The power supply, switch, ammeter and rheostat were connected in series with the 'U-shaped loop, with the positive terminal connected so that current flowed in the direction from *c* to *d*. A magnet was held vertically above *cd* with the north (N) end facing down. The switch was then closed and observations were recorded. This was repeated for a larger current. Next the direction of the current was reversed and the effect noted. Finally the magnetic pole was changed to a south pole and the effect was recorded.

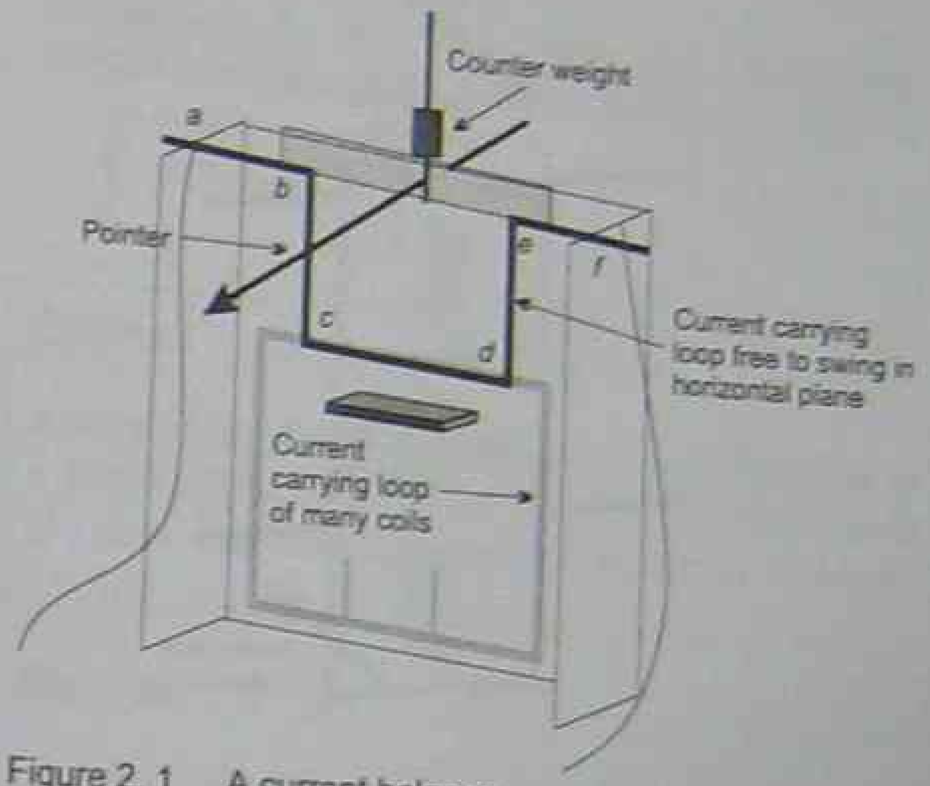


Figure 2. 1 A current balance

Results: When no current flows, no force acts on the current-carrying loop. When current flows, the loop swings, indicating a force was acting on it. The bigger the current, the bigger the force as indicated by the magnitude of deflection. The relationship between the directions of the force, the field and the current is shown in the diagrams (Figure 2.2). It was also found that if the field was made stronger with a stronger magnet, the force was bigger.

Conclusion: The results show that:

1 a force acts on a current-carrying wire in a magnetic field;

2 the direction of the force depends on the direction of the current and the direction of the magnetic field.

3 the force is *perpendicular* to both the *field* and the *current*.

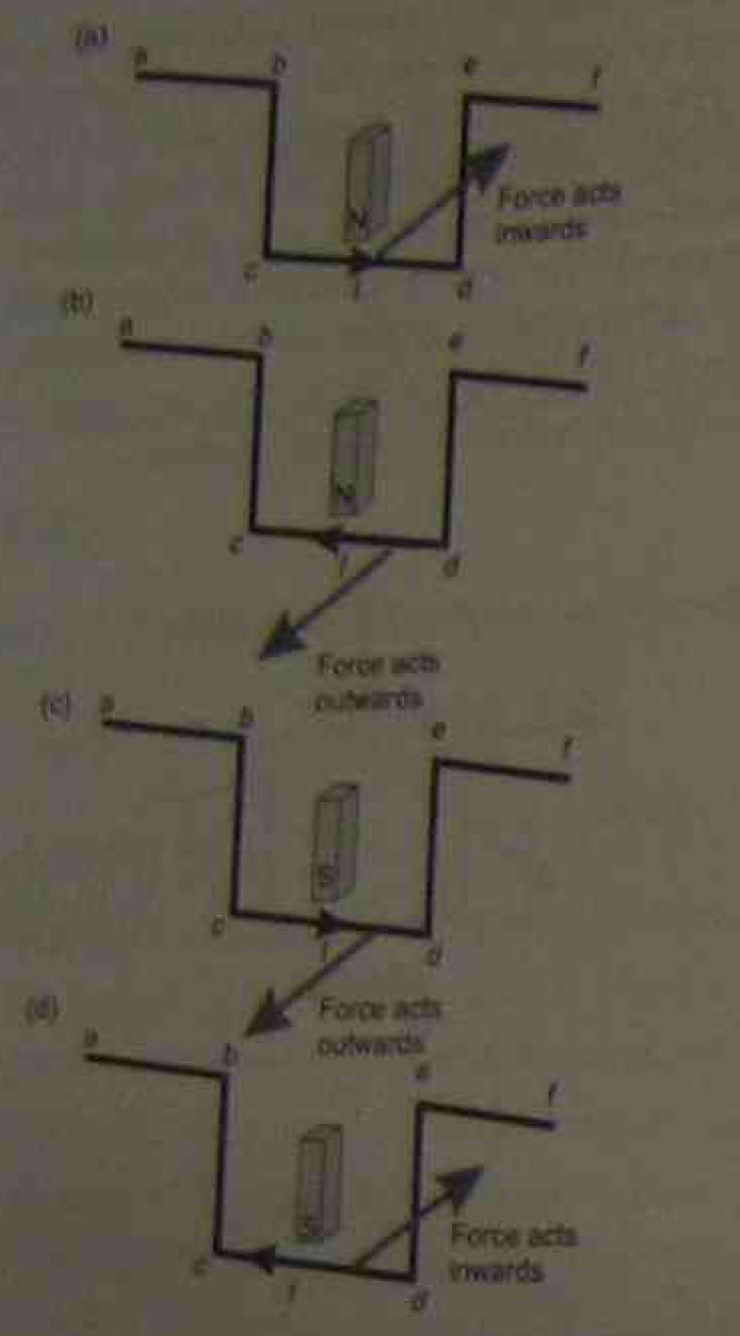


Figure 2.2 Force on a current carrying wire in a magnetic field

THE MOTOR EFFECT

Experiments such as the one just described indicate that:

> *A current-carrying wire in a magnetic field experiences a force*[1]. *This is the* **motor effect.**

This phenomenon is put to good use in *electric motors*[2].

> *In* **electric motors**, *electrical energy is converted into mechanical energy.*

Right-hand Palm Rule

Experiments similar to that shown in Figure 2.2 indicate that:

> *The* **direction of the force** *acting on a current-carrying conductor is perpendicular to both the direction of the current and the direction of the magnetic field*[3] (Figure 2.3).

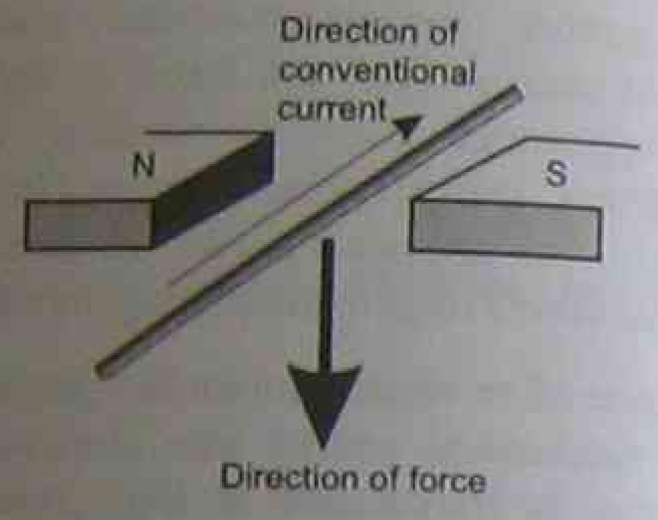


Figure 2.3 Force on a current-carrying wire in magnetic field

A simple way to determine the direction of the force is to use the *right-hand palm rule*:

> **Right-hand palm rule:** *If the fingers of the right hand point in the direction of the magnetic field and the thumb points in the direction of the conventional current, then the palm points in the direction of the force* (Figure 2.4).

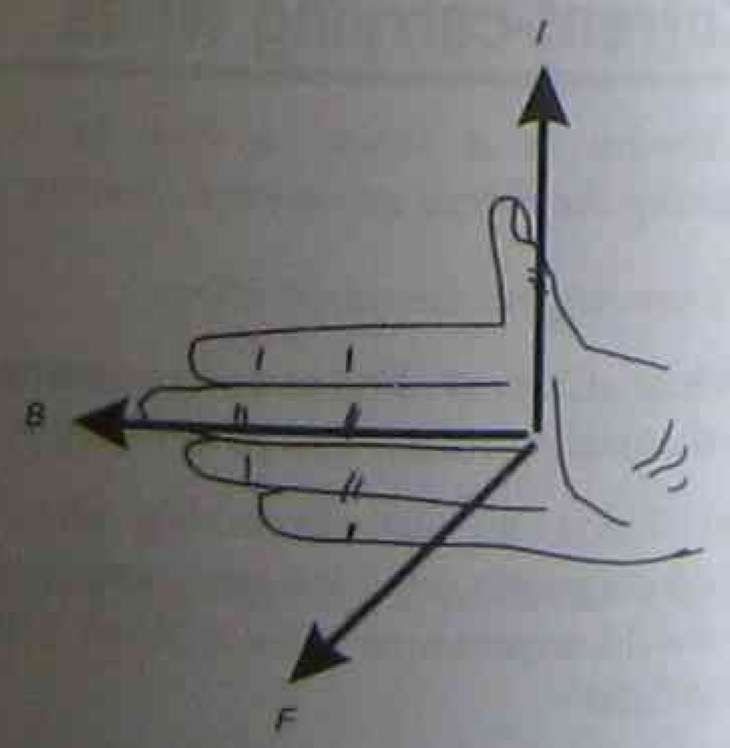


Figure 2.4 The right-hand palm rule

Catapults!

Alternatively the direction of the force on the current carrying wire can be worked out using the vector addition of fields. In Figure 2.5 the fields due to the magnets and the wire (the latter determined by the right-hand rule) are shown separately. Finally the resultant is drawn.

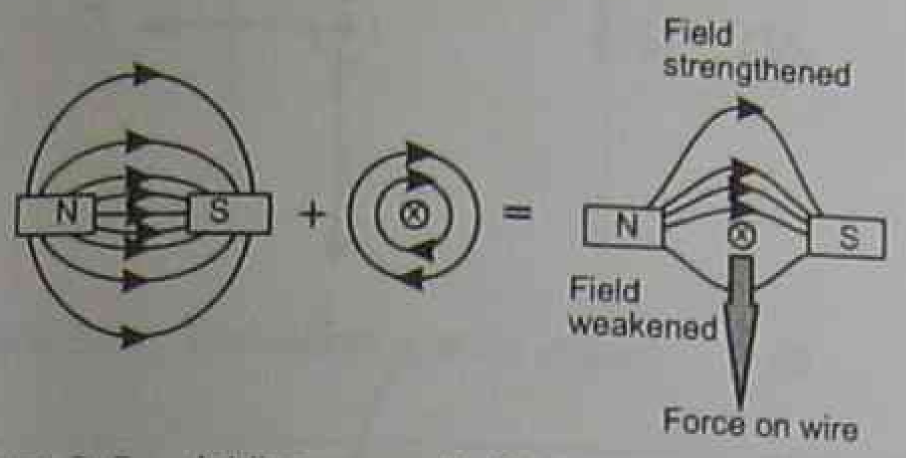


Figure 2.5 Adding magnetic fields

From the diagram it is evident that the wire is 'catapulted' from the region of strong magnetic field to that of a weaker field.

Further examples of forces on current-carrying wires are given in Figure 2.6.

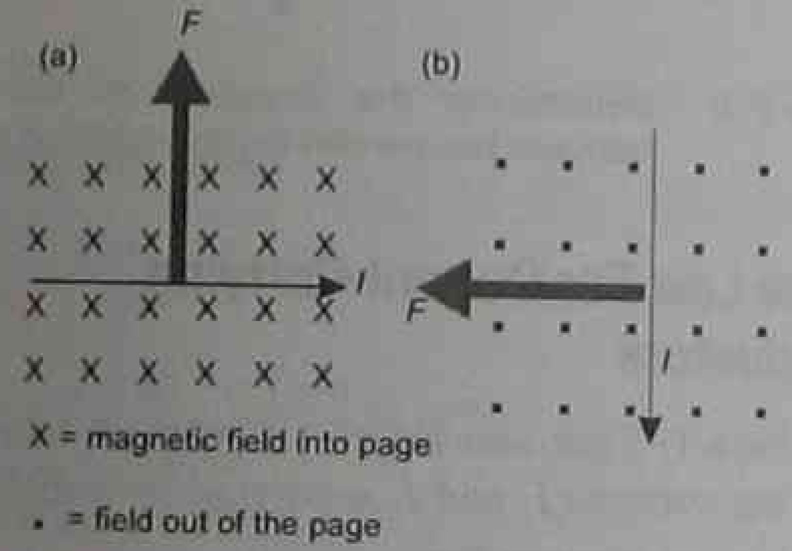


Figure 2.6 Examples of forces on current-carrying wires

What Factors Affect the Force Acting on a Current-carrying Conductor?

The force acting on a current-carrying conductor depends upon:

1 the strength of the magnetic field (B) in which it is situated;

2 the magnitude of the current (I) in the conductor;

3 the length of the conductor (l) in the magnetic field; and

4 the angle (θ) between the direction of the external magnetic field and the direction of the length of the conductor (Figure 2.7).

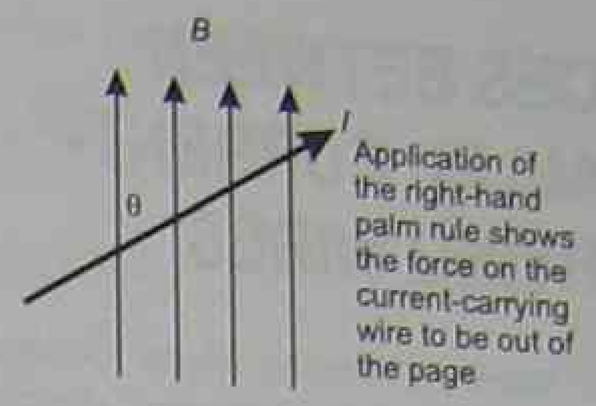


Figure 2.7 Angle between magnetic field and length of conductor

Mathematically we can write the relationship between the force, field, current, length and angle as:

$$\boxed{F = BIl \sin\theta}$$

EXAMPLE 1

A wire of length l = 20 cm is placed perpendicular to a magnet field of intensity B = 0.05 T. What force (F) does the wire experience if it carries a current I = 3A?

SOLUTION:

$$\begin{aligned} F &= BIl\sin\theta \\ &= 0.05\times3\times0.20\times\sin90\text{ N} \\ &= 0.03\text{ N} \end{aligned}$$

EXAMPLE 2

A conductor of length l = 60 cm is placed in a magnetic field B = 0.03 T at an angle of θ = 30°. What is the force (F) on the conductor if it carries a current I = 10 A?

SOLUTION

$$\begin{aligned} F &= BIl\sin\theta \\ &= 0.03\times10\times0.60\times\sin30\text{ N} \\ &= 0.09\text{ N} \end{aligned}$$

Units of *B*

The unit of $\vec{B}$ is the tesla (T) or weber/m^2 (Wb.m^{-2}). One tesla is that magnetic induction which results in a force of one newton acting on a one-metre length of wire carrying one ampere of current.

---

[1] This is often referred to as a Lorentz force.

[2] http://www.walter-fendt.de/ph11e/lorentzforce.htm Java applet of force on a conductor in magnetic field

[3] See Preliminary Course *Electricity in the Home*.

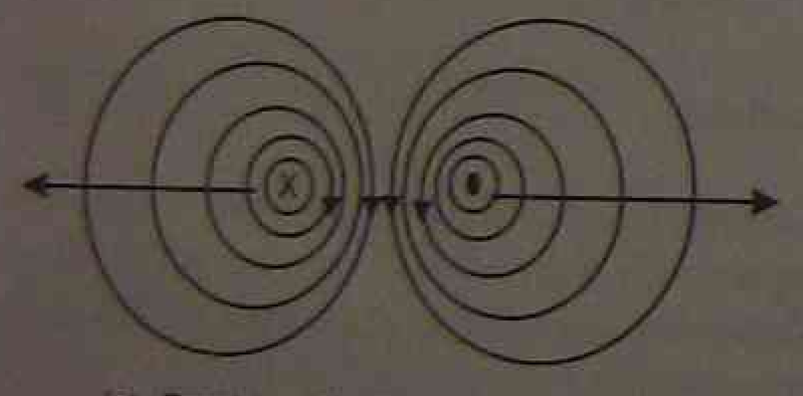
FORCES BETWEEN PARALLEL CURRENT-CARRYING WIRES

Within a week of hearing about Oersted's 1820 discovery of the link between electricity and magnetism, a French physicist André-Marie Ampère developed a quantitative analysis of Oersted's observations.

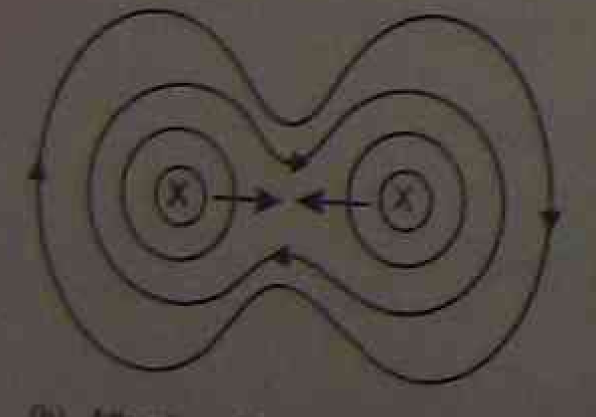
Ampère also went on to show that when two long parallel wires are near each other, and a current passes through the wires, a force of attraction or repulsion is observed between the wires. This force is *attractive* if the currents flow in the same direction and *repulsive* if they flow in opposite directions. That is:

> *'Like' currents attract and 'unlike' currents repel.*

Figure 2.8 shows a plan view of the fields around the wires (obtained from the right-hand grip rule). Note that the wires still move from the region of strong magnetic field to that of the weaker field.



(a) Repulsion of 'unlike' currents



(b) Attraction of 'like' currents

Figure 2.8 Fields around parallel current-carrying wires

Figure 2.9 shows the same wires but this time the field around one wire (Wire 1) only is shown (the **X** and the • in this case refer to the direction of the current, not the field).

Application of the right-hand palm rule to the current in the other wire (Wire 2) allows the direction of the force on the wire to be determined. Check to see that you get the same results as indicated in the diagram.

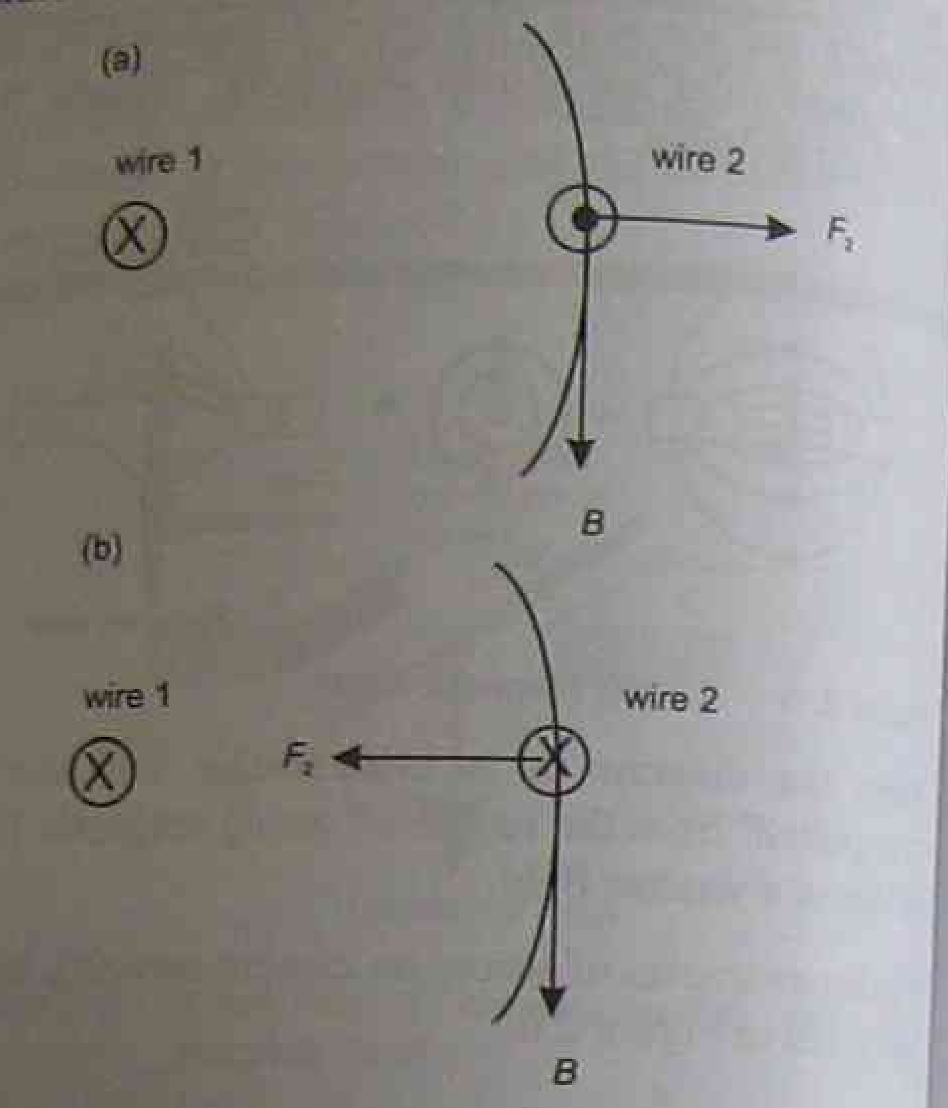


Figure 2.9 Determining the direction of the force between two parallel current-carrying wires

Force Law For Current-Carrying Conductors

The force (F) per unit length (l) between two wires carrying currents I_1 and I_2 separated by a distance d in a vacuum is given by:

$$\boxed{\frac{F}{l}=k\frac{I_1I_2}{d}}$$

The Ampere

The fundamental unit of electric current, the amper is defined in terms of the force between two paralle current carrying wires.

> *When one ampere of current flows in each of two infinitely long parallel wires separated by one metre in a vacuum, the force exerted on each metre of wire is exactly 2 x 10^{-7} newtons (Figure 2.10).*

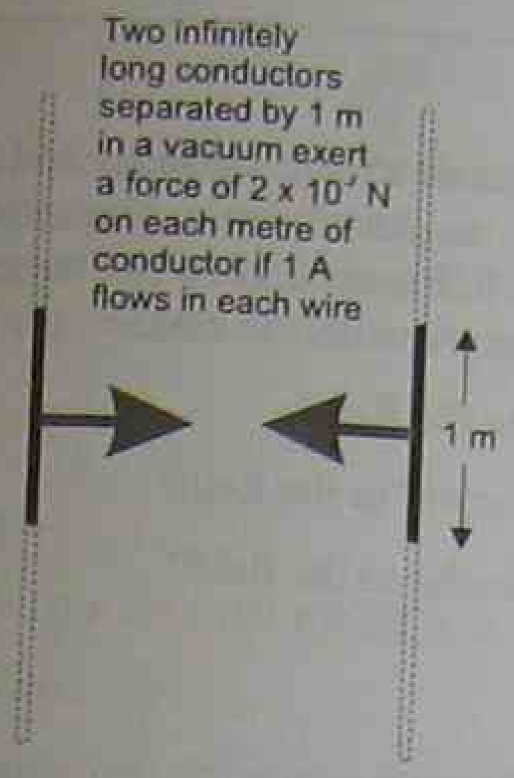


Figure 2. 10 The definition of the ampere

EXAMPLE 3

Two long straight wires carry currents of 2 A and 4 A respectively due north. Calculate the force, both size and direction, acting on a 1 m length of the wire carrying 2 A (which lies to the west of the other wire) if the wires are 1 cm apart in air.

SOLUTION:

The force law states:

$$\frac{F}{l}=\frac{kI_1I_2}{d}$$

$$=\frac{2\times10^{-7}\times2\times4}{0.01}\text{N.m}^{-1}$$

$$=1.6\times10^{-4}\text{ N.m}^{-1}$$

The direction can be found from the right-hand palm rule and is due east.

EXAMPLE 4

Two long parallel wires separated by a distance d carry currents of I_1 and I_2 respectively. They exert a force of F on each metre of wire. What is the new force if the currents are both doubled and the separation is halved?

SOLUTION

The force law states:

$$F=k\frac{I_1I_2}{d}l$$

Hence the new force is given by:

$$F'=k\frac{(2I_1)\times(2I_2)}{\frac{d}{2}}\times l$$

$$=8\times k\frac{I_1I_2}{d}l$$

$$=8F$$

That is, the force is 8 times greater.

TORQUE

Before we can understand how electric motors work, we need to introduce a new quantity called *torque*.

> **Torque** *is the turning effect of a force.*

Consider Figure 2.11, which shows a bar that is free to rotate about an axis O. A force F is applied as shown in the diagram. This force causes the bar to rotate (in this example, in an anticlockwise direction). The force F is said to exert a torque about the axis.

> **Torque** *is defined as the product of force and the perpendicular distance from the axis to the line of action of the force. Its unit is newton-metre (N.m)*

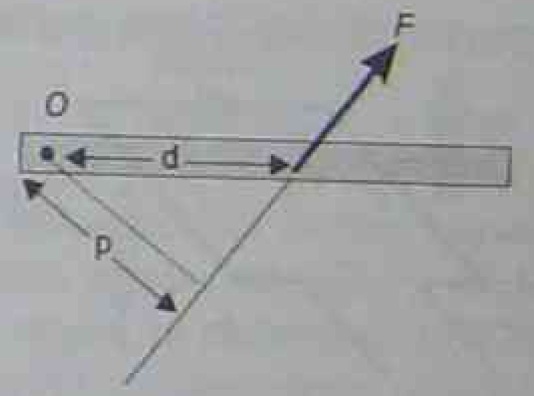


Figure 2. 11 Torque of a force

Mathematically:

$$\boxed{\tau=Fp}$$

TORQUE ON A COIL IN A MAGNETIC FIELD

Figure 2.12(a) represents a rectangular current carrying coil, lying in a plane parallel to a magnetic field B. Current flows anticlockwise when viewed from above. Sides AB and CD, which carry currents at right angles to the field, feel a force but sides BC and AD experience no force (because the current is parallel to the field). The net effect is that the coil experiences a torque causing it to rotate in a clockwise direction.

The force F acting on sides AB and CD is given by:

$$F = BIb$$

where b is the length of the sides AB and CD.

The torque is given by:

$$\tau = F\times\frac{a}{2}+F\times\frac{a}{2} = Fa$$

Substituting for F in the expression for torque:

$$\tau = BIab = BIA$$

where A is the area of the coil. For n coils:

$$\tau = nBIA$$

In general, when the coil is inclined at angle θ to the field (Figure 2.12(b)):

$$\boxed{\tau = nBIA\cos\theta}$$

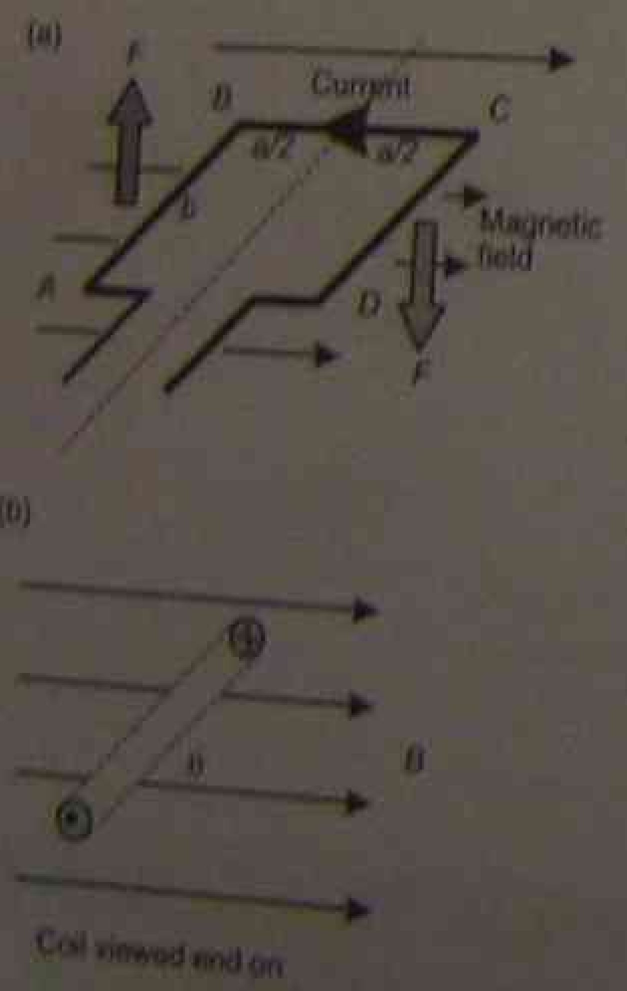


Figure 2.12 Torque on a rectangular coil in a magnetic field

EXAMPLE 5

A rectangular coil of $n = 25$ turns and with an area $A = 0.04$ m^2 is placed in a magnetic field with $B = 0.10$ T as in Figure 2.12. If the current $I = 4.0$ A, what is the torque when the coil is:

(a) parallel to the field?

(b) inclined at 45° to the field?

(c) perpendicular to the field?

SOLUTION

(a) $\tau = nBIA\cos\theta$
$= 25\times0.10\times4.0\times0.04\times\cos 0$ N.m
$= 0.4$ N.m

(b) $\tau = nBIA\cos\theta$
$= 25\times0.10\times4.0\times0.04\times\cos 45$ N.m
$= 0.28$ N.m

(c) $\tau = nBIA\cos\theta$
$= 25\times0.10\times4.0\times0.04\times\cos 90$ N.m
$= 0$ N.m

Radial Magnetic Fields

From these examples, it is obvious that as θ changes so too does the magnitude of the torque (being maximum when the coil is parallel to the field, that is, $\theta = 0°$). To ensure a constant torque, the pole pieces of the magnets are generally curved to produce a radial magnetic field (as in Figure 2.13). This ensures that the coil always lies parallel to the field, and hence the torque is always equal to its maximum value of $nBIA$.

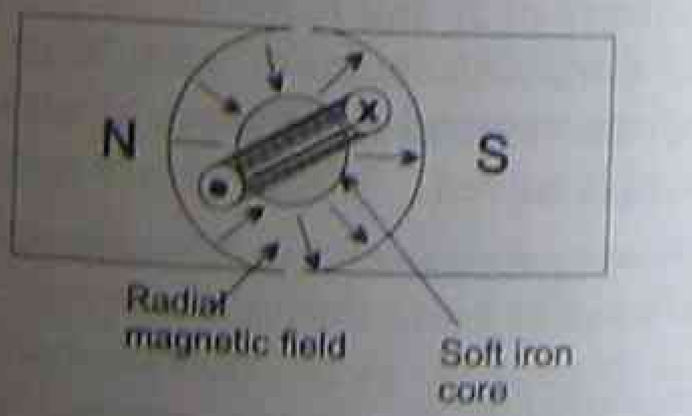


Figure 2.13 Radial magnetic field

EXAMPLE 6

A rectangular coil, consisting of 500 turns and with a width of 10 cm and a depth of 20 cm, is placed in a radial magnetic field of intensity 10 T. What torque does the coil experience if it carries a current of 2 A?

SOLUTION:

$\tau = nBIA$
$= 500 \times 10 \times 2 \times 0.10 \times 0.20$ N.m
$= 200$ N.m

The torque on a coil in a magnetic field is put to good use in electric motors.

ELECTRIC MOTORS

As we saw earlier:

> **Electric motors** *convert electrical energy into mechanical energy.*

Electric motors can be classified as either:

1 DC motors; or
2 AC motors.

These can be further divided into:

1 commutator motors;
2 induction motors; or
3 synchronous motors.

These differ in the manner in which the magnetic field is produced and the arrangement of the conductors.

Electric motors contain a rotating part—the *rotor*—and a stationary part—the *stator*. In some cases the rotor has the conductors that carry the current and the stator provides the magnetic field (which can be a permanent magnet or an electromagnet). In other cases, the magnetic field is on the rotor and the stator carries the current.

In this section we will look at the simplest motor—the commutator DC motor. (Induction motors will be studied in Section 5, see p.84.)

COMMUTATOR DC MOTOR

A commutator DC motor (Figure 2.14) essentially consists of:

1 an *armature* (the rotor);
2 a *magnetic field* (also called the *field structure*) produced by permanent magnets or by electromagnets. It is equivalent to the stator;
3 a *commutator* to reverse the current direction; and
4 conducting *brushes* to take the current to and from the armature.

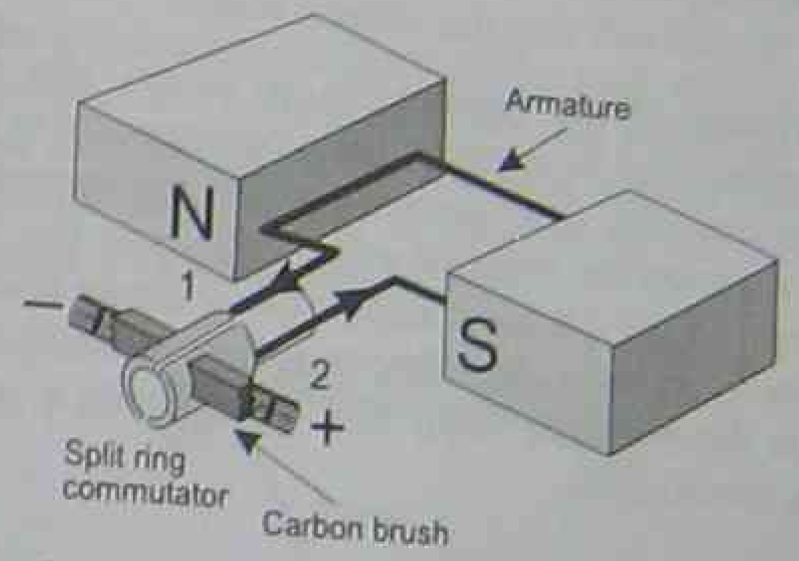


Figure 2.14 The essential components of a commutator DC motor

The Armature and Field Structure

The armature is made up of a large number of individual conducting coils (or *turns*) wrapped around an *iron core* that is free to *rotate* about a horizontal axis (hence, the *rotor*). These coils are arranged at angles to each other. (To minimise the air gap between the armature's conductors and the stator, the conductors are often imbedded in slots cut longitudinally into the metal core.)

In its simplest form, the field structure (stator) is made with permanent magnets (called *field magnets*), but it can be made from electromagnets (called *field coils*). The stator is approximately circular as this improves the smoothness of the torque (see p.57).

How Do the Armature and Field Structure Interact?

The rotor and stator interact as follows[4]: Figure 2.15(a) shows a rectangular coil of wire (for simplicity) placed between the poles of a magnet. In Figure 2.15(a), current is flowing anticlockwise around the armature (when viewed from above). Application of the right-hand palm rule shows that the two sides of the coil experience forces in opposite directions. The coil (viewed end on) experiences a clockwise torque.

As a result of this torque, the coil will find itself oriented as in Figure 2.15(b). Note that if the current has not been reversed then the coil will now experience an anticlockwise torque. The net effect is that the coil will stop in a vertical plane!

Obviously, if the motor is to be of any use, the armature must be made to rotate continuously in the same direction. This necessitates that the current in the armature be reversed every half cycle (so that current in the left-hand side of the armature always flows in the same direction, regardless of which arm is on the left-hand side). This is done with a *split-ring commutator*.

Split-ring Commutator

In its simplest form, the split-ring commutator consists of a copper cylinder divided into two electrically separated halves. Each half (called a commutator *segment*) is connected to one side of the armature (Figure 2.16). (In practice, motors have many coils and so there are many segments to the commutator.)

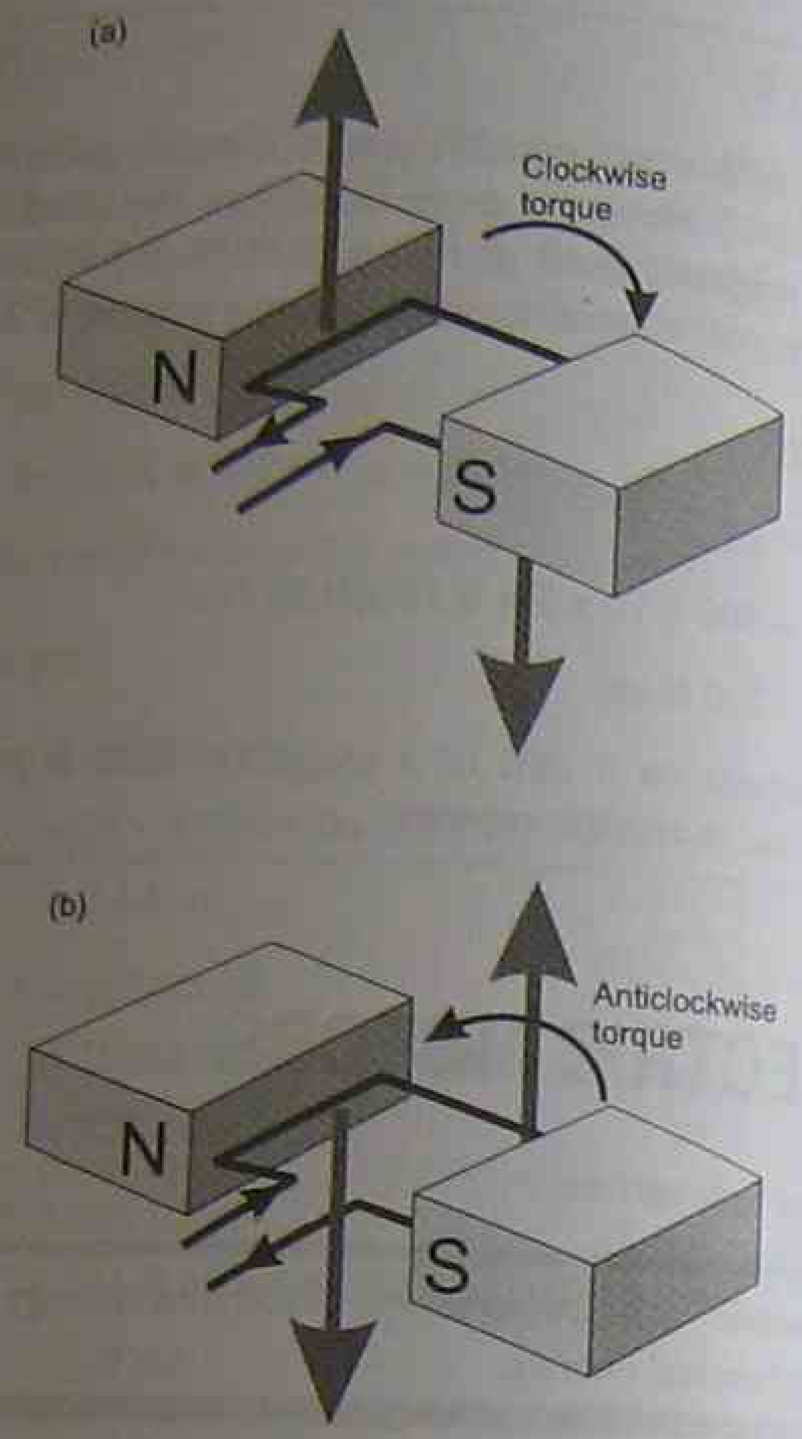


Figure 2. 15 The action of a DC motor

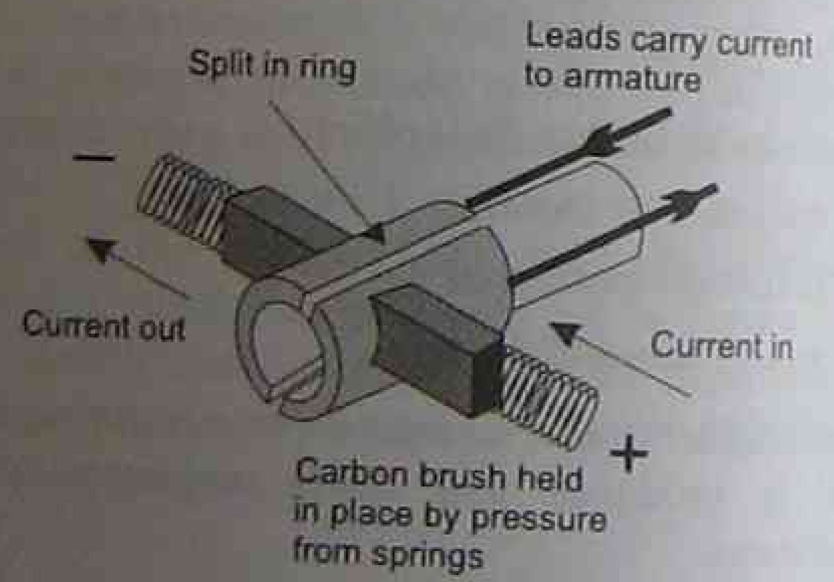


Figure 2. 16 A split-ring commutator with brushes

Conducting Brushes

In their simplest form, the brushes consist of the conducting material graphite (carbon) which has the added advantage of being a lubricant. The brushes make contact with the commutator as it rotates. Springs ensure that the brushes are held firmly against the commutator (to minimise sparking).

(By making the stator carry the currents rather than the rotor, the brushes can be eliminated in certain motors.)

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[4] http://www.walter-fendt.de/ph11e/electricmotor.htm Java applet showing the essential features of the operation of a DC commutator motor. Other excellent sites include http://www.howstuffworks.com/motor.htm, http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html#c1 and http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/motdc.html#c1

Operation of a Commutator

As the armature (Figure 2.17(a)) rotates, the two sides of the commutator make contact with the carbon conducting brushes. In this manner arms 1 and 2 are connected to the positive and negative terminals alternately as shown in Figure 2.17(b) and (d), thus effectively reversing the current in the sides of the coil. This ensures continuous rotation of the armature.

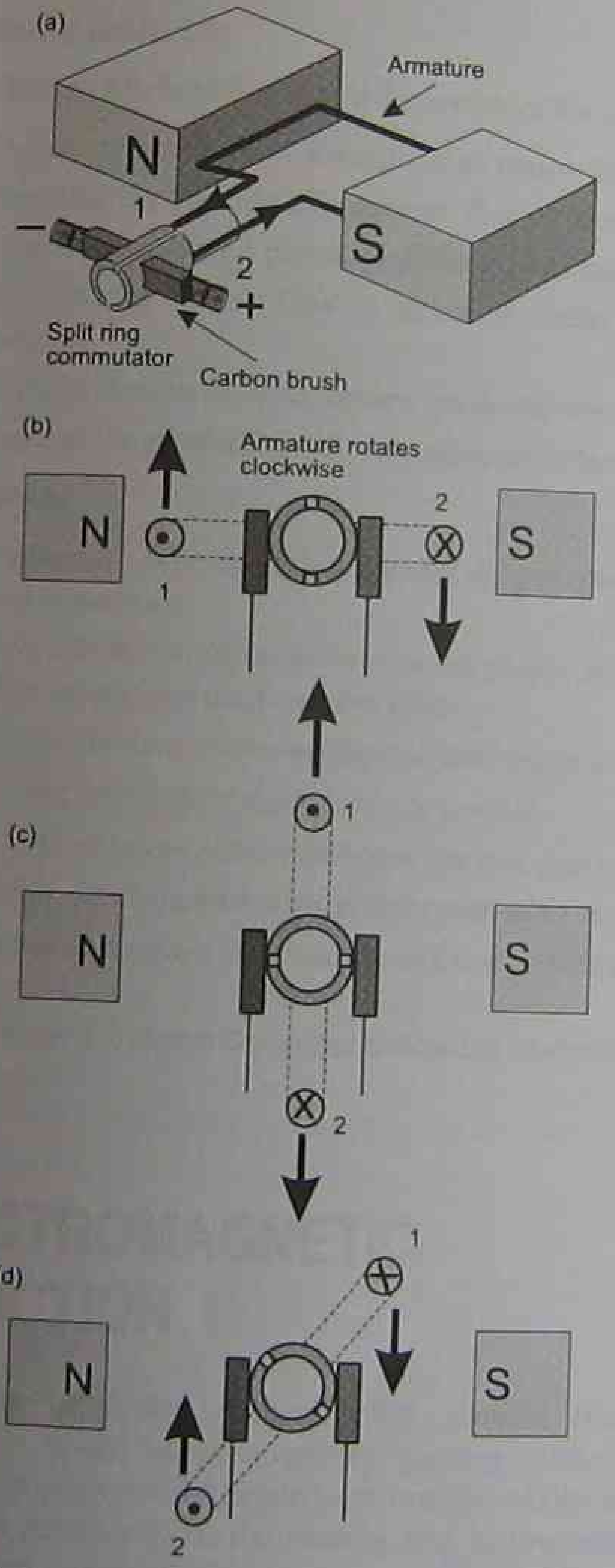

Figure 2. 17 The operation of a split-ring commutator

Secondary Source Investigation

Electric Meters

Electric meters, like the motors just discussed, work on the *motor principle*—that is, a conductor carrying a current in a magnetic field experiences a force that is proportional to the size of the current in the conductor (for constant *B* and *l*).

Ampère (see p.56) built the first primitive meter. He used a freely moving magnetised needle surrounded by a coil of wire to measure the electric current through the coil. This device was the forerunner of the *galvanometer*.

Moving Coil Meters

The galvanometer is the basis for most meters, both ammeters and voltmeters. It consists essentially of a coil of fine wire wrapped around an *iron core*. A delicate coiled spring is attached to the coil. A pointer is attached (Figure 2.18).

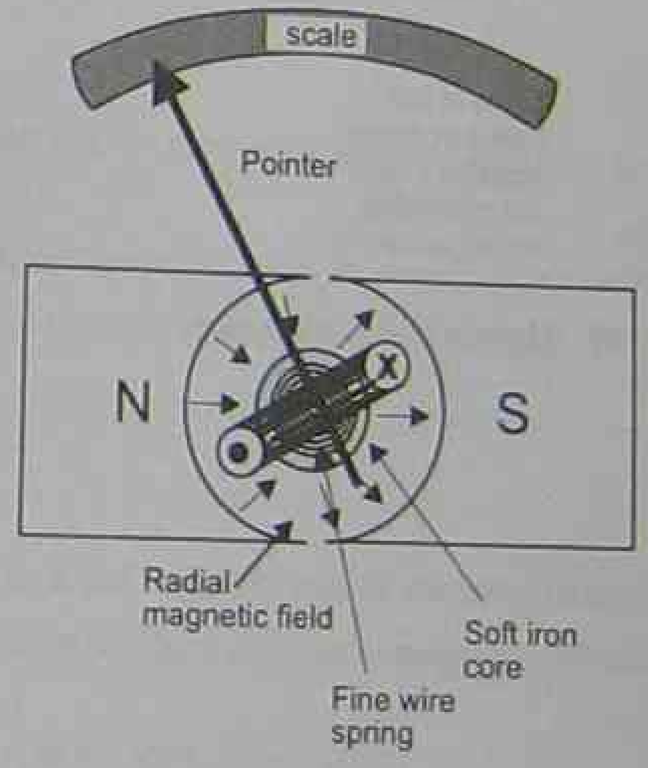

Figure 2. 18 A moving coil meter

As current flows through the coil, forces cause the coil to rotate—it experiences a torque. (A radial magnetic field ensures a constant torque.) As the coil rotates, so does the pointer; the coil rotates until the magnetic turning forces are balanced by the *restoring torque* of the spring. This restoring torque is proportional to the angle of rotation, which is proportional to the current in the coil.

By a suitable choice of scale, the amount of rotation indicated by the pointer can be calibrated and read in terms of current or voltage.

The Moving Coil Loudspeaker[5]

Figure 2.19 shows a *moving coil loudspeaker*. Varying currents from an amplifier are fed into the coil wrapped around a central pole piece. Interactions between the field of the coil and the field of the permanent magnet result in vibrations of the cone. This sets the air in motion and in this manner reproduces the sounds from the amplifier.

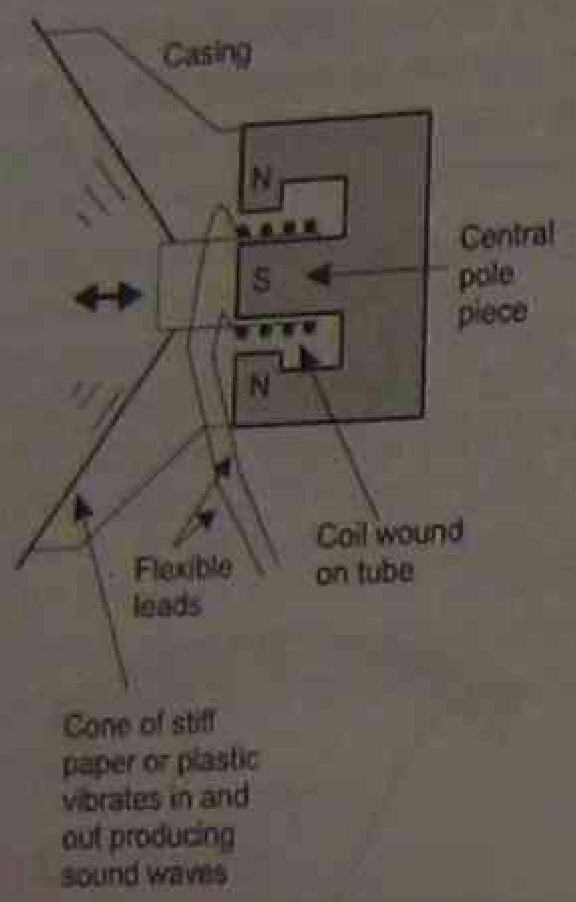

Figure 2. 19 Moving coil loudspeaker

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[5] http://hyperphysics.phy-astr.gsu.edu/hbase/audio/spk.html from the excellent hyperphysics site, this contains good information on the motor principle used in making a loudspeaker. Another site with an excellent animation is http://micro.magnet.fsu.edu/electromag/java/speaker/

SECTION 2: ELECTROMAGNETIC INDUCTION

BIG IDEA:

The relative motion between a conductor and a magnetic field is used to generate an electrical voltage.

OUTCOMES:

Students learn to:

1 Outline Michael Faraday's discovery of the generation of an electric current by a moving magnet.

2 Define magnetic field strength $\vec{B}$ as magnetic flux density.

3 Describe the concept of magnetic flux in terms of magnetic flux density and surface area.

4 Describe generated potential difference as the rate of change of magnetic flux through a circuit.

5 Account for Lenz's Law in terms of conservation of energy and relate it to the production of back *emf* in motors.

6 Explain that, in electric motors, back *emf* opposes the supply *emf*.

7 Explain the production of eddy currents in terms of Lenz's Law.

Students:

1 *Perform an investigation to model the generation of an electric current by moving a magnet in a coil or a coil near a magnet.*

2 *Plan, choose equipment or resources for, and perform a first-hand investigation to predict and verify the effect on a generated current when:*
   - *the distance between the coil and magnet is varied;*
   - *the strength of the magnet is varied;*
   - *the relative motion between the coil and magnet is varied.*

3 *Gather, analyse and present information to explain how induction is used in cook tops in electric ranges.*

4 *Gather secondary information to identify how eddy currents have been utilised in electromagnetic braking.*

ELECTROMAGNETIC INDUCTION

From the time that Oersted first showed that magnetism could be produced by passing electric currents through wires, people were convinced that it should be possible to do the reverse, that is, produce an electric current from a magnetic field—a phenomenon called *electromagnetic induction*.

Electromagnetic induction *involves the conversion of mechanical energy into electrical energy.*

Although many scientists looked for this effect, credit for the discovery is given to Michael Faraday[6] (1791-

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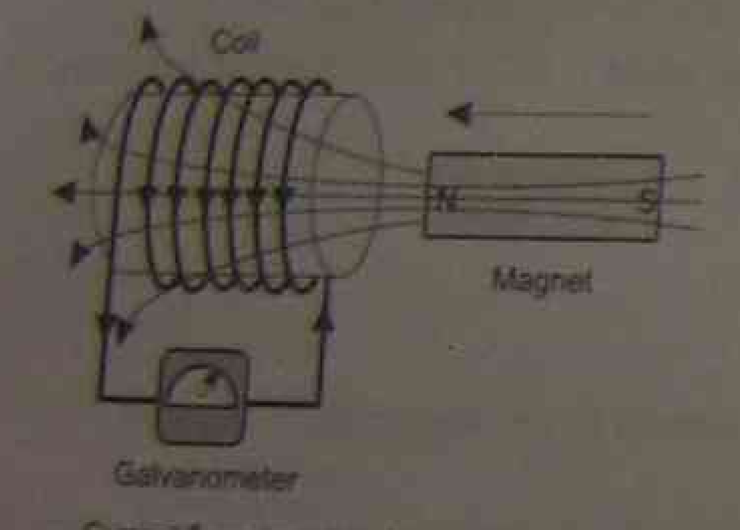
[6] http://www.ee.umd.edu/~taylor/frame1.htm links to brief biographies of famous people in the study and application of electricity, including Faraday, Henry and Lenz.

1867). Faraday was successful where others failed because he noticed that a *changing* magnetic field was needed to produce electricity. (History shows that another scientist, Joseph Henry, in America discovered electromagnetic induction a little before Faraday but took longer to publish his work.)

Consider Figure 2.20. When a magnet is pushed into a coil of many turns connected to a sensitive current-measuring device (a *galvanometer*), a current is produced as long as the magnet is moving relative to the coil (this could mean the magnet is moving and the coil is stationary or the coil is moving and the magnet is stationary)[7]. If there is no movement between the coil and magnet, no current is produced. When the magnet is withdrawn from the coil, current is again produced but it flows in the opposite direction to that when the magnet is inserted.



Current flows in coil as long as there is relative motion between the magnet and the coil.

Figure 2.20 Magnet being moved towards a conducting coil

Lines of Force

Faraday introduced the concept of *lines of force* ('tensions') to help explain electromagnetic induction. As indicated in Figure 2.20, the number of field lines 'cutting' the coil increases as the magnet approaches (and will decrease as the magnet moves away).

Faraday explained electromagnetic induction as follows:

> *Whenever there is relative motion between a conductor and a magnetic field such that field lines are 'cut', an emf (voltage) is induced between the ends of the conductor (and if a circu is provided, current will flow).*

MAGNETIC FLUX AND MAGNETIC FLUX DENSITY

> *The number of magnetic lines of force emerging through an imaginary surface in a magnetic field is called the* **magnetic flux** *of the field (Figure 2.21).*

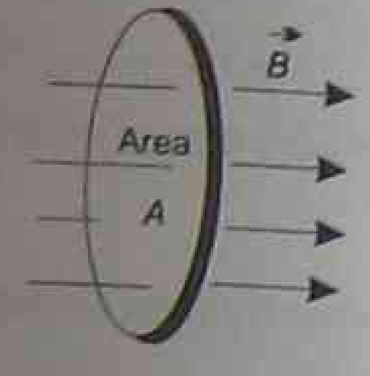


Figure 2.21 Magnetic flux

Magnetic Flux Density

This is the *magnetic flux per unit area* and is a measure of the magnetic field intensity, that is, the larger the flux density, the more intense the field in that region.

> *The magnetic field strength* (also called magnetic induction) $\vec{B}$ *is the* **magnetic flux density.**

Mathematically:

$$\boxed{B = \frac{\phi}{A}}$$

It follows that for an area (A) at right angles to magnetic induction (B), the magnetic flux (ϕ) given by:

$$\boxed{\phi = BA}$$

Another excellent biographical site is http://www.the-education-site.com/electric/history.htm

[7] http://micro.magnet.fsu.edu/electromag/java/faraday/ Good animation of Faraday's original experiment. Also http://micro.magnet.fsu.edu/electromag/java/faraday2/ has a good simulation of electromagnetic induction.

For an area (A) at an angle of θ to a magnetic induction (B) (Figure 2.22), the magnetic flux (ϕ) is given by:

$$\boxed{\phi = BA\cos\theta}$$

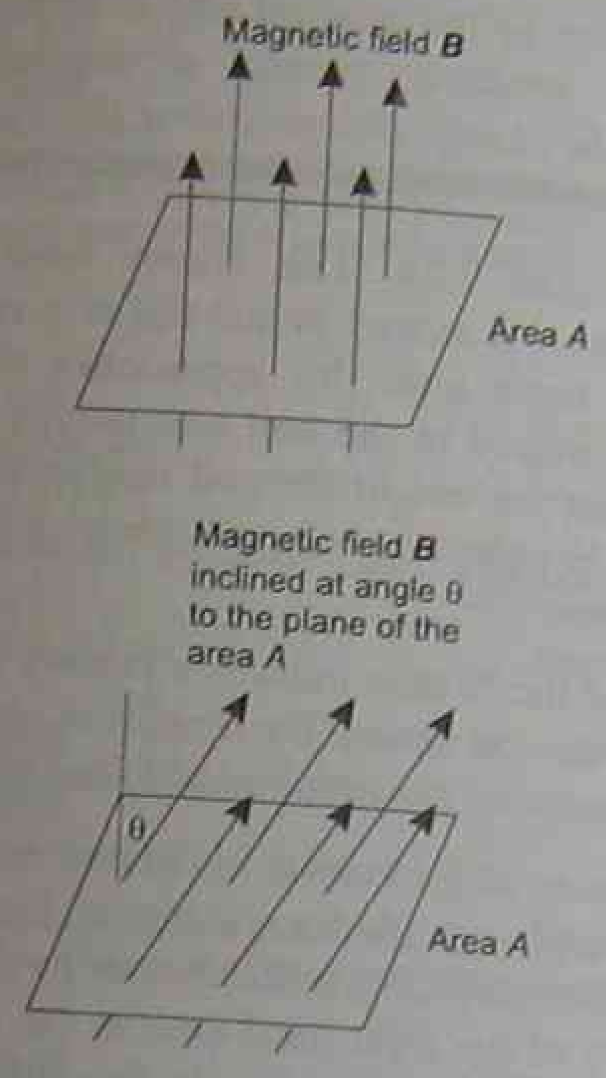


Figure 2.22 Magnetic flux through an area

Extension

emf

When a conductor is connected across the terminals of a battery or electric cell, a flow of charge, that is, a current results. As the charges flow through the energy source, they gain energy. The *emf* (electromotive force[8]) of a source of electrical energy is defined as the energy *supplied* to each unit of charge that passes through the source, that is:

$$emf = \frac{\text{energy supplied}}{\text{charge}}$$

emf and Potential Difference

When a charge q moves through a potential difference of V volts across a conductor, it does work given by $W = qV$. This work is equal to the energy transformed to heat in the conductor. Potential difference measures the energy *released* by an electric charge per unit of charge, that is:

$$\text{potential difference} = \frac{\text{energy released}}{\text{charge}}$$

Although at an elementary level we can think of *emf* and potential difference (voltage) as the same thing, there are differences between them.

Size of the Induced *emf*

Experiments show that the size of the induced *emf* depends upon:

1 the value of B;
2 the speed at which the conductor 'cuts' flux lines; and
3 the number of conductors.

The relationship between these variables is stated in *Faraday's Law.*

Faraday's Law[9]

> *The* **induced** ***emf*** *is proportional to the rate of change of flux through the circuit.*

Extension

Mathematically Faraday's Law can be written as:

$\varepsilon \propto \frac{\Delta\phi}{\Delta t}$ where ε is the induced *emf.* For n conductors this becomes:

$$\boxed{\varepsilon = -n\frac{\Delta\phi}{\Delta t}}$$

EXAMPLE 7

A circular coil of 100 turns and radius 20 cm is placed in and perpendicular to a magnetic field of intensity 2.5×10^{-2} T. If the intensity is reduced to zero in 0.01 s, what *emf* is induced in the coil?

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[8] The term 'electromotive force' is a misnomer. *emf* refers to energy, not force. For this reason we generally use the term *emf* as written.

[9] http://hyperphysics.phy-astr.gsu.edu/hbase/electric/farlaw.html#c1 Faraday's Law for the interested student.

SOLUTION

Initial flux through the coil is given by:

$$\phi = BA$$

Now for a circular coil, the area A is given by πr^2
Thus:

$$\phi = \pi \times 0.20^2 \times 2.5 \times 10^{-2}$$
$$= 3.14 \times 10^{-3} \text{ Wb}$$

Hence the induced *emf* is found from:

$$\varepsilon = -n\frac{\Delta\phi}{\Delta t}$$
$$= -100 \times \frac{3.14 \times 10^{-3}}{0.01} \text{ V}$$
$$= -31.4 \text{ V}$$

What Causes the Induced *emf*?

Consider Figure 2.23, which shows a wire of length l moving at right angles to a magnetic field of induction B. This wire has equal numbers of positive and negative charges in it but only the negatives—the electrons—can move (the positive charges, the nuclei are stuck in place). Application of the *right-hand palm rule* (see p.54) for these negative charges shows that they experience an inward force. This leaves a deficiency of electrons, that is, a positive charge, at the other end. Between the ends there is a *potential difference* or more correctly an *emf*.

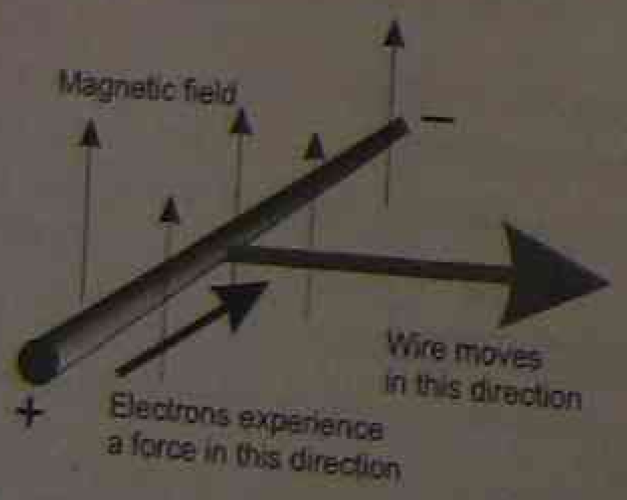

Figure 2.23 Cause of the induced *emf*

The charges continue to separate until the electric force of repulsion between like charges balances the magnetic force. The charges are now in equilibrium.

LENZ'S LAW[10]

The negative sign in Faraday's Law shows that the induced *emf* is in opposition to the flux change. This is stated in Lenz's Law:

> *The direction of the induced emf is such that the current it produces creates a magnetic field opposing the change that produced this emf.*

Consider Figure 2.24. This shows what happens when a magnet is moved in and out of a conducting coil. As a north pole (N) approaches the coil, a current is induced in the coil and moves in such a direction that the end of the coil nearest the magnet acts like a N pole, *opposing the entry of the N pole of the magnet.*

Removal of the N pole induces a current that causes the end of the coil nearest the magnet to act as a south (S) pole, *opposing the withdrawal of the N pole.*

(The direction of the current in the coil is found from the right-hand grip rule for a solenoid, first discussed in the Preliminary Course *Electricity in the Home*. If the fingers of the right hand curl in the direction of the current, the thumb points in the direction of the north pole.)

LENZ'S LAW AND ENERGY CONSERVATION

Lenz's Law is simply a consequence of energy conservation. If for example, the current aided the motion, a conductor would accelerate, producing more current, creating greater acceleration… and so the kinetic energy would increase indefinitely—*energy would be created*. Since this cannot happen the *induced current must oppose the change that gives rise to it.*

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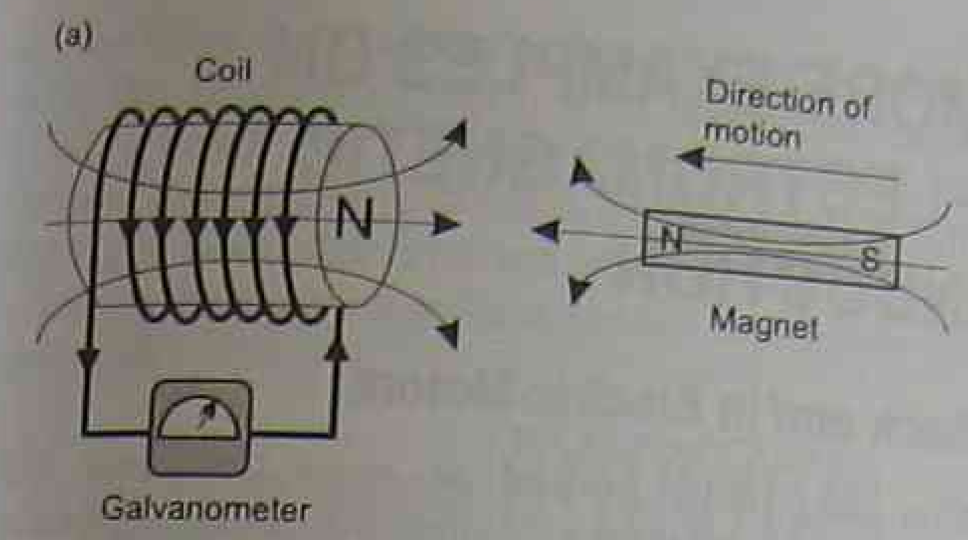
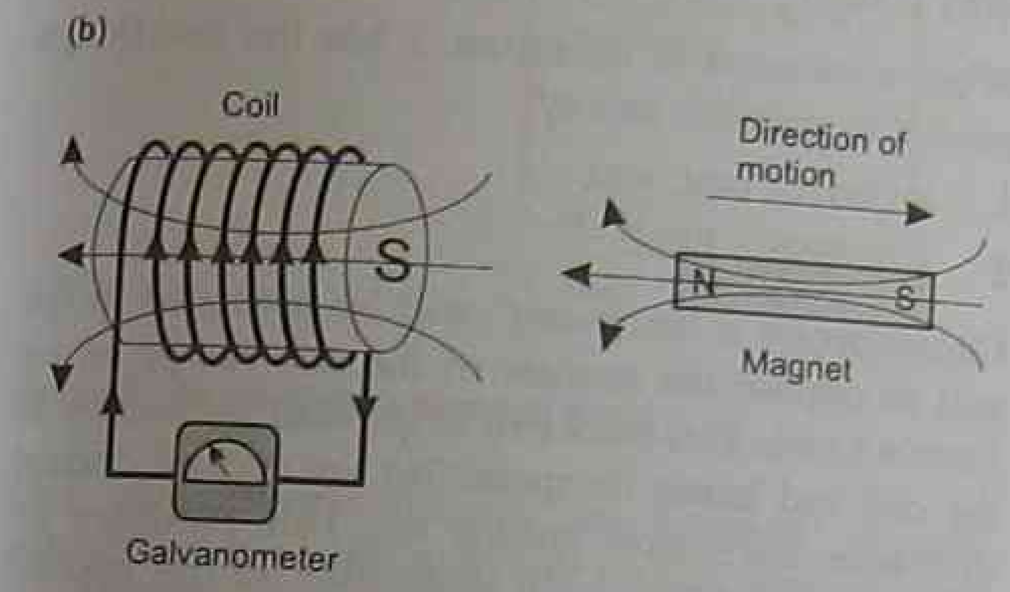
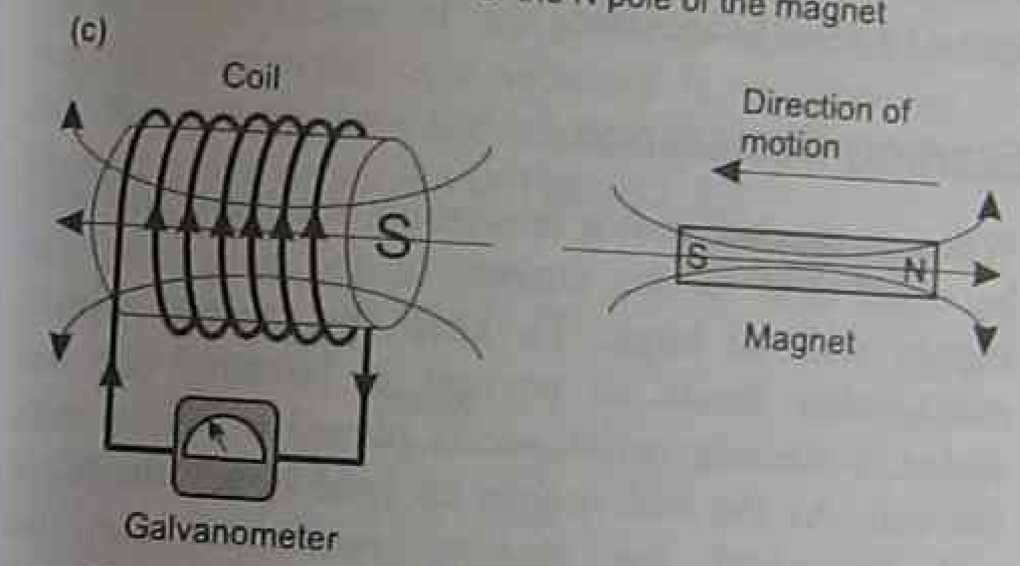
[10] http://micro.magnet.fsu.edu/electromag/java/lenzlaw/ Lenz's Law



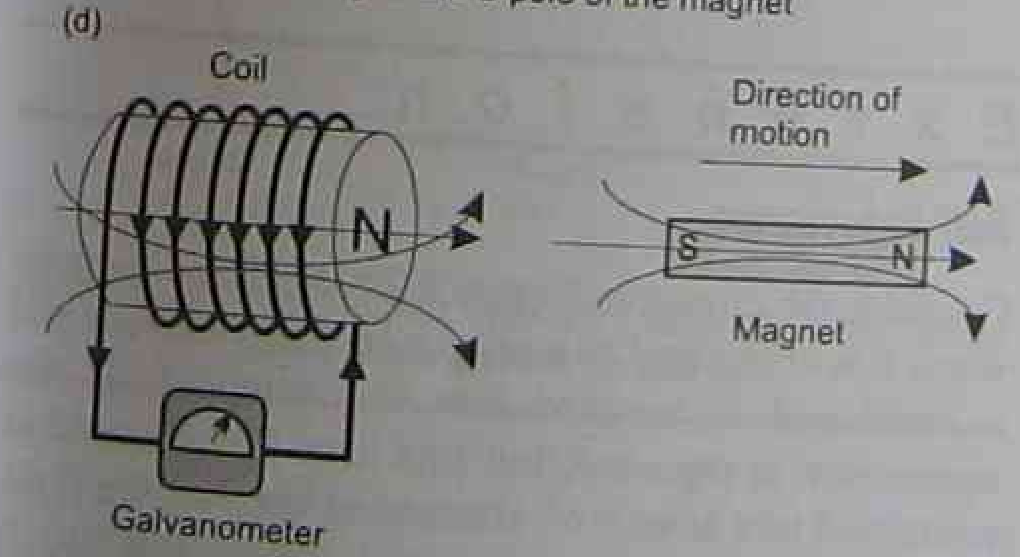
Current flows in coil in a direction to set up a N pole to oppose the entry of the N pole of the magnet



Current flows in coil in a direction to set up a S pole to oppose the withdrawal of the N pole of the magnet



Current flows in coil in a direction to set up a S pole to oppose the entry of the S pole of the magnet



Current flows in coil in a direction to set up a N pole to oppose the withdrawal of the S pole of the magnet

Figure 2.24 Lenz's Law. In all cases, the current flows in a direction to oppose the cause of the induced current.

Alternative View of Lenz's Law

Consider a straight wire moving through a magnetic field as shown in Figure 2.25. Use of the right-hand palm rule shows that positive charges in the wire experience a force pushing them to the top of the wire and negative charges would be forced to the bottom. (Note that only the negative charges, that is, the electrons, can move in a wire but the effect is the same as positive charges moving in the opposite direction.) This flow of positive charge *upwards* constitutes a *conventional current* flow from the bottom to the top. Use of the right-hand palm rule for *this current* shows that as a result of this current, a magnetic force is produced on the wire towards the left-hand side that is, opposing the applied force.

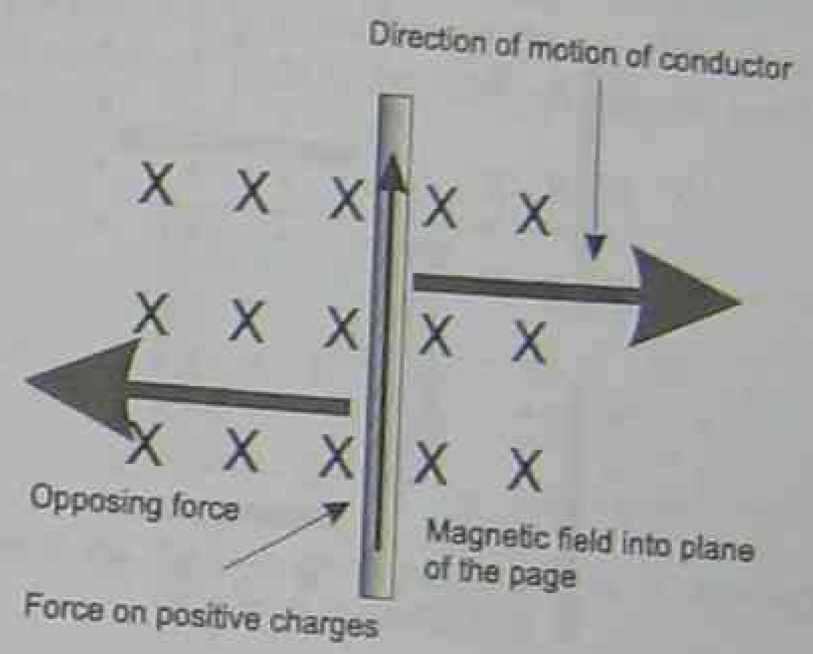


Figure 2.25 Alternative view of Lenz's Law

Confusion often occurs about which way conventional current flows. It flows from positive to negative in the external circuit but from negative to positive in the 'internal circuit'. The latter requires energy, for example, from your hand; this is how the charges gain the energy to do useful work in the external circuit.

Direction of the Induced Current

This can be found by using the right-hand palm rule again (Figure 2.26). In these cases, however, your palm points in the opposite direction to the applied force, that is, if your fingers point in the direction of the magnetic field and your palm points in the direction of the opposing force, then your thumb points in the direction of the induced (conventional) current.

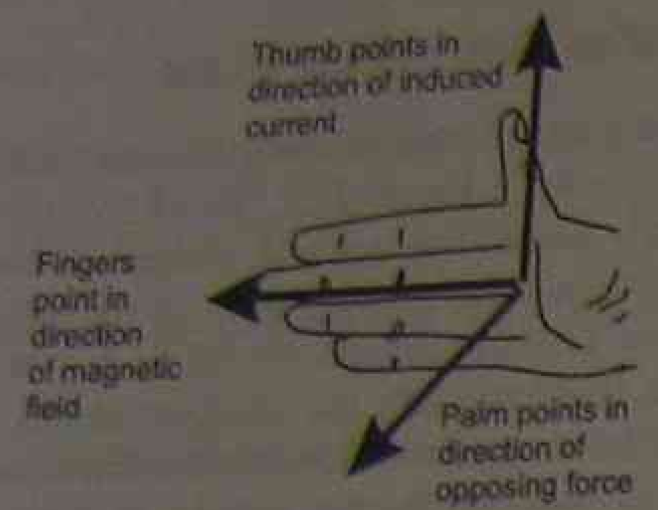
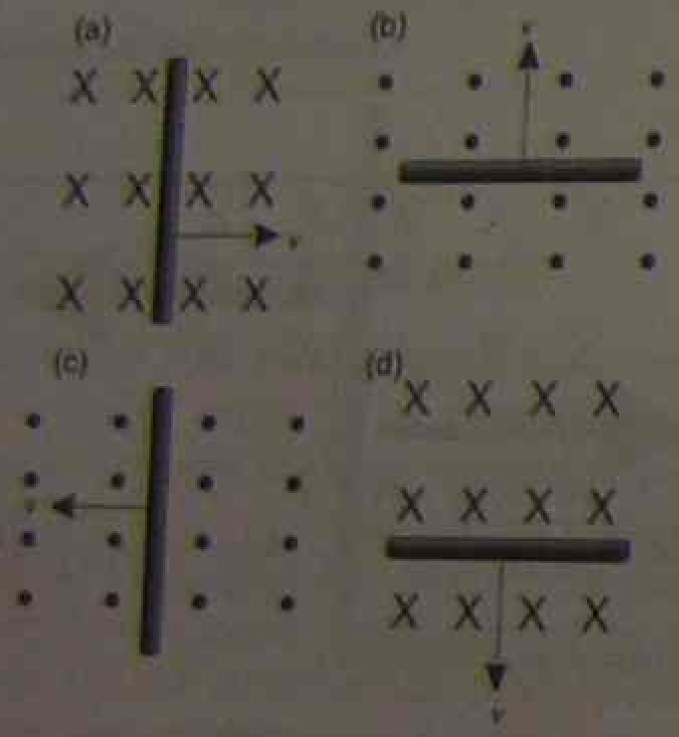


Figure 2. 26 Right-hand palm rule to find the direction of the induced current

EXAMPLE 8

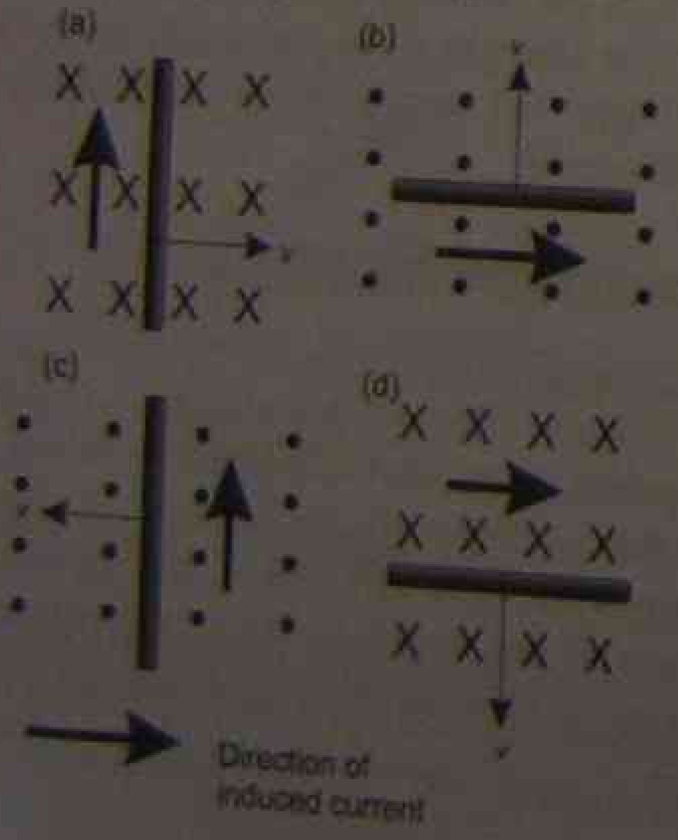
Determine the direction of the induced current in Figure 2.27. (Assume there is a complete circuit.)



igure 2. 27

OLUTION

y applying the right hand rule, the induced currents ow in the directions shown in Figure 2.28.



e 2. 28 Direction of induced currents

MORE EXAMPLES ON ELECTROMAGNETIC INDUCTION

Back *emf* in Electric Motors

You may have noticed at some time that the houselights momentarily dim when an appliance such as a refrigerator or clothes washer 'turns on'. Why is this?

When a motor is in operation, it has the two things needed to generate an *emf*:

1 a moving coil; and
2 a magnetic field.

Consequently a 'back *emf*' will be produced in the coil to oppose the motion of the coil (as given by Lenz's Law). This back *emf* helps limit the current in the coil and hence its speed. As the applied current increases, the motor speeds up. This produces an increasing *emf* that is in opposition to the applied voltage. The motor eventually reaches a steady speed (it is self-regulating).

Starting Resistance

When an electric motor is starting, the back *emf* will be small and so the current in the coil from the supply will be large. To keep the current within manageable limits to prevent it burning out the motor, a *starting resistance* is placed in series with the coil. As the coil speeds up (and hence the back *emf* increases) the starting resistance can be decreased and eventually removed.

Extension

Self-Inductance

Consider the circuit in Figure 2.29. Nothing happens when it is connected to a source of direct current and a metal rod is inserted into the solenoid. If the experiment is repeated, but this time the solenoid is connected to a source of alternating current, the light dims when the iron bar is inserted. Why is this?

In AC, the current is continually changing in magnitude and direction. This changing current produces a changing magnetic field in each coil of the solenoid. The coils are all in the changing flux of all the other coils; an *emf* is hence induced in each coil, the direction of which is to oppose the cause (Lenz's Law). This *back emf* effectively reduces the voltage forcing current through the lamp. As a result, the light dims. The iron rod simply magnifies the effect by concentrating the magnetic flux inside the solenoid.

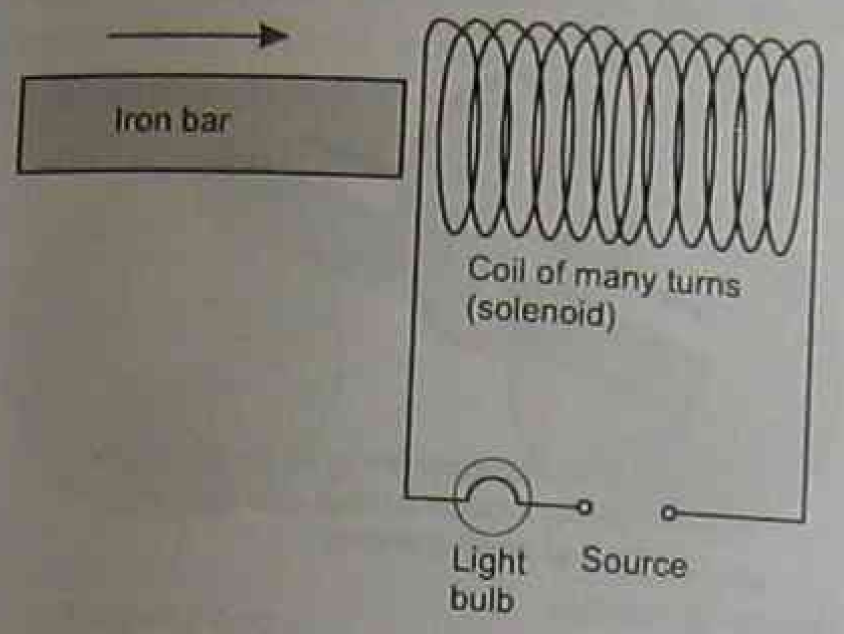


Figure 2. 29 Self-inductance in a coil

This experiment illustrates the property of self-inductance. It occurs with any coil of wire attached to an AC signal.

As a consequence of self-inductance, when a DC supply, connected to a solenoid is switched on or off, the current does not respond immediately but is slowed down as shown in Figure 2.30.

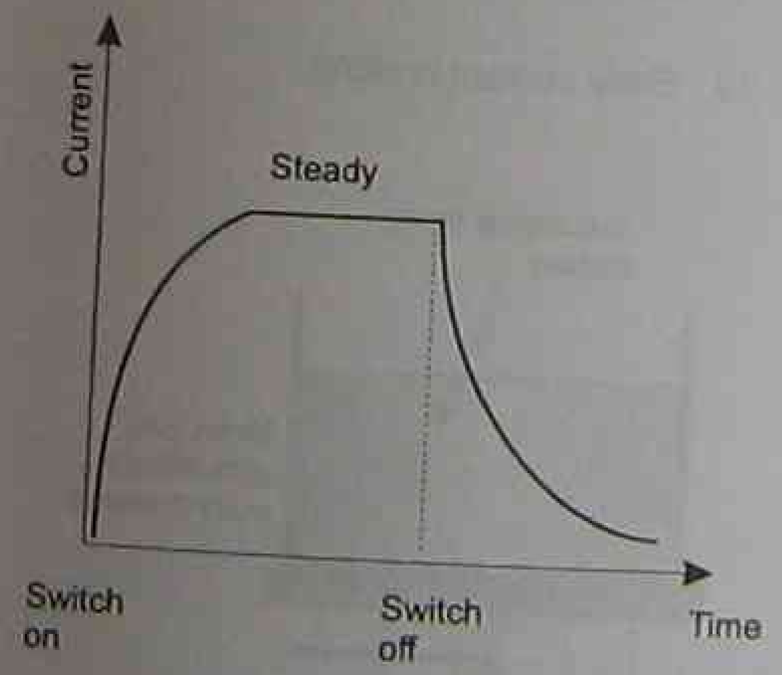


Figure 2. 30 The effect of an induced emf when switching a current on and off

Eddy Currents

An *emf* is induced in a conductor whenever it is placed in a region of changing magnetic flux. In the case of a solid conductor (such as a metal sheet), *circular eddy currents* are induced.

Eddy currents[11] *are circular currents induced in a conductor in the presence of a changing magnetic flux.*

This can result from moving a conductor through a magnetic field, or having the conductor in the presence of changing magnetic flux.

Consider a rectangular metal plate *ABCD* moving to the right and entering a magnetic field directed perpendicularly into the page as shown in Figure 2.31. Application of Lenz's Law and the right-hand palm-rule shows the current flows up the plate near the edge *BC* and down the other direction in that part of the plate not yet in the field. The result is a circular eddy current flowing anticlockwise. (Convince yourself that current flowing from *D* to *B* will produce a force to the left opposing the applied force.)

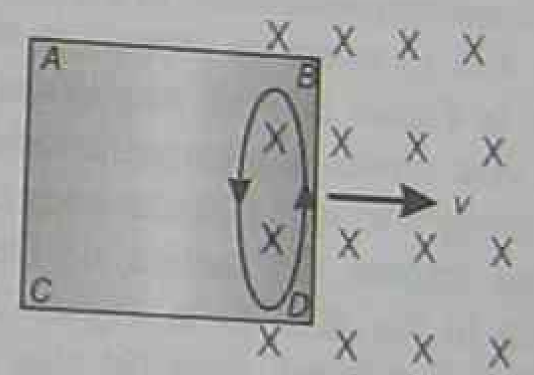


Figure 2. 31 Eddy current production in a conductor entering a magnetic field

As the plate leaves the field the current flows clockwise. When the plate is wholly in the field no currents are induced.

Now consider a conducting plate placed in a uniform magnetic field as shown in Figure 2.32(a). If the field is now increased as in Figure 2.32(b) current will flow in the plate to oppose the change. Since the field is into the page the induced current sets up a magnetic field *out* of the page (to oppose the increasing field). Application of the right-hand grip rule for current shows the induced current to flow anticlockwise.

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[11] The name comes from the fact that they resemble water eddies formed when water flows past an object.

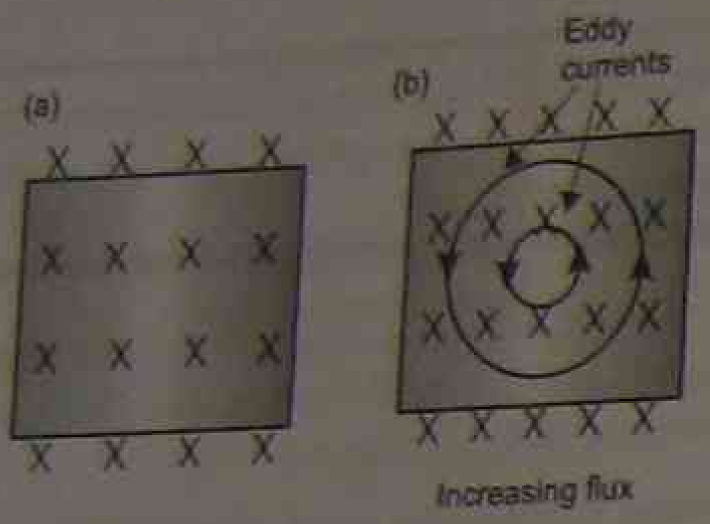
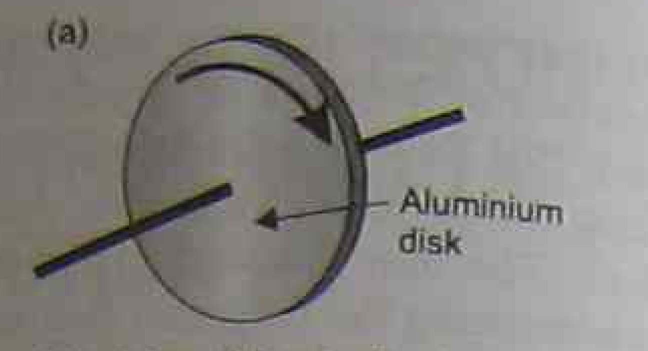


Figure 2. 32 Induced eddy currents in a region of changing magnetic flux

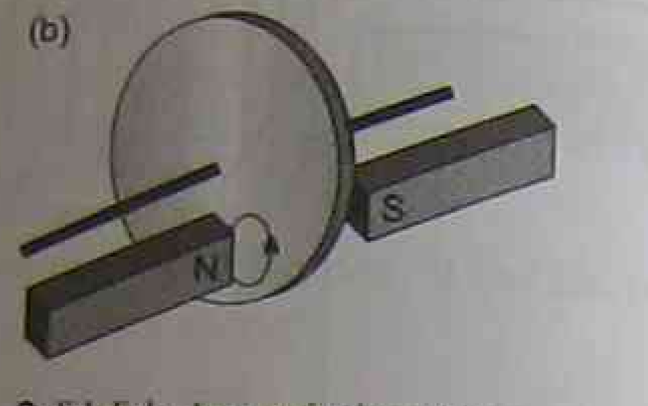
Electromagnetic Braking

These eddy currents are often used for *electromagnetic braking* as on school balances since the induced currents flow in a direction to oppose the change producing them (Lenz's Law).

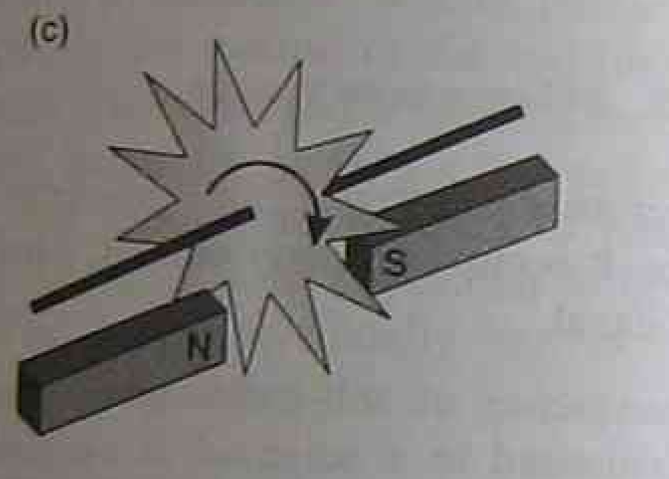
Consider Figure 2.33, which shows the effect of a magnet on a moving conductor. In Figure 2.33(a), an aluminium disk (it could be copper) is set spinning on an axle. In Figure 2.33(b), magnets are arranged so that the disk rotates in a magnetic field. The disk is quickly brought to rest! Circular eddy currents are induced and oppose the motion of the disk. By placing slits in the disk as in Figure 2.33(c), the braking effect is reduced, since the slits prevent the eddy currents from forming (or restrict them to very small currents). Eddy current braking has uses in industry and transportation (see later).



Aluminium disk spins freely on its axle



Solid disk stops spinning when magnetic field brought close to disk due to the creation of eddy currents



A disk with slits continues to spin for much longer than a solid disk in the presence of a magnetic field

Figure 2. 33 Eddy current braking

Secondary Source Investigation

Induction Cookers

Induction cookers use coils (inductors) placed beneath a glass-ceramic cook top to generate heat for cooking. Alternating current in the coils sets up an oscillating magnetic field which induces eddy currents in metal pans placed in the vicinity of the varying field (Figure 2.34). These currents cause the metal to get hot, heating its contents.

Induction heaters have the advantages that:

1 almost all the heat goes into heating the pan and its contents and not the element;
2 the glass-ceramic cook top is easy to clean as it is flat with no depressions; and
3 it is cheaper to operate.

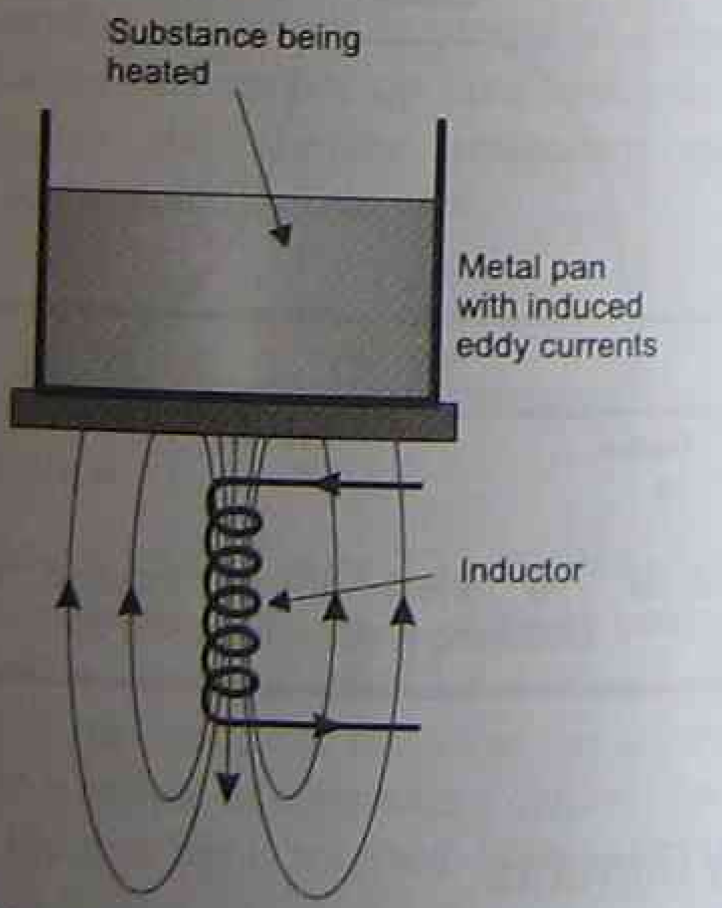


Figure 2. 34 Induction heating in cook tops

Heavy Duty Eddy Current Braking

Eddy currents are used in some modern trains (such as the 'bullet' trains of Japan) for braking. During braking, electromagnets are brought near to the moving metal wheels as in Figure 2.35. Eddy currents are induced in the wheels and flow in such a direction to oppose the motion of the wheel that produced them (Lenz's Law), slowing the train down (Figure 2.35(b)).

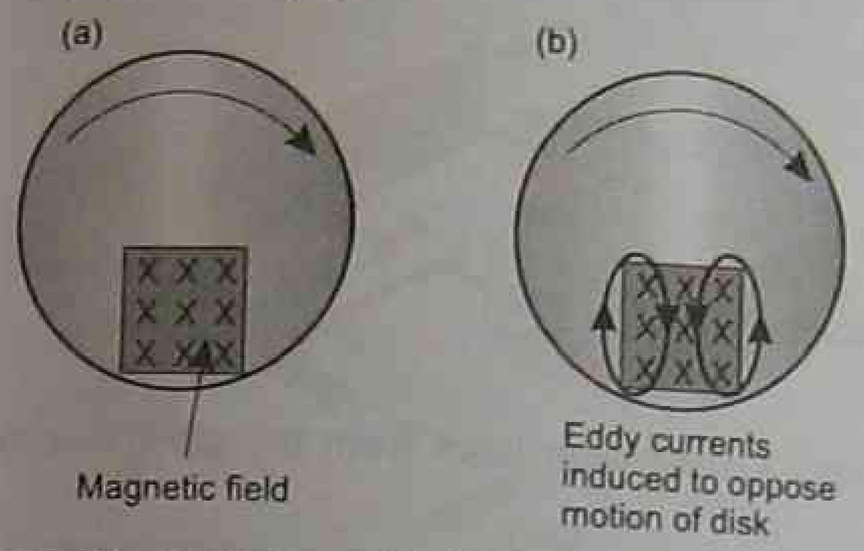


Figure 2. 35 Eddy current braking on metal wheels

Since the effect is greatest when the wheels are moving fastest, it follows that as the wheels slow down the braking decreases resulting in smooth braking.

Certain fun-park rides also use eddy current braking. For example, at *Australia's Wonderland* in Sydney there is a ride called *Space Probe 7* in which thrill-seekers free-fall some 36 m before being slowed to rest. Four strong magnets are placed in the seat of each passenger. As the seat (and passenger) fall in the last 25 m of the ride, they pass large copper sheets (fins). Eddy currents are induced in these sheets and set up forces opposing the falling magnets. In this way the seats (and the falling riders), are brought to rest.

SECTION 3: ELECTRIC GENERATORS

BIG IDEA:

Generators are used to provide large-scale power production.

OUTCOMES:

Students learn to:

1 Describe the main components of a generator.
2 Compare the structure and function of a generator to an electric motor.
3 Describe the differences between AC and DC generators.
4 Discuss the energy losses that occur as energy is fed through transmission lines from the generator to the consumer.
5 Assess the effects of the development of AC and DC generators on society and the environment.

Students:

1 *Plan, choose equipment or resources for, and perform a first-hand investigation to demonstrate the production of an alternating current.*
2 *Gather secondary information to discuss advantage/disadvantages of AC and DC generators and relate these to their use.*
3 *Analyse secondary information on the competition between Westinghouse and Edison to supply electricity to cities.*
4 *Gather and analyse information to identify how transmission lines are:*
- *insulated from supporting structures*
- *protected from lightning strikes.*

GENERATORS

A **generator** *is a device for producing electrical energy from mechanical energy (the reverse of an electric motor).*

A *prime mover* is the mechanical device that is used to drive a generator. It could be a steam turbine (driven by steam produced by burning coal, oil or natural gas or the heat produced by nuclear energy) or one driven by moving water (a water turbine). The kinetic energy of the turbine is converted into electrical energy through the phenomenon of electromagnetic induction.

In theory a motor can function as a generator and a generator can function as a motor. (They differ only in some mechanical details and their auxiliary equipment.)

It follows that a generator consists of:

1 an *armature*;
2 a *field structure* (which can be from an electromagnet or from a permanent magnet);
3 *slip rings* and *brushes* to take the induced current away; and

4 a *commutator* if it is a DC generator (AC generators do not have one).

A Simple AC Generator[12]

We will consider a simple generator to illustrate the principles on which all generators function (Figure 2.36).

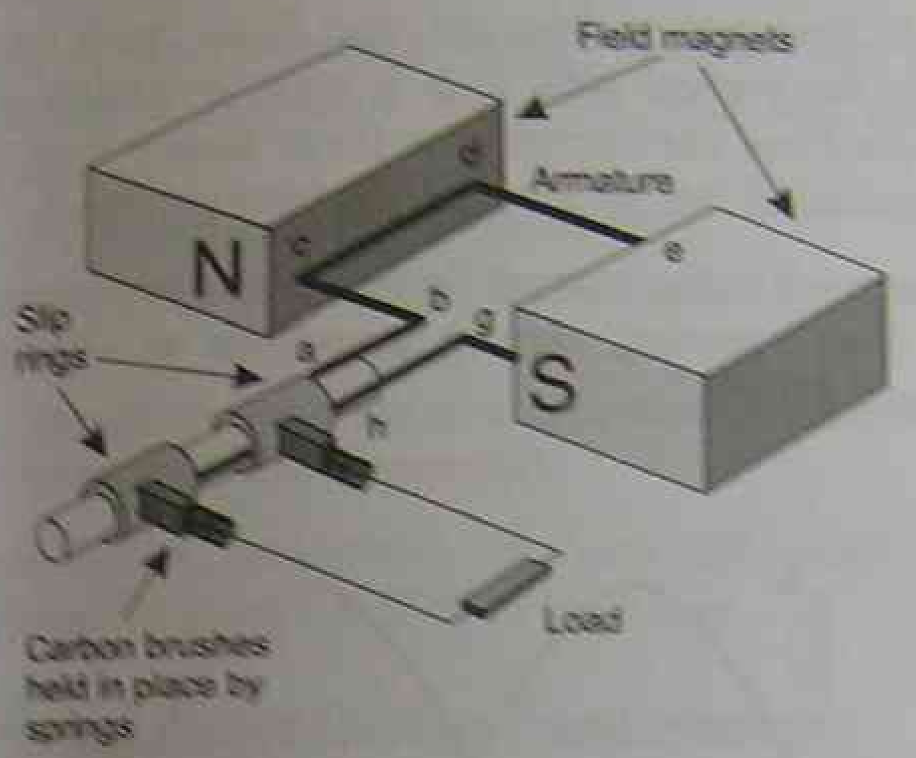


Figure 2. 36 A simple AC generator

A single coil of wire *abcdefgh* that is free to rotate about a horizontal axis is placed between the north and south poles of a magnet. Magnetic lines of force (magnetic flux) go from the north pole to the south pole. *Slip rings* are connected to the coil at ends *a* and *h*. Carbon brushes make contact with these slip rings and are connected to a load.

We will assume the coil rotates anticlockwise (for convenience). As it rotates, the coil 'cuts' through magnetic flux lines and by the principle of electromagnetic induction, an *emf* is induced between the ends of the coil (and a current is induced in the coil as it is part of a complete circuit).

The size of the induced *emf* depends on the position of the coil. Maximum *emf* is induced when the coil passes through the horizontal plane because it is now moving at right angles to the lines of force. When the coil is in position 2 shown in Figure 2.37 the current in the side of the coil *cd* (which is moving down) is in the direction shown, that is, from *d* to *c*. (This can be deduced from the right-hand palm-rule—where the palm points in the opposite direction to the applied force—in this case *up* and the fingers point from north to south. The thumb points towards *c*.) Similarly the current in the side *ef* flows from *f* to *e*.

As the coil passes through the vertical (position 3) the induced *emf* momentarily drops to zero since the coil is now moving parallel to the field and so no lines of force are cut.

Further rotation means that the side *cd* is now moving up through the field lines (position 4). As a result the current now flows from *c* to *d*. It follows that in each full revolution, the direction of the current reverses each half cycle. Alternating voltages (and currents) are induced.

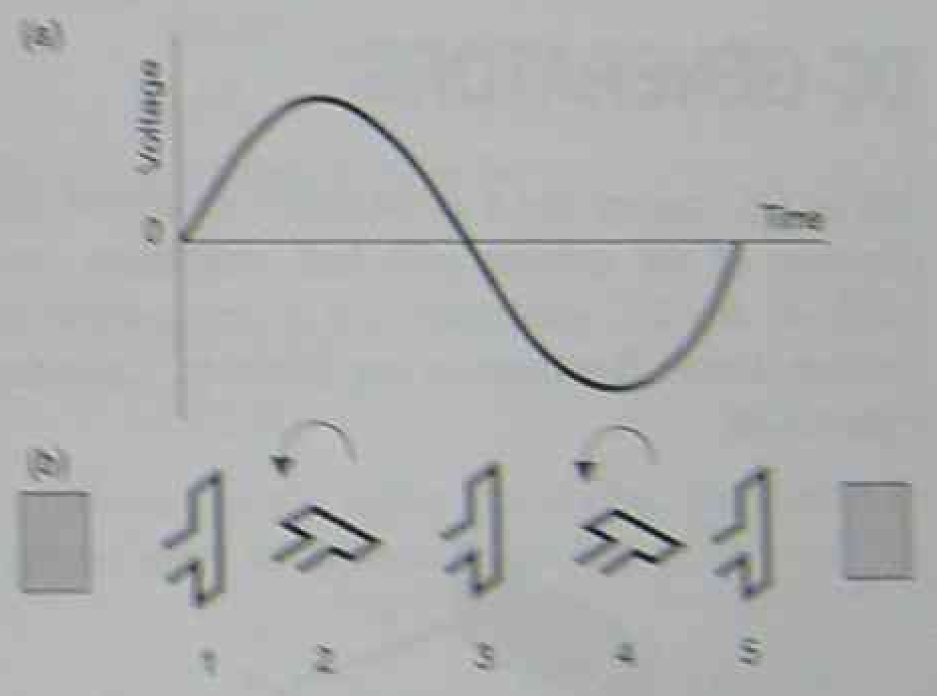


Figure 2. 37 AC generator operation and output

The current is taken away by the slip rings and brushes to the load.

A graph of *emf* versus angle is shown in Figure 2.37(a). This is a sine curve. In Australia the frequency of the *emf* is 50 hertz (50 Hz).

'Real' Generators

Real electric generators are a little more complex than the one just described but essentially function the same way (with some modifications).

1 Real generators use electromagnets to provide the field structure. An auxiliary DC generator (see later) called an *exciter*, provides the DC current for the electromagnets. (Some small generators, however, have permanent magnets for the field structure and are called *magnetos*.)

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[12] There is a range of excellent sites on the operation of generators including:
http://home.a-city.de/walter.fendt/physengl/generator engl.htm
http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/motorac.html#c2
http://micro.magnet.fsu.edu/electromag/electricity/generators/index.html
http://micro.magnet.fsu.edu/electromag/java/generator/ac.html

2 Instead of a single coil, a real generator's armature has hundreds of coils of copper wire wound around the iron core. (The more coils, the greater the *emf* that can be induced.)

3 In the majority of real AC generators, the armature is the stator and the field structure is the rotor. (The slip rings carry current from the exciter to the electromagnets of the field structure, rather than carry current from the armature. This reduces sparking at the brushes and slip rings since the exciter current is smaller.)

4 Most generators have more than one electromagnet. By having *three* sets of armature coils for each pole, separated by 120°, three *emfs* (and currents) can be produced during each revolution. Such *three-phase* generators are more efficient that *single-phase* generators.

DC GENERATORS[13]

Just as DC motors use a *commutator* to reverse the direction of the current each half revolution (see p.60), so too DC generators use a commutator to produce current that flows in one direction. Consider Figure 2.38.

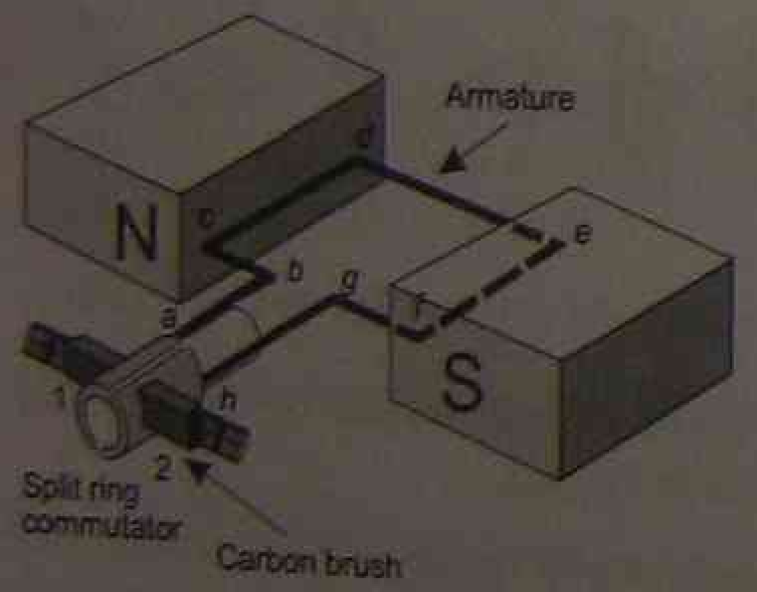

Figure 2. 38 A simple DC generator

As with the AC generator previously discussed, a single coil of wire *abcdefgh* is free to rotate about a horizontal axis and is placed between the north and south poles of a magnet. Ends *a* and *h* are connected to each segment of the commutator and carbon brushes (1 and 2) make contact with each segment of the commutator. The brushes are connected to a load.

Consider the situation in Figure 2.39(b) and assume the coil is rotated anticlockwise. The induced current is from *d* to *c* in side 1 and from *f* to *e* in side 2 (that is the current flows in the direction *hgfedcba*). When the coil reaches the vertical (position 3), the current is reduced to zero (the coil moves parallel to the field lines and so does not 'cut' flux). As it rotates past the vertical side 1, it is now in contact with brush 2 and the current now flows from *c* to *d*. The direction of current in side 1 has been reversed!

The result is that current flows in one direction only. It does, however, vary in magnitude as shown in Figure 2.39(a).

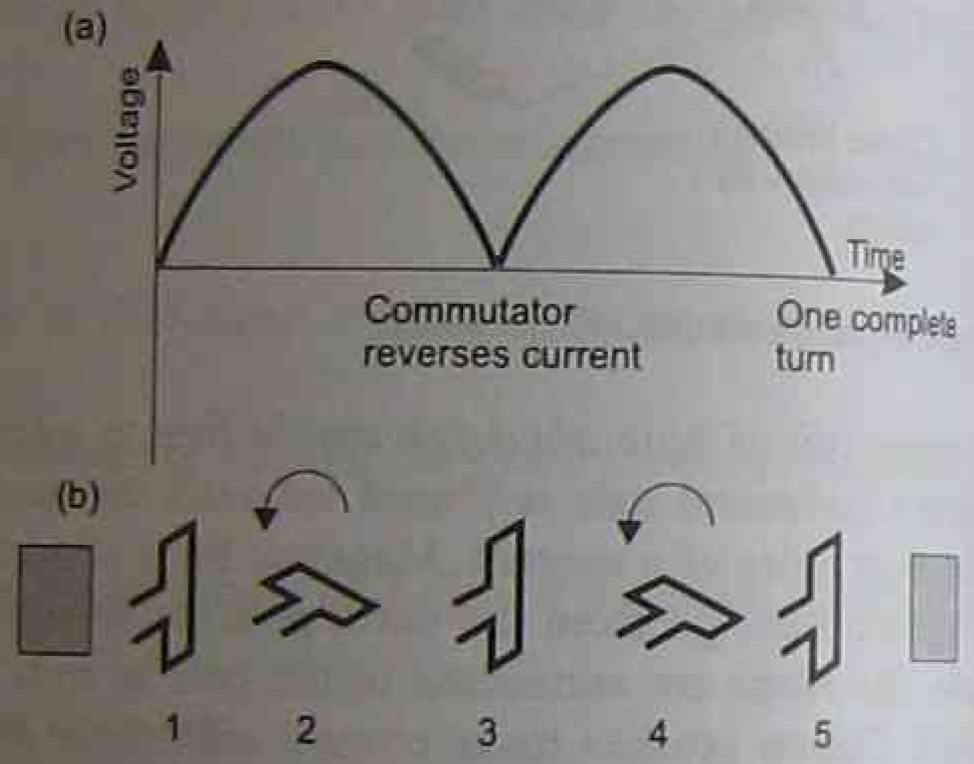

Figure 2. 39 DC generator operation and output

'Real' DC Generators

1 The armature is the rotor and the field structure is the stator (the opposite of most AC generators). This means large currents flow through the commutator.

2 Some DC generators—*separately excited generators*—use external DC current to produce the field structure. Others—*self-excited generators*, rely on *residual magnetism* in the electromagnets to generate DC current, some of which is used to excite the electromagnets.

3 Because problems can arise with commutators as in cars for example (due to their complexity especially when there are many segments), they use AC generators (*alternators*) and solid-state devices called *rectifiers* to convert the AC to DC.

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[13] http://micro.magnet.fsu.edu/electromag/java/generator/dc.html DC generator action.

4 DC generators are often used in tandem with AC motors (allowing AC to be converted into DC for certain applications, such as electrolysis for metal purification).

ENERGY LOSSES

Some of the mechanical energy used to drive the generator is converted into heat. This can occur because of:

1 friction in the bearings of the rotor;
2 heat generation in the conductors due to current; and
3 energy losses in the iron core (due to a magnetic property called *hysteresis*).

Nevertheless, generators are very efficient, with efficiencies as high as 97% in large ones.

Energy Losses During Transmission

Even good electrical conductors like copper used to supply electricity, sometimes through considerable cable lengths to towns and cities, generate substantial resistances (resistance is proportional to length of the conductor).

It follows that to minimise energy loss in the wires, the current needs to be kept low (heating losses vary as the square of the current). This is achieved by transmitting the energy at high voltages[14]. We can best illustrate this with an example.

EXAMPLE 9

A transmission cable has a resistance of 5 Ω. If 10 kW of power is fed into the cable, calculate the power wasted in the cable if it is transmitted at:

(a) 1000 V

(b) 100 000 V

SOLUTION

(a) The current in the cable is found from:

$$P = VI$$

$$I = \frac{P}{V}$$

$$= \frac{10 \times 10^3}{1000}\text{ A}$$

$$= 10\text{ A}$$

Hence the power dissipated in the cable is:

$$P = I^2R$$

$$= 10^2 \times 5\text{ W}$$

$$= 500\text{ W}$$

(b) For the higher voltage:

$$P = VI$$

$$I = \frac{P}{V}$$

$$= \frac{10 \times 10^3}{100\,000}\text{ A}$$

$$= 0.1\text{ A}$$

Hence power loss is given by:

$$P = I^2R$$

$$= 0.1^2 \times 5\text{ W}$$

$$= 0.05\text{ W}$$

It follows that the higher the voltage, the smaller the current hence the less power lost through the cables.

Secondary Source Investigation

High Voltage Transmission Line Insulation

It is obvious that high voltage transmission lines (as high as 500 kV, see p.81), need to be insulated from the tall towers—*pylons*—that support them.

Safety is a major concern. If the tower were to become 'live', it would kill any person who came in contact with it.

Secondly, insulation prevents a 'short circuit' where the electricity would take the path of least resistance (into the ground) and would never reach its destination. Porcelain is commonly used as an insulator being unaffected by weather and still functions well at high voltages.

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[14] See the next section on transformers to understand how this is done.

Protection From Lightning Strikes[15]

A protective wire strung above the conducting cables protects the transmission lines. This is sometimes called a *shield wire* or *overhead ground wire*. It is designed to intercept a lightning strike and divert it to earth.

In some countries power companies are making additional use of this wire. By placing a fibre optic core through the centre of the conductor they can expand the possibilities of telecommunications by exploiting the 'right of way' principle. (The wire still helps protect against lightning.)

IMPACT OF ELECTRICITY GENERATION ON SOCIETY

To understand how electricity has impacted on society, just imagine what would happen to your lifestyle if all electric power suddenly stopped. You would not be able to make a hot breakfast, your fresh food would probably spoil in a short time, you could not watch television, use your computer, fill your car (or parent's car!) with petrol (the pumps would not work), see a movie… Life as we know it would be vastly different.

Early 'Power' Sources

As we saw earlier in the Preliminary Course *Electricity in the Home*, the energy released from the burning of wood was the major source of domestic 'power' until the advent of the *Industrial Revolution* in the eighteenth century.

The Industrial Revolution brought with it ever-increasing energy demands leading to an exponential growth in the use of *coal* as an energy source in the factory (and also in the home as the supply of wood was exhausted). Steam engines fuelled by coal, powered the rapid industrialisation of many parts of the world in the eighteenth and nineteenth centuries notably Great Britain, America, Germany and latterly, Japan.

Faraday and Henry

The independent discovery in 1831 of *electromagnetic induction* by Michael Faraday[16] in England and Joseph Henry in America revolutionised the possibilities for industrial and domestic energy sources. As a result of their discovery, electricity was to become the primary source of industrial and domestic energy in the industrialised countries.

The first continuous current-generating device was devised by Faraday and consisted of a copper disk rotated between the poles of a magnet, the current being conducted away by copper brushes (Figure 2.40). While it was shown to be impractical, it nevertheless showed that continuous current generation was possible.

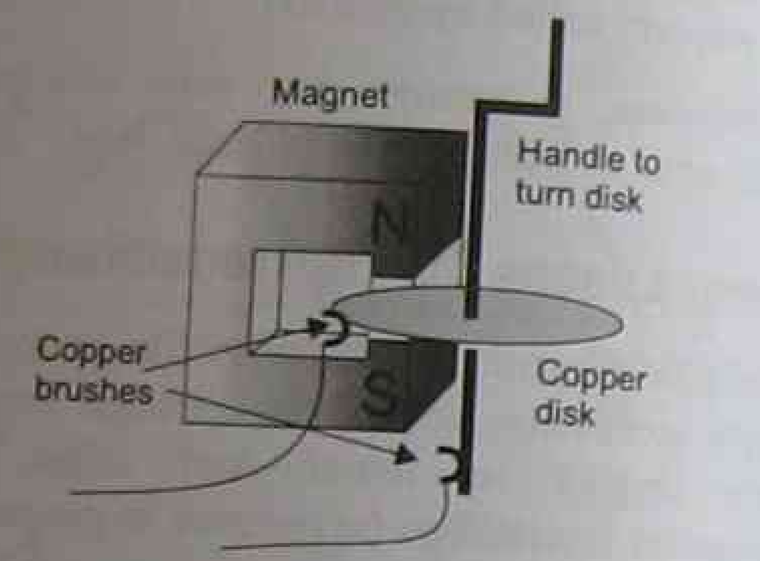

Figure 2. 40 The Faraday disc dynamo

Practical Generators

A lot of technical problems had to be overcome before practical large-scale generators were produced. By the late 1860s Zénobe-Théophile Gramme, a French engineer and inventor built a continuous-current generator that was to prove pivotal in the acceptance of electric power generation.

In 1873, an accidental discovery at the Vienna exhibition marked the beginning of the electric power age. A workman accidentally connected two *Gramme dynamos* together. The result was that the current generated in one dynamo passed to the other generator which ran as an electric motor[17]!

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[15] http://wvlightning.com/powerflash.html Site explaining how transmission towers are protected from lightning strikes.

[16] http://www.the-education-site.com/electric/INDEX.HTM links to brief biographies of famous people in the study and application of electricity including Faraday and Henry.

[17] Prior to this, batteries were the only sources of continuous current for motors!

Domestic Electricity

The growth of the electric power industry was given a significant impetus by Thomas Edison's invention of the incandescent light bulb in 1879. In 1882 Edison's Electric Light Company commenced installing lighting systems in homes[18]. Within a few years electricity was being used in homes where it continues today providing a myriad of devices to 'improve' our standard of living.

As we shall see, electricity has brought substantial benefits but left a legacy of significant social and environmental costs for humankind.

Social Implications of Electricity Generation

As discussed in *Electricity in the Home* the advent of the Industrial Revolution saw *textile looms* powered by steam engines effectively wipe out the textile cottage industry. The demand for labour in the new factories led to mass migration of people from rural communities to the larger towns and cities. Poor working conditions, overcrowding, inadequate sanitation… led to the formation of slums with their associated social problems. Many of these problems were exacerbated with the introduction of electric lighting, enabling workers to work even longer hours.

Environmental Costs

Today most electrical energy is produced in 'power stations' that burn *fossil fuels*—coal, oil and natural gas—with their associated environmental costs of *global warming* and *acid rain*. Other energy sources used to produce electricity include water (hydro-electric power) and nuclear (nuclear-power) as well as small amounts generated from wind (wind power) and the Sun (solar power). The least environmentally destructive of these is solar energy but it is still in its infancy.

Secondary Source Investigation

Edison and Westinghouse

One of the world's most prolific inventors was the American Thomas Alva Edison (1847—1931). Edison was responsible for the invention of a practical light bulb, the gramophone (the forerunner of the record player) and a myriad of other devices. When he died, he had literally thousands of patents.

In 1882 the *Edison Electric Light Company* began installing lighting systems. The company was successful in selling 200,000 lights in the first three years of operation. This led to the rapid development of electric power generation and distribution. Edison powered his electric lights using direct current (DC).

The American engineer George Westinghouse (1846—1914) developed an alternative system for generation and distribution using alternating current having purchased in 1885 the American patent rights of the AC pioneer, Nikola Tesla (1856—1943) (see p.83).

To try to preserve his monopoly, Edison began a smear campaign against Westinghouse claiming AC was unsafe because of the high voltages used. To 'illustrate' his point, Edison held a public demonstration in 1887 in New Jersey in which he used the electric current from a Westinghouse AC generator connected to a metal plate to execute a dozen live animals (leading to the term *electrocution*).

In 1884, following an investigation into 'humane' methods of execution, the New York State Government passed a law establishing electrocution as the state's method of execution (replacing hanging). Since there were two alternative systems (DC and AC), a committee was established to decide between them. Edison publicly campaigned for the AC system believing this would support his view that AC was more dangerous than DC! The committee (chaired by Dr Fred Peterson who was on the payroll of the Edison Company!) chose AC and on January 1 1889, the world's first electric execution law was established.

Westinghouse refused to sell his generators to the New York prison authorities and even funded appeals by death row prisoners on the grounds that electrocution was '…a cruel and unusual punishment'. His rival Edison, on the other hand testified that electrocution was a quick and painless form of death!

In 1887, businessmen in Buffalo, New York, offered $100,000 (an enormous amount back then), to anyone who could design a system for utilising the power of the Niagara River (some 30 km from

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[18] See Secondary Source Investigation following.

Buffalo). Both Edison and Westinghouse vied for the prize.

As far back as 1883, successful distribution of AC had been demonstrated in Paris. In 1884 an experimental line powering incandescent electric lights had been set up in London and a year later in Italy. Westinghouse had seen the Italian system designed by Tesla and this had prompted him to buy Tesla's patents.

The choice for the Buffalo project was still to be made in 1891 when a successful demonstration of he transmission of a significant amount of lectricity was made in Germany. AC was ransmitted from Frankfort to Lauffen, a distance of 160 km with a 77% efficiency (much further and r more efficient than with DC).

t the 1893 Chicago World's Fair the *General lectric Company* (which later merged with dison's company) offered to power the world's first l-electric fair for $1,000,000 using DC. estinghouse offered to do it for half that price and bsequently was given the contract. This was an portant win for the AC system. Later that year estinghouse's AC system was chosen over ison's DC system to power the fairgrounds of the *rld's Columbian Exposition* (celebrating the 400th iversary of Columbus' discovery of America.

In November 1896 the first transmission of electric power from Niagara Falls to Buffalo took place. The AC system was used!

What made AC superior to DC?

AC won out because it had a number of advantages over DC:

1 DC could not be transmitted far without significant loss of energy. To minimise this the wires needed to have low resistance meaning thick copper wires were needed. This had an associated high cost.

2 DC generators needed commutators and these were relatively inefficient. They also meant that the generator design was more complex. AC generators do not have commutators and so can be simpler.

3 DC voltages cannot be changed easily. The voltage depends on the speed of rotation of the armature of the generator. High speeds were needed for high voltages to allow for transmission over longer distances.

4 The use of a transformer means than high AC voltages have associated low AC currents and so less energy is lost in the wires (so thinner and hence cheaper wires could be used).

AC continues to power 99% of electrical devices in the world.

SECTION 4: TRANSFORMERS

BIG IDEA:

Transformers allow generated voltage to be either increased or decreased before it is used.

OUTCOMES:

Students learn to:

1 Describe the purpose of transformers in electrical circuits.

2 Compare step-up and step-down transformers.

3 Identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltage.

4 Explain why current transformations are related to conservation of energy.

5 Explain the role of transformers in electricity sub-stations.

6 Discuss why some electrical appliances in the home that are connected to the mains domestic power supply use a transformer.

7 Discuss the impact of the development of transformers on society.

Students:

1 *Perform an investigation to model the structure of a transformer to demonstrate how secondary voltage is produced.*

2 *Solve problems and analyse information about transformers using* $\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{n_p}{n_s}$

3 *Gather, analyse and use available evidence to discuss how difficulties of heating caused by eddy currents in transformers may be overcome.*

4 *Gather and analyse secondary information to discuss the need for transformers in the transfer of electrical energy from a power station to its point of use.*

TRANSFORMERS

Transformers *are devices for transferring electrical energy from one circuit to another while changing the size of an alternating (AC) voltage.*

They operate on the principle of electromagnetic induction. *Transformers cannot operate on DC.*

Transformers consist of two coils of wire, the *primary* and the *secondary* in close proximity, wrapped around an iron core (Figure 2.41). Changing AC voltages in the primary coil sets up changing magnetic fields (*flux*) in the iron core. These link with the secondary coil (through the iron core) which has a changing magnetic field through it and hence induces a voltage. (This linking is called *mutual induction*.)

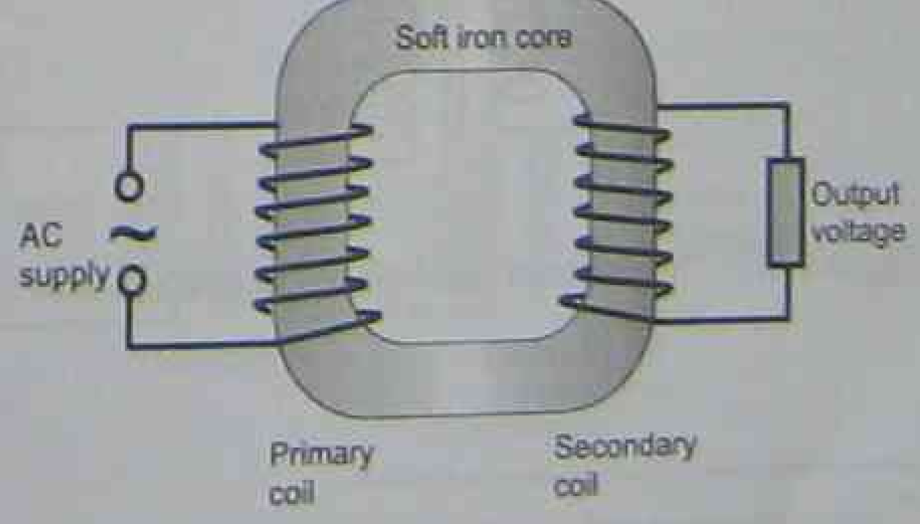


Figure 2. 41 A transformer

Transformers enable voltages to be altered by being either 'stepped-up' or 'stepped-down'.[19]

Step-up and Step-down Transformers

A **step-up** *transformer produces a greater voltage in the secondary than is in the primary coil. A* **step-down** *transformer produces a lower voltage in the secondary coil.*

Whether the transformer is a step-up or a step-down transformer depends on the *turns ratio.*

Turns Ratio

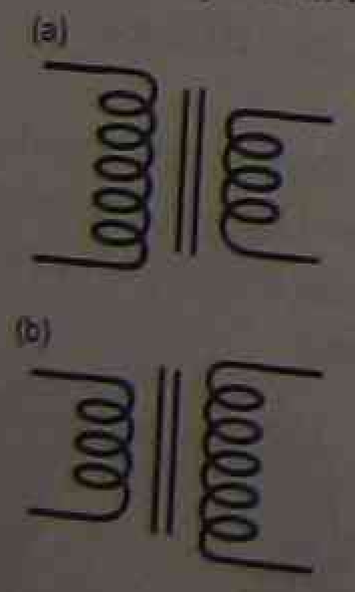
For an ideal transformer, there are no energy losses:

$$\frac{\text{voltage in primary}}{\text{voltage in secondary}} = \frac{\text{number of urns in primary}}{\text{number of turns in secondary}}$$

$$\boxed{\frac{V_p}{V_s} = \frac{n_p}{n_s}}$$

ere V_p and n_p are primary voltage and number of ns respectively. $\frac{n_p}{n_s}$ is called the *turns ratio.*

ollows that if $n_s > n_p$ then $V_s > V_p$ ('step-up' sformer). Similarly if $n_s < n_p$, then $V_s < V_p$ -down transformer). Figure 2.42 shows the ools for step-up and step-down transformers.



. 42 Transformer symbols (a) step-down and (b) step-up

Current Transformations and Energy Conservation

Not only is the voltage transformed, so too is the current. For an ideal transformer, no energy is lost in the process so:

Power in primary = Power in secondary

$$V_P I_P = V_S I_S$$

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{n_p}{n_s}$$

Hence if $n_s > n_p$ then $V_s > V_p$ but $I_s < I_p$. If $n_s < n_p$, then $V_s < V_p$ but $I_s > I_p$. That is, a step-up transformer increases voltage but decreases current; a step-down transformer decreases voltage but increases current.

EXAMPLE 10

The secondary coil of a step-down transformer consists of larger diameter wire than in the primary coil. Why is this?

SOLUTION

From the Preliminary Course *Electrical Energy in the Home* we saw that the resistance of a conductor is inversely proportional to the cross-sectional area. The bigger the area, the lower the resistance. In a step-down transformer, the current in the secondary is greater than the current in the primary. To minimise energy losses due to heating effects, the resistance needs to be as low as possible, hence the larger diameter wire.

EXAMPLE 11

A transformer has a primary of 5000 turns and a secondary of 250 turns. If the primary voltage is 240 V, what is the secondary voltage?

SOLUTION

From the relationship between the voltage and the number of turns we have:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

$$\frac{240}{V_s} = \frac{5000}{250}$$

$$V_s = \frac{250}{5000} \times 240 \text{ V}$$

$$= 12 \text{ V}$$

EXAMPLE 12

A 12 V 24 W globe is connected to the secondary in the previous example. If it operates at its correct power rating:

(a) What power is used in the primary?

(b) What current is in the primary?

SOLUTION

(a) Assuming a perfect transformer, the power in the secondary is equal to the power in the primary, that is, power = 24 W

(b) In the primary:

$$P = VI$$

$$24 = 240 \times I$$

$$I = 0.1 \text{ A}$$

Transformer Rectifier Units

Most school laboratories use *transformer rectifier units* which use devices called rectifiers to provide safe voltages for classroom use. These can be 'tapped' at different turns ratios (by selecting a switch) to give a range of values (generally from 2 V AC to 12 V AC in 2 V steps).

Similarly, transformers in electricity sub-stations lower the voltage from the power station to a safer voltage (NB: The 240 V for household use is *not* safe).

POWER TRANSMISSION

In a power station a *turbine* drives the alternator. This is achieved either by using the force of moving water (hydro-electricity) or the pressure of steam produced by burning coal, oil, or natural gas, or by using the heat energy released from nuclear reactions.

Each alternator produces *three-phase* electricity (see p.77) with voltages as high as 25,000 V (25 kV) and currents as large as 20,000 amperes! Large step-up transformers further boost the voltage to as high as 500,000 V (500 kV) for distribution over the power lines which form part of the *electricity grid.* (Other common transmission voltages in Australia are 330 kV, 220 kV and 132 kV.) As we have seen, this increased voltage results in decreased current which lessens the heating losses in the transmission power lines.

Additional transformers between the power station and the consumer reduce energy losses and gradually lower the voltage. By the time it gets to household users it is reduced to 240 V (Figure 2.43). Usually industry uses it at higher voltages (415 V).

The transfer of electricity over the power grid requires significant infrastructure of power stations, sub-stations, power lines and the towers to support the line. These are expensive to set up and maintain.

It follows that transformers are an integral part of the distribution of electricity across the country.

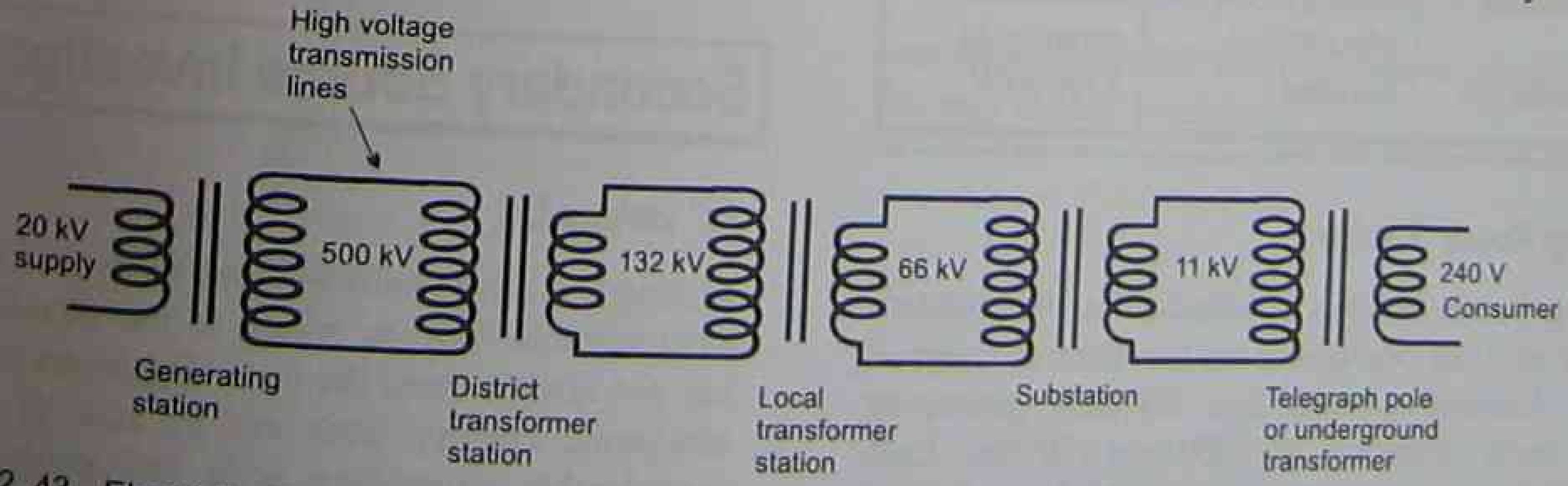


Figure 2. 43 Electricity distribution

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icro.magnet.fsu.edu/electromag/java/transformer/ Java how a transformer works.

Extension

Three-phase Transmission

Pylons carry cables in multiples of three for the three phases of the AC voltages. You may have noticed on transmission lines a single wire linking the tops of the pylons: this is the *neutral wire* (held at 0 V) and it is much thinner than the rest.

This wire can be thinner because it need only carry a smaller current back to the power station (to complete the circuit). Because the three live wires have different phases at any one time, two of the phases cancel each other out leaving only a single current to return to the station. (This current is smaller than the current in each of the separate live wires.) This reduces costs.

NSW Power Stations

In NSW there are four generating entities. Each has a number of power stations with varying capacities as indicated in Table 2.1

Table 2.1 NSW power stations

Generating Entity	Power stations	Generators x rating
Macquarie Electricity	Liddell	4 x 500 MW
	Bayswater	4 x 660 MW
Pacific Power	Eraring	4 x 660 MW
Delta Electricity	Vales Point	2 x 660 MW
	Munmorah	2 x 300 MW
	Wallerawang	2 x 500 MW
	Mt Piper	2 x 660 MW
Federal and State governments	Snowy Mountains Scheme	3 stations with capacity of 3370 MW

Eraring Power Station

Eraring Power Station is situated on the western shores of Lake Macquarie on the Central Coast of NSW. Eraring operates four 660 MW generating units, each operating at 3000 rpm (50 Hz). Each generator produces voltages of 23 kV. Units 1 and 2 send this to a 330 kV *switchyard* where the voltage is boosted to 330 kV; units 3 and 4 go to a 500 kV switchyard for stepping-up. Units 3 and 4 were the first in NSW to be connected to a 500 kV switchyard; this voltage is deemed to be the most suitable for bulk power supply requirements.

Home Appliances

Many electronic devices in the home are designed to operate on low DC voltages (~2.5 V—12 V). Examples include cordless telephones, external modems, laptop computers, video camera chargers, mobile phone charger… These often have a '*power cube*' transformer that plugs directly into the mains to provide the desired voltage. Rectifiers in the cube convert AC to DC.

TVs also contain transformers, at least one of which is a step-up transformer for producing the high voltages needed for the cathode ray tube to operate.

Secondary Source Investigation

Eddy Currents

As we saw earlier (see p.69), eddy currents are produced when conductors are placed in the presence of varying magnetic fields. In a transformer, such fields are essential to the transformation of voltages, so it follows that transformers will experience eddy currents. These currents produce heat and so represent a potential energy loss.

To minimise these losses in the soft-metal 'yoke' of the transformer, the yoke is *laminated*, that is, it is divided into thin sheets, each electrically isolated from those on either side (often by lacquer). This reduces the size of the eddy currents significantly and so reduces any energy losses.

Secondary Source Investigation

AC versus DC

Although it now seems obvious to us that AC is the most suitable form in which to use electricity, this has not always been the case. Engineers in the late nineteenth century were not so sure as they had considerable experience with DC generators and motors and much less with AC generators and motors.

Inherent problems in DC however, became more obvious as the demand for electricity increased. One problem lay in the commutator which complicated the generator design. This was exacerbated at high speeds which occurred when steam turbines were introduced in the 1890s. Another disadvantage was that there were no simple ways to change the DC voltage. Transformers on the other hand, make the conversion of AC voltages relatively simple.

In 1883 the first AC system was demonstrated in Paris followed by systems using transformers in London and Italy in 1884. In 1886 an AC system was set up in Buffalo, New York. The final 'nail in the DC coffin' occurred in 1891 when an AC line in Germany successfully carried electricity from Frankfurt to Lauffen with 77% efficiency. When, in 1886, the Niagara Falls power plant commenced operation with AC, the era of AC made possible by transformers, had arrived.

Nikola Tesla

Central to the utilisation of AC is the Serbian-American inventor, Nikola Tesla. Tesla was responsible for the discovery of the rotating magnetic field central to the operation of AC motors. In 1883 Tesla built the first induction motor.

Arriving in America in 1884, Tesla got a job with the American inventor of the light globe and powerful advocate for DC generation and transmission, Thomas Edison, but soon left. In 1885 Tesla sold his patent rights for AC dynamos, transformers and motors to George Westinghouse. Westinghouse, using Tesla's patents, built an AC generation and transmission system for the Niagara Falls power plant (see above), that effectively wiped out Edison's DC system. In recognition of his pioneering work, a statue of Tesla has been erected at Niagara Falls.

Extension

AC versus DC

You would be forgiven if you thought that all high voltages are transmitted as AC after the previous comments. You would, however, be wrong! Throughout the world, more and more *high voltage direct current (HVDC) transmission* is occurring. There are a number of reasons for this:

1 A phenomenon called the *'skin effect'* means that AC tends to travel through the outer portion of a conductor. This reduces the 'effective' cross-sectional area and hence increases the resistance; heating losses are increased. DC on the other hand, uses the entire conductor.

2 Three-phase AC transmission (the most common type) requires at least three conductors. DC transmission only requires two conductors. Although this may not seem significant, the cost of conductors over long distances must be considered. (Other costs, however, such as the devices to convert AC to DC and vice versa are so expensive that the overall cost advantage is not so great.)

3 With the large-scale integration of electrical power across state borders into a national grid in countries such as Australia, the different AC generating stations must be *synchronised* so that they operate at the same frequency and are kept in phase with each other. DC links do away with this requirement.

4 Underground or underwater cables transmit DC more effectively than AC. A *HVDC* link is used to transfer electrical energy between England and France for this reason. Similarly a 500 kV DC submarine line in Japan connects Shikoku with Kansai. It is the world's largest-scale DC power transmission line, with a capacity of 2800 MW.

Currently no HVDC links operate in Australia but this may change over time.

SECTION 5: ELECTRIC MOTORS

BIG IDEA:

Motors are used in industries and the home usually to convert electrical energy into more useful forms of energy.

Students learn to:

1 Describe the main features of an AC electric motor.

Students:

1 *Perform an investigation to demonstrate the principle of an AC induction motor.*

2 *Gather, process and analyse information to identify some of the energy transfers and transformations involving the conversion of electrical energy into more useful forms in the home and industry.*

Physics Stage 6 Syllabus Outcomes © Board of Studies NSW, 1999 (Amended 2000, 2001, 2002, 2003)

ELECTRIC MOTORS

As stated in the big idea above, electric motors are used in industry and the home to convert electrical energy into more useful forms of energy. In the home they are used in CD and DVD players, refrigerators, washing machines, hair dryers, electric shavers, fans, clocks, power tools…

Electric motors can be of two basic types: DC and AC. We have earlier discussed the principle of operation of DC motors (see p.59). Now let us look at their advantages and disadvantages.

DC motors have a number of advantages:

1 They have large starting torques, that is, they are able to get large loads moving quickly.

2 They have reasonably constant torques even as the load varies. The back *emf* (see p.59), decreases when a load is applied. As a result the current increases providing additional torque. Similarly, if the motor speeds up as the load is reduced, the back *emf* increases lessening the current and lowering the torque—the motor is self-regulating.

3 Controlling the strength of the electromagnets (by changing the field current) controls the motor's speed. The greater the field strength the faster the motor will operate.

4 Reversing the polarity of the field magnets (by reversing the direction of the field current) will reverse the direction of rotation of the armature.

DC motors have the disadvantages of:

1 Wear and tear of the commutator.

2 Sparking at the commutator (producing dangerous ozone and creating electrical interference as well as the potential danger if near flammable materials.

3 Noise due to contact of the brushes with the commutator.

4 The need for a starting resistor.

However, their advantages are such that DC motors are the most useful type of electric motor for industrial applications. They are also commonly used for domestic power tools especially where variable rotation rates are required.

AC electric motors, on the other hand, are best used in applications where the starting torque is small. Examples include domestic white good applications such as refrigerators, dish washing machines, dryers… and some other domestic appliances.

AC ELECTRIC MOTORS

AC electric motors are similar to DC motors except they do not have a commutator (since the AC reverses direction 50 times per second anyway). They consist of:

1 an *armature*;

2 a *field structure*; and

3 in some AC motors *slip rings* (Figure 2.44) that conduct electricity to and from the motor.

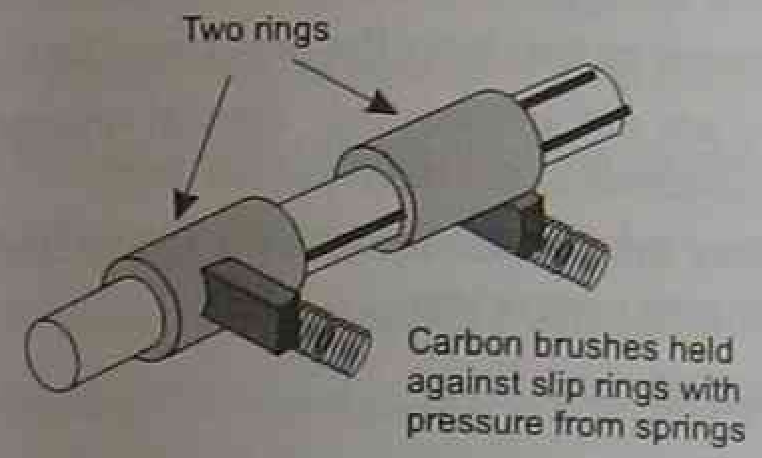

Figure 2. 44 Slip rings

In AC motors, the rotating part is the *rotor* and the stationary part is the *stator*.

Brushed AC Motor

In its simplest form, an AC motor is like an AC generator that operates in reverse, that is, electricity is fed into the coil by slip rings and brushes (hence *brushed* AC motor) and the coil experiences a torque. The direction of the current reverses 50 times per second (the mains AC frequency is 50 Hz) eliminating the need for a commutator.

This simple AC motor has a number of disadvantages:

1 it is not self-starting;

2 the torque varies with the load—too big a load and the motor stops.

3 it can only operate at 50 Hz (3000 rpm) although gear boxes can be used to change the rotation rate.

The more useful AC motors than the simple brushed motor include:

1 *induction* motors; and

2 *synchronous* motors.

INDUCTION MOTORS

These are the most commonly used type of AC motors. As we saw in the previous section on generators, when a coil rotates in a magnetic field a current is induced so long as the turning torque is applied. The converse is also true: *a rotating magnetic field will exert a torque on a stationary coil.* This is the principle behind the AC induction motor[20] (Figure 2.45).

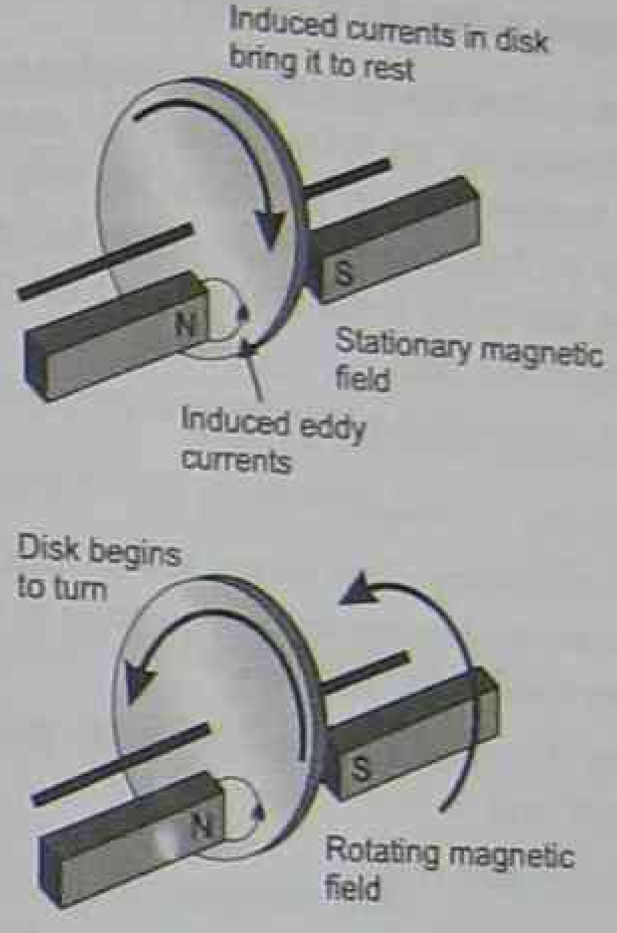

Figure 2. 45 The induction motor principle

The rotor of an induction motor consists of a cylindrical core with copper rods embedded in longitudinal slits in the coil. These rods are connected to a thick copper ring at each end of the core forming a so-called *squirrel cage* (Figure 2.46).

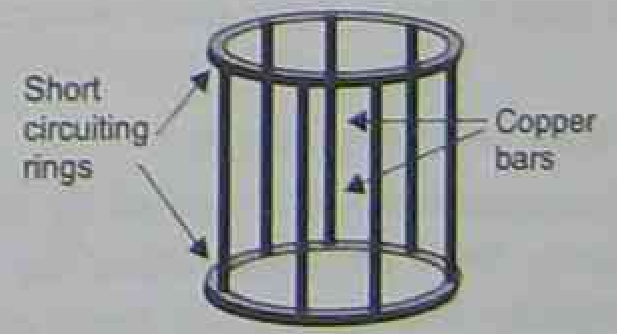

Figure 2. 46 A squirrel cage

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[20] http://www.phys.unsw.edu.au/%7Ejw/HSCmotors.html UNSW site with a good explanation of induction motor fundamentals. Another excellent site is http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/indmot.html#c1

Alternating current in the field coils of the stator are arranged to produce a *rotating magnetic field*. By electromagnetic induction, this rotating field will *induce* an electric current in the rotor (hence an 'induction' motor), which sets up a second magnetic field. The two fields interact with the rotating field of the stator 'dragging' the rotor around[21].

Extension

Advantages of Induction Motors

Induction motors can be either single-phase or three-phase, depending on what electricity supply they use. AC motors used in the home are single-phase. There are probably more single-phase AC induction motors in use today (~95%) than the total of all the other types combined.

They are widely used due to their:

1. simplicity of design;
2. high efficiency (and hence low maintenance—there are no brushes or commutators to wear out as there are in DC motors);
3. ability to self-start (not the case for all AC motors; and
4. relatively low cost.

Single-phase induction motors power refrigerators, vacuum cleaners and power tools such as band saws and planes that do not require variable speed. They have relatively low power, of the order of 0.5—1.0 kW.

Heavy-duty AC motors used in industry tend to be three-phase.

Disadvantages of Induction Motors

Induction motors have some disadvantages. These include:

1. they must have an AC supply;
2. their maximum speed is limited by the supply frequency (A50 Hz supply limits the motor to 3000 rpm);
3. they have low starting torque; and
4. their speed drops as the load increases.

Synchronous Motor

These differ from an induction motor in that while the stator still produces a rotating magnetic field, the rotor is fed current directly from an external supply via 'slip rings' (see Figure 2.44).

The rotor moves at a speed determined by the speed of rotation of the stator's field (which is itself determined by the frequency of the AC supply). For fixed frequency AC (which is the most common case), the synchronous motor maintains a constant speed. This makes it especially useful in clocks and other devices requiring a constant rate of rotation.

Synchronous motors have the limitations that:

1. they are not self-starting. Special arrangements are required to get them started; and
2. if they are slowed down by a heavy load, they may stop completely.

Universal Motors

Some electric motors—*universal motors*—can operate on single phase AC or DC. They have a commutator with many segments and look like the DC motor discussed earlier.

They include motors used in portable drills and food mixers and appliances where variable speed is important.

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[21] The actual process is quite complicated and beyond the scope of the syllabus.

SUMMARY

- Charges moving in a magnetic field experience a force.
- A current-carrying conductor in a magnetic field experiences a force given by $F = BIl\sin\theta$. This is the motor effect.
- The right-hand palm rule allows the direction of this force to be determined.
- Two parallel current-carrying conductors exert forces on each other given by: $\frac{F}{l} = k\frac{I_1I_2}{d}$
- Torque is the turning effect of a force.
- A current-carrying coil in a magnetic field experiences a torque given by $\tau = nBIA\cos\theta$
- DC electric motors consist of an armature, field structure, commutator and brushes.
- A split-ring commutator reverses the direction of the current each half cycle.
- Moving coil meters and loudspeakers use the motor effect.
- Electromagnetic induction involves the conversion of mechanical energy into electrical energy.
- Magnetic flux is a measure of the number of lines of force emerging from a given area.
- Magnetic flux density is synonymous with magnetic induction.
- Faraday's Law states that the induced *emf* is proportional to the rate of change of magnetic flux.
- Lenz's Law states that the induced *emf* is in a direction to oppose its production.
- When a motor is operating it produces a back *emf*.
- Eddy currents are induced in bulk conductors in the presence of changing magnetic flux.
- Eddy currents are put to good use in electromagnetic braking.
- Generators convert mechanical energy into electrical energy.
- Generators consist of an armature, field structure, slip rings and brushes (and a commutator for DC generators).
- Generators work by moving a coil relative to a magnetic field.
- Some energy is lost in transmission from the power station to where it is used.
- Electricity has profoundly affected society.
- Controversy exists about the alleged harmful affects of living close to power lines.
- Transformers allow AC voltages to be easily changed in size $\frac{V_p}{V_s} = \frac{n_p}{n_s} = \frac{I_s}{I_p}$
- AC induction motors are cheap, reliable and simple to manufacture which accounts for their wide use.

Key Terms:

AC
AC induction motor
armature
back *emf*
brushes
commutator
DC
eddy currents
electric motor
electromagnetic induction
Faraday's Law
field structure
galvanometer
generator
induced current
Lenz's Law
magnetic field
magnetic flux
magnetic induction
motor effect
right-hand palm rule
rotor
stator
step-down transformer
step-up transformer
torque
transformer
Van Allen belts

QUESTIONS AND PROBLEMS ON *MOTORS AND GENERATORS*

SECTION 1: THE MOTOR EFFECT

1 What is the 'motor effect' in relation to electromagnetism?

2 Describe a hand rule or palm rule that will allow you to determine the direction of the force on a current-carrying conductor in a magnetic field.

3 Determine the direction of the force in the following situations (Figure 2.47):

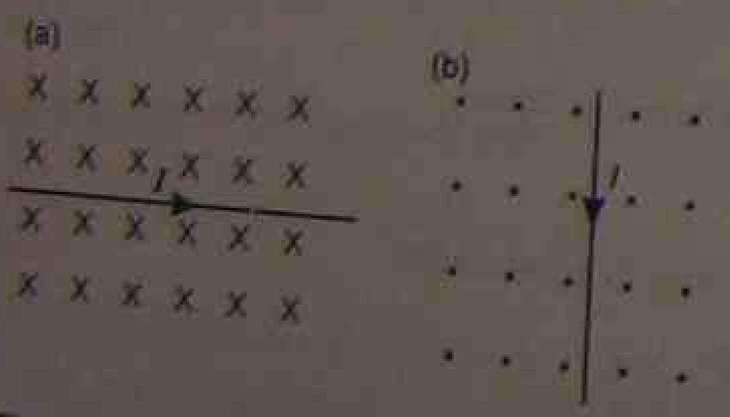

Figure 2. 47

4 A wire 1.5 m long and carrying a current of 5 A is situated in a magnetic field of 10 T. What force does the wire experience if it is:

(a) parallel to the field?

(b) at 60° to the field?

(c) at right angles to the field?

5 State the force law between parallel current-carrying wires, in words and symbols. State the units of all quantities used in the mathematical expression.

6 Two parallel wires carrying currents of 2 A and 3 A respectively are placed 5 cm apart in air. What is the size of the force between them and what is its direction if the currents flow in opposite directions in the wires and the wires are 2 m long?

7 Define the following terms:

(a) armature

(b) field structure

(c) commutator

(d) brushes

(e) torque.

8 A rectangular coil of wire, 2 cm by 4 cm, consisting of 200 turns is placed in a magnetic field of 0.02 T. If a current of 4 A is flowing in the coil, find:

(a) the angle between the plane of the coil and the plane of the field when maximum torque is experienced.

(b) the maximum torque experienced by the coil.

SECTION 2: ELECTROMAGNETIC INDUCTION

1 Explain the meaning of electromagnetic induction.

2 Write down the non-mathematical form of Faraday's Law. Explain all terms used.

3 State Lenz's Law.

4 Lenz's Law is a consequence of the Law of Conservation of Energy. Explain how this is so.

5 Write down a rule that enables us to find the direction of the induced current.

6 Label the direction of the induced current in the following situations as shown in Figure 2.48.

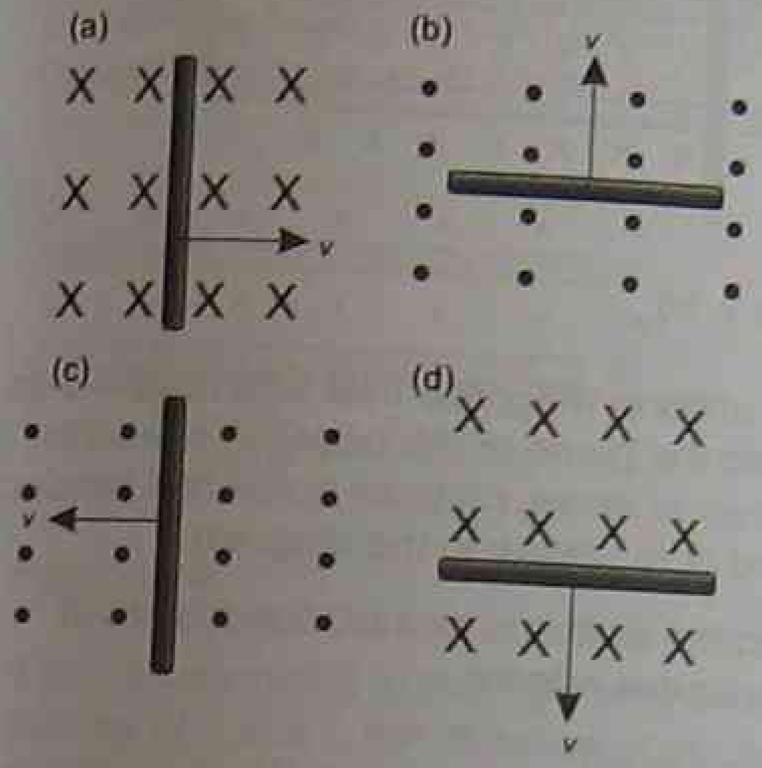

Figure 2. 48

7 * A rectangular coil of wire, 2.0 cm x 4.0 cm is placed perpendicular to a magnetic field of 0.02 T. The magnitude is reduced to zero in 0.1 s. Find:

(a) the initial flux through the coil; and

(b) the size of the induced emf.

8 * A student in a practical lesson set up a circuit consisting of a solenoid of 500 turns, a lamp and a transformer. She first connected the lamp, solenoid and transformer in series with the transformer set on 12 V DC. Upon placing some iron rods in the centre of the coil, no obvious changes occurred. She repeated this with the transformer set on 12 V AC and this time found that the lamp dimmed and the rods vibrated and became hot. Explain the student's observations.

9 What are eddy currents?

SECTION 3: ELECTRIC GENERATORS

1 What is the 'generator effect'?

2 Briefly describe how a generator works.

SECTION 4: TRANSFORMERS

1 Briefly describe how a transformer works.

2 A transformer has a primary of 500 turns and a secondary of 10 000 turns.

(a) What type of transformer is it?

(b) Calculate the secondary voltage if the primary voltage is 20 000 V. (Assume 100% transformer efficiency.)

3 Explain why voltages are increased to as high as 500 kV for transmission from power stations.

4 Describe how eddy currents are reduced in transformers.

SECTION 5: ELECTRIC MOTORS

1 It is said that an electric motor acts as a motor and a generator at the same time. Explain this statement.

2 Briefly explain the principle of operation of the AC induction motor.

TEST ON *MOTORS AND GENERATORS*

MULTIPLE CHOICE QUESTIONS

Choose the letter A, B, C or D that corresponds to the best answer.

1 Two parallel wires carry currents of 3 A and 4 A respectively as shown in Figure 2.49.

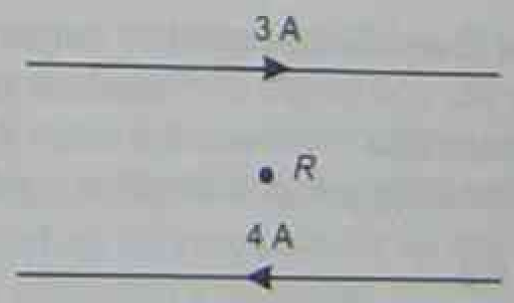

Figure 2. 49

At the point *R*, midway between the wires, the direction of the magnetic field is best shown in Figure 2.50 as:

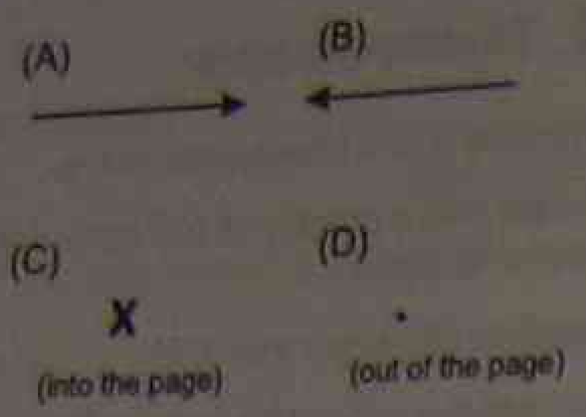

Figure 2. 50

(A) A

(B) B

(C) C

(D) D.

2 Two long parallel wires aligned north-south carry currents of 2 A and 3 A respectively (in the same direction). If separated by 5 cm in air, what is the force per metre between the wires?

(A) 2.4×10^{-5} N attraction

(B) 2.4×10^{-5} N repulsion

(C) 24.8×10^{-6} N attraction

(D) 4.8×10^{-6} N repulsion.

Questions 3 and 4 refer to Figure 2.51. Two parallel wires *R* and *S* separated by a distance *d* carry conventional currents, as shown in the diagram.

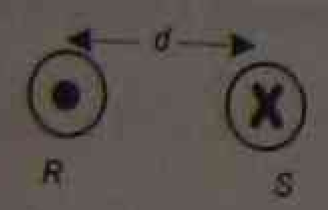

Figure 2. 51

3 Wires *R* and *S* separated by *d* metres exert a force per unit length of *F* newtons per metre. If the separation between the wires is reduced to *d*/2, the force per unit length is now:

(A) *F*/4

(B) *F*/2

(C) 2*F*

(D) 4*F*

4 There is a force on the wire *S* due to the fact that it is in the magnetic field produced by the current in wire *R*. The direction of this force on *S* is given as in A, B, C or D in Figure 2.52?

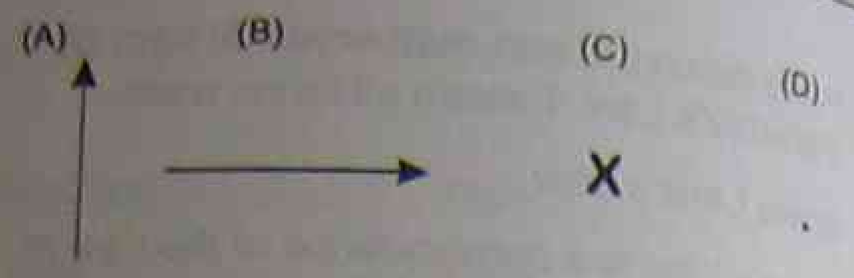

Figure 2. 52

Questions 5, 6 and 7 refer to Figure 2.53.

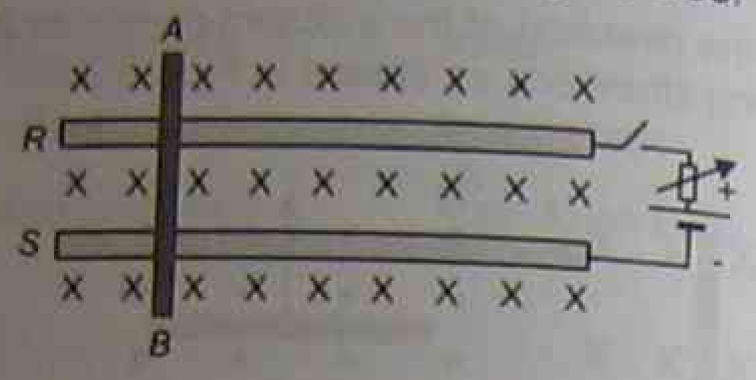

Figure 2. 53

A vertical uniform magnetic field acts downwards (that is, into the plane of the page). A conductor *AB*, which is free to move, rests on horizontal conducting rods *R* and *S* as shown in the diagram.

5 When the switch is closed, conductor *AB* experiences a force:

(A) to the left

(B) to the right

(C) upwards that is, out of the plane of the page

(D) downwards that is, into the plane of the page.

The following changes can be made separately to the system:

(i) The battery connection to the rods can be reversed.

(ii) The current can be increased by changing the rheostat settings.

(iii) The direction of the magnetic field can be reversed.

(iv) The rod *AB* can be reversed with end *A* now on *S* and end *B* now on *R*.

(v) The strength of the field can be increased.

6 Which of these changes, made separately, can reverse the direction of motion from that selected in question 5?

(A) (i) and (ii) only

(B) (ii) and (iii) only

(C) (i), (iii) and (iv) only

(D) (i) and (iii) only.

7 Which of the changes (i) to (v) made separately would increase the size of the force acting on *AB*?

(A) (i) and (v) only

(B) (ii) and (v) only

(C) (i), (iv) and (v) only

(D) (ii) only.

8 A conducting rod *AB* makes contact with two metal rails *CD* and *EF* in a uniform magnetic field directed perpendicular into and out of the plane of the page as in Figure 2.54.

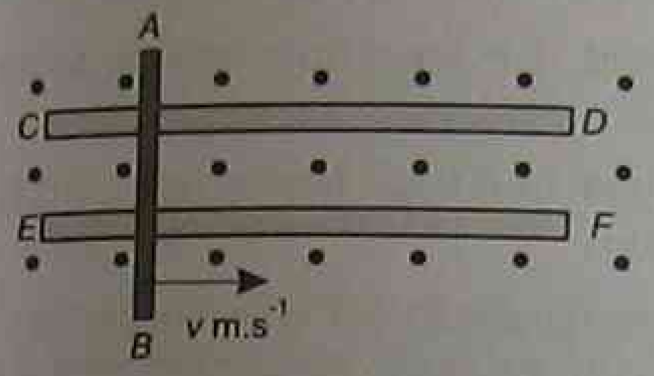

Figure 2. 54

If the rod is moved to the right with a constant velocity of *v* m.s^{-1}, the direction of the force acting on an electron in *AB* is:

(A) from B to A

(B) from A to B

(C) there is no force since the circuit is not complete

(D) out of the page.

9 The north pole of a magnet is brought towards a circular metal ring that hangs freely from a vertical string as in Figure 2.55. Looking towards the ring:

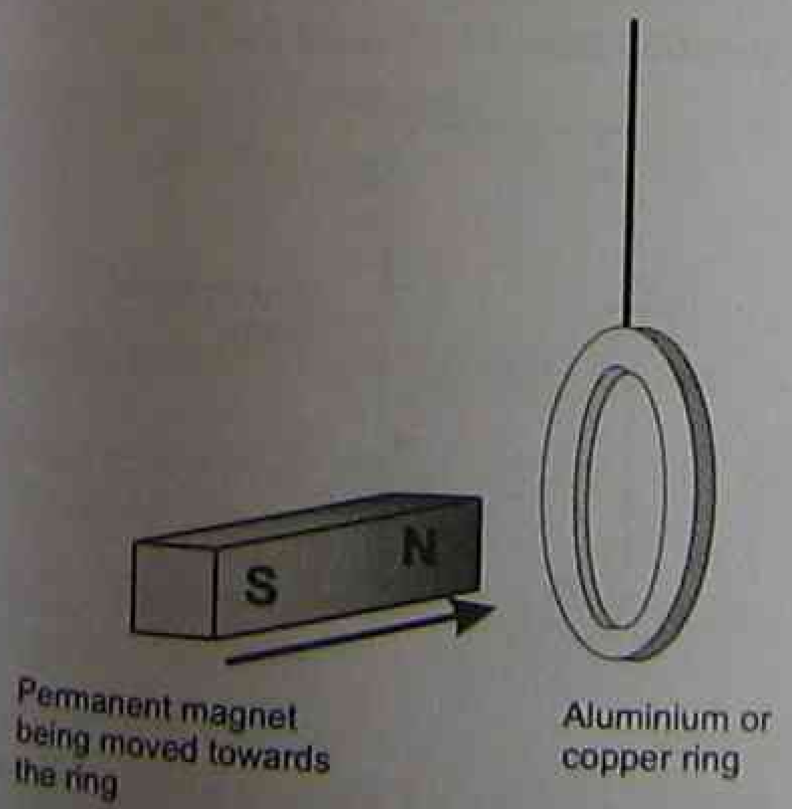

Figure 2. 55

(A) a current is induced in a clockwise direction setting up a north pole

(B) a current is induced in a clockwise direction setting up a south pole

(C) a current is induced in an anticlockwise direction setting up a north pole

(D) a current is induced in a anticlockwise direction setting up a south pole.

10 A *back emf*:

(A) is found in AC motors only

(B) is found in DC motors only

(C) adds to the supply voltage

(D) subtracts from the supply voltage.

11 AC generators:

(A) are only available in small power ratings

(B) have a split-ring commutator

(C) have slip rings

(D) are less efficient than DC generators.

12 In a transformer, the iron core:

(A) is used to aid the flux linkage

(B) is used to trap eddy currents

(C) makes it easy to wrap the coils

(D) allows the magnetic fields of the coils to be separated.

13 For a transformer, the ratio of the power output to the power input is:

(A) less than 1 in all cases due to heat losses

(B) less than 1 for a step-down transformer

(C) more than 1 for a step-up transformer

(D) more than 1 if it has an iron core rather than an air core.

14 Voltages generated in electric power stations are stepped up by transformers for transmission to distant consumers because:

(A) transmission occurs faster at higher voltages

(B) there is less danger if the wires break

(C) less insulation is needed

(D) the wires can be thinner and therefore cheaper.

15 In the late 1880s the American engineer George Westinghouse pioneered a system for electricity distribution. This system:

(A) used high speed DC generators to transfer energy

(B) used AC generators and transformers to transfer energy

(C) was less efficient but safer than the alternative system advocated by Edison

(D) used low speed DC generators and transformers to transfer energy.

SHORT ANSWER QUESTIONS

In keeping with the format of the HSC, sample marks are given for each question.

Answer the following questions in approximately three lines of writing, calculation or diagram.

16 Two parallel wires *AB* and *CD* are carrying currents of 2 A and 4 A respectively. They are separated by 1 cm in air.

(a) Calculate the force per unit length acting between the wires. (2 marks)

(b) If the current *AB* is reversed predict what happens to the force. (1 mark)

17 This question refers to Figure 2.56.

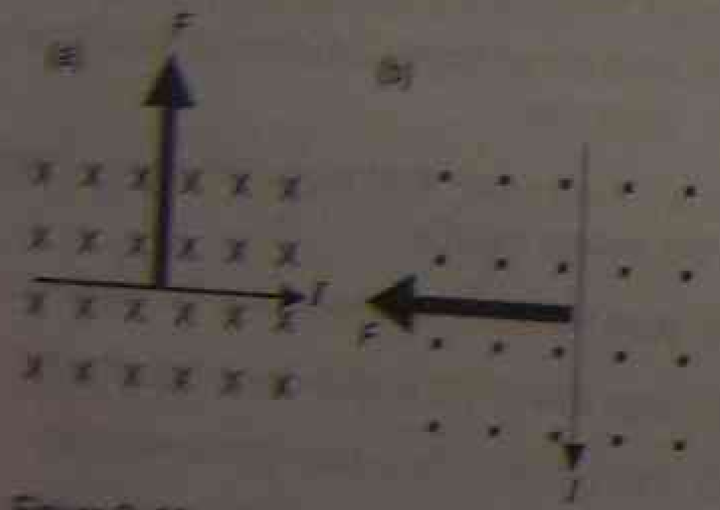

Figure 2. 56

The diagrams are of a wire carrying a current in a magnetic field. Draw on them the direction of the force acting on the wire. (2 marks)

8 A copper rod of length 20 cm and mass 0.20 kg is suspended by insulating threads from a spring balance so it hangs horizontally in a north-south direction. The rod is placed in a horizontal magnetic field of intensity 0.50 T directed due east as shown in Figure 2.57.

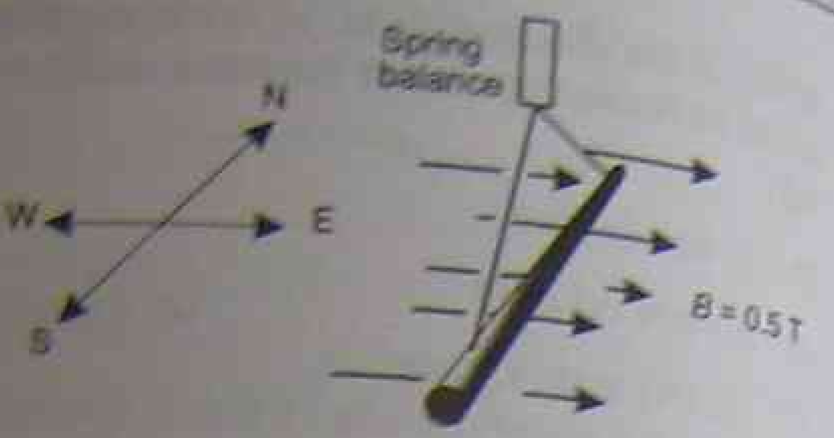

Figure 2. 57

Calculate the reading on the spring balance when:

(a) no current flows in the rod. (1 mark)

(b) current of 10 A flows from north to south. (1 mark)

(c) current of 10 A flows from south to north. (1 mark)

19 A 0.1 m long conductor *XY* which is free to move rests on horizontal conducting rods *A* and *B*. A vertical uniform magnetic field of intensity 0.5 T acts out of the page as shown in Figure 2.58.

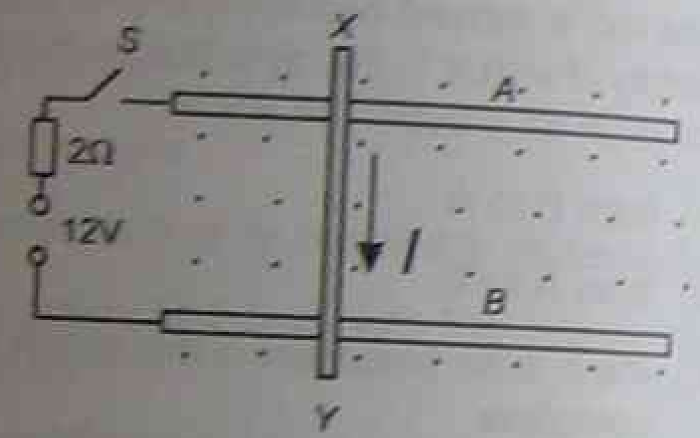

Figure 2. 58

When switch *S* is closed, determine:

(a) the direction of the force on *XY*. (1 mark)

(b) the magnitude of the force on *XY*. (1 mark)

20 This question refers to Figure 2.59.

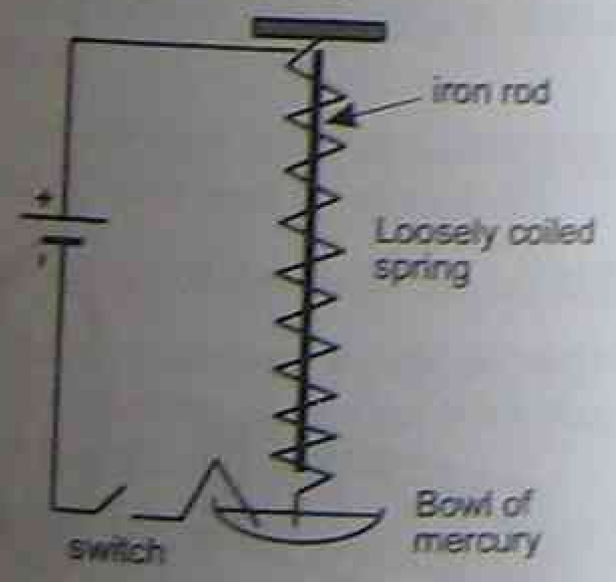

Figure 2. 59

A student set up the equipment above. When he closed the switch the coiled spring started to jump up and down. Explain why this occurred. (3 marks)

21 This question refers to Figure 2.60.

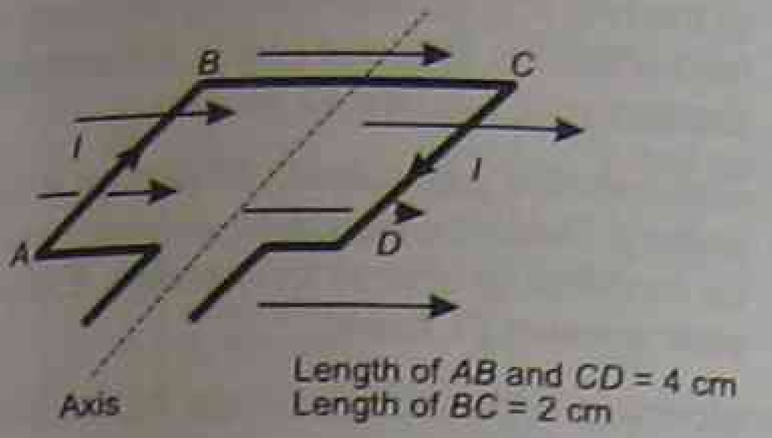

Figure 2. 60

A rectangular coil *ABCD* of 100 turns lies in a plane parallel to the magnetic induction *B* of 10 T. A current of 2 A flows from a battery along the path *ABCD*.

(a) Predict the direction of the force on the sides *AB* and *CD*. (1 mark)

(b) Calculate the size of the force acting on sides *AB*, *BC* and *CD*. (2 marks)

(c) If the side *BC* is 2 cm long and *AB* is 4 cm, calculate the maximum torque acting on the coil. (2 marks)

22 A 240 V transformer may burn out when connected to a 240 V DC supply. Explain. (Hint: The resistance of transformer windings is low.)

23 Calculate the power wasted by a transmission line cable of resistance 0.5 ohm when 10 kW is to be transmitted:

(a) at 1000 V (1 mark)

(b) at 200 000 V (1 mark)

24 Explain how electromagnetic braking works. (3 marks)

25 Explain the basic principle behind the operation of AC induction motors. (3 marks)

LONGER ANSWER QUESTIONS

In keeping with the format of the HSC sample marks are given for each question.

Answer the following questions in approximately five lines of writing, calculation or diagram.

26 A rectangular coil of wire 6 cm long by 2 cm wide consisting of 100 turns and carrying a current of 5 A is placed in a magnetic field of intensity 0.2 T as shown in Figure 2.61.

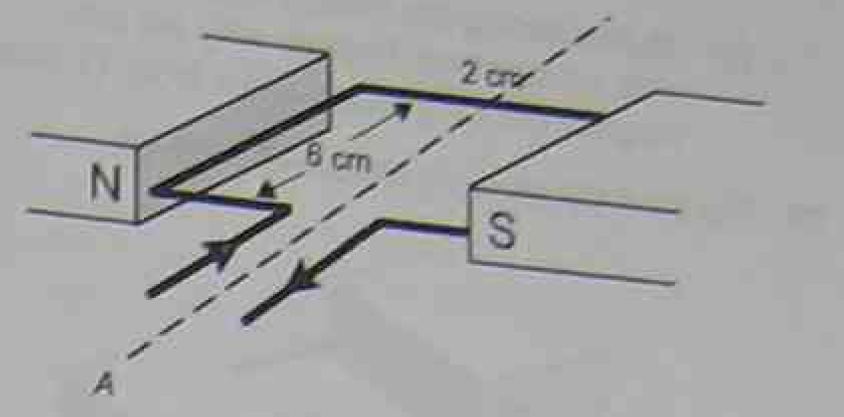

Figure 2. 61

(a) Predict the direction the coil will begin to rotate when viewed from *A*. (1 mark)

(b) To ensure the coil rotates continuously, describe what must be done to the current in the coil. (2 marks)

(c) Calculate the flux through the coil when the coil is:

(i) parallel to the field.

(ii) perpendicular to the field.

(d) Calculate the torque when the coil is:

(i) parallel to the field. (1 mark)

(ii) perpendicular to the field. (1 mark)

27 In an experiment designed to measure the magnetic field in the centre of a solenoid, the apparatus in Figure 2.62 was used.

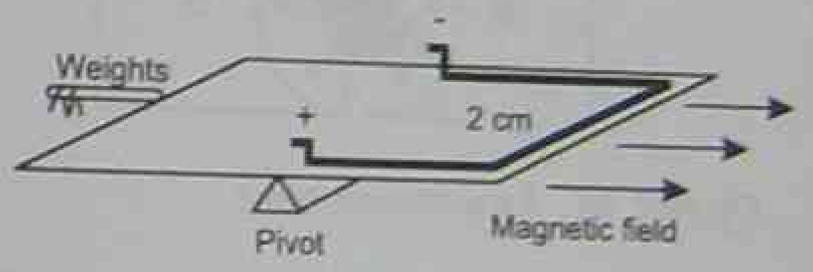

Figure 2. 62

The loop is balanced when no current flows in the solenoid. When current flows in the solenoid and in the loop circuit, the loop experiences a downward force on the end inserted in the solenoid. To rebalance the loop, a weight of 2.0×10^{-4} N is required.

(a) List two changes you could make to the circuit(s) that would change the direction of the force acting on the loop. (2 marks)

(b) If the loop is 2 cm long, and a current of 4 A flows through the solenoid when a current of 2 A flows in the loop, calculate the magnetic field in the solenoid. (2 marks)

(c) In measuring the loop, the end piece only was considered. Explain why we can neglect the long sides of the loop. (1 mark)

28 Figure 2.63 shows a simple DC motor.

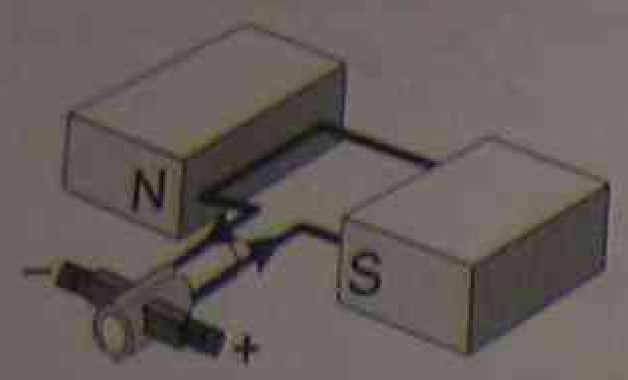

Figure 2. 63

(a) Label all parts. (2 marks)

(b) Explain the function of a 'split-ring' device. (2 marks)

(c) List three things that could be changed in the design to improve the function of the motor. (3 marks)

29 Figure 2.64 is a schematic diagram of a moving coil meter.

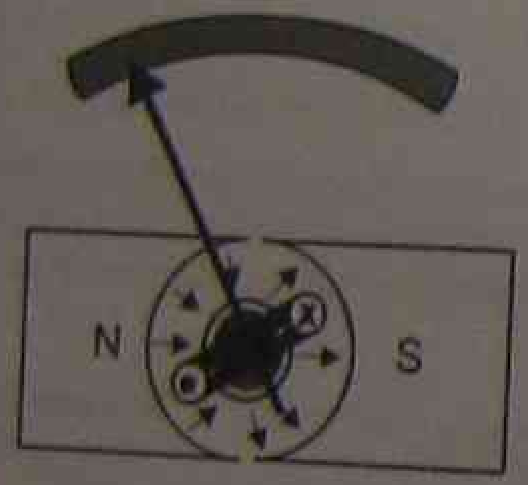

Figure 2. 64 A moving coil meter

(a) Briefly describe how it works. (3 marks)

(b) Explain the significance of the radial magnetic field. (1 mark)

30 Figure 2.65 shows a simple generator.

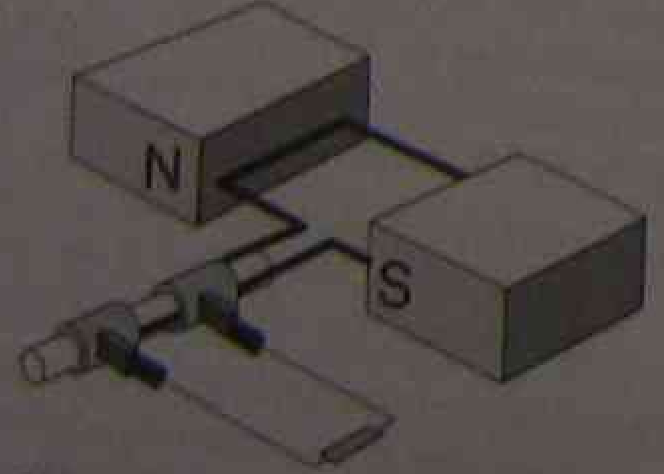

Figure 2. 65

(a) Label its parts. (2 marks)

(b) Explain why an *emf* is induced when the coil is rotated. (2 marks)

(c) Identify the relationship between the plane of the coil and the direction of the magnetic field when the induced *emf* is a maximum. Explain your answer. (2 marks)

(d) The output is not suitable to charge a car battery. Describe how the generator could be modified to charge the battery. Explain your answer. (1 mark)

31 Transformers are used to change AC voltages.

(a) The primary and secondary coils of a transformer have 4000 and 200 coils respectively. If the primary is connected to 240 V AC, calculate the voltage across the secondary. (Assume 100% efficiency). (2 marks)

(b) Describe how energy losses in transformers are kept to a minimum. (2 marks)

32 A student set up an experiment shown schematically in Figure 2.66.

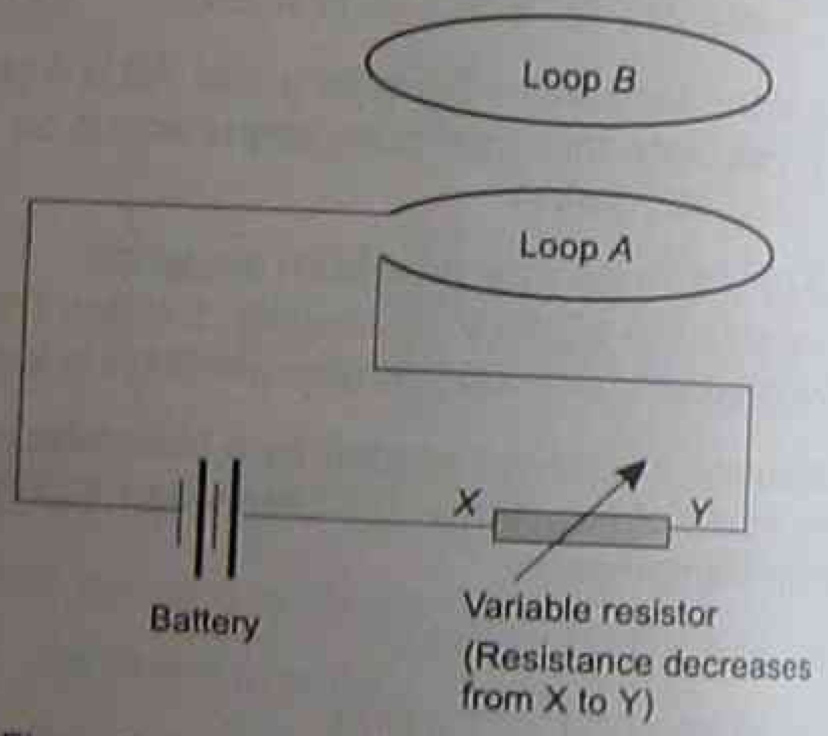

Figure 2. 66

(a) Describe what is observed in loop *B* when the circuit is as shown, with a steady resistance. Explain. (2 marks)

(b) Predict what happens in loop *A*, as the resistance is steadily decreased in the variable resistor (rheostat). Explain. (2 marks)

33 A current balance that can be used to investigate the relationships between the forces on a current-carrying wire, the currents in the wire, the length of the wire and the separation of the wires is shown in Figure 2.67. Current can be varied in the 'fixed loop' and the 'movable loop'; the separation between the coils can be varied; and the length of the movable loop can also be changed.

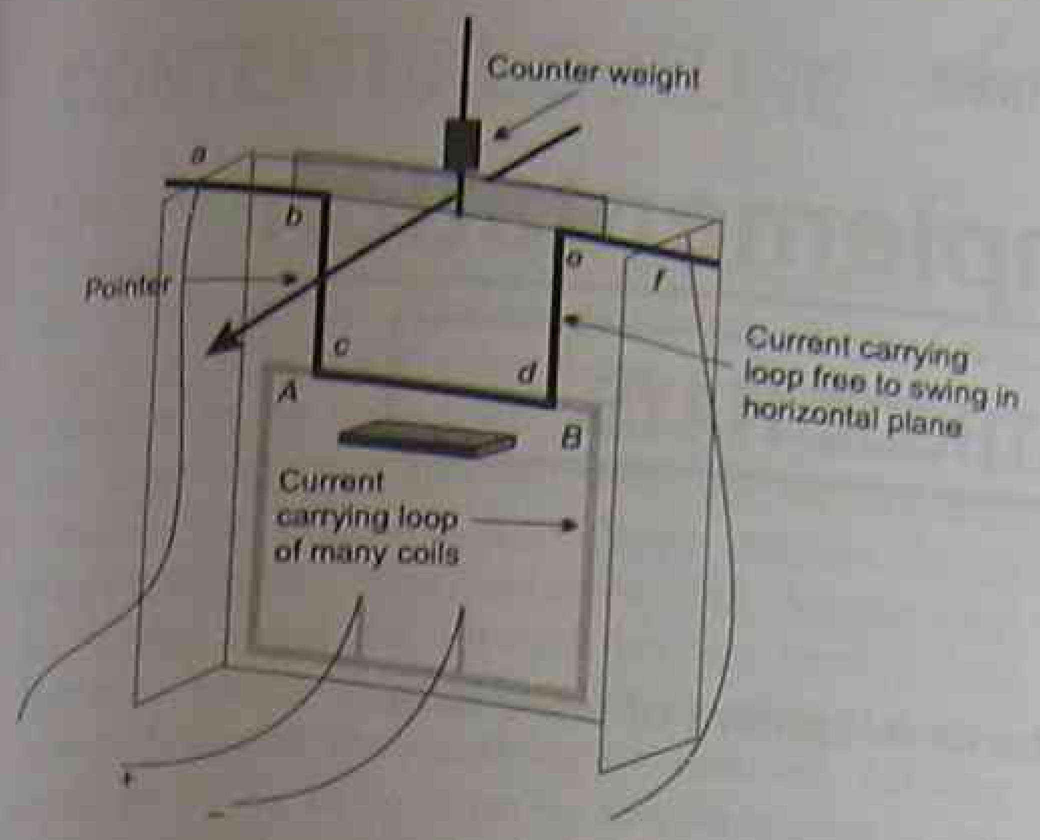

Figure 2. 67 A current balance

(a) Explain why a force acts on the loop when a current flows through both loops. (2 marks)

(b) If current is arranged to flow from *A* to *B* in the fixed loop, predict in what direction must the current flow in the movable loop if the pointer is to swing upwards. (1 mark)

(c) Briefly explain how the force between the two loops can be measured. (2 marks)

(d) Sketch a graph that you might expect showing the relationship between the product of the currents ($I_1 I_2$) and the separation of the loops (*d*). (2 marks)

34 Briefly discuss the impact on society of electric generators and transformers. (6 marks)

Chapter Three

From Ideas to Implementation

SECTION 1: CATHODE RAYS

BIG IDEA:

Increased understandings of cathode rays led to the development of television.

OUTCOMES:

Students learn to:

1 Identify that moving charged particles in a magnetic field experience a force.
2 Explain that cathode ray tubes allowed the manipulation of a stream of charged particles.
3 Explain why the apparent inconsistent behaviour of cathode rays caused debate as to whether they were charged particles or electromagnetic waves.
4 Identify that charged plates produce an electric field.
5 Describe quantitatively the force acting on a charge moving through a magnetic field $F = qvB\sin\theta$
6 Discuss qualitatively the electric field strength due to a point charge, positive and negative charges and oppositely charged parallel plates.
7 Describe quantitatively the electric field due to oppositely charged parallel plates.
8 Outline Thomson's experiment to measure the charge/mass ratio of an electron.
9 Outline the role of:
  - electrodes in the electron gun
  - the deflection plates or coils
  - the fluorescent screen

in the cathode ray tube of conventional TV displays and oscilloscopes.

Students:

1 *Perform an investigation and gather first-hand information to observe the occurrence of different striation patterns for different pressures in discharge tubes.*
2 *Perform an investigation to demonstrate and identify properties of cathode rays using discharge tubes:*
  - *containing a Maltese cross*
  - *containing electric plates*
  - *with a fluorescent display screen*
  - *containing a glass wheel*

and analyse the information gathered to determine the sign of the charge on cathode rays.

3 *Solve problems and analyse information using:* $F = qvB\sin\theta$ and $E = \dfrac{V}{d}$

Physics Stage 6 Syllabus Outcomes © Board of Studies NSW, 1999 (Amended 2000, 2001, 2002, 2003)

CONTEXTUAL OUTLINE

Following on from the work of Newton in the seventeenth century on mechanics and gravity, and the work of the Scottish physicist James Clerk Maxwell on light and other forms of electromagnetic radiation in the nineteenth century, it appeared that the stage had been reached when all the disparate elements of scientific knowledge seemed to be coming together. Many scientists felt that the total knowledge about the universe lay just beyond their horizon. Future generations of scientists, it was believed, would have nothing to discover. All they could do would be to improve measurements so any changes would occur 'in the fifth decimal point'.

Towards the end of the nineteenth century, however, doubt was cast on this view. Although cathode rays were shown to be electrons and X-rays to be a form of electromagnetic wave, nevertheless the structure of matter was unknown[1].

This topic begins with the discovery and identification of cathode rays and how this led ultimately to modern television. We then look at how *black body radiation* and the *photoelectric effect* led to a new view of the nature of electromagnetic radiation with the quantum theory of Planck. We conclude by looking at how the study of subatomic particles led ultimately to the invention of the transistor and to the discovery of superconductivity.

MAGNETISM AND MOVING CHARGES

In the Preliminary Course *Electricity in the Home* we saw that:

> *Stationary electric charges exert an* **electric force** *on each other.*

We also saw that magnets exert forces on each other (like poles repel and unlike poles attract) and that Hans Oersted had shown in the nineteenth century that *a current carrying wire is surrounded by a magnetic field*. Since a current is a flow of charge it might be expected that a moving charge would have a magnetic field associated with it and hence would experience a force in a magnetic field. In fact experiments show that:

> **Moving charges** *experience a force in a magnetic field*[2].

You can demonstrate this quite easily. If you bring a magnet near to a TV screen, the image is distorted near the magnet. (**Warning:** On some TV models this may give a permanent result!) The electrons (negative charges) are affected by the magnetic field of the magnet. We conclude that:

> *Moving electric charges interact through* **magnetic fields**.

THE DISCHARGE TUBE

In 1855 the German glassblower Heinrich Geissler invented a vacuum pump that was efficient enough to reduce the pressure inside a strong glass tube to 0.01% of normal air pressure. It was to lead to the opening up of a major new area of scientific research.

Under normal conditions of temperature and pressure, air is an insulator. At reduced pressure, however, air (and all other gases) conducts electricity. In 1862 Julius Plücker, a friend of Geissler, found that by placing metal *electrodes* in the ends of one of Geissler's tubes and joining the electrodes to a high voltage source (Figure 3.1) he could get electricity to flow through the tube.

Figure 3. 1 Discharge tube

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[1] http://www.nobel.se/cgi-bin/laureate-search?physics=on&silent=on&list=readyshort Lists all physics Nobel laureates from 1901 to the present. Just choose a year and a biography of the physicist will be shown. Refer back to this as you progress through the chapter.

[2] http://webphysics.ph.msstate.edu/javamirror/ipmj/java/partmagn/index.html Java applet of a charged particle in a magnetic field.

Plücker showed that as the pressure is reduced in the *discharge tube*, a series of changes progressively take place. You can investigate these changes in the laboratory.

First Investigation: Discharge Tubes

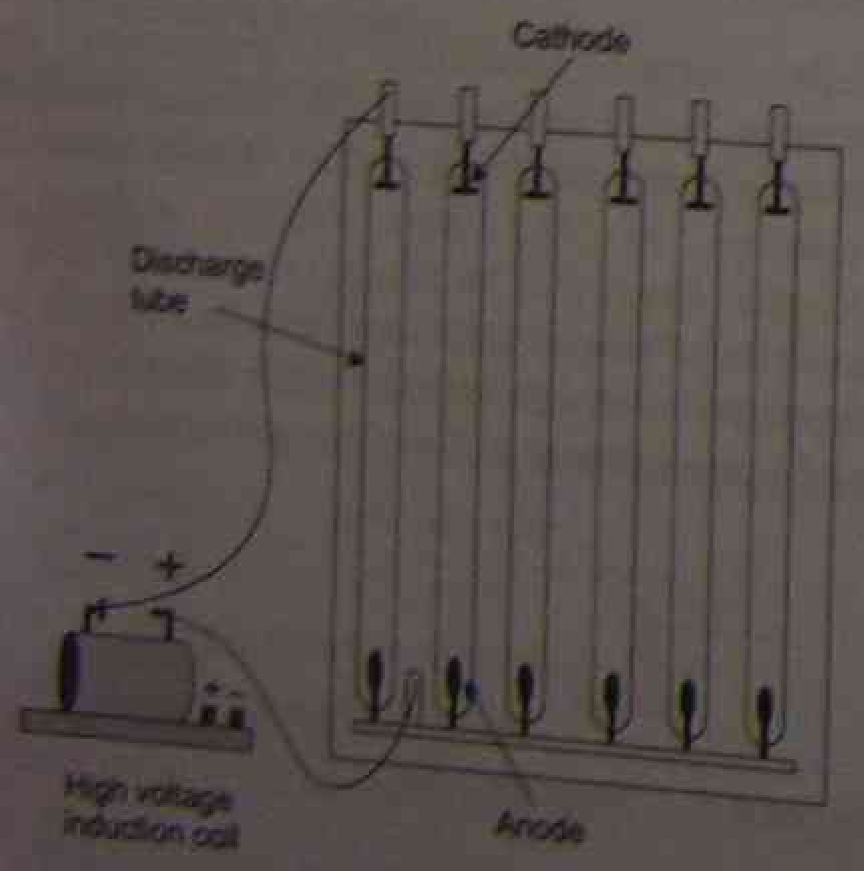
Following is a sample report similar to that which a student may have written for a practical class. It is written in the formal manner preferred by many teachers.

Aim: To investigate the effect of different gas pressures on an electric discharge passing through a series of discharge tubes.

Apparatus: Power supply, induction coil, discharge tubes of varying pressure, connecting wires.

Theory: When a high voltage from an induction coil is applied across the terminals of a discharge tube, a discharge may result. Electrons from the cathode travel towards the positive terminal exciting electrons in the atoms of the gas as they collide. The gas density affects the type of collision between the gas atoms (often hydrogen) resulting in different effects.

Method: The apparatus was set up as in the diagram (Figure 3.2).



igure 3. 2 Experimental set up to examine the effect of pressure on the electric discharge through a gas

The induction coil was adjusted so that a continuous spark was produced. The negative terminal of the induction coil was connected to the top plug of the first discharge tube (the cathode) and the positive terminal was connected to the bottom plug (the anode). Observations were made of the effect of different pressures on the discharge by moving the top plug along to different tubes.

Results: The following observations were made:

1 Coloured 'streamers' appear and both the anode and cathode are surrounded by a luminous glow.

2 At a pressure of ~0.1–0.2 kPa the positive glow extends along the tube, taking up approximately half its length. Between the positive glow and the negative glow is an area called the *Faraday dark space* (Figure 3.3).

3 As the pressure is reduced further the positive column breaks up into a series of *striations*.

4 At a pressure of ~0.01 kPa, Crookes' dark space fills the entire tube and a green glow appears in the glass at the end of the discharge tube opposite the cathode.

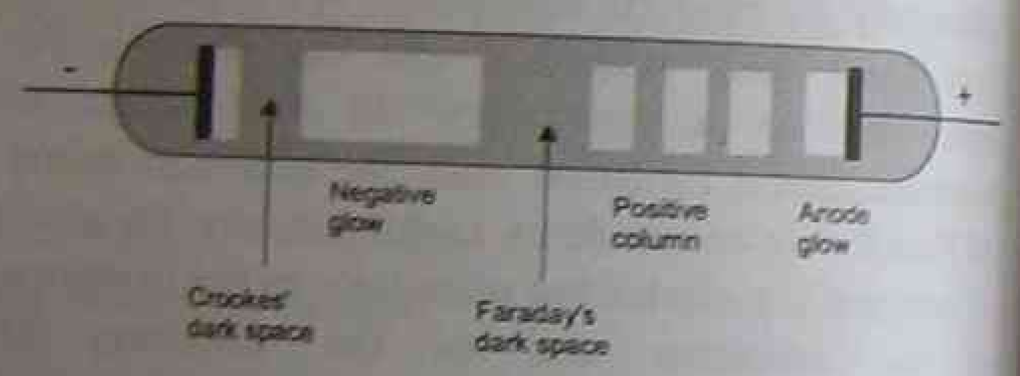


Figure 3. 3 Gas discharge

Conclusion: As the pressure of the gas was reduced in the discharge tube, there were changes in the discharge. At the lowest pressure, no gas glow was observed but a glow from the cathode rays was noted in the glass opposite the cathode.

CATHODE RAYS[3]

By 1875 Sir William Crookes had made further discoveries about the green glow in his *Crookes tubes* (variations of the tubes used by Geissler and Plücker) and reached a number of conclusions. He said the glow was made by *cathode rays* that:

1 are identical, regardless of the cathode material used;

2 emanate from the cathode and travel in straight lines towards the anode (as demonstrated in the *Maltese Cross* experiment (Figure 3.4(a));

3 cause glass to fluoresce[4];

4 are deflected by magnetic fields (as demonstrated by holding a magnet close by as in Figure 3.4(b));

5 carry energy and momentum (as demonstrated in the *'paddle wheel experiment', see* Figure 3.4(c)) which suggested a particle nature; and

6 cause chemical reactions (that is, they affect a photographic plate).

Crookes also suspected, but could not show it, that the rays were affected by an electric field.

(We can now easily demonstrate they are deflected by electric fields proving their negative charge as in Figure 3.4(d).)

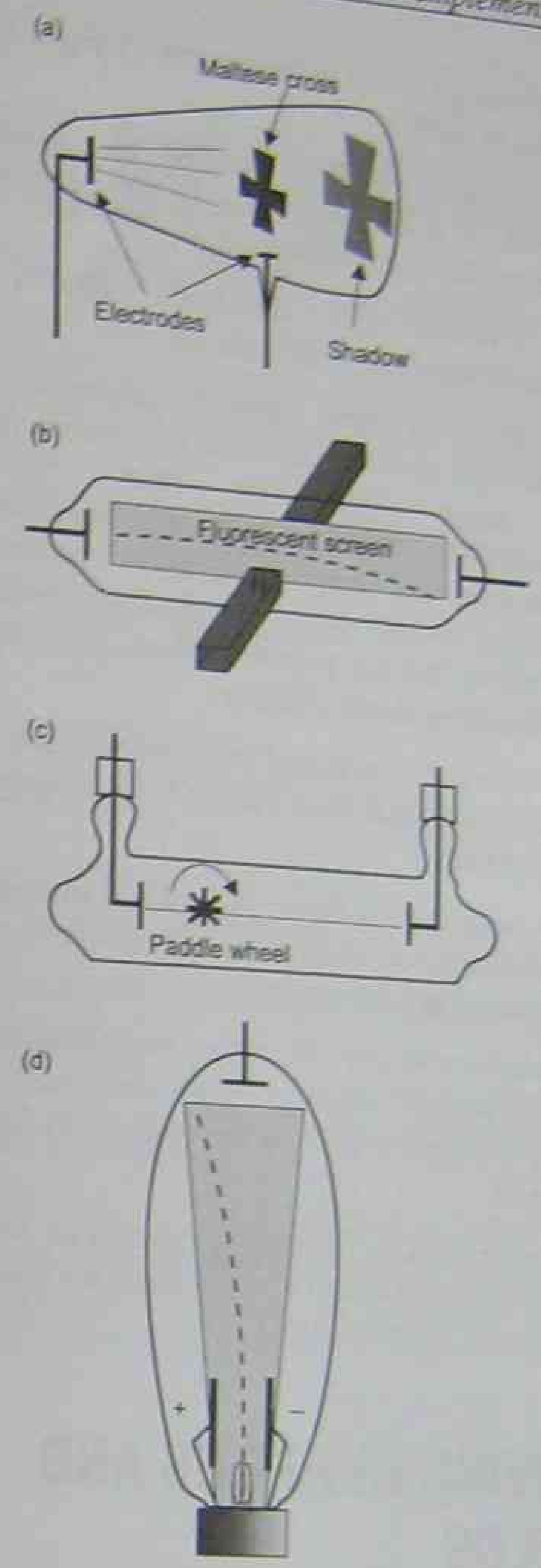


Figure 3. 4 Cathode ray tube experiments

WAVE OR PARTICLE?

Some important dates and events in the investigation and identification of cathode rays include:

1871—C. F. Varley proposed that cathode rays are composed of particles. Crookes believed these to be negatively charged molecules.

1874—G. J. Stoney estimated the unit of charge to be ~10^{-20} C. Proposed the name 'electrine' for the

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[3] http://learn.lincoln.ac.nz/phsc102/ChemTeamIndex/WW200.ht Cathode Ray History with links to articles on Thomson

[4] *Fluorescence* is a phenomenon whereby certain materials emit visible light after absorbing invisible light such as ultraviolet. The light stops when the external energy source is removed. *Phosphorescence* is a similar phenomenon but the light persists when the external source is removed.

unit of charge on the hydrogen ion. Changed this to *electron* in 1891.

1876—Eugene Goldstein proved the source of radiation in a discharge tube is the cathode. He introduced the term 'cathode rays'.

1881—Herman von Helmholtz showed the 'quantum' nature of electric charge.

1883—Heinrich Hertz showed (incorrectly) that cathode rays are not deflected by electric fields[5]. This, along with their other 'light-like' characteristics—travelling in straight lines, causing fluorescence and causing chemical reactions as shown by Crookes—led to the idea that cathode rays were waves and not particles. (Remember, light is not affected by electric fields.)

1892—Hertz demonstrated that cathode rays could penetrate thin metal foils. This he believed supported a wave nature.

1895—Jean-Baptise Perrin showed that cathode rays deposited negative charges on impact with an object, suggesting a particle nature.

The controversy over the nature of cathode rays[6]—wave or particle, raged for many years until it was finally resolved in 1897 by the British physicist J.J. Thomson.

Before we look at Thomson's experiment, we need to look at the effects of charged particles moving in electric and magnetic fields.

MOVING CHARGES AND FIELDS

In the Preliminary Course, *Electrical Energy in the Home* we were introduced to the concept of fields, in particular electric and magnetic fields. We saw how charges experience forces in these fields.

Electric Fields

Figure 3.6 shows the electric field lines around isolated charges, between two opposite charges (a *dipole*), between two like charges and between two oppositely charged parallel plates.

It follows that since the electric field is greatest where the field lines are closest:

1 the field decreases with increasing distance from the isolated charges;

2 the field between two oppositely charged plates— a *capacitor*— is uniform (except near the edges).

This uniform field is particularly useful.

The Electric Field of a Parallel Plate Capacitor

If the potential difference between the two plates is V and the separation of the plates is d then the electric field E is given by:

$$\boxed{E=\frac{V}{d}}$$

A charge moving in this field will experience a force (in this case causing it to move in a parabolic curve as indicated in Figure 3.5).

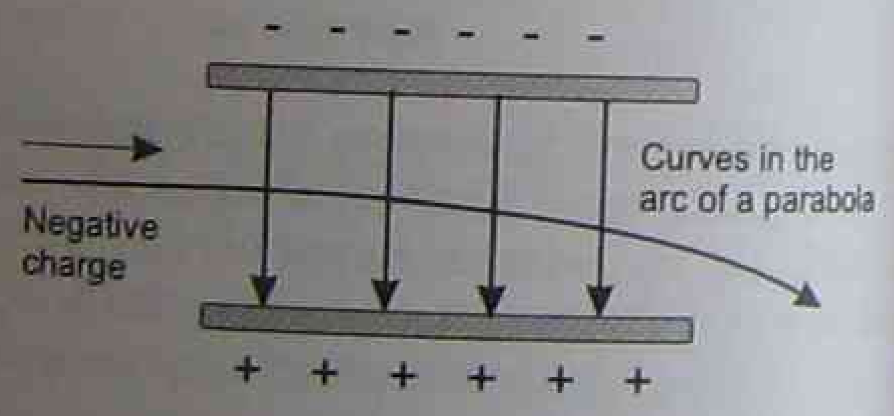


Figure 3. 5 The motion of a charge in a uniform electric field

The force (F) acting on a charge (q) in an electric field (E) is given by $\vec{F}=q\vec{E}$.

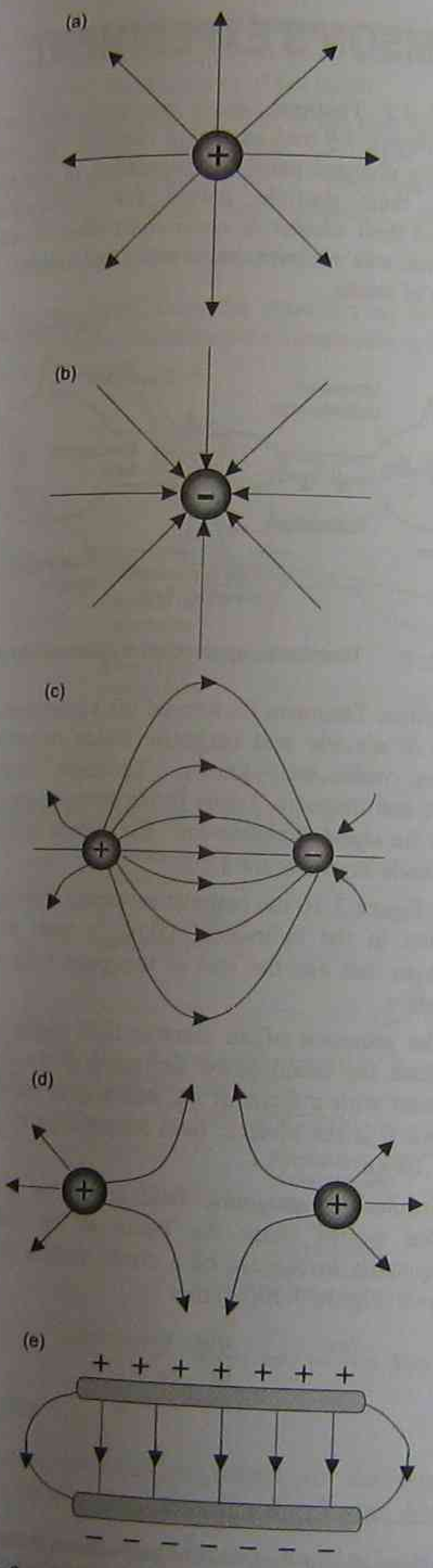


Figure 3. 6 Electric fields of various charges

EXAMPLE 1

A parallel plate capacitor consists of two plates separated by 1.0 cm with a potential difference of 1000 V between them.

(a) What is the electric field between the plates?

(b) What force acts on an electron between the plates?

SOLUTION

(a) $E=\frac{V}{d}$

$=\frac{1000}{0.01}\text{V.m}^{-1}$

$=100{,}000\ \text{V.m}^{-1}$

(b) $F=qE$

$=-1.6\times10^{-19}\times100{,}000\ \text{N}$

$=-1.6\times10^{-14}\ \text{N}$

That is, the force acts towards the positive plate of the capacitor.

Magnetic Fields

We also saw in the HSC Course, *Motors and Generators* that a charge moving in a magnetic field experiences a force, the direction of which can be found from the right-hand palm rule (Figure 3.7).

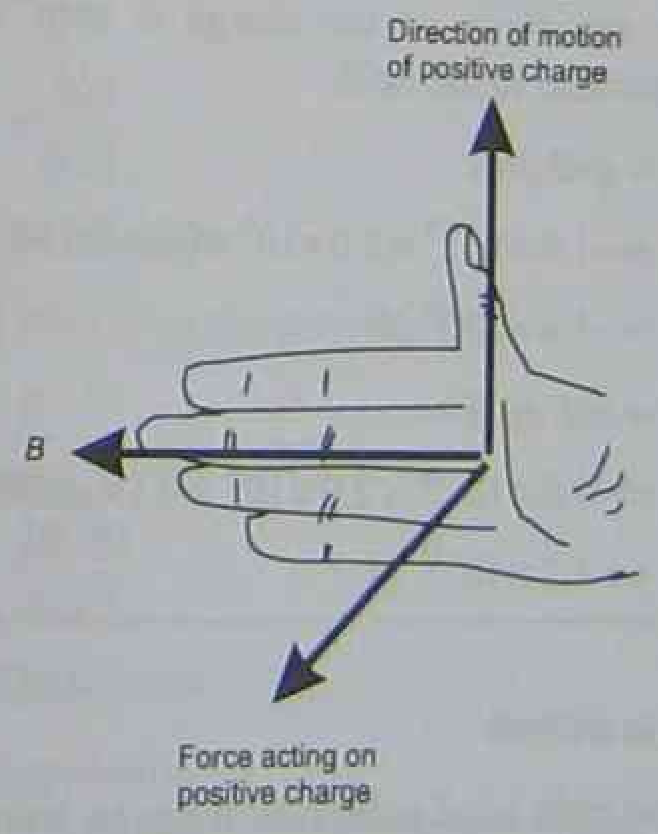


Figure 3. 7 Right-hand palm rule

The force (F) acting on a charge (q) moving with a velocity (v) at an angle θ to a magnetic field (B), (Figure 3.8) is given by:

---

[5] Thomson was late to show that this was because the cathode rays ionised the gas molecules in the tube. Charged ions were then attracted to the oppositely charged plate effectively neutralising the charge on the plates and eliminating the electric field!

[6] The German scientists believed cathode rays to be waves while the British scientists believed they were particles. (Eventually both were proven to be correct!)

$$\boxed{F = qvB\sin\theta}$$

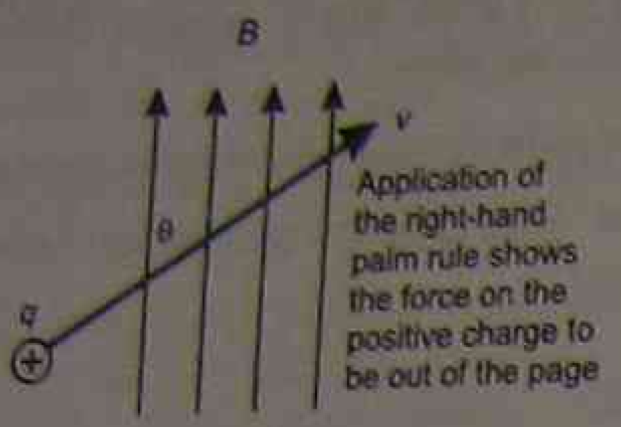


Figure 3. 8 Force on a charge moving in a magnetic field

EXAMPLE 2

An electron of charge –1.6 x 10^{-19} C travelling at a speed of 2.0 x 10^6 m.s^{-1} enters a magnetic field of 0.1 T. Calculate the force on the charge if it enters the field at an angle of:

(a) 0° (that is, parallel to the field)

(b) 30°

(c) 90° (that is, at right-angles to the field).

SOLUTION

(a) $F = qvB\sin\theta$

$$= -1.6\times10^{-19}\times2.0\times10^{6}\times0.1\times\sin 0$$

$$= 0$$

That is, the force on the charge is zero when it travels parallel to the field.

(b) $F = qvB\sin\theta$

$$= -1.6\times10^{-19}\times2.0\times10^{6}\times0.1\times\sin 30$$

$$= -1.6\times10^{-14}\text{ N}$$

(c) $F = qvB\sin\theta$

$$= -1.6\times10^{-19}\times2.0\times10^{6}\times0.1\times\sin 90$$

$$= -3.2\times10^{-14}\text{ N}$$

Motion in a Circle

From the right-hand palm rule, it can be seen that the force acts at right angles to the direction of motion. Hence a charged particle entering a uniform magnetic field at 90° will move in the *arc of a circle.*

THOMSON'S EXPERIMENT[7]

In 1897, J.J. Thomson, using apparatus similar to that in Figure 3.9 and assuming cathode rays were negatively charged particles, succeeded in not only proving their particle nature but successfully measured their *charge to mass ratio* (that is, *q/m*). This ratio was to have important implications for theories of atoms.

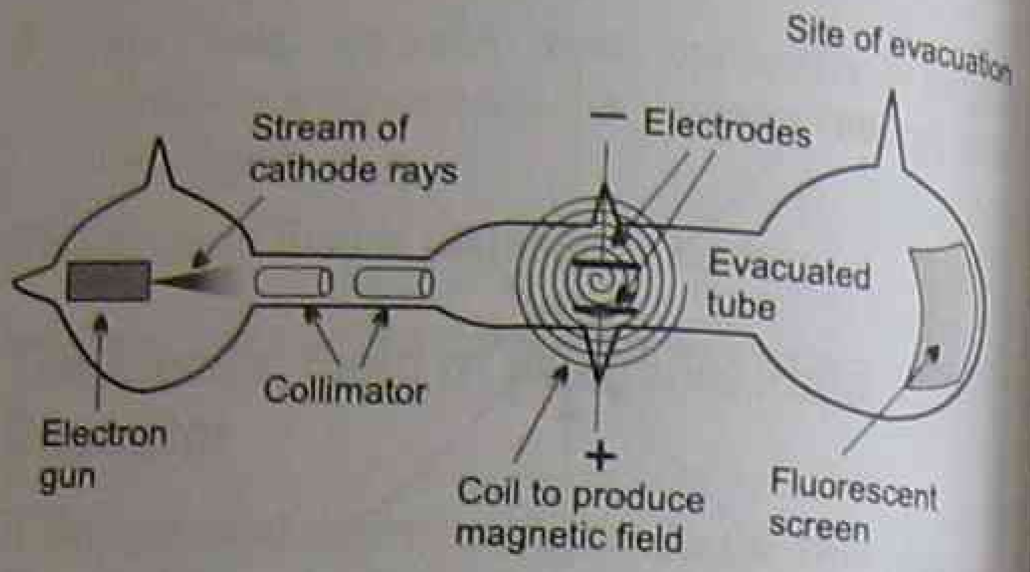


Figure 3. 9 Thomson's apparatus for determining *q/m*

By the time Thomson performed his experiment the effects of electric and magnetic fields on charged particles were well known. Thomson arranged electric and magnetic fields in his cathode ray tube so that he could 'balance out' the forces acting on the cathode rays (Figure 3.10).

1 In Figure 3.10 the cathode rays pass through the slots in the cylinders making a near parallel beam that hits the end of the glass tube in the centre.

2 The presence of an electric field alone would cause the beam to be deflected down (in this case) with a force of qE where q is the charge and E is the electric field strength as in Figure 3.10(a).

3 Similarly a magnetic field could be arranged that would cause the beam to be deflected upwards in the arc of a circle with a force of qvB (Figure 3.10(b)) that is:

$$qvB = \frac{mv^2}{r} \quad\Rightarrow\quad \frac{q}{m} = \frac{v}{Br}$$

B could be calculated from the geometry of the coil and the current in it and r could be found from the displacement of the beam.

4 By arranging the strength of the two forces, the beam could be made to pass through undeflected (Figure 3.10(c). When this happens the two forces are balanced, that is, $qE = qvB \Rightarrow v = \dfrac{E}{B}$ and since E and B could be calculated from the geometry of the plates and coils, v could be found and hence q/m could be calculated.

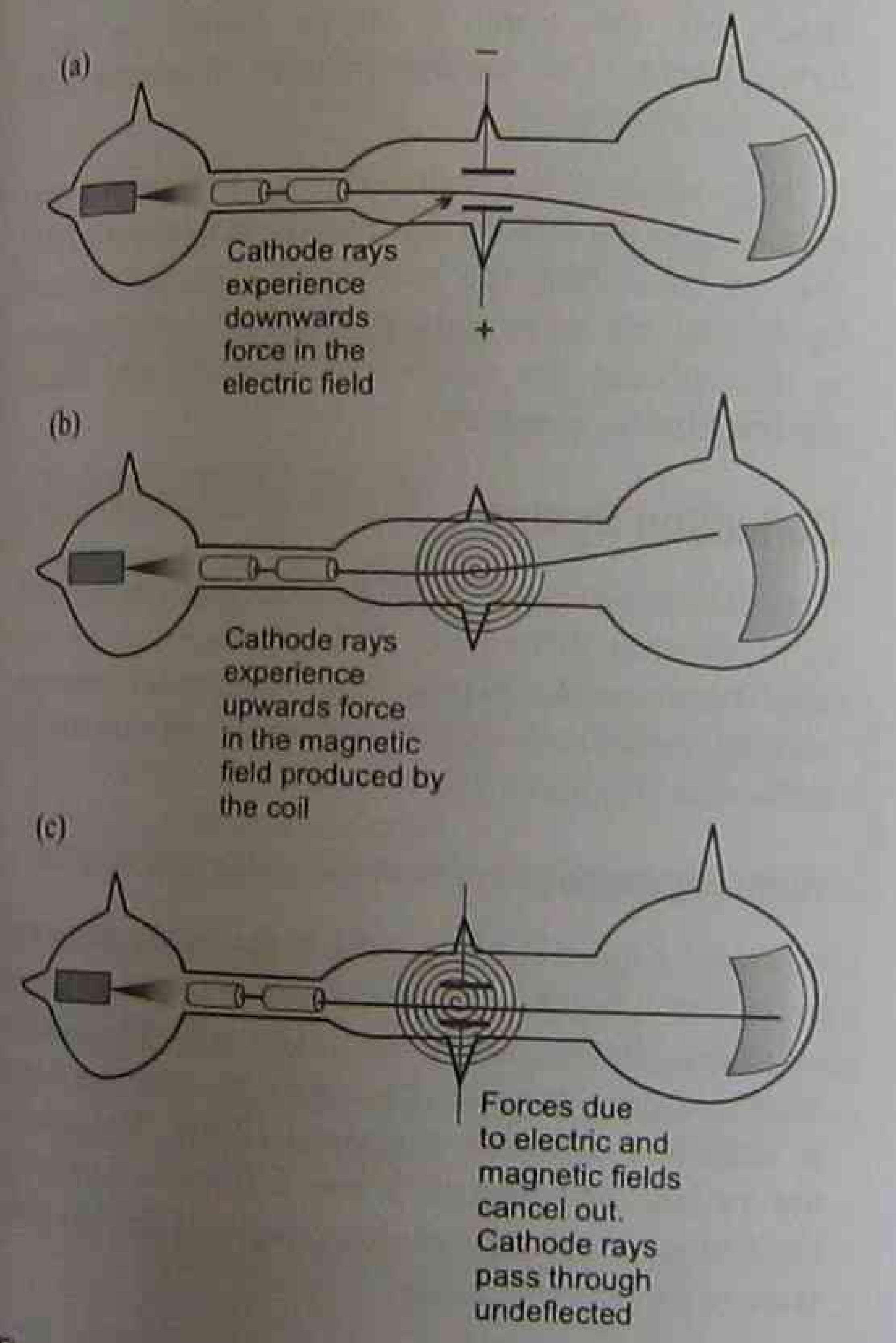


Figure 3. 10 Determining *q/m*

q/m ratio

Thomson found that regardless of the type of cathode material he used, *all cathode rays had the same q/m ratio*, that is: $\dfrac{q}{m} = 1.76\times10^{11}$ C.kg^{-1}. This value was 1800 times greater than the ratio for hydrogen ions obtained by other methods such as electrolysis. This meant that either the charge of the cathode rays was 1800 times that of the hydrogen ion or the mass of the cathode rays was $\frac{1}{1800}$ the mass of the hydrogen ion. Thomson made the latter conclusion—the mass of the cathode rays is $\frac{1}{1800}$ the mass of a hydrogen ion.

From these measurements Thomson proposed that *cathode rays are a constituent of all atoms.* We now know that cathode rays are, in fact, electrons.

EXAMPLE 3

In a 'Thomson type' experiment, the magnetic field of 0.001 T was sufficient to allow the electrons to pass undeflected through the parallel plates. The plates were 0.01 m apart and had a potential difference of 200 V across them.

(a) What is the electric field strength between the plates?

(b) What is the speed of the electrons?

(c) What force acts on the electrons due to the magnetic field?

SOLUTION

(a) $E = \dfrac{V}{d}$

$$= \frac{200}{0.01}$$

$$= 20000\text{ V.m}^{-1}$$

(b) We have from the previous page:

$$v = \frac{E}{B}$$

$$= \frac{20000}{0.001}$$

$$= 2\times10^{7}\text{ m.s}^{-1}$$

(c) $F = qvB\sin\theta$

$$= 1.6\times10^{-19}\times2\times10^{7}\times0.001\times\sin 90$$

$$= 3.2\times10^{-15}\text{ N}$$

---

[7] http://www.aip.org/history/electron/jjhome.htm A brilliant site on the discovery of the electron. Includes details of Thomson's experiment.

APPLICATIONS OF CATHODE RAYS

As often happens, a scientific discovery or piece of apparatus eventually finds its way into normal society in a way not envisaged at the start. Examples include X-rays and lasers, both of which have had a profound influence on our lives.

In addition, the essential features of the early cathode ray tubes have found practical applications in:

1 cathode ray oscilloscopes;
2 television sets; and
3 electron microscopes.

We will look at the major feature of these devices—the *cathode ray tube* (CRT).

CATHODE RAY TUBES

A *cathode ray tube* (Figure 3.11) consists of three main components:

1 a fluorescent screen;
2 an electron gun; and
3 a system of deflection plates.

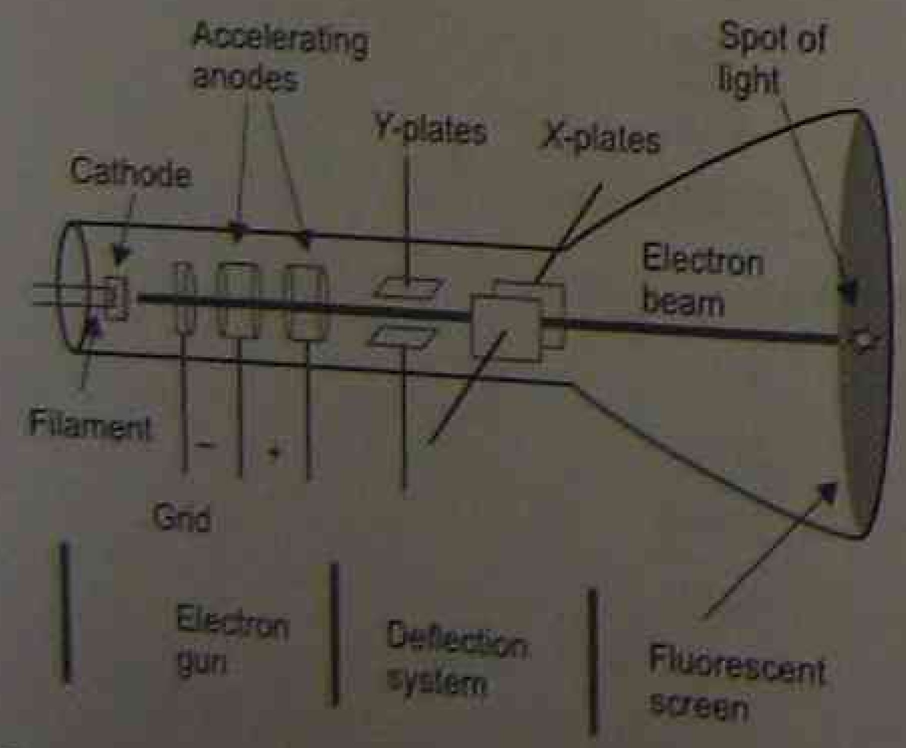


Figure 3. 11 Cathode Ray Tube (CRT)

Fluorescent screen

The inside glass of the end of the tube is coated
a fluorescent material for example, zinc sul
When an electron beam (that is, a steady strea
electrons produced by an electron gun) hits
screen, the coating fluoresces and a spot of lig
seen on the screen.

Electron 'Gun'

This produces a narrow beam of electrons. It co
of a *filament*, a *cathode* and two open-cyl
anodes (Figure 3.11). The filament produces
electrons by thermionic emission, that is, elec
'boil' off the wire as it is heated to
temperatures. The anodes help to accelerate
focus the electrons.

A ring shaped electrode—the *grid*—between
cathode and the anodes controls the brightness of
spot by controlling the number of electrons e
by the gun. By making the grid negative with re
to the cathode, the number of electrons and he
the brightness, is reduced.

Deflection System

This consists of two sets of parallel plates conne
to a potential difference. This produces an el
field between the plates. The *Y*-plates contr
vertical deflection and the *X*-plates the horiz
deflection (Figure 3.11).

Vertical deflection

Consider Figure 3.12(a), which shows the effe
the electron beam with no voltage between both
of plates. If the plates are given a steady vo
such that the top plate is positive, the electron
is deflected upwards (Figure 3.12(b)). The g
the voltage, the greater is the deflection. Sim
the beam would deflect downwards if the top
were to be made negative.

It follows that if the top plate were
alternatively positive and negative, the beam
move up and down (Figure 3.12(c)). This is wh
alternating (AC) voltage would do, with the
moving up and down at the frequency of the vo
For 50 Hz AC, the spot would move up and do
times per second, so fast that it would appear
steady vertical line.

Cathode ray tubes find an important use in *cathode ray oscilloscopes*.

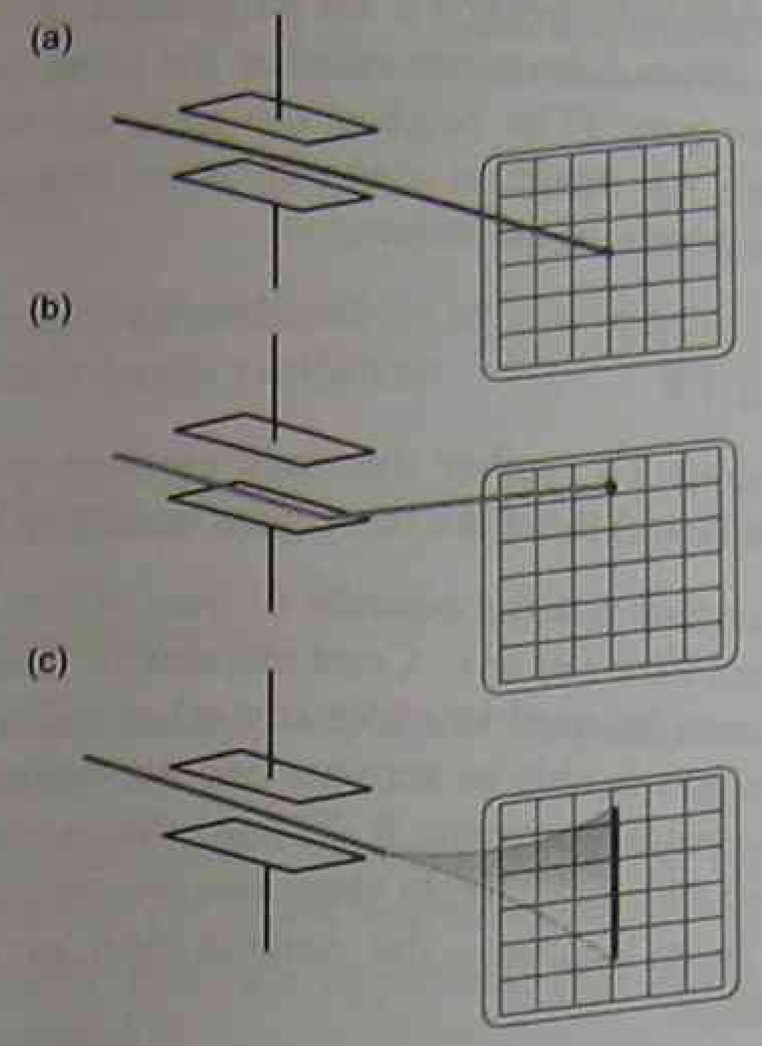


Figure 3. 12 Vertical deflection

CATHODE RAY OSCILLOSCOPE

> **A cathode ray oscilloscope** *(or CRO for short) is an electronic device used to 'view' electrical signals, that is, waveforms.*

The oscilloscope (Figure 3.13) 'graphs' the relationship between two or more variables. The horizontal axis generally represents time and the vertical axis generally represents voltage which is produced by an input signal.

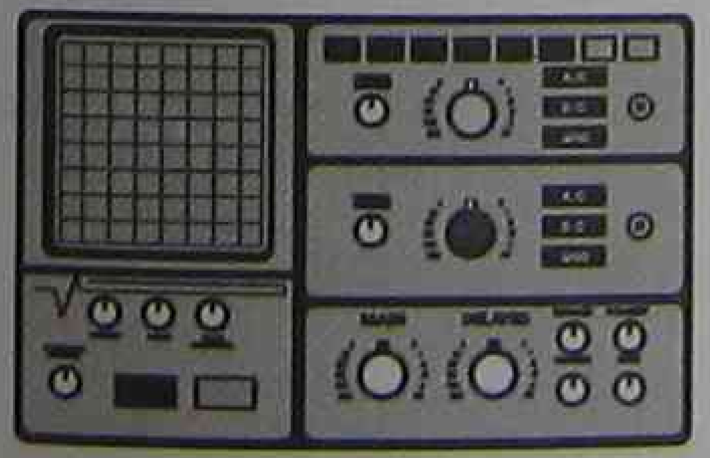


Figure 3. 13 A cathode ray oscilloscope

Since many physical phenomena can be converted into voltage, the oscilloscope is a versatile scientific tool. The CRO is one of the most widely used test instruments: its uses range from acoustics, to communication, to electronics, to heart monitoring... the list is endless.

Vertical Deflection

The vertical grid on the screen is generally divided into cm and the deflecting control is expressed in volts/cm ($V.cm^{-1}$). There is a range of values available, depending on the size of the applied voltage. If, for example, the setting is 10 $V.cm^{-1}$ then an amplitude of 2 cm would mean an applied voltage of 20 V.

Horizontal Deflection—Time Base Circuit

Imagine that you were to move your pen up and down in a straight line on a piece of paper. Obviously a vertical line would result. If, however, the paper were pulled horizontally at a constant speed as you moved your pen up and down, a wavy line—a *waveform*—would result.

A *time-base circuit* in the CRO has the same effect as pulling the paper. The spot is swept horizontally across the screen and when it reaches the edge it goes back to the start. This is achieved by using a *saw-tooth* voltage as shown in Figure 3.14. (The rapid change makes it fly back to the start.)

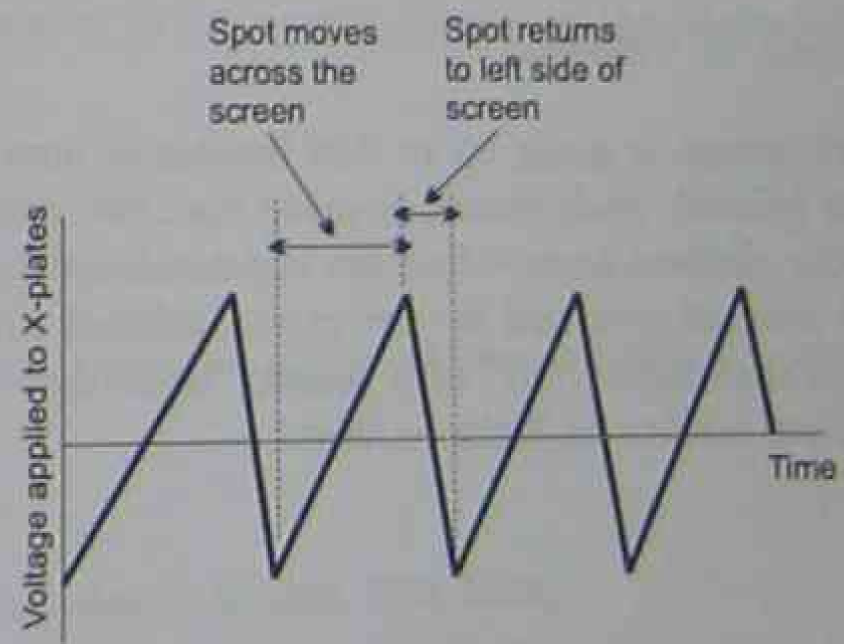


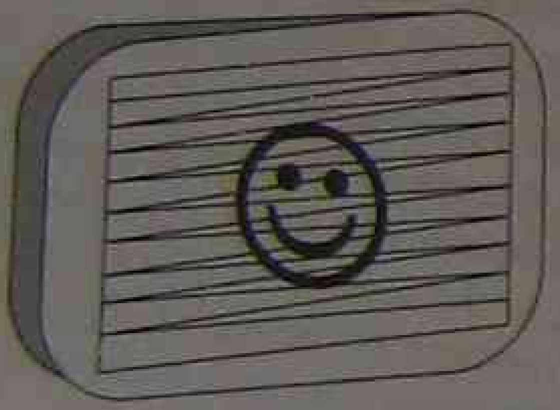
Figure 3. 14 Saw-tooth voltage

Each time the spot sweeps across the screen a new waveform is 'drawn'. By adjusting the *time-base control* each waveform can be 'drawn' over the previous one resulting in a stationary image.

The time-base control is calibrated in units of time/cm. For example, a value of 10 $ms.cm^{-1}$, means that the spot moves 1 cm in 10 ms (10 milliseconds). By measuring the distance between two successive crests (or troughs) the *period* and hence the *frequency* can be determined. For example, if the time-base is set at 10 ms.cm^{-1} and the distance between two successive crests is 4 cm, then the period is 40 ms and the frequency is found from $f=\frac{1}{T}=\frac{1}{40\times10^{-3}}=25\text{ Hz}$.

TELEVISION

A television set is similar to a CRO but is much more sophisticated. Instead of electric fields it uses magnetic fields to deflect the electron beam (the magnetic coils allow for a wider angle beam than would be possible with electric fields from plates) and has two time-base circuits—one for the vertical deflection and the other for the horizontal deflection. The result is that the electron beam 'zigzags down the screen as shown in Figure 3.15.



gure 3. 15 Television

ch image is made up or 625 horizontal lines of ts (pixels). Each picture is made from two passes the electron beam—first the odd-numbered lines scanned followed by the even-numbered lines. h scan takes 1/50th of a second, faster than the can react so no flicker is seen.

Black and White TV

On a black and white TV the brightness of the spot on the screen determines whether the point is white black or grey. (The brighter the spot, the whiter i appears.) An image is made up from thousands of spots or *pixels* on the screen.

Colour TV

In a colour TV, rather than one electron gun (one electron beam) there are three guns and three beams.

The phosphor coating consists of trios of dots in red, green and blue (RGB). Combinations of these three colours can be used to make any other colour. Each electron gun is able to activate one dot colour and a *shadow mask* prevents it hitting the wrong spot (Figure 3.16). Effectively three images are produced in the three colours—the combination giving the final image.

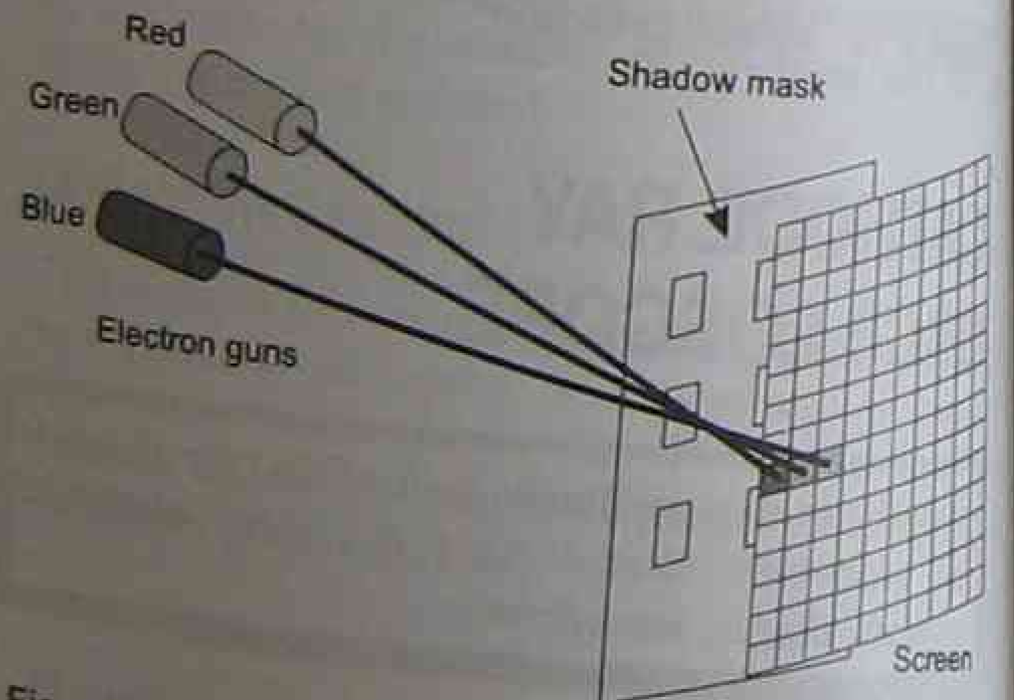


Figure 3. 16 Formation of a colour image

SECTION 2: QUANTUM THEORY

BIG IDEA:

The reconceptualisation of the model of light led to an understanding of the photoelectric effect and black body radiation.

OUTCOMES:

Students learn to:

1. Outline qualitatively Hertz's experiments in measuring the speed of radio waves and how they relate to light waves.
2. Describe Hertz's observation of the effect of a radio wave on a receiver and the photoelectric effect he produced but failed to investigate.
3. Identify Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantised.
4. Identify Einstein's contribution to quantum theory and its relation to black body radiation.
5. Explain the particle model of light in terms of photons with particular energy and frequency.
6. Identify the relationships between photon energy, frequency, speed of light and wavelength: $E=hf$ and $c=f\lambda$

Students:

1. *Perform an investigation to demonstrate the production and reception of radio waves.*
2. *Identify data sources, gather, process and analyse information and use available evidence to assess Einstein's contribution to quantum theory and its relation to black body radiation.*
3. *Identify data sources, gather, process and present information to summarise the use of the photoelectric effect in:*
   - *solar cells*
   - *photocells.*
4. *Solve problems and analyse information using* $E=hf$ *and* $c=f\lambda$
5. *Process information to discuss Einstein and Planck's differing views about whether science research is removed from social and political forces.*

HERTZ

It was not until 1887 that Heinrich Hertz demonstrated experimental evidence for the existence of electromagnetic waves which had first been postulated in 1865 by the Scottish physicist James Clerk Maxwell. Maxwell had proposed a link between electricity and light in the form of four mathematical equations[8]. The solutions to these equations predicted the existence of transverse electromagnetic waves with a range of frequencies, that would all travel at a speed of ~3 x 10^8 m.s^{-1}.

Hertz's apparatus is shown schematically in Figure 3.17. It consists of a source of waves and a detector. As sparks jumped across the gap in the induction coil, sparks were also noticed jumping across the air gap in the detector.

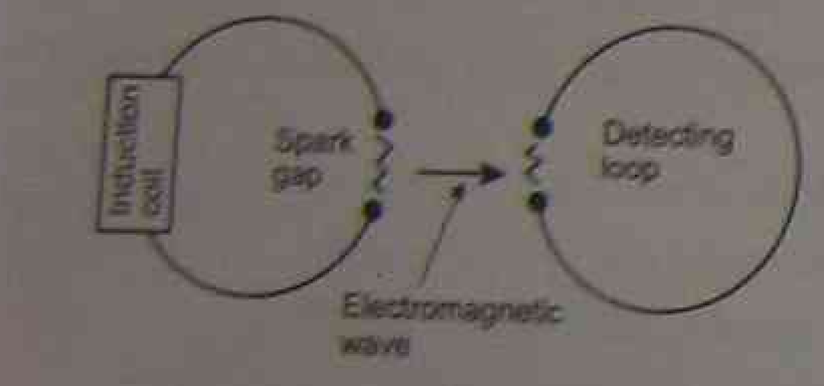


Figure 3. 17 Hertz's apparatus for producing and detecting electromagnetic waves

Hertz hypothesised that the sparks set up *changing electric and magnetic fields that propagated as an electromagnetic wave*, as postulated by Maxwell. These waves, falling on the spark gap, set up electric and magnetic fields inducing a spark.

Hertz also noticed that the gap in the detector could be made greater and a spark would still occur if *ultraviolet light* was shone onto the gap, but he did not investigate further. (We will return to this shortly.)

The waves were found to exhibit the properties of:

1 reflection;
2 refraction;
3 interference;
4 diffraction;
5 polarisation; and
6 they travelled at *c* (the speed of light, 3 x 10^8 m.s^{-1}).

These properties are also exhibited by light and so Hertz was able to provide experimental evidence that *light is a form of transverse electromagnetic wave.*

The waves produced by Hertz were in fact what we refer to today as radio waves (electromagnetic waves with long wavelengths). Oscillating charges in antennae produce radio waves.

PLANCK AND BLACK BODY RADIATION—THE QUANTUM THEORY

In the Preliminary Course, *The Cosmic Engine* we were introduced to the concept of a *black body* as a perfect emitter or absorber of energy.

It had long been known that there was a relationship between the dominant wavelength of electromagnetic radiation emitted by a hot object and its temperature. This is illustrated in Figure 3.18. Try as they might, physicists, using *classical physics* (the physics of Newton and Maxwell, that is, physics prior to 1900), could not get agreement between theory and experiment to explain the black body radiation curves[9]. A radical change in approach was needed. This was the *quantum theory* of physics.

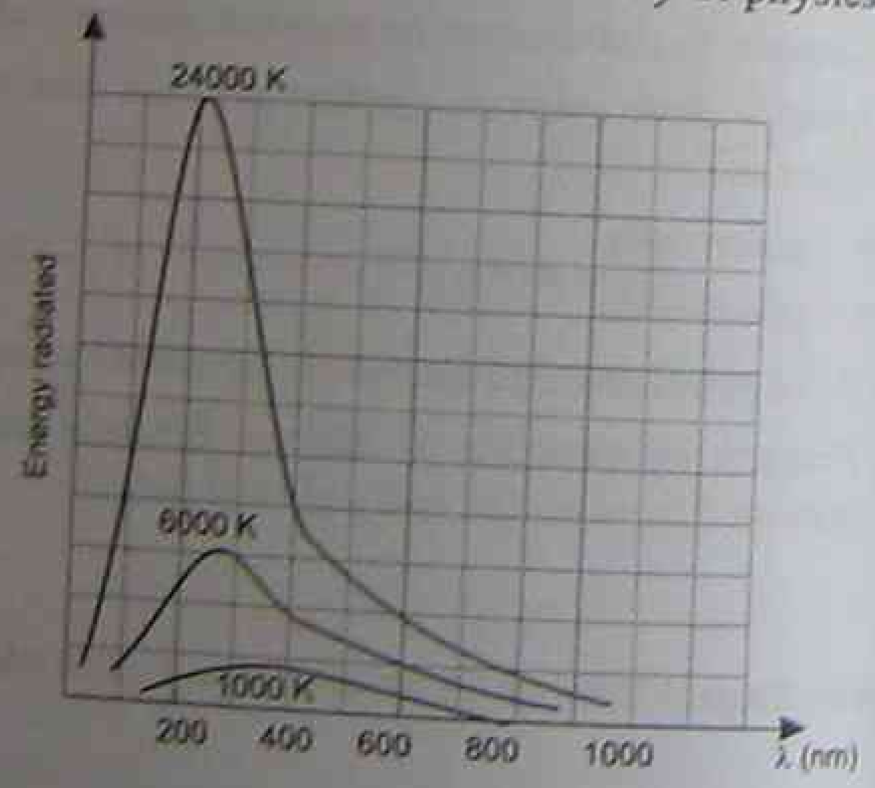


Figure 3. 18 Black body radiation curves

Quantum physics began in 1900 with the German physicist Max Planck. Planck found that he could only get the necessary agreement between theory and experiment for black body radiation by making a fundamental change to the laws of physics! He proposed that:

> *Radiation (energy) is not emitted or absorbed by a black body continuously as classical physics said it should, but rather it is emitted or absorbed in little 'bursts' or 'packets of energy'* **quanta (or photons)** *of energy.*

Mathematically we write:

$$\boxed{E = hf}$$

where E is the energy of the photon, h is a constant called Planck's constant (= 6.626 x 10^{-34} J.s) and f is the frequency.

The concept that energy is quantised, lies at the heart of modern physical theories. It ranks as a major milestone in science and the development of our concept of the world around us.

EXAMPLE 4

A photon of red light has a wavelength of 600 nm (1 nm = 10^{-9} m). Calculate:

(a) the photons frequency; and

(b) the photon's energy.

(The speed of light is 3.0 x 10^8 m.s^{-1}.)

SOLUTION

(a) From our study of waves in the Preliminary Course *The World Communicates* we know that the speed, frequency and wavelength are related by $v = f\lambda$. Hence:

$$f = \frac{v}{\lambda} = \frac{3.0\times10^{8}}{600\times10^{-9}}\text{ Hz}$$
$$= 5\times10^{14}\text{ Hz}$$

(b) From Planck's equation:

$$E = hf = 6.6\times10^{-34}\times5\times10^{14}\text{ J}$$
$$= 3.3\times10^{-19}\text{ J}$$

THE PHOTOELECTRIC EFFECT

> *The* **photoelectric effect**[10] *is the emission of electrons from substances, in particular metals, when they are bombarded with light (usually in the high frequency range, such as ultraviolet).*

As previously mentioned, Hertz first discovered the photoelectric effect in 1887 while he was investigating the generation and properties of Maxwell's electromagnetic waves. He failed however, to investigate this phenomenon any further.

In 1900 the German scientist Philipp Lenard[11] had shown that the charges emitted in the photoelectric effect were identical to the cathode rays discovered by Thomson in 1897 (see p.102), that is, they were electrons. Then in 1902, using apparatus similar to that shown schematically in Figure 3.19(a), Lenard studied the relationship between the energy of the emitted *photoelectrons* and the intensity and frequency of the incident light. The incident light caused photoelectrons to be given off from the emitter and move towards the collector. The resulting current was registered on a meter. By making the collector negative, Lenard was able to reduce the photocurrent to zero (Figure 3.19(b)). (The greater the energy of the photoelectrons the greater the negative potential would need to be to repel them. The maximum kinetic energy of the photoelectrons could be found from the relationship between the work done in stopping the electrons and the energy, that is: $qV_{stop} = \frac{1}{2}mv^2 = E_{k_{max}}$ where V_{stop} is the 'stopping voltage'.) Lenard was also able to investigate the effect of using light of different wavelengths.

---

[8] Maxwell's work places him on the same level as Newton and Einstein in describing the world around us.

[9] Classical physics predicted that as the wavelength of the radiant energy decreased (say from the visible to the ultraviolet), the intensity of the radiation would increase without limit. This would violate the law of conservation of energy. This effect became known as the 'ultraviolet catastrophe'.

[10] http://www.walter-fendt.de/ph11e/photoeffect.htm Java applet of the photoelectric effect

[11] http://www.nobel.se/laureates/physics-1905-1-bio.html Biography of Philipp Lenard

http://www.phys.virginia.edu/classes/252/photoelectric_effect.html The photoelectric effect

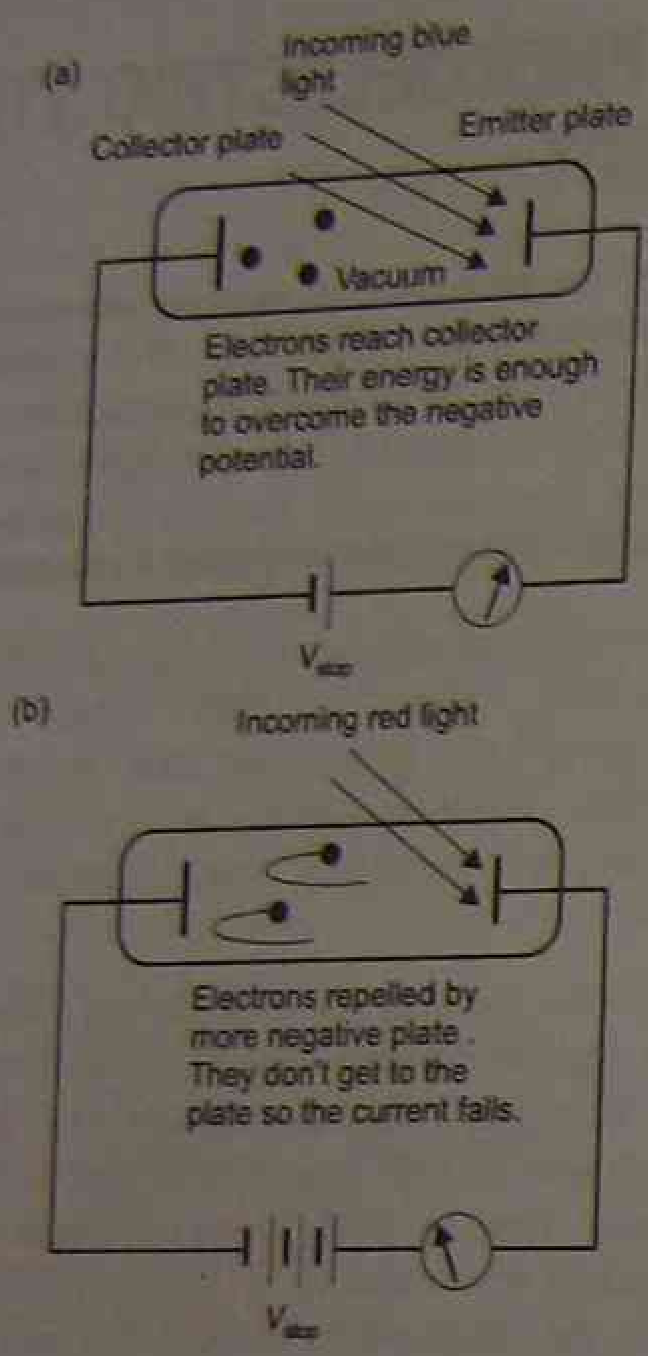


Figure 3. 19 Lenard's apparatus for studying the photoelectric effect

Classical physics made certain predictions regarding the photoelectric effect. These are summarised in Table 3.1. Lenard's experimental results are also shown for easy comparison. It is obvious that there are differences between the expected and actual results.

> *The* **classical wave theory***—the model that said that light was a wave—was unable to successfully explain the photoelectric effect.*

EINSTEIN'S EXPLANATION

The results of the photoelectric effect cast grave doubt on the wave model of light that had previously been so successful in explaining the properties of light including *interference* and *diffraction*.

The genius of Albert Einstein was required to give an adequate explanation of the phenomenon. The basis of his explanation lay in Planck's quantum idea but Einstein expanded the concept.

Adopting a *particle model* in conjunction with Planck's hypothesis, Einstein proposed that:

1 The energy of light is not evenly spread out over the wavefront, but is concentrated in 'bundles' or 'packets' of energy—*photons*.

Table 3. 1 The photoelectric effect

Characteristic	Classical Predictions	Experimental Results
Intensity	As the light intensity increases, the photocurrent will increase.	As the light intensity increased, so did the photocurrent.
Emission time	For low intensity light, the time for the electrons to be emitted will be long, in the order of minutes.	If emission occurred, it was instantaneous. (Emission did not always occur—see next point.)
Frequency	Emission is independent of frequency.	Emission was frequency dependent. Below a certain frequency (the *critical* or *threshold* or *cut-off* frequency) no electrons were emitted, regardless of the intensity of the light.
Energy	As the light intensity increases, the kinetic energies of the photoelectrons will increase.	As the intensity increased, the maximum kinetic energy ($E_{k_{max}}$) remained constant. $E_{k_{max}}$ was found to depend on the frequency of light used and the type of surface.

2 Each photon has energy given by Planck's relationship: $E = hf$ where h is Planck's constant ($= 6.626 \times 10^{-34}$ J.s) and f is the frequency of light.

3 A photon could give up all (or none) of its energy to one electron, but it could not give only a part of it—the *'all or nothing'* principle.

4 The maximum kinetic energy of the emitted electron ($E_{k_{max}}$) was equal to the initial photon energy minus the work done in overcoming the attractive forces near the surface; that is,

$$\boxed{E_{k_{max}} = hf - \phi = qV_{stop}}$$

where ϕ is the *work function* ($\phi = hf_o$) and f_o is the *threshold* (or *critical*) frequency; that is, the minimum frequency that would cause photoemission.

Photon Explanation

Let's apply Einstein's model to the factors tested in Lenard's experiment:

1 *Intensity* is measured by the number of photons per unit area. This means that as the intensity is increased the number of photons will be increased. Hence the photocurrent is increased.

2 A photon transfers all its energy to the electron. Provided this energy is greater than the work function, the electron will leave immediately (that is, in the order of microseconds). If, however, $hf < \phi$ the electron will not be emitted.

3 *Frequency*—since the energy of the photon is dependent on frequency, then it follows, if the frequency is too low the available energy may be too low to release the electron.

4 Intensity is independent of photon energy. Since it is the photon energy that determines the $E_{k_{max}}$ of the electron, then $E_{k_{max}}$ must also be independent of intensity.

Verification of Einstein's model

From $E_{k_{max}} = hf - hf_o = h(f - f_o)$ Einstein predicted that different surfaces would have graphs similar to that of Figure 3.20—that is, straight lines with slope *h*. In 1916 Millikan (who had earlier measured the electronic charge) succeeded in showing experimentally that this was true. This provided irrefutable evidence in support of Einstein's theory.

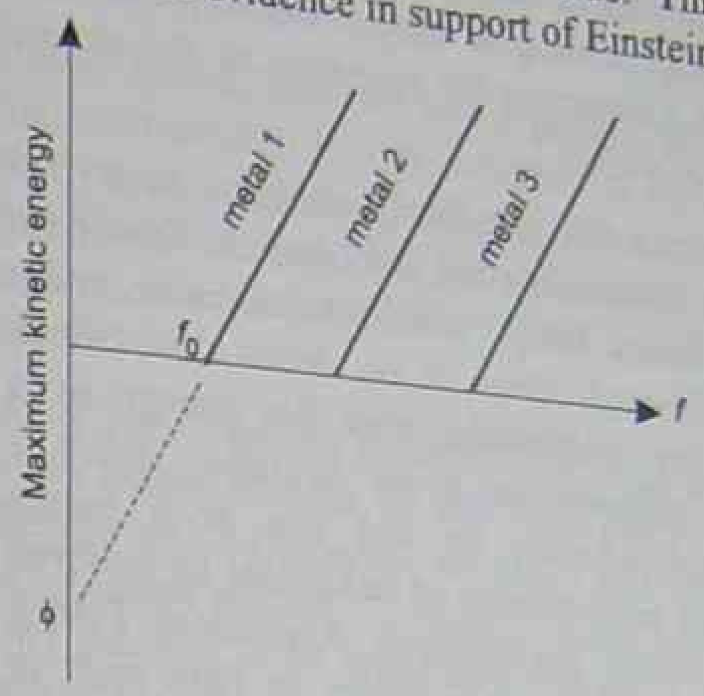


Figure 3. 20 Millikan's verification of Einstein's explanation of the photoelectric effect

EXAMPLE 5

Orange light of wavelength 600 nm is incident on a metal surface with a work function of 2.4×10^{-19} J. Calculate the maximum kinetic energy of the emitted photoelectrons.

SOLUTION

$$E_{k_{max}} = hf - \phi = h\frac{c}{\lambda} - \phi$$

$$= \left(6.6\times10^{-34} \times \frac{3.0\times10^{8}}{600\times10^{-9}}\right) - 2.4\times10^{-19} \text{ J}$$

$$= 9.0\times10^{-20} \text{ J}$$

Secondary Source Investigation

Einstein's Contribution to Quantum Theory

Albert Einstein (1879–1955) is considered to be one of the most brilliant men to have ever lived, ranking with Newton in changing humankind's view of the universe and how it works.

In 1905 he made three of the most important scientific contributions of all time:

1 The *photoelectric effect* (for which he was awarded the 1921 Nobel Prize in physics).

2 The theory of *special relativity*.

3 A theory of *Brownian motion* (the random and rapid motion of tiny particles suspended in air or liquids). This later theory was to prove vital in final acceptance by scientists of the atomic theory of matter[12].

In recent times the previously accepted view that Planck was responsible for the quantum theory (in relation to black body radiation) has come under scrutiny. Although there is no doubt that Planck postulated the relationship that the energy of a quantum is proportional to its frequency, there is debate about whether he did this as a purely mathematical convenience or rather that he believed that it had wider implications. Regardless, Planck did not propose a particle theory of light prior to Einstein's theory.

Debate still rages among physics historians about the true originator of quantum theory.

Secondary Source Investigation

The photoelectric effect has important applications in today's world in *photocells* and *solar cells*.

Photocells

Photocells (or photoelectric cells) are cells in which the electrons initiating an electric current are produced by the photoelectric effect. Essentially photocells consist of a cathode and anode (Figure 3.21). The cathode is coated with a photosensitive material that emits electrons when light falls on it. The *photoelectrons* are accelerated to the anode (by a potential difference between them) resulting in a *photocurrent* which is proportional to the intensity of the light falling on the cathode.

Some uses of photocells include:

1 electric 'eyes';

2 radiation detectors; and

3 light meters.

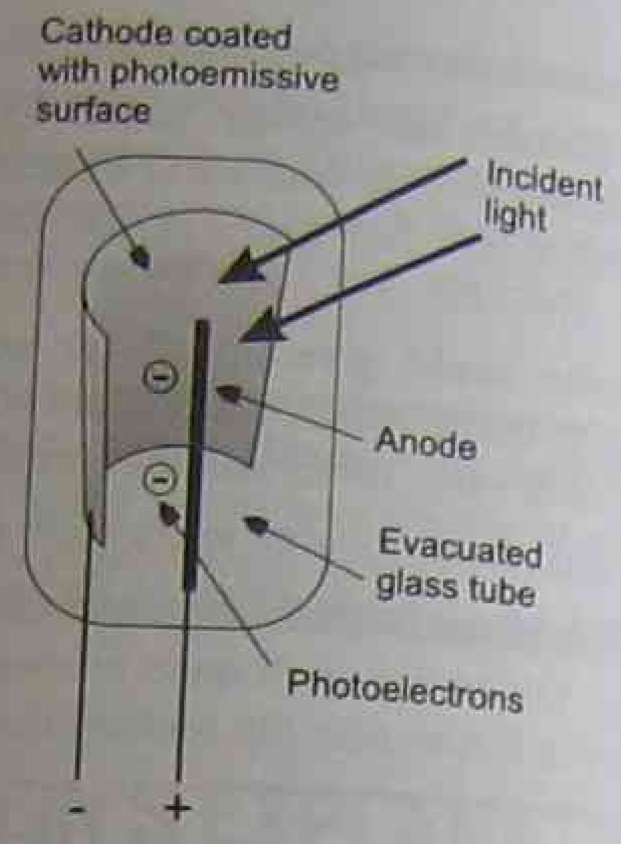


Figure 3. 21 A photocell

Solar Cells

Solar cells—*photovoltaic devices*—employ the *semiconductor* silicon (see p.117), and utilise the photoelectric effect. (For details see p.119).

Solar cells are becoming more and more efficient. Typically they convert 10-15% of the incident energy into electrical energy. They are used extensively in space to power satellites and are becoming more available for homes and offices as an environmentally friendly alternative energy supply.

Secondary Source Investigation

Planck and Einstein

In the late nineteenth century and into the early part of the twentieth century Germany was the pre-eminent European power. It was a cultural centre for literature, philosophy and importantly the sciences.

German scientists (along with scientists in Great Britain) led the charge to discover the fundamental workings of the universe. German physicists were held in such high regard that physicists from around the world flocked to German universities. Foremost among the German physicists were Max Planck (1858—1947) and Albert Einstein (1879—1955).

In 1914 Germany entered World War I. Planck was an avowed nationalist and as such believed in the righteousness of the German cause and its inevitable victory. He even signed his name to the *Appeal of the Ninety-three Intellectuals*, a document strongly supporting the German military. In doing so he alienated himself from his European and British colleagues. Following the defeat of Germany, German science was isolated from the rest of Europe. Planck decided that the only way to restore German science to its 'rightful position' was to extol German scientists to excel once again. Planck believed that the increased respect for German science would inevitable lead to greater respect for Germany as a whole.

The emergence of Hitler and his Nazi party in the 1930s resulted in German science once again being marginalised as the rest of the world recoiled from the German governments policies with many scientists (including Einstein) fleeing the country. Planck, however, still the fervent nationalist, stayed behind to *work within the system* to save German science and with it, he believed, his beloved Germany. Unlike Einstein, Planck saw no moral imperative to *oppose* the Nazi regime.

In 1930 Planck has been appointed as president of the *Kaiser Wilhelm Institute*, Germany's most prestigious scientific research facility. He resigned this position in 1937 in protest against the Nazi party's anti-Semitic policy to sack all Jewish teachers from German Universities. Planck also spoke out against the anti-Semitism directed towards Einstein and negotiated, with minimal success, to at least spare Jewish scientists.

Planck's anti-Nazi views led him to refuse to work on any of Germany's war research projects. He paid a heavy personal price when his fervently anti-Nazi son Erwin was implicated in the 1944 July plot to assassinate Hitler and died in early 1945 during interrogation by the Gestapo.

Planck died on 4 October 1947. The Kaiser Wilhelm Institute was renamed the *Max Planck Institute* in recognition of his pioneering work in quantum physics.

Albert Einstein was awarded the Nobel Prize for Physics in 1921 for his work on the photoelectric effect. This was three years after Planck has received his award for the discovery of quantum physics.

Unlike Planck, Einstein was a pacifist who took out Swiss citizenship in 1901 because of his opposition to German militarism. Whereas Planck signed the Manifesto of the Ninety-three Intellectuals (see earlier), Einstein and three others signed a counter manifesto.

As a Jew, Einstein suffered prejudice in Germany even before the rise of the Nazi party. He toured Europe making speeches on peace and disarmament. An avowed pacifist, Einstein told his audiences that *'my pacifism is an instinctive feeling, a feeling that possesses me because the murder of men is disgusting.'*

When Hitler rose to power in 1933, Einstein was in California. Fearing what would happen if he returned to Germany (his house was trashed by Hitler's 'brown shirts) he decided not to return home but rather to tour Europe making speeches explaining what was happening in Nazi Germany.

In 1934 he emigrated to the USA taking up the position of professor of mathematics at Princeton University which became his permanent home, never returning to Germany. Contrary to his previous pacifist views he now advocated re-armament of democratic government to oppose the Nazi tyranny.

In 1939 Einstein warned President Roosevelt of the potential for a German atomic bomb. This led to the *Manhattan Project* (see *Quanta to Quarks*). He said this was one of the most difficult decisions of his life.

In his latter years Einstein devoted much of his time advocating the concept of a world government to eliminate the threat of atomic war.

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[12] In the early 1900s scientists still had not universally accepted the atomic theory.

SECTION 3: SOLID STATE DEVICES

BIG IDEA:

Limitations of past technologies and increased research into the structure of the atom resulted in the invention of transistors.

OUTCOMES:

Students learn to:

1 Identify that some electrons in solids are shared between atoms and move freely.
2 Describe the difference between conductors, insulators and semiconductors in terms of band structures and relative electrical resistance.
3 Identify absences of electrons in a nearly full band as holes, and recognise that both electrons and holes help to carry current.
4 Compare qualitatively the relative number of free electrons that can drift from atom to atom in conductors, semiconductors and insulators.
5 Identify that the use of germanium in early transistors is related to the lack of ability to produce other materials of suitable purity.
6 Describe how 'doping' a semiconductor can change its electrical properties.
7 Identify differences in *p*-type and *n*-type semiconductors in terms of the relative number of negative charge carriers and positive holes.
8 Describe differences between solid state and thermionic devices and discuss why solid-state devices replaced thermionic devices.

Students:

1 *Perform an investigation to model the behaviour of semiconductors, including the creation of a hole or positive charge on the atom that has lost the electron, and the movement of electrons and holes in opposite directions when an electric field is applied across the semiconductor.*
2 *Gather, process and present secondary information to discuss how shortcomings in available communication technology lead to an increased knowledge of the properties of materials with particular reference to the invention of the transistor.*
3 *Identify data sources, gather, process, analyse information and use available evidence to assess the impact of the invention of transistors on society with particular reference to their use in microchips and microprocessors.*

ELECTRICAL CONDUCTIVITY

You are all aware that different materials conduct electricity differently. Metals are good conductors; plastics are poor conductors (good insulators).

The differences in conductivity relate to the ease of movement of the atom's electrons. As we have seen in the Preliminary Course *Electricity in the Home*, the 'electron sea' model can represent metals. In this model—Figure 3.22—the electrons are *delocalised* and so are free to move through the crystal lattice of positive ions.

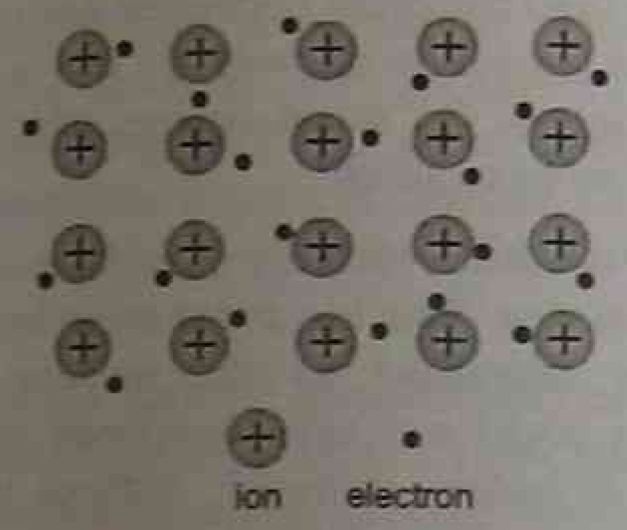


Figure 3. 22 Electron sea model of a metal

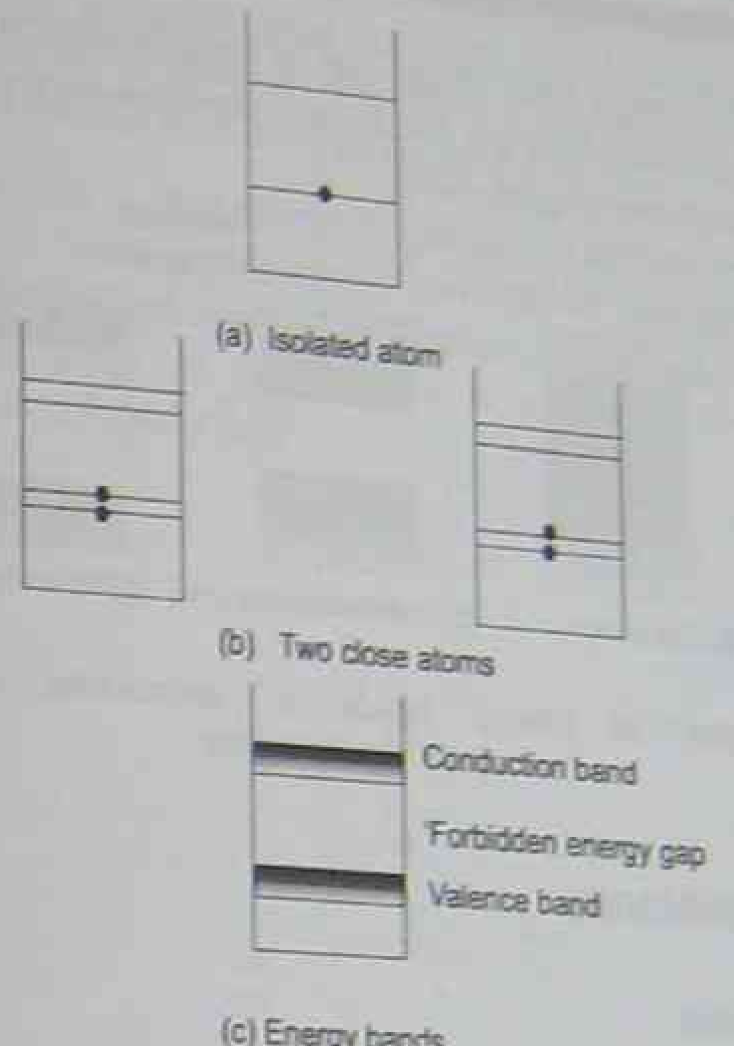
BAND STRUCTURE OF MATTER

In an isolated atom, the electrons occupy a series of energy states (levels) around the positive nucleus. Electrons fill up the lowest possible energy state first—the *ground state*—with each level capable of holding a certain *maximum* number of electrons: two in the first level, eight in the second level, eighteen in the third level… A typical atom containing many electrons has its lower energy levels filled. The highest occupied energy level, however, may or may not be filled depending on the element.

When atoms come together to form a crystal, electrons in the upper level—the *valence electrons*—'feel' the attraction of surrounding nuclei. As a result, the energy levels are split (Figure 3.23(b)).

Two atoms brought close enough to each other to interact will result in the two-atom system having two closely spaced energy levels; twenty atoms would result in twenty closely spaced energy levels.

(The Pauli exclusion principle states that no two electrons can have exactly the same energy. Hence as atoms are squeezed closer together in solids, the energy levels spread out to allow for the varying energies.)



(a) Isolated atom

(b) Two close atoms

(c) Energy bands

Figure 3. 23 Formation of energy bands

Since any finite sample of a crystal contains millions of atoms ($\sim10^{23}$ atoms per cubic centimetre), the individual energy levels combine to form *energy bands* within the crystal (Figure 3.23(c)).

Energy Bands

The highest energy band that is occupied by electrons is the *valence (or valency) band.*

> *The* **valence band** *contains the valence electrons and is partly or completely filled.*

Above the valence band is the *conduction band.*

> *The* **conduction band** *is the upper energy band and corresponds to the higher energy levels in the isolated atom. It is empty.*

Some energies have no levels at all resulting in *band gaps.*

The forbidden energy gap *lies between the valence and conduction bands. It corresponds to the gap between the energy levels in the isolated atom.*

The energy band model can be used to illustrate the difference between *conductors*, *semiconductors* and *insulators* (Figure 3.24).

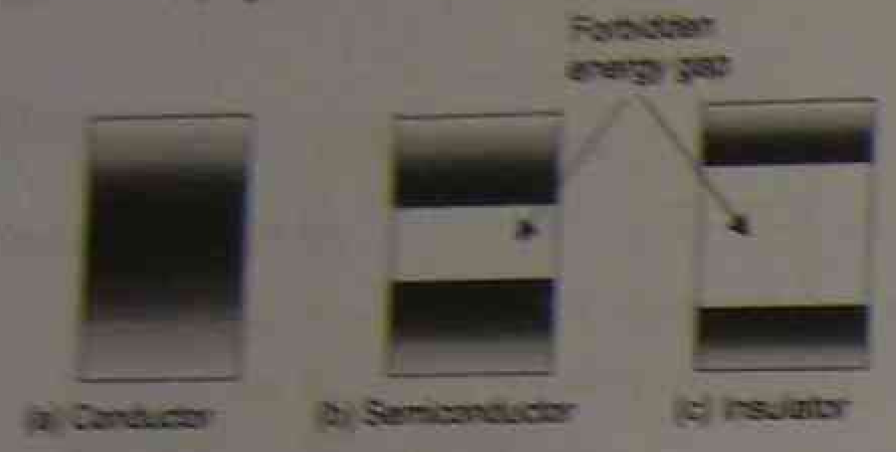


Figure 3. 24 Energy bands in conductors, semiconductors and insulators

Resistance

Metals

Materials conduct electricity when there are free electrons. Only those electrons in the valency band can be 'moved' into the conduction band by supplying them with energy (for example, by an electric field). Because a metal's valency band is only partly filled, an electron supplied with additional kinetic energy can occupy a higher energy level in the valency band. For conductors such as metals, the conduction and valence bands overlap. Hence there are many valence electrons available for conduction. As a result, metals have *low* electrical resistance.

Semiconductors

For a semiconductor, thermal energy may provide the necessary energy for an electron to 'jump the gap' to the conduction band and be available for conduction. This leaves a 'hole' behind in the otherwise full valency band. This hole is equivalent to a positive charge (an absent electron) and moves in the opposite direction. (This does not happen at room temperature unless the sample is *doped* (see p.117)).

The forbidden energy gap (for the two most important semiconductors) is 1.1 eV for silicon and 0.7 eV for germanium.

Semiconductors have electrical resistances between that of metals and insulators.

Insulators

The energy gap is large for insulators (~10 eV) and so no electrons are normally available for conduction. Insulators have high electrical resistance.

SEMICONDUCTORS

The invention of the transistor in 1948 produced unprecedented progress in technology, allowing computers (and computer controlled devices) to have as great an impact on the way we live and work as the invention of the steam engine, which powered the Industrial Revolution.

The late twentieth century has been called the *Information Age*. This has come about as a result of the power unleashed by the modern computer. Computers could not have developed to the stage they are at today, however, without the use of semiconductors, in particular germanium and silicon.

Germanium

Germanium (symbol, Ge) is a Group IV element in the periodic table. A silvery-grey *metalloid*, it was discovered in 1886 (but its existence had been predicted in 1871 by Mendeleev following his work on formulating the periodic table).

Never found free in nature, germanium is a rare element (making up only 1.5 parts per million in the Earth's crust). Brittle rather than ductile, it gained economic significance after 1945 when its semiconducting properties were recognised as being useful in electronics.

Germanium is produced by dissolving the appropriate mineral ores in hydrochloric acid. The resulting chloride is converted into germanium oxide which is reduced with hydrogen. The powdery metal produced is then melted and cast in ingots.

For use in electronic devices the germanium ingots are further purified and then doped using minute amounts of arsenic, gallium or other elements. Using a *seed crystal*, single crystals are generated from the melt.

Silicon

Silicon (Si) is also a Group IV element. Too reactive to be found free, silicon is the second most abundant element (after oxygen) by weight in the Earth's crust.

It is produced by the reduction of silica (silicon dioxide, SiO_2—common sand) with coke in an electric furnace. As with germanium, for use in electronics, single crystals are grown by slowly withdrawing a *seed crystal* from molten silicon.

Silicon versus Germanium

Germanium was *the* semiconductor used up to about 1960 when it was surpassed by silicon. Suitable purification methods for germanium had been developed during the 1940s. (It is important that the semiconductor be as pure as possible. Contamination as low as *one part per billion* affects its conducting properties.)

In the 1950s suitable purification methods were devised for silicon. From about 1960, silicon became the preferred semiconductor material for *solid state* devices. The reasons for this were:

1 Silicon is much more abundant than germanium (and hence is cheaper).
2 Silicon retains its semiconducting properties at higher temperatures than germanium. (We say Si has a much lower 'leakage current' than Ge.)
3 Unlike germanium, silicon forms an insulating oxide layer when heated to high temperatures in oxygen. (This film is critical in the manufacture of integrated circuits.)

DOPING[13]

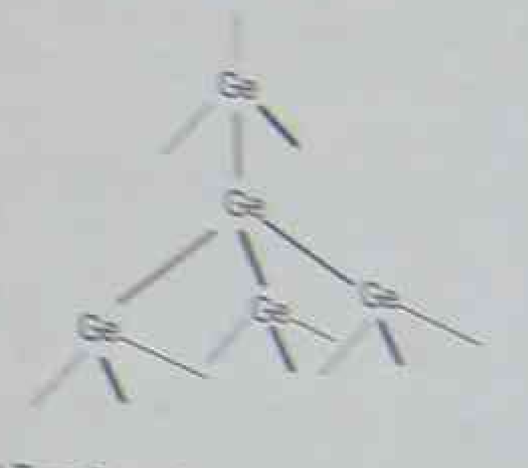
As we have seen, semiconductors are found in Group IV of the periodic table with the most common ones being silicon and germanium. The structure of these elements is *tetrahedral* with each atom sharing one *valence electron* with each of its four neighbours (Figure 3.25).

Electron-Hole Pairs

Near absolute zero, the electrons in the outer shell are tightly bound and hence there are no *free carriers*—the element acts as an insulator. As the temperature rises, some electrons gain sufficient energy to escape from the bond and exist as free electrons. In doing so they leave a *hole* behind. The electron and hole form an *electron-hole pair*.

The hole is 'free to move' (actually, electrons move to fill the hole, creating a new hole as they do so) under the influence of an electric field. Conduction takes place via holes and electrons and is termed *intrinsic conduction*.

(a) Tetrahedral structure



(b) Two dimensional representation

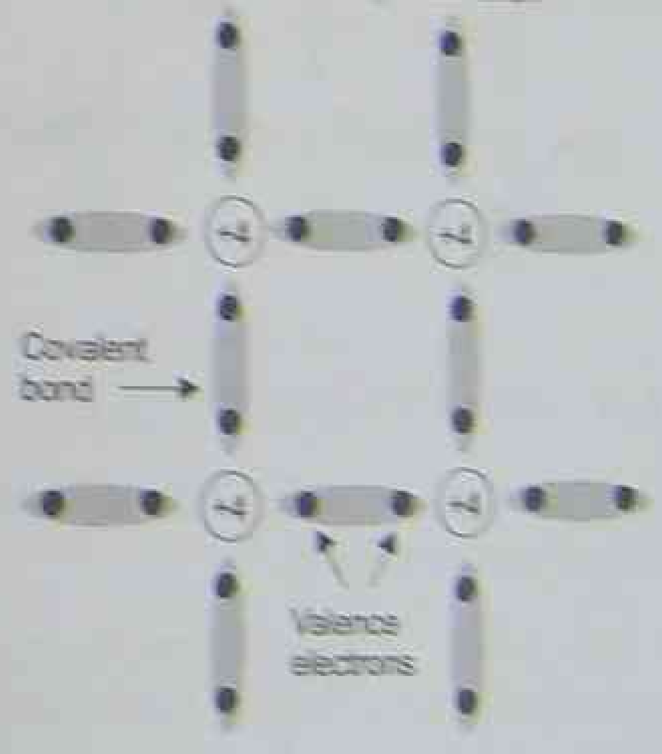


Figure 3. 25 Structure of Group IV elements. In (a) each atom is bonded to 4 other Ge atoms which are bonded to 4 other Ge atoms which...

Doped Semiconductors

As we have seen, silicon in the pure state, is a medium (*semi*) conductor, that is, its conductivity lies between a conductor and an insulator. *Doping* can significantly increase its conductivity.

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[13] http://ridge.arch.uwa.edu.au/topics/thermal/solar/photovoltaics.htm From the University of Western Australia, this has a colourful explanation of electrons and holes.

> **Doping** *occurs when atoms from Group III or Group V of the periodic table replace some of the atoms of the Group IV element being doped.*

Group III elements include boron, aluminium, gallium and indium; while Group V elements include nitrogen, phosphorus, arsenic and antimony.

Doping creates a 'hole' (unfilled covalent bond) if a Group III atom is used, or provides an excess electron if a Group V atom is used. Conduction occurs by these holes and free electrons.

p-type Semiconductor

When a Group III atom replaces one of the Group IV atoms only three valence electrons are available to complete the covalent bonds. If the remaining unfilled covalent bond is filled by a valence electron from a neighbouring atom a *mobile hole is created* which is available for conduction[14] (Figure 3.26).

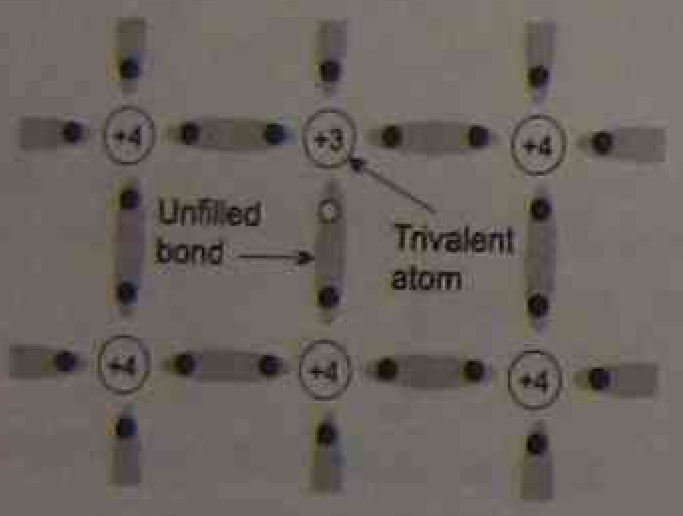

Figure 3. 26 Doped *p*-type semiconductor

The *trivalent* atom is called an *acceptor* atom because it accepts an electron.

Silicon with Group III impurity atoms is called a *p-type* semiconductor (because conduction occurs via *positive* holes) as well as by the intrinsic conduction discussed previously.

> *In* **p-type** *material, positive holes constitute the majority carriers and electrons (from normal electron-hole pair formation) are minority carriers.*

n-type Semiconductor

When a Group V atom replaces an atom of either silicon or germanium (Figure 3.27), only four of the available five electrons are used to form covalent bonds—the remaining electron is available for conduction.

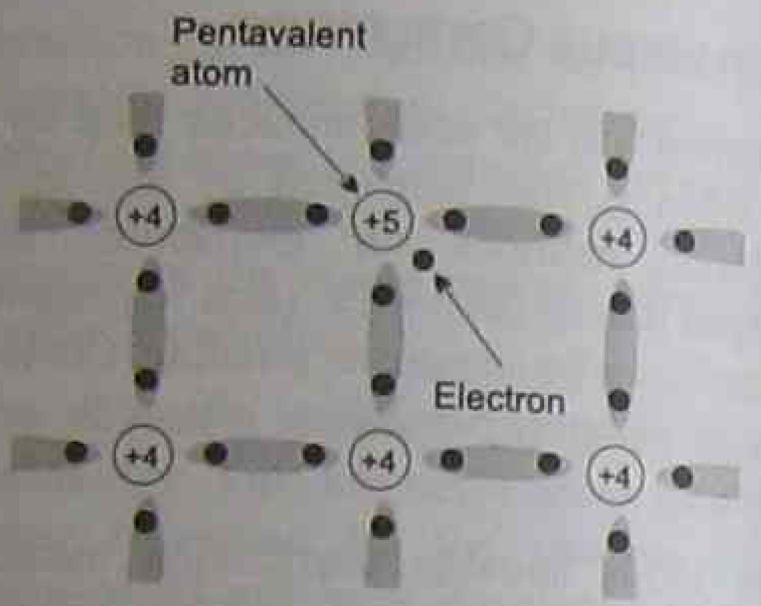

Figure 3. 27 *n*-type semiconductor

The *pentavalent* atom is a *donor* atom because it donates an electron.

Silicon with Group V impurity atoms is called an *n-type* semiconductor (because conduction occurs via *n*egative electrons).

> *In* **n-type** *material, negative electrons constitute the majority carriers and holes (from normal electron-hole pair formation) are minority carriers.*

Extrinsic conduction

> *Conduction in doped semiconductors is called* **extrinsic semiconduction** *(as opposed to intrinsic semiconduction in pure semiconductors)*

THERMIONIC DEVICES

> **Thermionic emission** *is the spontaneous emission of electrons from solids (and liquids) when heated to high temperatures.*

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[14] Consider this analogy to help understand the movement of holes. Imagine a series of rows of seats at a movie theatre. Suppose that there is one vacant seat in the front row and all other rows are full. If a person in the second row 'jumps' into the vacant seat in the front row, a vacancy is created in the second row. This vacancy represents a 'hole'. Movement of the person (the electron) one-way results in the movement of the empty seat (the hole), the other way.

Thermionic emission is utilised in thermionic devices such as valves. Thermionic valves consist of an *evacuated* tube (hence the alternative name of vacuum tubes) with a cathode (the electron emitting electrode) and at least one other electrode. (A diode has a total of two electrodes; a triode has three electrodes; and a pentode has five electrodes. Diodes were used as *rectifiers* and triodes and pentodes as *amplifiers*.)

Thermionic valves were once used extensively in electronics. They have subsequently been superseded by solid state devices, because:

1 Physically, thermionic devices are much bigger than solid state devices. This limits the minimum size of any electronic device. (Miniaturisation has been essential in the progress of electronics.)

2 Thermionic valves consume a lot more electrical energy than solid state devices and produce much more heat.

3 Valves cannot operate as fast as solid state devices.

4 Valves require a 'start up' time to become operational; semiconductor devices do not.

Secondary Source Investigation

Solar Cells (Photovoltaic Cells) and the Photoelectric Effect[15]

Photons falling onto a piece of doped silicon may provide electrons with sufficient energy to jump the *forbidden energy gap* and become free. The electron leaves a *hole* behind and so an *electron-hole pair* is created. By joining *p*-type and *n*-type silicon in a *p-n* junction, electrical energy can be produced as follows:

1 In the *n*-type region there are many electrons (but the silicon is neutral); in the *p*-type there are relatively few electrons (but the silicon is still neutral) as in Figure 3.28(a). Consequently when the two pieces are joined electrons from the *n*-type diffuse into the *p*-type (and recombine with holes near the boundary) leaving *positive ions* behind. Similarly holes form the *p*-type silicon diffuse into the *n*-type (where they recombine with electrons near the boundary) leaving *negative ions* behind (Figure 3.28(b).

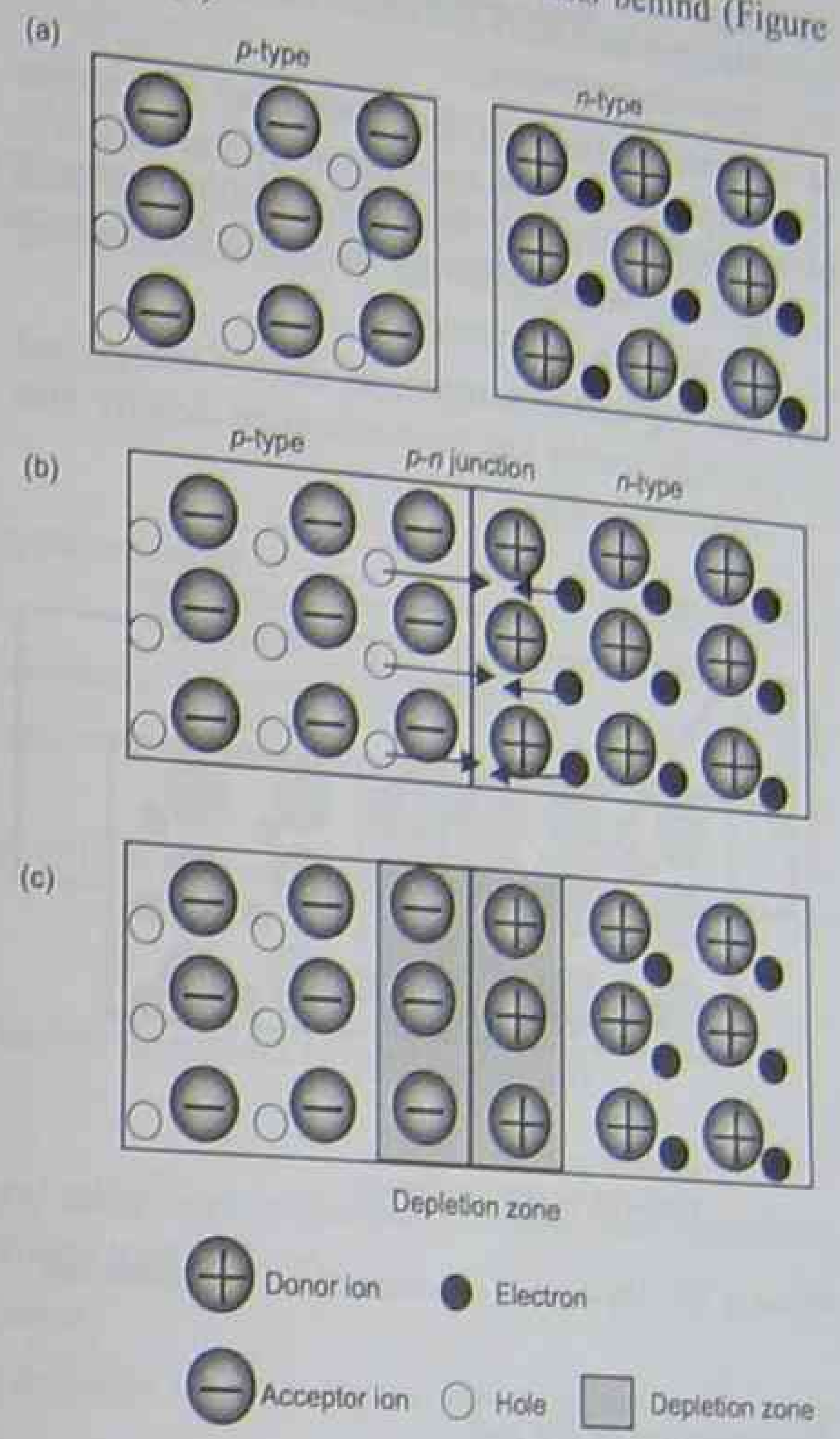

Figure 3. 28 Operation of a *p-n* junction

2 This diffusion of carriers results in a *depletion zone* near the boundary (depleted of free majority carriers) as in Figure 3.28(c). The silicon is now electrically charged; the *p*-type is negative and the *n*-type is positive. As a result, an electric field is set up that creates a *potential barrier* opposing further diffusion. Under the effect of this field, minority carriers (electrons in *p*-type and holes in *n*-type) drift across the boundary. At equilibrium, the drift of minority carriers in the opposite direction balances the diffusion of majority carriers across the boundary. This barrier will also act to move any electrons *created* in the silicon *into* the *n*-type and any holes *into* the *p-type*.

3 When exposed to light, *photo-ionisation* creates electron-hole pairs. The potential barrier causes separation of these pairs (electrons are attracted

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[15] http://www.howstuffworks.com/solar-cell.htm and http://acre.murdoch.edu.au/ago/pv/pv.html are two useful sites for explaining the workings of solar cells and other photovoltaic devices.

into the positive *n*-type material), setting up an *emf* in the process (Figure 3.29). This *emf* is dependent on the rate of creation of these electron-hole pairs and hence the intensity of the incoming radiation.

4 Metal contacts on the surface of the *n*-type silicon conduct the electrons away and if there is a complete circuit they pass through the load and move back to the *p*-type silicon doing useful work in the process.

5 The *emf* acts as a source of electric energy and so light energy has been converted directly into electrical energy.

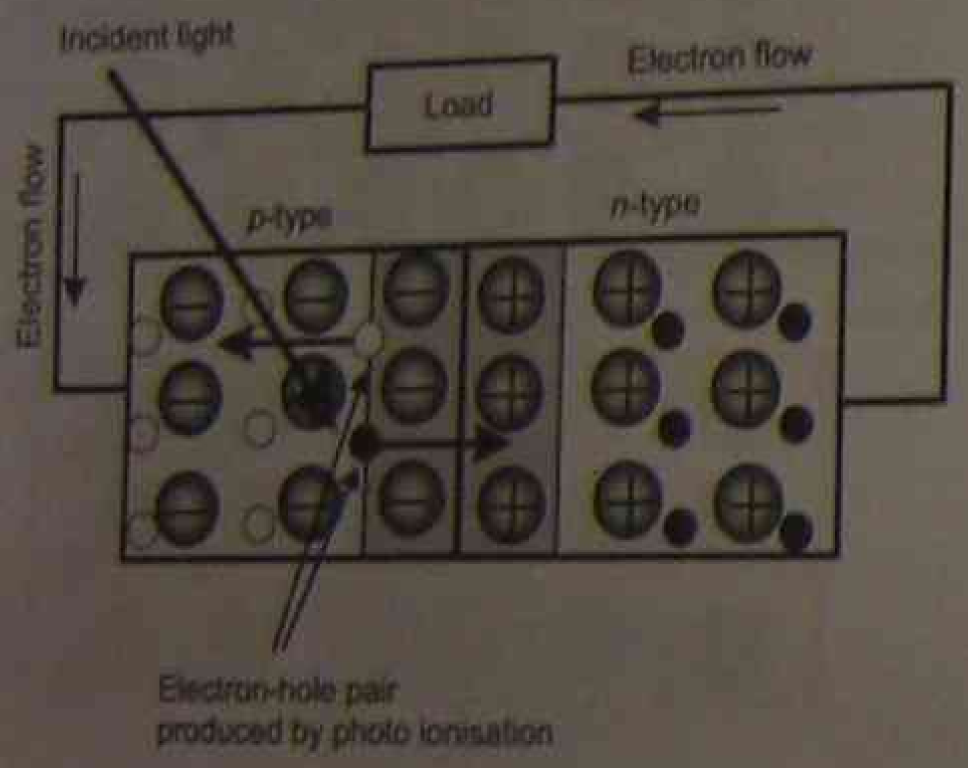
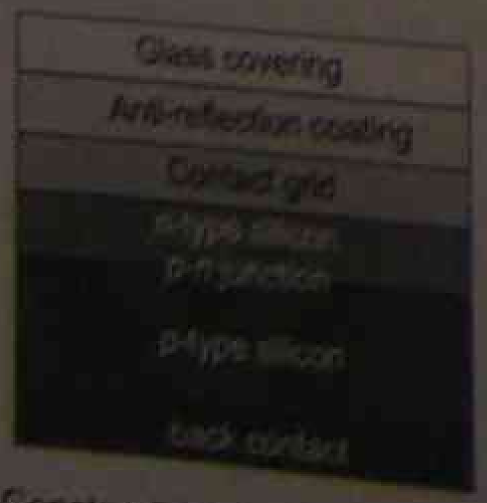


Figure 3. 29 Principle of operation of a photovoltaic cell

Construction of PV cell

Figure 3.30 illustrates the basic construction of a photovoltaic cell. The glass covering protects the semiconductor material; the anti-reflection layer maximises the amount of light that penetrates the cell; the contact grid collects the photoelectrons; the n and *p* type material form the *p-n* junction and the back contact provides a pathway back for the electrons.



igure 3. 30 Construction of a PV cell

Secondary Source Investigation

The Impact of the Invention of Transistors on Society

One way to assess the impact of transistors on our society is to think back to the doomsday predictions associated with the Y2K 'bug' at the turn of the century (2000). Many people throughout the world predicted the end of civilization as we know it as a result of assumed 'date problems' with the world's computers. Computers, of course use thousands of transistors in so-called *integrated circuits*.

Three scientists working in the Bell laboratories in America, John Bardeen, Walter H. Brattain and William B. Shockley invented the transistor in 1947. (They were searching for a replacement for vacuum tubes whose technology was seriously limiting long-distance telephone calls.)

By 1960 transistors began to rapidly replace vacuum tubes in electronics. The development of integrated circuits—a single silicon chip with initially dozens and currently millions of transistors—paved the way for an 'explosion' of electronic devices.

By 1971 the first *microprocessor* appeared. Microprocessors contain the three essential elements of a computer's central processing unit (CPU)—an *arithmetic* circuit, a *logic* circuit and a control circuit. This invention set the stage for 'computers' to be used in a whole range of electronic devices.

As a result, our world has changed dramatically. Just think of some of the devices that use microprocessors: radios, TVs, mobile phones, computers, scanners, video recorders, digital cameras, calculators, digital clocks… the list is endless. Microprocessors are also found in cars, in ships and planes, in 'smart bombs', in guidance systems, in satellites… Truly, our world would be a vastly different place without the invention of transistors.

SECTION 4: SUPERCONDUCTIVITY

BIG IDEA:

Investigations into the electrical properties of particular metals at different temperatures led to the identification of superconductivity and the exploration of possible applications.

OUTCOMES:

Students learn to:

1 Outline the methods used by the Braggs to determine crystal structure.
2 Identify that metals possess a crystal lattice structure.
3 Describe conduction in metals as a free movement of electrons unimpeded by the lattice.
4 Identify that resistance in metals is increased by the presence of impurities and scattering of electrons by lattice vibrations.
5 Describe the occurrence in superconductors, below their critical temperature, of a population of electron pairs unaffected by electrical resistance.
6 Discuss the BCS theory.
7 Discuss the advantages of using superconductors and identify limitations to their use.

Students:

1 Process information to identify some of the metals, metal alloys and compounds that have been identified as exhibiting the property of superconductivity and their critical temperatures.
2 *Perform an investigation to demonstrate magnetic levitation.*
3 *Analyse information to explain why a magnet is able to hover above a superconducting material that has reached the temperature at which it is superconducting.*
4 *Gather and process information to describe how superconductors and the effects of magnetic fields have been applied to develop a Maglev train.*
5 *Process information to discuss possible applications of superconductivity and the effects of those applications on computers, generators and motors and transmission of electricity through power grids.*

X-RAY DIFFRACTION

We are all familiar with the coloured patterns seen on the bottom of a compact disk when light reflects off it. The CD acts as a *diffraction grating*. Light reflects off the surface causing interference (see *Superposition* in the Preliminary Course Topic *The World Communicates*). Depending on the angle of incidence, the interference can be constructive or destructive. In constructive interference two or more waves interact to produce maximum amplitude; in destructive interference two or more waves interact to produce minimum amplitude.

Diffraction is a wave characteristic (for details refer to p. 232). If a phenomenon shows diffraction, then it is wave-like. In addition, diffraction is only obvious when the wavelength is comparable to the spacings of the 'lines' making up the grating.

In 1895 Wilhelm Conrad Röntgen discovered X-rays. It was believed that they were waves but it was not until 1913 that X-ray wavelengths were measured to any degree of precision. Experiments indicated that the wavelength was of the order of 10^{-10} m, which is about the interatomic spacing in solids. In 1913, the German physicist Max von Laue hypothesised that if the atoms in a crystal were arranged in a regular manner they might act as a three-dimensional diffraction grating for X-rays.

Freidrich and Knipping conducted the experiment (Figure 3.31) and found *diffraction patterns* from the crystal. In doing so they succeeded in proving not only the wave nature of X-rays but also the regular arrangement of atoms in crystals!

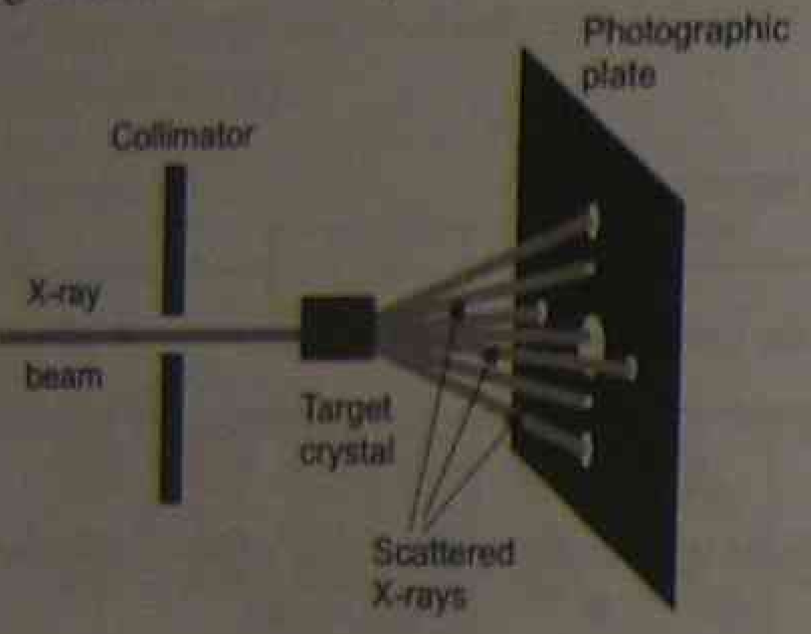


Figure 3. 31 Schematic of X-ray diffraction

Bragg Diffraction[16]

The British physicist Sir William Bragg[17] (1862-1942) and his son Lawrence (1890-1971) applied X-ray diffraction to the study of crystals—*X-ray crystallography*—and were subsequently made joint winners of the 1915 Nobel Prize for physics.

They proposed that the short wavelength X-rays could penetrate and reflect[18] from the atomic planes. In some directions, constructive interference would occur; in others, destructive interference occurs.

William and Lawrence Bragg devised a formula for diffraction: $n\lambda = 2d\sin\theta$ where n is the 'order' of the diffraction pattern, d is the interatomic spa and θ is the angle of reflection (Figure 3.32).

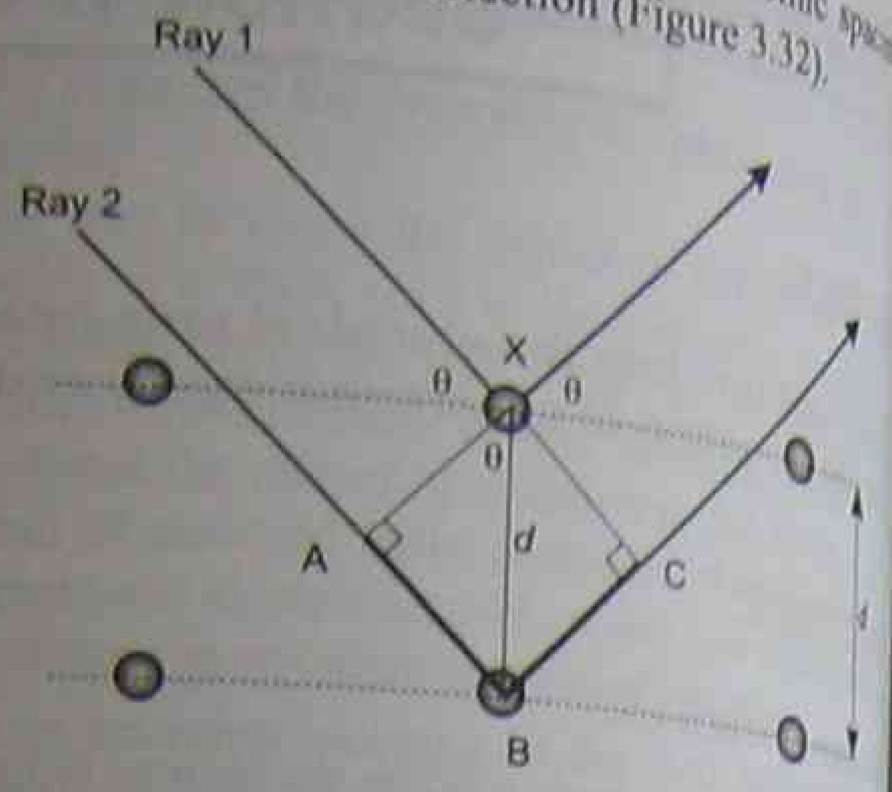


Figure 3. 32 Bragg diffraction

Extension

Consider Figure 3.32. Rays 1 and 2 represent X-ray falling at an angle θ on the surface of a crystal. Fo convenience we will consider two rows only o atoms (or ions). The two rays are initially in pha Ray 1 reflects (scatters) off an atom in the top laye Ray 2 is scattered by atom B in the next layer. It i obvious that ray 2 travels a longer distance than ra 1. This distance is $AB + BC = 2AB$. Simple trigonometry shows that this is equal to $2d\sin\theta$.

For constructive interference to occur, this pat *difference* must equal an integral number o wavelengths, that is: $n\lambda = 2d\sin\theta$

The complexity of X-ray diffraction patterns can b understood when we realise that there are man planes of atoms (ions) that the X-rays can diffract as shown in Figure 3.33.

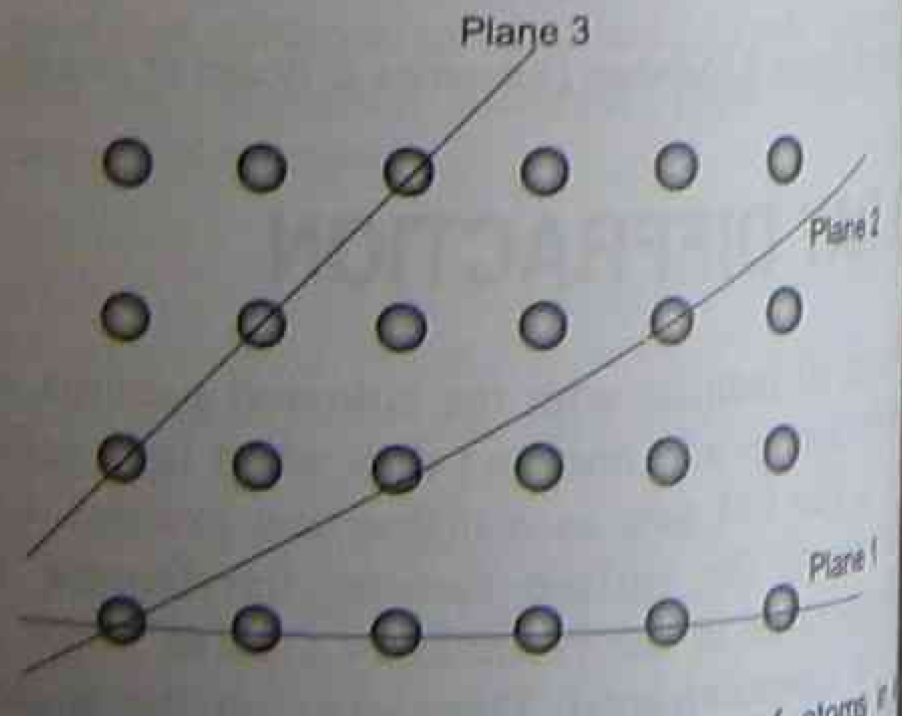


Figure 3. 33 Three of the many planes of atoms i crystal that lead to the complex diffra patterns obtained

From the Bragg formula it is possible to determine the wavelength or the interatomic spacing (depending on what is known).

X-ray diffraction is an extremely important tool used in research of matter and its structure. It was responsible for the discovery of the *double helix* structure of DNA—the molecule of life.

CRYSTALS

Crystals *are composed of an orderly three-dimensional arrangement of atoms. In each type of crystal structure a certain fundamental grouping of atoms is repeated indefinitely in three dimensions—this is called a* **unit cell**.

There are several types of crystals:

1 molecular crystals; and
2 infinite arrays.

Infinite arrays include:

1 metallic crystals;
2 ionic crystals;
3 continuous covalent crystals.

METALS

From your earlier studies you may be aware that in general, metals have only one, two or three electrons in their outer energy shells. These electrons are only loosely bound to the positive ions.

The *electron sea model* of a metal can be pictured as consisting of a lattice of positive ions surrounded by a 'sea' of electrons that are free to move under the influence of an electric field (Figure 3.34).

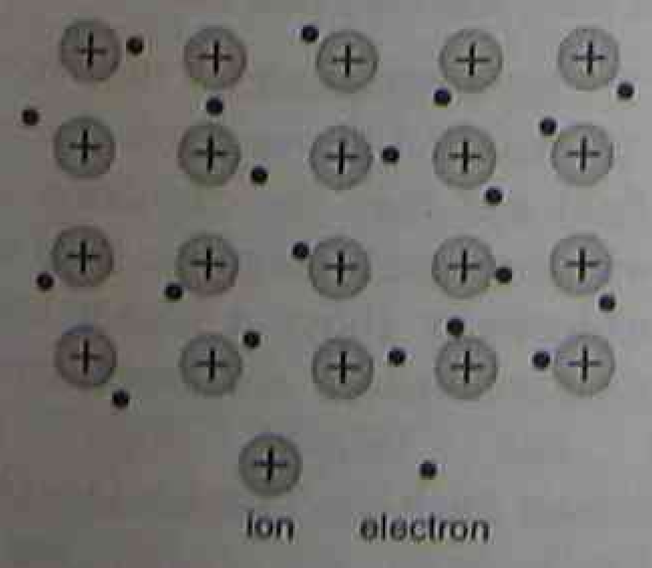


Figure 3. 34 'Electron sea' model of a metal

Drift Velocity

Consider the case of a metal conductor. The electrons in the wire's *electron sea* move randomly at enormous speeds ~10^6 m.s^{-1}, colliding with each other, and with 'impurity' atoms and imperfections of the lattice. In doing so they lose energy which is converted into heat. After a collision, the electrons again accelerate and then decelerate at the next collision. Because of their random motion, there is no net movement of charge. No electric current exists unless the conductor (wire) is connected to a source of potential difference ('voltage').

When connected to a source such as a battery, an *electric field* is set up in the wire. This field exerts a force on the electrons ($F = qE$) which results in a net *drift* of electrons towards the positive (high 'potential') terminal as indicated in Figure 3.35.

The *drift velocity* is proportional to the applied electric field. This velocity is small, ~10^{-4} m.s^{-1} compared to the speed attained by the electrons between collisions.

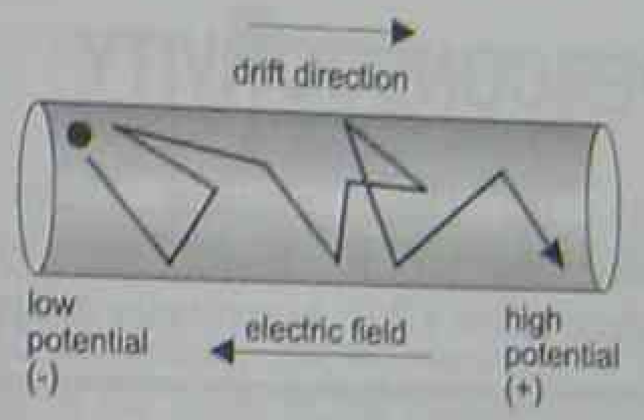


Figure 3.35 The drift of electrons under the influence of an electric field

Although the drift velocity is small, the speed at which the *influence* of the current moves is close to the speed of light (which is the fastest possible speed!).

Resistance

It is as a result of the collisions of the electrons with impurity ions or imperfections that the metal offers *resistance* to the current[19]. As the temperature of the metal increases, the ions of the lattice vibrate more, increasing the probability of the conduction electrons colliding and so increasing the resistance (Figure

---

[16] http://www.journey.sunysb.edu/ProjectJava/Bragg/home.html Bragg's Law of Diffraction. You can vary the angle, the separation and the wavelength to investigate X-ray diffraction. Well worth the visit.

[17] In 1885 William Bragg became the first professor of maths and physics at Adelaide University. His son, Lawrence, was born in Adelaide in 1890. They became the only father and son to share a Nobel Prize (1915).

[18] The X-rays are actually absorbed and then re-emitted. That is, they are scattered. It can be shown that this is similar to reflection from the atoms and so we will refer to reflection in our analysis.

---

[19] The electrons don't collide with the normal ions in the lattice since the electrons 'know where they are'. It is collisions with other electrons and imperfections in the lattice that causes the resistance.

3.36(a)). (Compare this with the resistance-temperature graphs for semiconductors (Figure 3.36(b) where resistance decreases with increasing temperature.)

Since resistance increases with increasing temperature, it was reasoned that decreasing the temperature should lead to a decrease in resistance. It was as a result of research into this hypothesis that *superconductivity* was discovered.

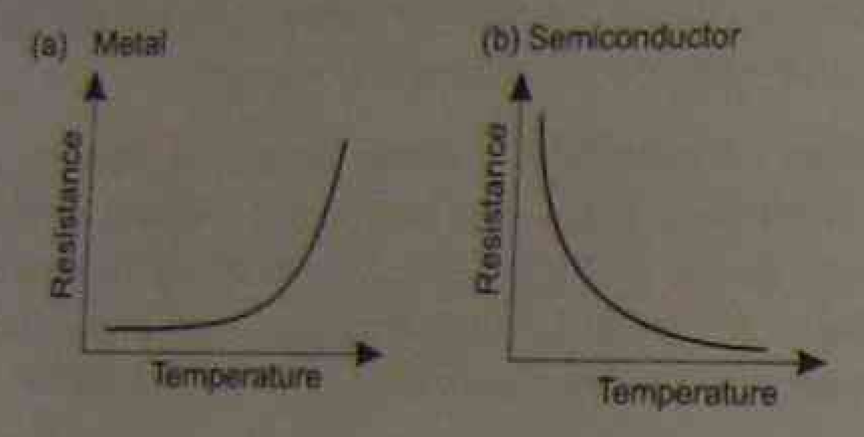


Figure 3. 36 Resistance-temperature graph for (a) metal and (b) semiconductor

SUPERCONDUCTIVITY[20]

In 1911, the Dutch physicist Heike Onnes discovered that if he cooled mercury to a temperature below 4.2 K, its resistance disappeared!

> **Superconductivity** *is the phenomenon exhibited by certain conductors where they have no resistance to current.*

The temperature of the transition from resistance to no resistance is the *critical* (or *transition*) temperature T_c (Figure 3.37).

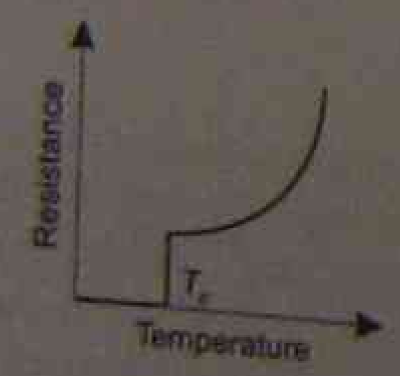


Figure 3.37 Resistance-temperature curve for a superconductor

Superconductivity is dependent on both the temperature and the intensity of the magnetic field. Prior to 1986 the highest temperature was 23.2 K in niobium-germanium compounds. Since then the transition temperature has risen to 134 K for a mercury-barium-calcium-copper oxide (see Table 3.2).

The Meissner Effect

In 1933 W. Meissner and R. Ochsenfeld discovered that a superconductor does not allow a magnetic field to penetrate its interior. (The external field induces a current to flow that produces a magnetic field inside the superconductor that just balances-out the field that would otherwise have penetrated the substance.) That is, in addition to being perfect conductors, superconductors are repelled by magnetic fields.

This exclusion of a magnetic field is called the *Meissner effect* and is a dramatic way of demonstrating superconductivity. A magnet placed above a superconductor will 'float in the air'. This magnetic levitation may be put to use one day in *Maglev* trains (see p.126).

The Meissner effect occurs for relatively small values of magnetic field. Studies showed that if the magnetic field is above a critical value, it does penetrate the metal and as a result the superconductivity is lost.

E x t e n s i o n

Type I and Type II Superconductors

Type I superconductors lose their superconductivity above a critical value of magnetic field as the field penetrates the material. They are very pure metals and include lead, mercury and tin.

In Type II superconductors, the field initially penetrates the material above a low critical value of magnetic field and then the expulsion of the field increases with increasing magnetic field until it loses its superconductivity above a higher critical value. Type II superconductors are more common than Type I and include high temperature superconductors such as $YBa_2Cu_3O_7$ (YBCO) and $Bi_2Sr_2Ca_2Cu_3O_{10}$.

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[20] http://physicsweb.org/bestof/superconductivity and http://superconductors.org/ are excellent sites relating to superconductivity.

Secondary Source Investigation

As we have seen, not only does mercury exhibit superconductivity at a temperature near absolute zero, so too lead, tin and certain alloys are also found to be superconductors at this temperature.

In 1986 Georg Bednorz and Alex Müller in Switzerland, found that certain *ceramic*[21] materials became superconductors at temperatures as high as 35 K. Soon after, other researchers around the world found a ceramic that became superconducting at 90 K. This was especially significant because it now meant that liquid nitrogen could be used as a refrigerant rather than the more expensive liquid helium. Since then an increasing number of *high temperature superconductors* have been identified. Some of these, along with other materials, are shown in Table 3.2 along with their corresponding transition temperature.

Table 3. 2 Superconductors and their transition temperature

Compound	**Transition temperature (K)**
$SnSe_2(Co(C_5H_5)_2)_{0.33}$	6.1
$PbMo_6S_8$	12.6
Cs_3C_{60}	19.3
Nb_3Ge	23
$Nd_{1.85}Ce_{0.15}CuO_4$	24
$Ba_{0.6}K_{0.4}BiO_3$	30
$La_{1.85}Sr_{0.15}CuO_4$	40
$YBa_2Cu_3O_7$	92
$Bi_2Sr_2Ca_2Cu_3O_{10}$	110
$Tl_2Ba_2Ca_2Cu_3O_{10}$	127
$HgBa_2Ca_2Cu_3O_{8+x}$	134

THE BCS THEORY OF SUPERCONDUCTIVITY

In 1957 three American physicists, John Bardeen, Leon Cooper and J. Robert Schrieffer developed a model—the BCS model (named from the first letter of their surnames)—to explain how superconductivity works. It is essentially a quantum mechanical phenomenon and hence is difficult to explain simply but it goes roughly like this:

Consider Figure 3.38.

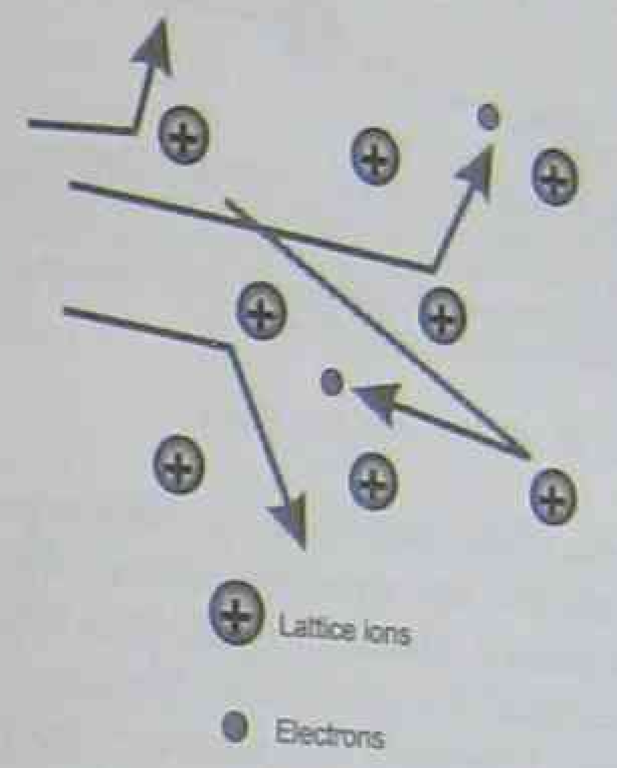


Figure 3. 38 Electrons colliding with impurity atoms

As stated previously, the resistance of a metallic conductor is the result of the collisions of the free electrons with impurity atoms or imperfections in the crystal lattice. In a superconductor, however, the electrons behave differently. They pass unimpeded through the lattice. Since they don't interact with the lattice atoms, they do not lose energy—the resistance is effectively zero.

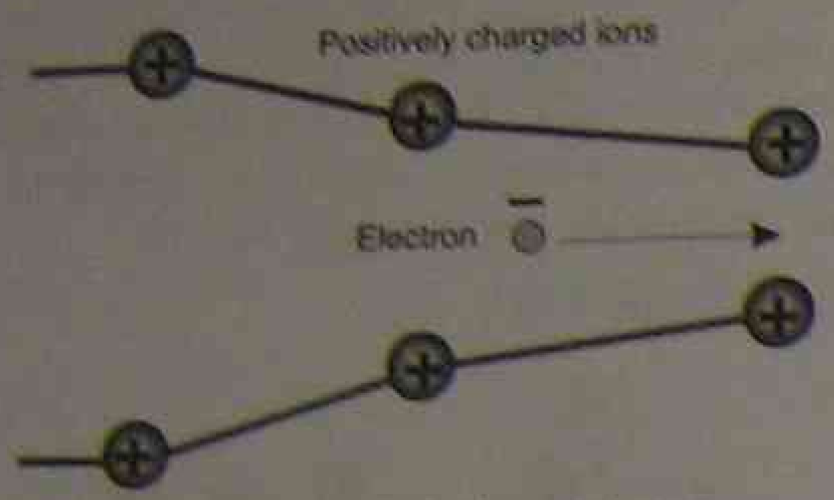
It might be thought that simply lowering the temperature would reduce the lattice vibrations and so reduce the resistance. This does happen to a degree, but it is not the explanation for superconductivity. In fact, according to the BCS theory, the vibration of the lattice is what causes the superconductivity! *Phonons*—packets of sound energy present in the vibrating lattice—mediate the process as follows.

Consider Figure 3.39 which shows an electron passing through the lattice. As it moves, it causes the lattice to distort. As a result of this distortion phonons are emitted, forming a 'trough' of increased *positive charge density* around the electron. Before

---

[21] These ceramics contain: rare-Earth elements such as lanthanum and yttrium; the alkaline-Earth elements bismuth or thallium; the elements barium or strontium as well as copper and oxygen.

the electron can pass the ion and before the lattice rebounds to its normal position a second electron is attracted to the first and pairs up (despite the fact that like charges repel). This pair of electrons—called a *Cooper pair*—passes easily through the lattice (Figure 3.40).



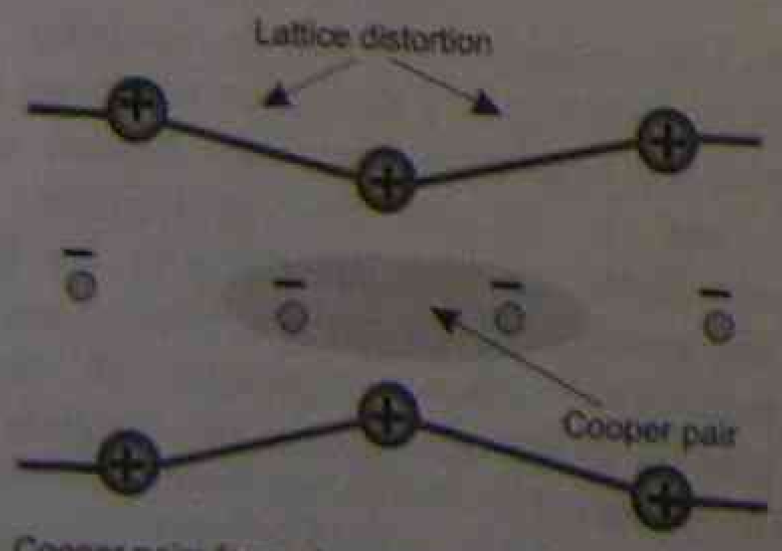
The passage of the negatively charged electron between the positively charged lattice ions causes the ions to move inwards, distorting the lattice. The resulting increase in positive charge concentration attracts another electron to the area.

Figure 3. 39 Distortion of the lattice

When one of the electrons of the Cooper pair passes near a positive ion, attraction between the opposite charges cause a vibration to pass from lattice ion to lattice ion until it is absorbed by the second electron of the pair. Effectively one electron of the pair emits a phonon and the other member absorbs it—it is this exchange of phonons that keeps the Cooper pairs together.

Cooper pairs are continually being formed, broken and reformed but essentially electrons 'pair up'.

The pairing of electrons in this way is favoured because it results in a lower energy state (need quantum mechanics to understand why).



Cooper pairs form when two electrons become 'locked together' and travel through the lattice.

Figure 3. 40 Formation of a Cooper pair

As the temperature rises, the lattice vibrations increase and break apart the Cooper pairs causing the superconductivity to diminish. It is for this reason that metals need to be cooled to temperatures only a few degrees above absolute zero for superconductivity to occur.

USES OF SUPERCONDUCTORS

Magnetic Resonance Imaging

Because they can carry large electric currents without heat losses, superconductors can be used to generate large magnetic fields. Such fields are used in a variety of devices including magnetic resonance imaging (MRI) machines. MRI machines are used to provide doctors with three-dimensional images of the internal structure of the human body.

Electronic Switches

Superconducting switching devices are being tested for use in high-speed computers since they can operate at speeds up to ten times the speed of an equivalent semiconductor switch.

Electricity Transmission

Energy losses in electricity transmission occur because of resistance of the wires. If this can be eliminated, enormous amounts of energy would be saved. In addition, power plants, with their environmental problems such as greenhouse gas emission, could be built well away from centres of population.

Magnetic Levitation

As mentioned previously, the *Meissner effect* means that a magnet will float above a superconductor. Plans are in place for trains to be magnetically levitated above the tracks. The reduced friction will enable very high speeds to be obtained (see opposite).

SQUID

When two superconducting materials are separated by a very thin layer of insulator, current flows as Cooper pairs across the insulator—this is the *Josephson effect*. A SQUID (**S**uperconducting **QU**antum **I**nterference **D**evice) is an extremely sensitive device that relies on this effect to detect tiny magnetic fields. For example, SQUIDs are extensively used in geophysics to measure oscillations in the Earth's magnetic field. They are also used to make magnetograms of the human brain as they can measure the magnetic fields associated with the tiny currents that flow.

LIMITATIONS OF SUPERCONDUCTORS

The original superconductors operated at temperatures only a few degrees above absolute zero. This is still the case for metals. Over the years though, *high temperature superconductors* have been produced, some operating at temperatures as high as 134 K (see Table 3.2). This means that liquid nitrogen can be used to cool them. This is much cheaper and more efficient at cooling than is liquid helium which is required for metals. These superconductors, however, are ceramic and have several limitations including:

1 they are brittle;
2 they are difficult to manufacture;
3 it is difficult to make them into wires (for electricity transmission);
4 they are chemically unstable in some environments.

Secondary Source Investigation

The Maglev Train

One of the major proposed applications of superconductivity is in the *Superconducting Magnetically* **Levitated** *Vehicle (Maglev)*. This is an extremely high speed transport system that utilises magnets and linear electric motor technology. Its advantages include very high speed, reliability, safety, minimum maintenance and low environmental impact.

Magnetic levitation can be achieved in two ways:

1 In Germany levitation results from attraction. Devices on the sides of the train wrap around the *guideway*. Electromagnets energised in the 'skirts' are attracted up to iron rails on the guideway's edges and lift the train.
2 In Japan, levitation is achieved as a result of repulsion. Helium-cooled superconducting magnets on the vehicle interact with coils in the guideway in such a way that repulsion between 'like poles' causes the train to lift off the guideway.

Both systems use a 'magnetic wave' travelling along the track to propel the suspended vehicle.

Research and development began in Japan in 1970. By 1987 a manned two-car vehicle sped along a specially constructed 7 km test track at a speed of 400 $km.h^{-1}$!

In 1990, construction of the *Yamanachi Maglev Test Line* commenced and was opened on 3 April 1997. On 12 December of that year a manned three-car vehicle reached a speed of 531 $km.h^{-1}$. On 14 April 1999 a five-car vehicle reached 552 $km.h^{-1}$ in a manned run.

SUMMARY:

- Cathode ray tubes allow the manipulation of charged particles by electric and magnetic fields.
- The nature of cathode rays—wave or particle—was long debated.
- A uniform electric field exists between two parallel plates: $E = \frac{V}{d}$
- A charge moving in a magnetic field experiences a force given by: $F = qvB\sin\theta$
- In 1897, Thomson measured the q/m ratio for cathode rays.
- A cathode ray tube (CRT) has an electron gun, a deflecting system and a fluorescent screen.
- CRTs are used in oscilloscopes, electron microscopes and TVs.
- Hertz discovered the photoelectric effect while investigating the generation of electromagnetic (radio) wave
- Electromagnetic waves are produced by charges oscillating in conductors (for example, radio antennae).
- Planck proposed that emission and absorption of radiation for a black body is quantised.
- Einstein explained the photoelectric effect and showed the particle nature of light.
- Conductors, semiconductors and insulators differ in their band structure.
- Holes represent the absence of electrons.
- Electric current is carried by both holes and electrons.
- Doping a semiconductor alters its electrical properties.
- In *p*-type semiconductors, holes are the majority carriers and electrons are the minority carriers.
- In *n*-type semiconductors, electrons are the majority carriers and holes are the minority carriers.
- Silicon is the preferred semiconductor material.
- Solid-state devices have all but replaced thermionic devices.
- X-ray diffraction was used by the Braggs to investigate the internal structure of crystals.
- Conduction in metals results from the drift of a large number of electrons through the lattice.
- Drift velocity depends on the density of electrons, the cross-sectional area and the charge.
- Heat is generated as the lattice impedes the electrons.
- Superconductors allow electrons to flow unimpeded.
- The BCS model of superconductivity is a quantum-mechanical effect where two electrons pair up and unimpeded by the lattice.

Key Terms:

band structure
Bragg
cathode ray
cathode ray tube
conduction
Cooper pair
critical frequency
crystal lattice
drift velocity
electric field
electron diffraction
electron gun
electron microscope
Einstein
fluorescent screen
Hertz
holes
Maglev
Maltese cross
n-type
photoelectric effect
photon
Planck's constant
p-type
q/*m* ratio
quantum
semiconductor
silicon
solid-state devices
striations
superconductor
thermionic devices
Thomson
threshold frequency
work function
X-ray diffraction

QUESTIONS AND PROBLEMS ON *FROM IDEAS TO IMPLEMENTATION*

SECTION 1: CATHODE RAYS

1 Define the following terms:
  (a) discharge tube
  (b) anode
  (c) cathode
  (d) cathode rays
  (e) striations.

2 Describe what happens inside a discharge tube when it is connected to a high voltage and the pressure is reduced.

3 What evidence suggested that cathode rays were:
  (a) waves?
  (b) particles?

4 An electric field exists between two parallel plates connected to a potential difference.
  (a) Draw the field between the plates.
  (b) Calculate the size of the field if the plates are separated by 1 mm and have 10,000 V across them.

5 A proton ($q = 1.6 \times 10^{-19}$ C) travelling at 2.5×10^{6} m.s^{-1} enters a magnetic field of 0.20 T. Calculate the force acting on the charge if it enters the field:
  (a) at 0° (that is parallel to the field).
  (b) at 45° to the field.
  (c) at 90° to the field.

6 Explain why a charge entering a magnetic field at 90°, travels in the arc of a circle.

7 Briefly describe how Thomson measured the *q*/*m* ratio for cathode rays.

8 What is the role of the following in a cathode ray tube (CRT):
  (a) electron gun?
  (b) deflecting plates/coils?
  (c) fluorescent screen?

9 Briefly describe the operation of a cathode ray oscilloscope.

SECTION 2: QUANTUM THEORY

1 Describe Hertz's experiment on the production and detection of electromagnetic waves.

2 What was the effect of ultraviolet light on the experiment?

3 What is the photoelectric effect?

4 What was Planck's hypothesis?

5 Explain how Einstein's use of the photon allowed an explanation of the photoelectric effect.

6 A photon of blue light has a wavelength of 450 nm. Calculate the:

(a) photon's energy

(b) photon's momentum.

(The speed of light $c = 3 \times 10^8$ m.s^{-1} and Planck's constant $h = 6.6 \times 10^{-34}$ J.s)

7 Give three uses of the photoelectric effect.

SECTION 3: SOLID STATE DEVICES

1 Define the following terms:

(a) conductor

(b) semiconductor

(c) insulator

(d) energy band

(e) valence band

(f) conduction band

(g) forbidden energy band

(h) hole

(i) doping.

2 What is the main difference in terms of charge carriers between *n*-type and *p*-type semiconductor material?

3 Compare thermionic devices with solid-state devices.

SECTION 4: SUPERCONDUCTIVITY

1 Define the following terms:

(a) crystal lattice

(b) Bragg diffraction

(c) drift velocity.

2 What is the cause of resistance in a metal conductor?

3 What is superconductivity?

4 Briefly describe the BCS theory of superconductivity.

5 List three current or potential uses of superconductors.

TEST ON FROM IDEAS TO IMPLEMENTATION

MULTIPLE CHOICE QUESTIONS

Choose the letter A, B, C or D that correspond the best answer.

1 Which of the following properties of cathode r is *incorrect*? Cathode rays:

(A) come from the cathode of a discharge tub

(B) have a *q/m* ratio less than that of the hydrogen ion

(C) cause glass to fluoresce

(D) carry energy and momentum.

2 J. J. Thomson succeeded in discovering the of a cathode rays:

(A) charge

(B) mass

(C) charge to mass ratio

(D) radius.

Questions 3 and 4 refer to the following informatio

Some metals will emit electrons when bombarded with high frequency light.

3 If the frequency of the light is increased without increasing the intensity:

(A) more electrons will be emitted with unchanged speed

(B) the same number of electrons will be emitted with increased speed

(C) more electrons will be emitted with increased speed

(D) the same number of electrons will be emitted with unchanged speed

4 If the intensity is increased without increasing the frequency:

(A) more electrons will be emitted with unchanged speed

(B) the same number of electrons will be emitted with increased speed

(C) more electrons will be emitted with increased speed

(D) the same number of electrons will be emitted with unchanged speed

5 *p*-type semiconductors:

(A) have electrons as the majority charge-carriers

(B) have holes as the majority charge-carriers

(C) contain Group V donor atoms

(D) are better conductors than *n*-type semiconductors.

6 Silicon is preferred over germanium for semiconductor devices because:

(A) silicon is more abundant and hence is cheaper

(B) silicon has a higher 'leakage current' than germanium

(C) silicon is more difficult to dope than germanium

(D) silicon is harder than germanium.

7 Conduction in semiconductors is by:

(A) electrons only

(B) holes only

(C) electrons and holes

(D) depends on whether it is *p*-type or *n*-type.

8 Doping:

(A) increases the resistance of semiconductors

(B) decreases the resistance of semiconductors

(C) decreases the number of charge carriers

(D) is called intrinsic semi-conduction

9 The resistance of a metal results from:

(A) collision of electrons with other electrons only

(B) collision of holes with other holes only

(C) collision of electrons with imperfections in the crystal lattice

(D) collision of holes with imperfections in the crystal lattice.

10 Bragg diffraction:

(A) proved the particle nature of X-rays

(B) proved the wave nature of X-rays

(C) proved the regular structure of a crystal lattice

(D) both B and C above.

11 The correct statement is:

(A) in insulators, the valence band and conduction band overlap

(B) in conductors the valence band and conduction band overlap

(C) in semiconductors, the forbidden energy gap is larger than for insulators

(D) in conductors, the valence band is empty.

12 Superconductors:

(A) have zero resistance near 0 K

(B) have zero resistance near 0°C.

(C) attract magnetic fields.

(D) have resistance between that of conductors and insulators.

13 Graphs of resistance versus temperature for three materials *X*, *Y* and *Z* are shown in Figure 3.41. *X*, *Y* and *Z* are respectively:

(A) semiconductor, metal, superconductor

(B) metal, superconductor, semiconductor

(C) metal, semiconductor, superconductor

(D) superconductor, metal, semiconductor.

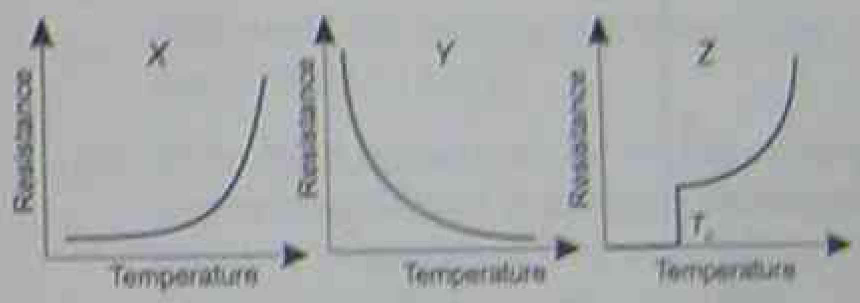


Figure 3. 41

14 As temperature decreases:

(A) the resistance of metals increases

(B) the resistance of semiconductors increases

(C) the resistance of semiconductors decreases

(D) all substances become superconductors.

15 The exclusion of a magnetic field by a superconductor is called:

(A) the photoelectric effect

(B) the Meissner effect

(C) Bragg diffraction

(D) ferromagnetism.

SHORT ANSWER QUESTIONS

In keeping with the format of the HSC sample marks are given for each question.

Answer the following questions in approximately three lines of writing, calculation or diagram.

16 List four properties of cathode rays. (2 marks)

17 In 1888 Hertz demonstrated two phenomena that were to have important implications for science. These were the transmission and reception of 'radio waves' and the photoelectric effect. Explain how observations of these two phenomena support:

(a) Maxwell's electromagnetic theory of light (2 marks) and

(b) Einstein's quantum theory. (2 marks)

18 Explain why the photoelectric effect supports the particle model of light rather than the wave theory. (3 marks)

19 It is found that when light above a certain frequency illuminates the surface of a metal, electrons are liberated from the metal. In an experiment to determine how the maximum kinetic energy of the emitted electrons varies with frequency, the graph in Figure 3.42 was obtained.

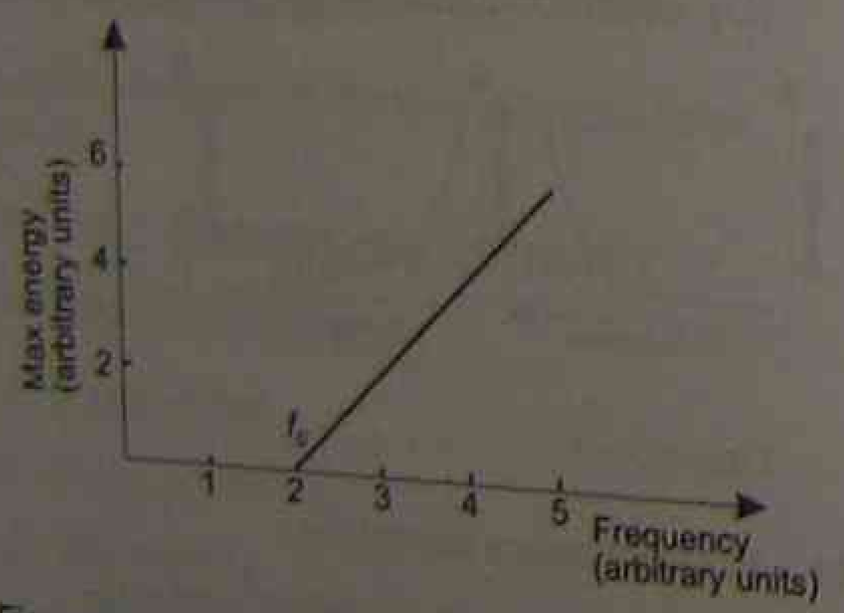


Figure 3. 42

(a) Write an equation for this line. (1 mark)

(b) Explain the significance of the frequency f_o. (1 mark)

(c) Predict the maximum kinetic energy of the emitted electrons at frequency 3 f_o. (1 mark)

20 Blue light of wavelength 450 nm (1 nm = 10^{-9} m) is incident on a metal surface whose work function is 2.4 x 10^{-19} J. Calculate the maximum kinetic energy of the resulting photoelectrons. (2 marks) (Planck's constant = 6.6 x 10^{-34} J.s and c = 3 x 10^{8} m.s^{-1}.)

21 The German physicist Heisenberg stated in 1924 that: "Light and matter are but single entities, the apparent duality of their nature in the limitations of language". Recall two experiments which show that light has:

(a) a wave nature (1 mark) and

(b) a particle nature. (1 mark)

22 A wave packet can be visualised as in Figure 3.43. In what way does this diagram illustrate the wave-particle duality of light? (2 marks)

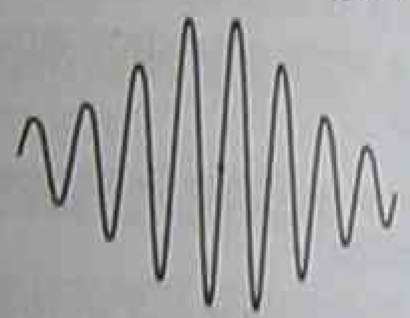


Figure 3. 43

23 Cathode ray tubes (CRTs) have three main components.

(a) Recall these components. (2 marks)

(b) Recall the purpose of each of them. (3 marks)

24 In 1900 the German physicist Max Planck hypothesised that energy is quantised.

(a) Recall the phenomenon led Planck to this conclusion. (1 mark)

(b) Explain why he made this proposal. (2 marks)

25 Describe how the photoelectric effect is used one of the following:

(a) photocell (1 mark)

(b) solar cell (1 mark)

26 Light of frequency greater than the threshold frequency of lithium is shone onto a lithium surface. If the intensity of the incident light is increased, describe the effect on:

(a) the number of photoelectrons emitted

(b) the maximum kinetic energy of the emitted photoelectrons (1 mark)

(c) If the frequency is now increased further above the threshold frequency and the intensity is unchanged, describe the effect on:

(i) the number of photoelectrons emitted (1 mark)

(ii) the maximum kinetic energy of the emitted photoelectrons. (1 mark)

27 Light of frequency 6.0 x 10^{14} Hz is incident on a metal plate causing electrons to be emitted with a maximum kinetic energy of 1.5 x 10^{-19} J.

(a) Calculate the work function of the metal surface. (1 mark)

(b) Predict the minimum frequency that will result in photoemission. (1 mark)

28 Silicon is the preferred semiconductor material in use today. Recall *three* reasons why this is the case. (2 marks)

29 Semiconductors have all but completely replaced thermionic valves in modern electronics.

(a) What are thermionic valves? (1 mark)

(b) Recall *three* reasons why semiconductors now predominate. (2 marks)

LONGER ANSWER QUESTIONS

In keeping with the format of the HSC sample marks are given for each question.

Answer the following questions in approximately five lines of writing, calculation or diagram.

30 In Figure 3.44 *X* and *Y* are two parallel horizontal metal plates separated by 10.0 mm in a vacuum. A potential difference of 100 V is maintained between the plates and the polarity is arranged such that the top plate is positive. A horizontal magnetic field of 0.04 T exists and is perpendicular to the electric field between the plates.

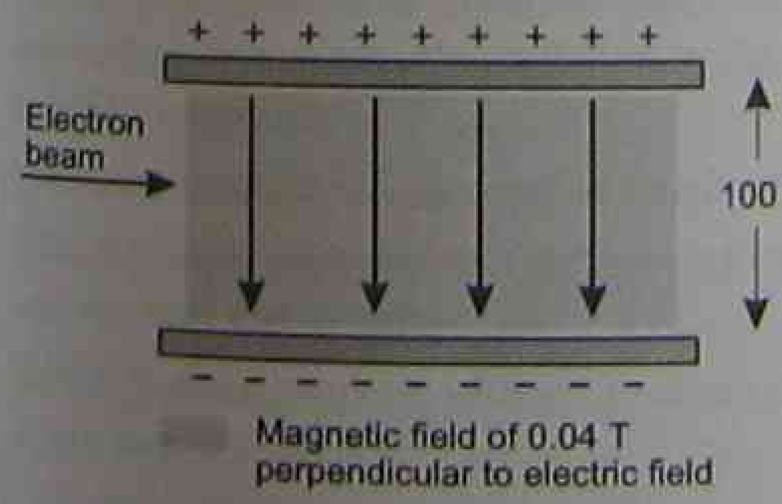


Figure 3. 44

A horizontal beam of electrons is fired between the plates so they enter the magnetic field at right angles.

(a) Calculate the size of the electric field between the plates. (1 mark)

(b) Calculate the size and direction of the electric force acting on one electron. (1 mark)

(c) In which direction should the magnetic field be directed to provide a downward force? (1 mark)

(d) Neglecting gravity, calculate the speed of an electron that will allow it to pass undeflected between the plates. (2 marks)

31 In 1897, J.J. Thomson used apparatus similar to that shown in Figure 3.45.

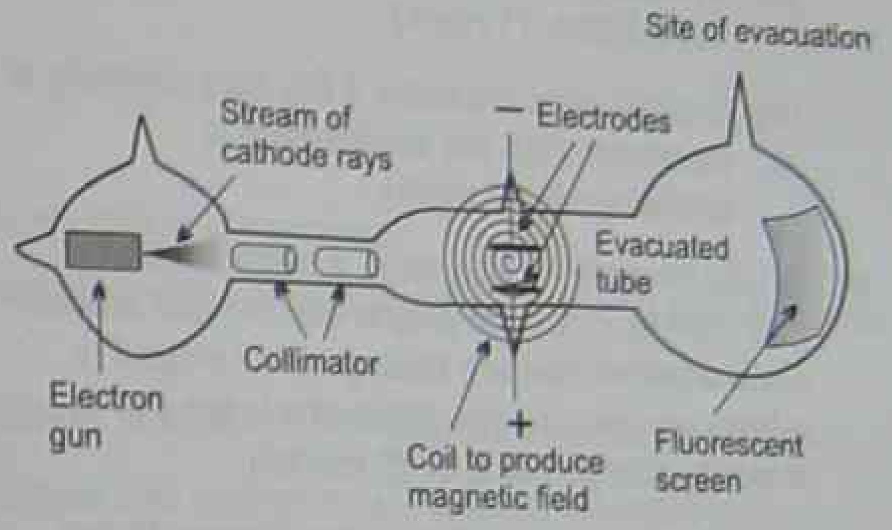


Figure 3. 45

He arranged for electric and magnetic fields to act on cathode rays as they passed through the tube.

(a) If the electric field acted alone, recall what path would the cathode rays follow in the electric field. (1 mark)

(b) Write down expressions for the force acting on the cathode rays due to both the electric field and the magnetic field. Explain the meaning of each term used. (3 marks)

(c) By making these fields the same magnitude, Thomson was able to allow the cathode rays to pass through un-deflected. From this he was able to determine the speed of the cathode ray. Explain using equations, how this was done. (2 marks)

(d) Thomson showed that cathode rays had a q/m ratio of 1.76 x 10^{11} C. kg^{-1}. Explain the significance of this. (2 marks)

32 Heinrich Hertz is an important figure in science as he was the first to generate electromagnetic waves.

(a) Briefly explain how Hertz demonstrated and explained the generation and detection of electromagnetic waves. (4 marks)

(b) Recall five characteristics of these electromagnetic waves. (2 marks)

(c) Recall what phenomenon Hertz discovered about the use of ultraviolet light in his experiments. (1 mark)

33 Light of wavelength 600 nm is shone onto a clean sodium surface. Sodium has a work function of 3.7 x 10^{-19} J.

(a) Recall what is meant by the 'work function'. (1 mark)

(b) Calculate the energy of the light photon. (1 mark)

(c) Predict what happens when light shines on the surface. (1 mark)

(d) Explain what happens if the light intensity is increased (but the wavelength is unchanged). (1 mark)

34 Briefly describe how doping a semiconductor can alter its electrical properties. In your answer state whether you are talking about *p*-type or *n*-type and ensure you state which are the majority charge carriers. (5 marks)

35 Describe the contribution of the Braggs to our understanding of the structure of matter. (4 marks)

36 Conduction in semiconductors involves both holes and electrons.

(a) Define the meaning of a hole. (1 mark)

(b) Explain how holes move. (2 marks)

37 Metals are good conductors because they have a large number of 'free' electrons. In the absence of a potential difference there is no current in the conductor. When a potential difference is applied across the ends of a metal conductor, however, the electrons drift along

(a) Describe a model of metal structure that explains the good conductivity. (2 marks)

(b) Explain why a potential difference is needed for a current. (2 marks)

(c) Explain what is meant by the term 'drift velocity'. (1 mark)

38 The phenomenon of superconductivity was discovered in 1911.

(a) Define the meaning of 'superconductivity' (1 mark)

(b) Recall the first metal to be discovered that demonstrated this phenomenon. (1 mark)

(c) Recall three current or potential uses of superconductors. (2 marks)

(d) Explain how superconductivity is used on one of the applications identified in (c) above. (3 marks)

(e) Recall two advantages and two disadvantages of currently available superconductors. (2 marks)

39 Briefly describe the BCS theory of superconductivity. (5 marks)

Chapter Four

Medical Physics

SECTION 1: ULTRASOUND

BIG IDEA:

The properties of ultrasound waves can be used as diagnostic tools.

OUTCOMES:

Students learn to:

1 Identify the differences between ultrasound and sound in normal hearing range.
2 Describe the piezoelectric effect and the effect of using an alternating potential difference with a piezoelectric crystal.
3 Define acoustic impedance $Z = \rho v$ and identify that different materials have different acoustic impedances.
4 Describe how the principles of acoustic impedance, reflection and refraction are applied to ultrasound.
5 Define the ratio of reflected intensity to initial intensity as $\frac{I_r}{I_o} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$
6 Identify that the greater the difference in acoustic impedance between two materials, the greater the reflected proportion of the incident pulse.
7 Describe the situations in which *A*- scans, *B*- scans, phase scans and sector scans would be used and the reasons for the use of each.
8 Describe the Doppler effect in sound waves and how it is used in ultrasonics to obtain flow characteristics of blood moving through the heart.
9 Outline some cardiac problems that can be detected through the use of the Doppler effect.

Students:

1 *Solve problems and analyse information to calculate the acoustic impedance of a range of materials, including bone, muscle, soft tissue, fat, blood and air, and explain the types of tissues that ultrasound can be used to examine.*
2 *Gather secondary information to observe at least two ultrasound images of body organs.*
3 *Identify data sources and gather information to observe the flow of blood through the heart from a Doppler ultrasound video image.*
4 *Identify data sources, gather, process and analyse information to describe how ultrasound is used to measure bone density.*
5 *Solve problems and analyse information using* $Z = \rho v$ *and* $\frac{I_r}{I_o} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$

CONTEXTUAL OUTLINE

In addition to its uses in communication, the electromagnetic spectrum has found many uses in diagnostic technologies. Non-invasive imaging techniques including computerised axial tomography (CAT) using X-rays, positron emission tomography (PET) and magnetic resonance imaging (MRI) provide doctors and other medical practitioners with clear diagnostic pictures. Another imaging technique (that does not rely on electromagnetic radiation) is ultrasound.

This chapter commences with the diagnostic uses of *ultrasound*. We then look at how *X-rays* and *radioactivity* are used as diagnostic tools. We conclude with a review of the use of *magnetic fields* in *medical diagnosis*.

ULTRASOUND

As we saw in the Preliminary Course *The World Communicates*, sound is a longitudinal mechanical wave, that is, it needs a medium through which it can be propagated. These waves consist of a series of compressions and rarefactions.

The normal range of hearing for humans is ~20 Hz to ~20,000 Hz.

> **Ultrasound** *is sound with frequencies greater than 20,000 Hz.*

Ultrasound, because of its high frequency has short wavelengths. As a result, ultrasound (*ultrasonic waves*) is easily reflected, producing echoes.

PRODUCING ULTRASOUND

Ultrasound can be produced by *ultrasound transducers* in a number of ways, including:

1. *Mechanical transducers*—for example whistles. (Dog whistles produce sound inaudible to the human ear but audible to dogs.)
2. *Electromechanical transducers*—these devices convert other forms of energy into ultrasonic vibrations.

Electromechanical transducers are the most common and include *piezoelectric crystals*.

Piezoelectric Crystals

When certain crystals including quartz, Rochelle and certain ceramics such as *lead zirconate* (*PZT*) are subject to mechanical deformation, a potential difference is produced between the faces the crystal. If the mechanical deformation repetitive, an oscillating potential difference created. The converse is also true.

> **Piezoelectric crystals** *convert an oscillating potential difference applied to the crystal into mechanical vibration (and a mechanical vibration into an oscillating potential difference).*

$$\text{vibrations} \xleftrightarrow{\text{piezoelectric crystal}} \text{changing PD}$$

This phenomenon is the *piezoelectric effect* (Figure 4.1).

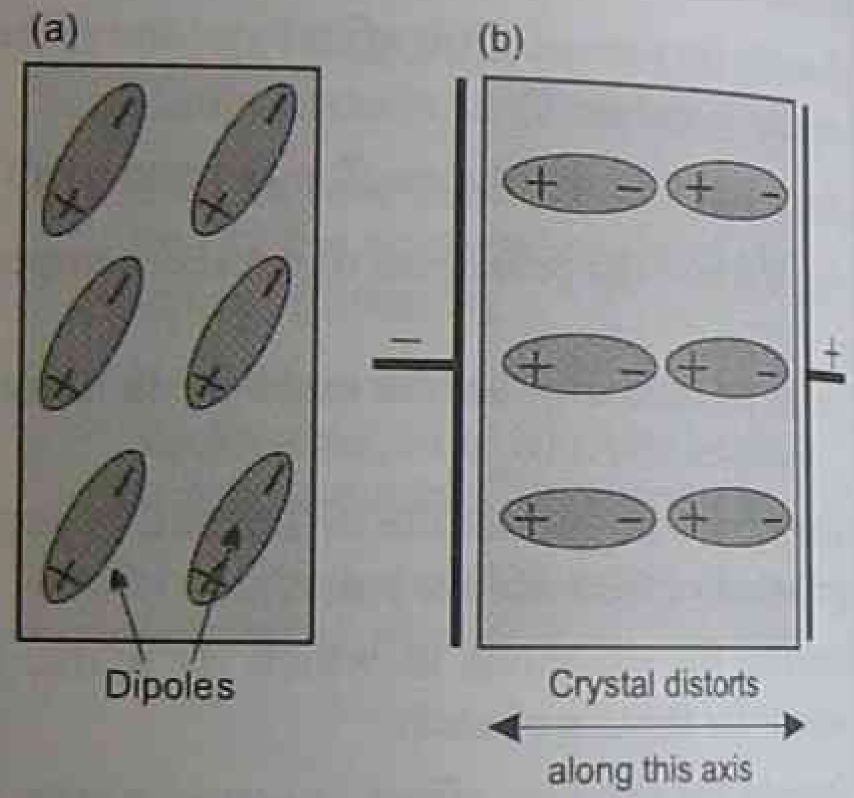


Figure 4. 1 The piezoelectric effect (a) A potential difference applied between the faces causes the dipoles to align resulting expansion of the crystal (b)

Piezoelectric crystal transducers operate over the entire range of ultrasound frequencies and at all output levels.[1]

ACOUSTIC IMPEDANCE

> *The* **acoustic impedance** *Z of a medium is a measure of how easy it is to transmit sound waves through that medium.*

---

[1] Mechanical transducers generally operate at low ultrasonic frequencies.

It is found that acoustic impedance depends on the speed of the wave in the medium and the density of the medium. Since speed and density vary between media, it follows that *different media have different acoustic impedances.*

Table 4.1 shows the velocity of sound waves in different media.

When ultrasound meets an interface between different media, the wave undergoes reflection, transmission (refraction) and absorption. The greater the 'difference' in the media, the more energy will be reflected, forming an echo.

Table 4. 1 Approximate velocity of sound in different biological media

Material	**Velocity (m.s^{-1})**
air	331
fat	1450
water (50°C)	1540
average human soft tissue	1540
brain	1541
liver	1549
kidney	1561
blood	1570
muscle	1585
lens of eye	1620
skull-bone	4080

How Can Acoustic Impedance be Calculated?

For a medium with a density ρ and a velocity of sound in the medium v, the acoustic impedance Z is given by:

$$\boxed{Z = \rho v}$$

The unit of acoustic impedance is the *pascal second per metre* (also called the *rayl* after Lord Rayleigh), that is, Pa.s.m^{-1}. This is equivalent to kg.m^{-2}.s^{-1}.

Table 4.2 lists the acoustic impedance of typical body substances.[2]

If Z_1 is the acoustic impedance in medium 1 and Z_2 is the acoustic impedance in medium 2, the ratio of the *reflected* energy (I_r) to the *original* energy (I_o) is given by:

$$\boxed{\frac{I_r}{I_o} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}}$$

(Note that it is not important which medium you consider to be medium 1 and which you consider to be medium 2.)

Table 4. 2 Typical acoustic impedance of various body substances

Material	**Acoustic impedance x 10^6 (rayls)**
air	0.0004
fat	1.38
water	1.54
brain	1.68
blood	1.61
kidney	1.62
liver	1.65
muscle	1.70
lens of eye	1.84
bone (average)	6.5
skull-bone	7.8

EXAMPLE 1

Using Tables 4.1 and 4.2, calculate the approximate density of fat.

SOLUTION

From Table 4.1, the velocity of sound in fat is ~1450 m.s^{-1}, and from Table 4.2, the acoustic impedance of fat is ~1.38 x 10^6 kg.m^{-2}.s^{-1}. Hence:

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[2] These values vary slightly with the frequency used.

$$Z = \rho v$$

$$\rho = \frac{Z}{v}$$

$$= \frac{1.38\times10^{6}}{1450}\,\text{kg.m}^{-3}$$

$$= 0.95\times10^{3}\,\text{kg.m}^{-3}$$

(The density of water is 1.0 x 10^3 kg.m^{-3}. These densities are similar because of the high water content in fat.)

EXAMPLE 2

Calculate the ratio of the reflected intensity to that of the incident intensity for:

(a) an air/water interface

(b) a water/fat interface

(c) a water/liver interface.

SOLUTION

(a) We have:

$$\frac{I_r}{I_o} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$$

$$\frac{I_r}{I_o} = \frac{\left[(0.0004 - 1.54)\times10^{6}\right]^2}{\left[(0.0004 + 1.54)\times10^{6}\right]^2}$$

$$= 0.999$$

That is, 99.9% of the incident energy is reflected at the interface.

(b) $$\frac{I_r}{I_o} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$$

$$\frac{I_r}{I_o} = \frac{\left[(1.38 - 1.54)\times10^{6}\right]^2}{\left[(1.38 + 1.54)\times10^{6}\right]^2}$$

$$= 0.003$$

(c) $$\frac{I_r}{I_o} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$$

$$\frac{I_r}{I_o} = \frac{\left[(1.65 - 1.54)\times10^{6}\right]^2}{\left[(1.65 + 1.54)\times10^{6}\right]^2}$$

$$= 0.0012$$

That is, 0.12% of the incident energy is reflected at the interface.

From these examples it can be seen that:

The greater the difference in **acoustic impedance** *between two materials, the greater will be the reflected proportion of the incident pulse.*

(This is analogous to the reflection of light. The greater the difference in refractive index, the more light will be reflected.)

ULTRASONOGRAPHY

Ultrasonography *is the use of ultrasound in medical and industrial situations.*

Medical Uses

The medical uses of ultrasound can be classified as either *active* or *passive*.

Active Uses (Therapeutic)

These uses affect certain materials. For example, ultrasound can be used to break up kidney stones and gallstones (the stones literally 'shake themselves apart'). They are also used to destroy some types of brain tumours and can be useful in treating soft-tissue injuries (by heating the surrounding tissue which stimulates circulation).

Passive Uses (Diagnostic)

This is where ultrasound is used to obtain information, for example in the diagnosis of tumours, heart disease, blood flow and to view foetuses while still in the womb (the last is probably the most common use of ultrasound).

We will now look in more detail at the diagnostic use of ultrasound.

MEDICAL DIAGNOSIS

Diagnostic ultrasound *works on the principle that different tissues and organs in the human body have different acoustic impedances and so reflect the ultrasound differently.*

The ultrasound machine produces *pulses* of ultrasound (about 1 ms apart) that can be aimed in a specific direction. These waves obey similar laws to light in regard to reflection and refraction (for example, the angle of incidence equals the angle of reflection). Just as light travelling from one medium to another undergoes partial reflection and refraction at the interface between the two media, so too does ultrasound.

A transducer is held against the skin, for example the abdomen, and a pulse is emitted. Coupling gel provides an air free contact between the skin and transducer. This is necessary because of the large difference in the acoustic impedance of air and skin which would result in most of the signal being reflected at the skin. The pulse reflects off various interfaces in the body. The transducer that produced the initial pulse also detects the reflected wave or echo (Figure 4.2(a)). (The transducer is used as a detector 99% of the time.)

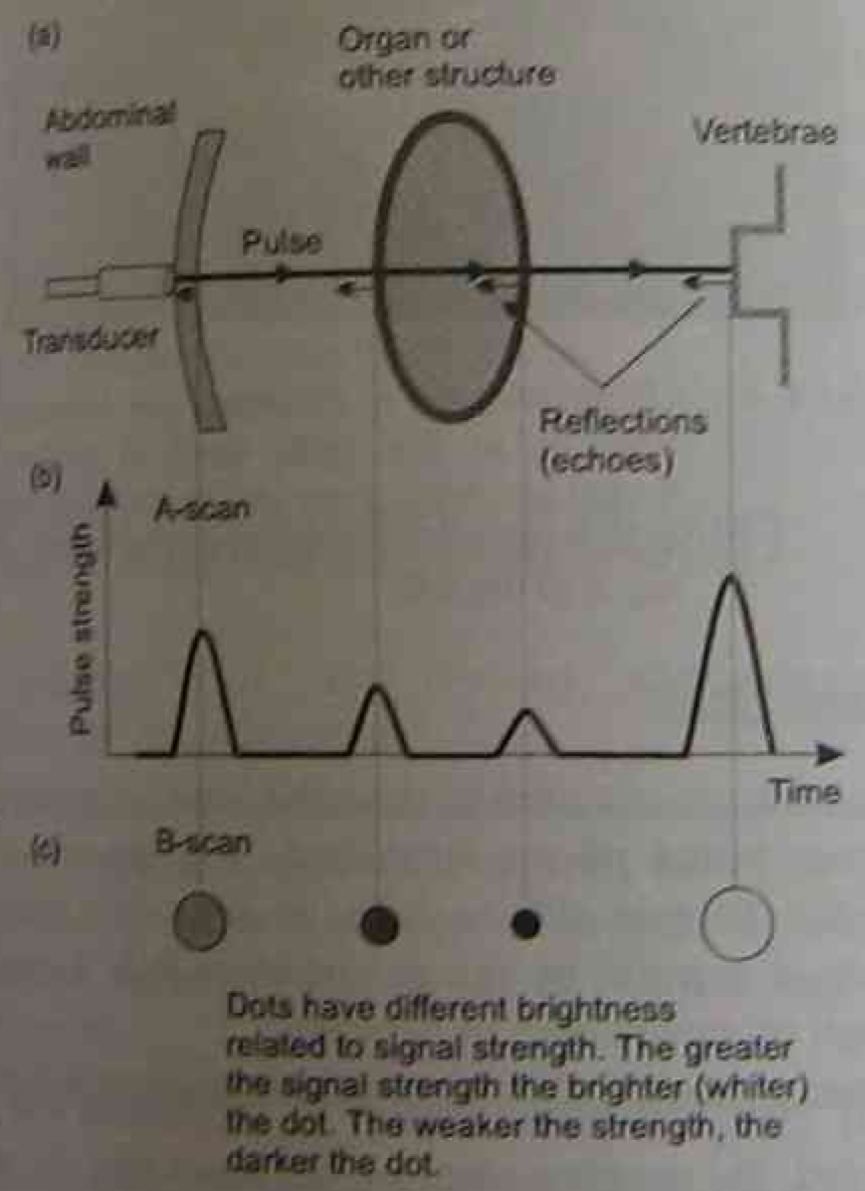

Figure 4.2 (a) Ultrasound pulses pass through abdomen and reflect off surfaces in its path (b) Reflected pulse plotted as a function of time (*A*-scan). (c) *B*-mode display for the same echoes: brightness of each dot depends on the field strength.

Sound waves travel at a characteristic speed in various media (see Table 4.1, p.141), and by measuring the time to receive an echo, the distance, size and location of different hard and soft-tissue structures can be determined in relation to the origin of the sound.

The time elapsed from when the pulse is emitted to when its echo is detected is proportional to the distance to the reflecting surface.

EXAMPLE 3

Assume the distance to the vertebrae in Figure 4.2(a) is 25 cm, how long does it take an echo to be detected?

SOLUTION

The pulse travel to and from the vertebrae and so travels 50 cm. Assuming the speed of the ultrasound is 1540 m.s^{-1} the time from emission to detection is given by:

$$s = vt$$

$$t = \frac{s}{v} = \frac{2\times0.25}{1540}\,\text{s}$$

$$= 3.2\times10^{-4}\,\text{s}$$

$$= 320\,\mu\text{s}$$

At 10 cm, an echo will be detected in 130 µs.

Computers convert the returning pulses into scans, as in Figure 4.2(b) or images as in Figure 4.2(c) depending on the scan type (see *Scan Types*). These are displayed on a cathode ray tube (TV screen) and can be recorded on videotape and/or on film.

SCAN TYPES

A-Scan (*A*mplitude mode)

In this type of scan a single transducer (Figure 4.2(a)) scans along a line in the body and the resulting echoes are plotted as a function of time (Figure 4.2(b)).

This mode is rarely used but when it is it is used to measure the size and distance to internal organs or for detailed measurements of the eye.

B-Scan (*B*rightness mode)

In the *B-scan* mode a linear array of transducers scan a plane in the body (that is, a 'slice' from front to back).

In a *B*-scan mode, a point represents the echo for each scan. The point's position is given by the time delay and the brightness depends on the signal strength (Figure 4.2(c)). (The largest amplitude corresponds to the brightest spot, displayed as almost white. The smallest amplitude is the dullest spot and is almost black. Intermediate brightness is represented by various shades of grey.)

The strength of the reflected pulse depends on the acoustic impedance of the materials on either side of the interface. As we saw earlier, $Z = \rho v$, that is, the acoustic impedance depends on the density and speed of sound in the medium. For most body materials the speed of sound is within a few per cent of 1540 m.s^{-1} except for air and bone. At air or bone interfaces, most of the incident ultrasound is reflected so that ultrasound cannot be used to 'probe' beyond such interfaces (so it cannot be used on the skull or to investigate the lungs or digestive system).

Two Dimensional *B*-scans (Sector Scan)

It is possible to take a series of B-scans (Figure 4.3(a)) and by plotting them under each other can result in the information being displayed on a TV screen as a two-dimensional plot (Figure 4.3(b)).

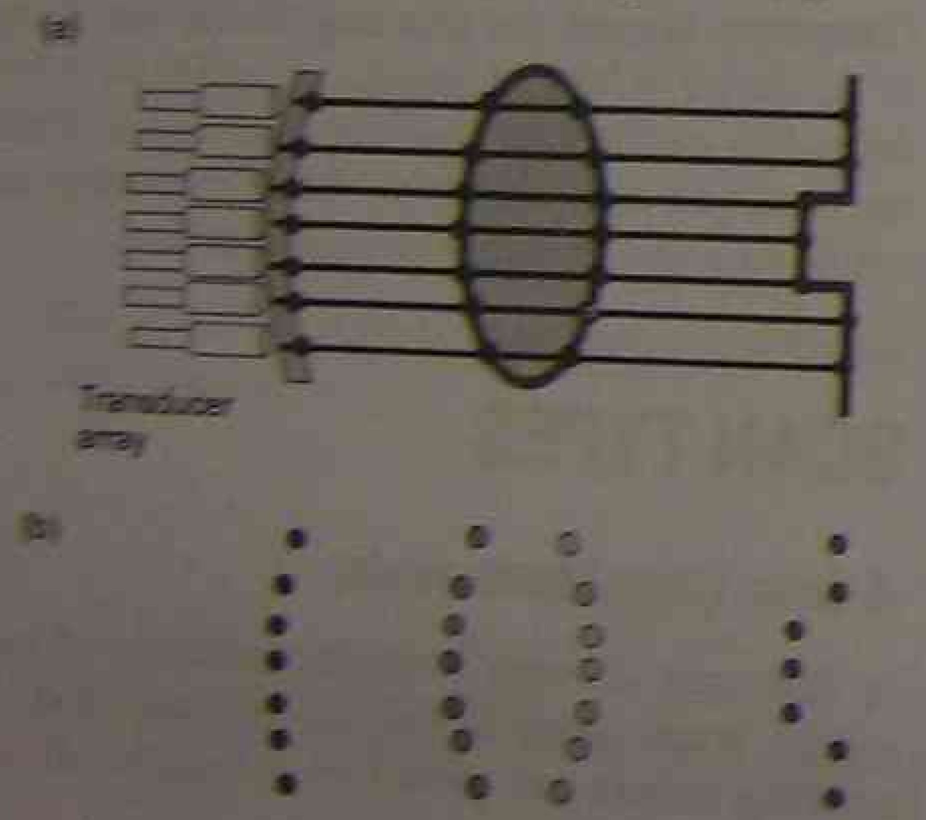

Figure 4.3 Formation of a 'real-time' ultrasound image from a B-scan. The 'quality' of the image can be improved by having more transducers in the array.

In older scans, the probe was 'rocked back and forth'. This altered the angle at which the beam entered the tissue and resulted in a slightly different image.

Today's probes do the same task as 'rocking' in one of two ways:

1 Each successive beam is *mechanically* made to make a small angle with the previous beam. The result is a sector scan (which is the familiar 'wedge' shaped image we see associated with ultrasound pictures of foetuses, see Figure 4.4).

2 Modern ultrasound scanners have a scan head consisting of more than 100 piezoelectric transducer elements. Each element is a block of *PZT* less than 1 mm wide and ~1 cm tall. The 'phased array' is electronically controlled to make a sector scan.[4] (By changing the phase between each element, the beam is made to sweep across the area being imaged.)

Figure 4.4 Ultrasound of a 20-week old foetus. The head is at the right, seen in profile and facing upwards. Also visible is the vertebrae of the spine, a hand (above the torso) and a leg is at the left.

Phase Scan

Three factors are used to describe a wave: *amplitude*, *frequency* and *phase*. Amplitude and frequency are familiar to you. Phase tells us what the wave is doing at a point in space—whether it is a crest, a trough or somewhere in between.

Until 1996 the phase aspect of ultrasound was not utilised. By sending ultrasound pulses into the body and detecting the phase of a number of returning echoes from adjacent points (for example, four) on the tissue, a clearer image can be determined. An 'image-former' not only focuses the sound into an image of any of the spots in the body, but using the phase information it can reproduce an image of the spots between the original spots, producing a clearer image.

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[3] http://www.ob-ultrasound.net/ is a site dealing with the use of ultrasound in obstetrics. Another good site from the English A Level Physics course is found at http://www.qub.ac.uk/edu/niesu/physics/Medical_Imaging/index.htm

[4] http://www.explorescience.com/activities/Activity_page.cfm?ActivityID=4 Excellent simulation of a phased array. Needs Shockwave

SCAN LIMITATIONS

As we saw earlier, the greater the difference in acoustic impedance between adjacent tissues, the more reflective is their boundary. As a result, highly reflective interfaces such as bone/tissue and air/tissue prevent effective imaging of weaker echoes from deep soft-tissue interfaces.

High frequency ultrasound permits better resolution of small structures than low frequency ultrasound. Higher frequencies, however, tend to be absorbed and scattered by soft tissue and have lower penetrative ability.

The frequencies used in ultrasound diagnosis lie in the range 1 to 15 MHz with 3 MHz being a compromise value. With the speed of sound in the body tissues averaging ~1540 m.s^{-1}, the wavelength of a 1 MHz wave is ~0.5 mm; this sets a limit to the size of objects that can be detected.

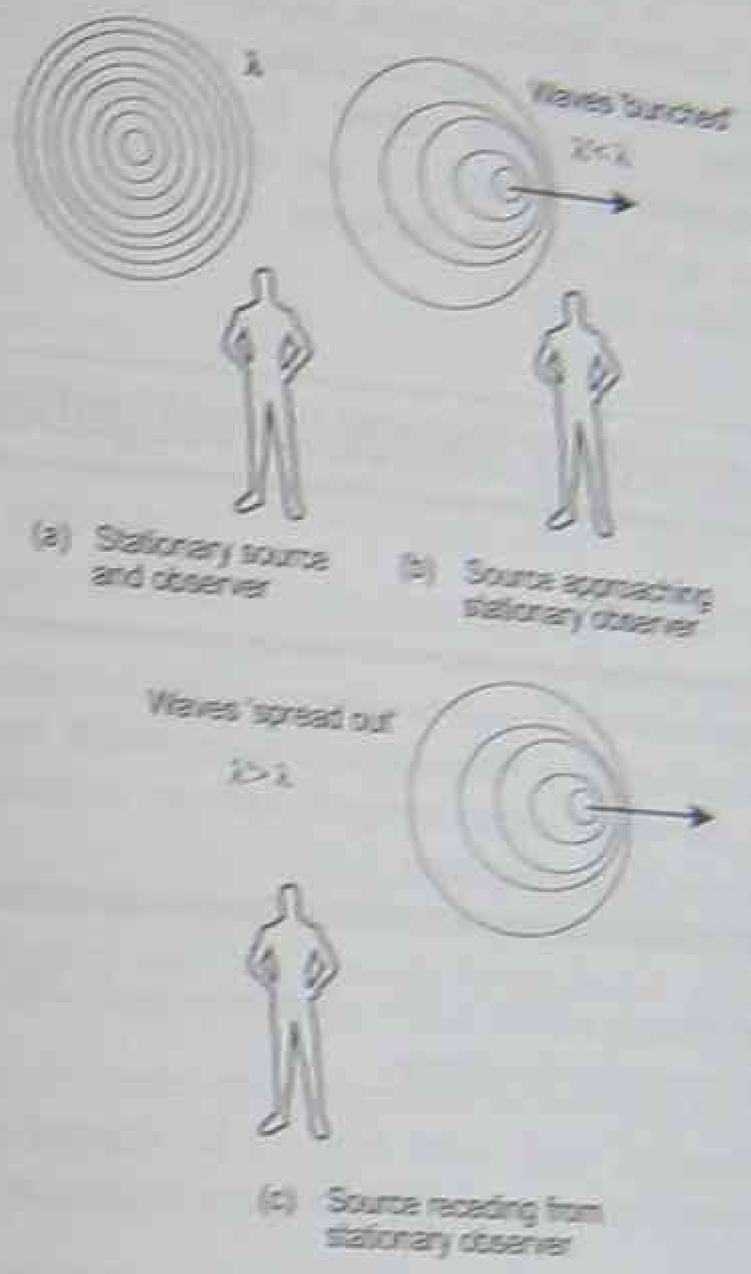
DOPPLER ULTRASOUND

In addition to *A*- and *B*-scans, ultrasonography utilises the *Doppler effect*.[5]

> **The Doppler effect (Doppler shift)** *is the apparent frequency change when there is relative motion between a source of waves and an observer.*

When a source of sound approaches an observer, the apparent frequency (as measured by the observer) increases because the waves 'bunch up' (Figure 4.5(b)). As the source recedes from the observer, the apparent frequency decreases because the waves 'spread out' (Figure 4.5(c)). (Police radar uses the same principle to measure the speed of moving cars except they use electromagnetic waves of short wavelength instead of ultrasound.)

Doppler ultrasound is commonly used to examine liquid flow. In medicine it is used to determine the condition of the circulatory system, in particular the blood flow in arteries and veins. It allows the precise location of any blockages and is commonly used in foetal heart monitoring.



(a) Stationary source and observer
(b) Source approaching stationary observer
(c) Source receding from stationary observer

Figure 4.5 The Doppler effect

ECHOCARDIOGRAPHY

> **Echocardiography** *is the use of ultrasound to diagnose heart (cardiac) problems.*

In its simplest form, a transducer placed on the chest wall emits a short pulse of ultrasound. The reflection (echo) is detected from cardiac structures such as valves and heart muscle walls. From this, the condition of the heart and its components can be determined. This is the preferred method for detecting heart valve infection (*endocarditis*) and intracardiac tumours.

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[5] http://www.walter-fendt.de/ph11e/dopplereff.htm Java applet on the Doppler effect.

Doppler Echocardiography

The most common form of echocardiography is *Doppler echocardiography*. In this method, ultrasound waves reflect off individual blood cells moving towards or away from the transducer. If the blood flow is parallel to the ultrasound beam, the velocity of blood flow can be measured. The greater the speed of flow, the more the frequency shifts.

To improve the information displayed with Doppler ultrasonography, the computer can add 'false colour'. Commonly blood flow towards the transducer is coloured *red* and flow away is *blue*. The speed can be indicated by variations in brightness and colour.

Secondary Source Investigation

Osteoporosis

Osteoporosis *is a bone disease characterised by decreased bone mass (bone density) which leads to decreased bone strength and an increased chance of bone fractures.*

Osteoporosis affects ~30% of women and ~8% of men, especially the elderly.

If diagnosed early, bone loss can be stopped and even partially reversed. This decreases the likelihood of fractures which results in improved quality of life for patients and reduced health costs to the community.

Diagnosis

The diagnosis of osteoporosis can be done in a number of ways including:

1 *DEXA—Dual Energy X-ray Absorptiometry*—is currently the most accurate means of measuring bone density. Bone density is determined by the absorption of X-rays: the more the X-rays are absorbed, the more dense the bone. DEXA is quick, painless and uses less radiation than a dental X-ray. It is generally used on the hips and spine.

2 A newer method is *Quantitative UltraSound* (QUS) which measures the energy loss and the speed of ultrasound waves travelling in one direction through the heel bone. While able to measure bone quality, it cannot measure bone density or strength. For this reason it is considered a screening tool only. Patients initially diagnosed with osteoporosis by this method go on to have DEXA of the hip and spine. (A recent article from the *Medical Journal of Australia*, suggested that ultrasound screening of the susceptible adult population followed by DEXA for those identified is more expensive than DEXA screening alone. This may change as the technology improves.)

SECTION 2: ELECTROMAGNETIC RADIATION

BIG IDEA:

The physical properties of electromagnetic radiation can be used as diagnostic tools.

OUTCOMES:

Students learn to:

1 Describe how X-rays are currently produced.
2 Compare the differences between 'soft' and 'hard' X-rays.
3 Explain how a computed axial tomography (CAT) scan is produced.
4 Describe circumstances where a CAT scan would be a superior diagnostic tool compared to either X-rays or ultrasound.
5 Explain how an endoscope works in relation to total internal reflection.
6 Discuss differences between the roles of coherent and incoherent bundles of fibres in an endoscope.
7 Explain how an endoscope is used in:
  - observing internal organs
  - obtaining tissue samples of internal organs for further testing.

Students:

1 *Gather information to observe at least one image of a fracture on an X-ray film and X-ray images of other body parts.*
2 *Gather secondary information to observe a CAT scan image and compare the information provided by CAT scans to that provided by an X-ray image for the same body part.*
3 *Perform a first-hand investigation to demonstrate the transfer of light by optical fibres.*
4 *Gather secondary information to observe internal organs from images produced by an endoscope.*

X-RAYS

On 8 November 1895 Wilhelm Roentgen was studying cathode rays using a Crookes tube when he noticed a fluorescent screen glowing on a nearby table. Roentgen investigated this further and showed that the fluorescence was due to invisible rays coming from the Crookes tube. These rays were capable of passing through opaque black paper that was wrapped around the tube. Not knowing what they were, he called them X- (for unknown) rays.

Roentgen had accidentally discovered that when cathode rays hit the glass walls of an evacuated tube, X-rays are produced. Subsequent investigations found them to be extremely high frequency—short wavelength (0.001 nm – 10 nm)—*electromagnetic waves*.

X-ray Production

Modern X-ray tubes (Figure 4.6) consist of a highly evacuated tube containing three main components:

1 A cathode consisting of a filament that produces the electrons and a hood to help direct them in the right direction.

2 An accelerating potential of 25,000—250,000 volts.

3 An anode with a high temperature metal target such as tungsten (to withstand the high temperatures generated). The face of the anode is set at 45° to the electron beam. This ensures that the X-rays, which are emitted perpendicularly to the electron beam direction, emerge through the sidewall of the tube. In many cases a thin 'window' is put in the tube wall to facilitate the exit of the X-rays.

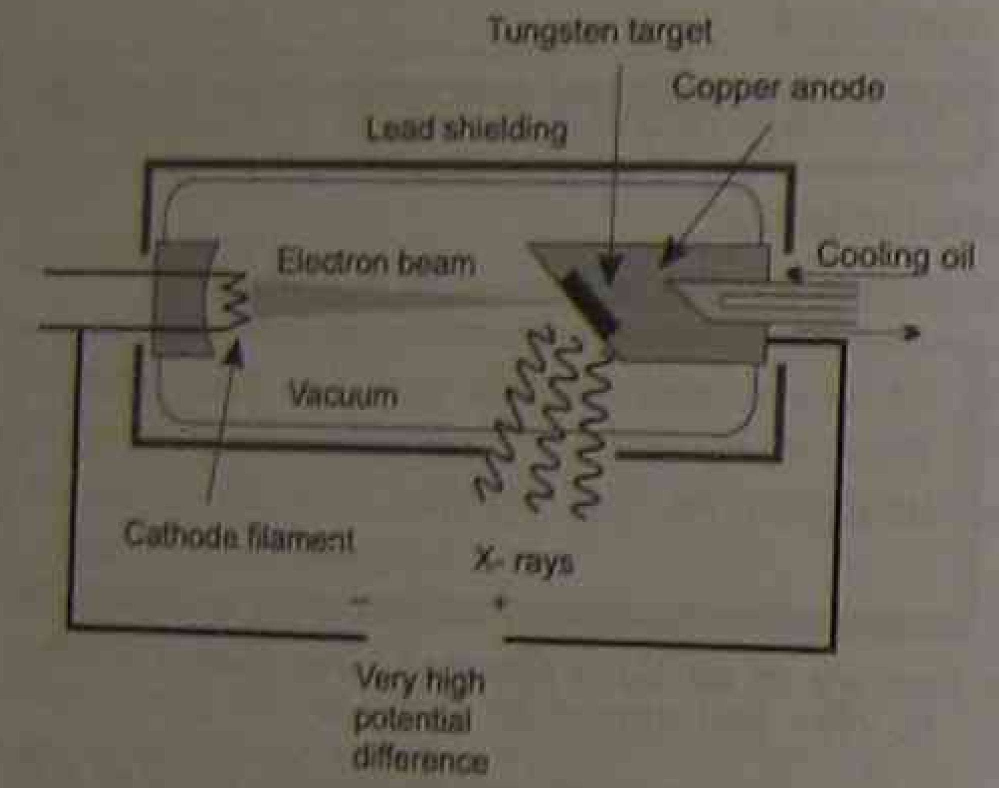

Figure 4.6 Modern X-ray tube

Electrons emitted from the heated filament are accelerated by the high potential difference and strike the tungsten target. The electrons rapidly accelerate and produce X-rays (and heat).

X-ray production is very inefficient. Approximately 99% of the electron's energy is converted to heat in the anode with only 1% being converted into X-rays. The heat must be conducted away and this is done by the use of cooling fins on the copper support rod and, in the case of high output tubes, by oil flowing through the target block.

A graph of intensity versus frequency for X-rays is given by Figure 4.7. This graph shows that:

1 The X-rays cover a continuous range of frequencies. (These X-rays are referred to as *bremsstrahlung* from the German for braking radiation).

2 For a given accelerating voltage there definite maximum frequency (which as the accelerating voltage increases).

3 'Spikes' appear on top of the spectrum. These are characteristic of the material and the X-rays are referred characteristic X-rays; that is, different materials have different 'spikes'. (Th analogous to the light emission spectra elements.)

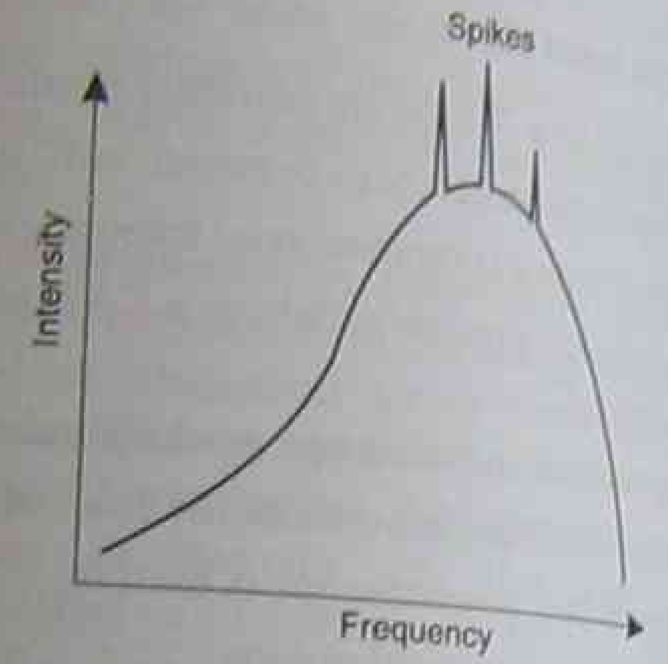

Figure 4.7 X-ray spectrum

In the common Coolidge tube, the X-ray intensity proportional to the number of electrons striking target. This in turn depends on the filame temperature (which can be controlled by altering current through the filament).

The penetrating power or *'hardness'* of the X-ray depends on the energy with which the electrons the target. This in turn depends on the accelerating potential. It follows that the intensity and hardness can be independently controlled.

Hard and Soft X-rays

As we have seen, when the accelerating potential (voltage) is increased, the X-ray frequency increases (that is the wavelength decreases) and penetration increases. We say the *quality* of X-rays increases.

Very short wavelength X-rays (~0.01 nm commercial tubes for medical uses), are called X-rays. Long wavelength (~1 nm) X-rays are *soft X-rays* and are less penetrating.

MEDICAL USES OF X-RAYS

The high frequency of X-rays imparts to them the ability to penetrate deeply into materials including those opaque to light.

The degree of penetration depends on the material. High-density materials absorb X-rays more readily than low-density materials. For example, bone absorbs more X-rays than soft tissue and cancerous tissue absorbs differently from healthy tissue.

A *radiograph* made by passing X-rays through a patient and allowing them to fall on a photographic film (Figure 4.8), produces an image showing dense tissue such as bone as clear areas and soft tissue such as lung alveoli, as opaque areas. This allows doctors to 'see inside' the patient to check for fractures (see Figure 4.9) or diseases of certain organs.

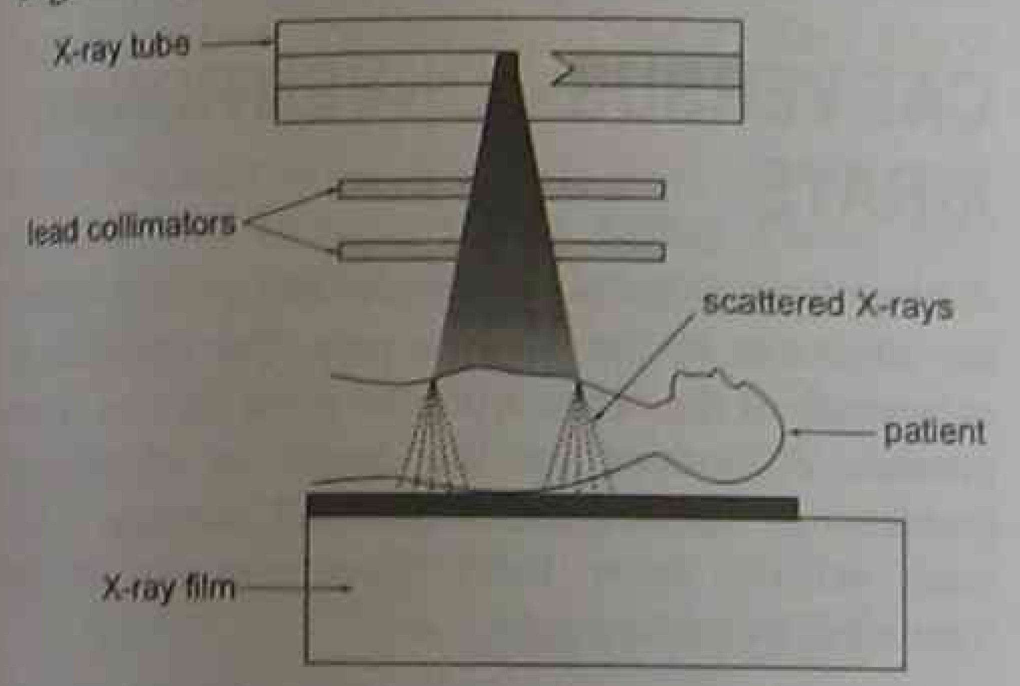

Figure 4. 8 Patient undergoing an X-ray

Figure 4. 9 Radiograph of a severe compound fracture of the shaft of the humerus. This type of fracture is usually accompanied by severe pain, swelling and tenderness of the affected site.

Soft tissue anatomy is not very clear with standard radiography. Clarity is markedly improved by using X-rays and computers together in *computerised axial tomography*[6] *(CAT)*.

COMPUTERISED AXIAL TOMOGRAPHY (CAT) OR COMPUTERISED TOMOGRAPHY (CT)

> **Computerised axial tomography**[7] *is a non-invasive technique that uses X-rays to produce images of various internal parts of the body such as the head, heart and abdomen.*

To produce a CAT (or CT) image, the patient lies on a table that is able to pass through a circular-scanning machine called a *gantry* (see Figure 4.10). (The table lies along the *axis* of the gantry, hence the use of the term *axial* in CAT.)

Figure 4. 10 A woman having a scan of her stomach. She is seen in the background lying on a mobile table which is passing through the circular scanner. In the foreground is the control room in which a radiologist remotely operates the scan. On the screen (at right) are 'slice' images obtained of the patient's stomach.

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[6] The word 'tomography' comes from the Greek: *tomos* = *slice* and *graph* = *picture*.

[7] Also known as computer assisted tomography.

A narrow fan-shaped beam of X-rays from the gantry is fired at the organ being scanned and passes through the tissue. The degree of absorption—*attenuation*—depends on the tissue type (for example bone) that it passes through. Detectors (crystal photo-diodes) measure the amount of X-rays that pass through the patient (Figure 4.11). The gantry rotates around the patient and X-rays are fired from different angles. The data is analysed by a computer which uses an *algorithm* to produce a cross-sectional 'slice' on a video screen. A series of 'slices' (think of a sliced loaf of bread) can be made to build a picture of an entire organ or even the whole body.

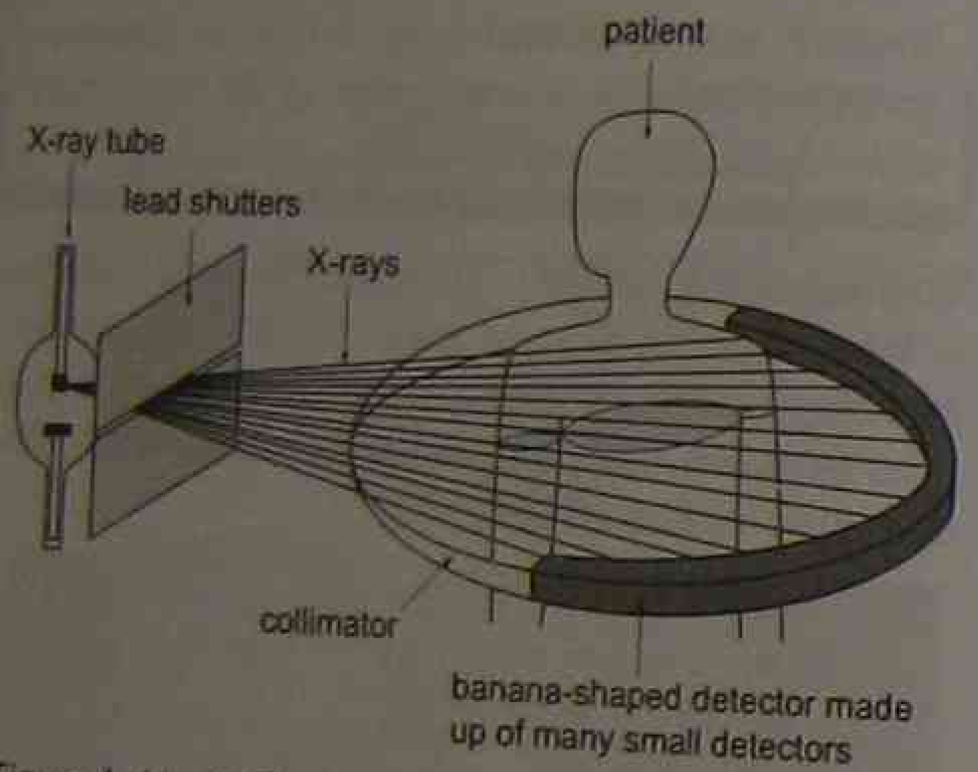

Figure 4. 11 CAT scan. The fan-shaped beam of X-rays and the detector rotate together around the patient. X-rays penetrate the patient from different angles allowing a 'slice' of the patient to be reconstructed. A series of slices can be combined to produce a three-dimensional image.

Tomographic images are made up of small squares or *'pixels'* (*picture elements*), each of which can be given a *grey-scale* value ranging from 1 (black) to 256 (white). A pixel represents a square of tissue approximately 1 mm by 1 mm. The thickness of each slice is ~3–5 mm creating a volume element or *'voxel'*. *CAT scans are capable of producing high-resolution anatomical images* (see Figure 4.12).

CAT scans are used in an ever increasing range of diagnostic applications including the detection of cancerous tumours, infections, bone fractures and even blood clots.

To improve the contrast between the organ being scanned and surrounding tissue, *contrast solutions* such as iodine and barium sulphate can be used.

Figure 4. 12 CAT scan of a cancer patient's liver showing metastatic (secondary malignant cancers) represented by the darker areas. The vertebral column is the lighter area seen in the middle right of the picture.

CAT VERSUS CONVENTIONAL X-RAYS

A conventional X-ray system shows an image of all the structures in the X-ray's path. For example, a radiograph of the lungs will also show the ribs. This presents difficulties for the doctor in identifying problems in the lungs such as small tumours. CAT scans on the other hand allow the ribs to be 'removed' from the image.

CAT is much more sensitive than ordinary X-radiographs making the detection of abnormalities easier and more reliable. Conventional X-rays have approximately 30 shades of grey (which relate to film exposure). CAT, on the other hand, has 256 grey scales. This allows better discrimination and so easier identification of cancerous cells, blood vessel blockages… CAT can also distinguish between the white and grey matter and the spinal fluid in the brain.

ENDOSCOPY

Endoscopy *is the medical examination of the interior of the body by inserting an optical tube—an* **endoscope**—*through an opening in the body (either natural of as a result of an incision).*

The endoscope generally used today is the *fibre optic endoscope* (Figure 4.13).

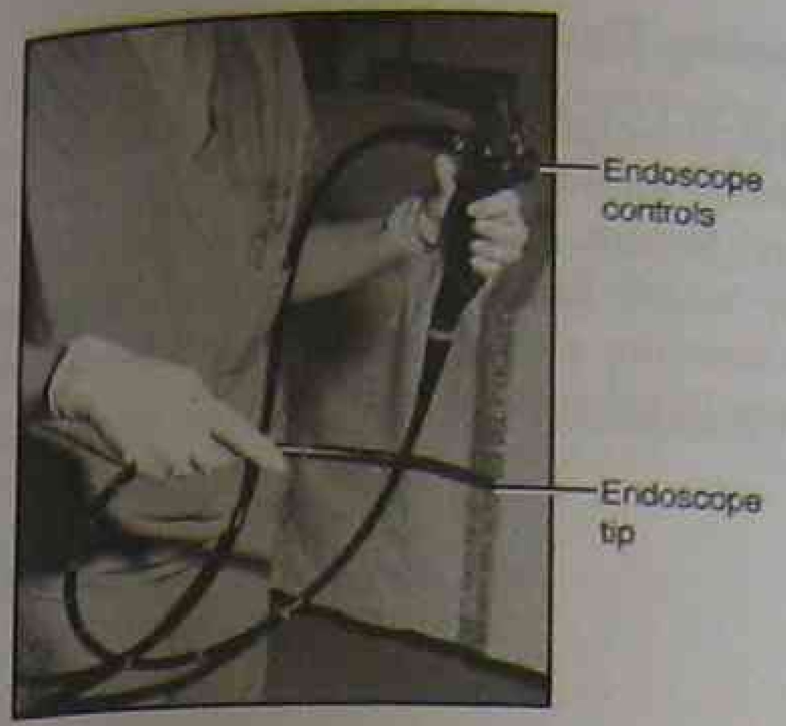

Figure 4. 13 A fibre optic endoscope

This consists of a large number of fine glass-fibre bundles (up to 40,000) that are flexible enough to allow the *endoscopist* to 'see around corners'. The fibres work on the principle of total internal reflection (see Preliminary Course *The World Communicates*).

Light 'bounces along' the fibre, even when the fibre is bent. This is achieved by having a core fibre surrounded by cladding with a lower refractive index as in Figure 4.14.

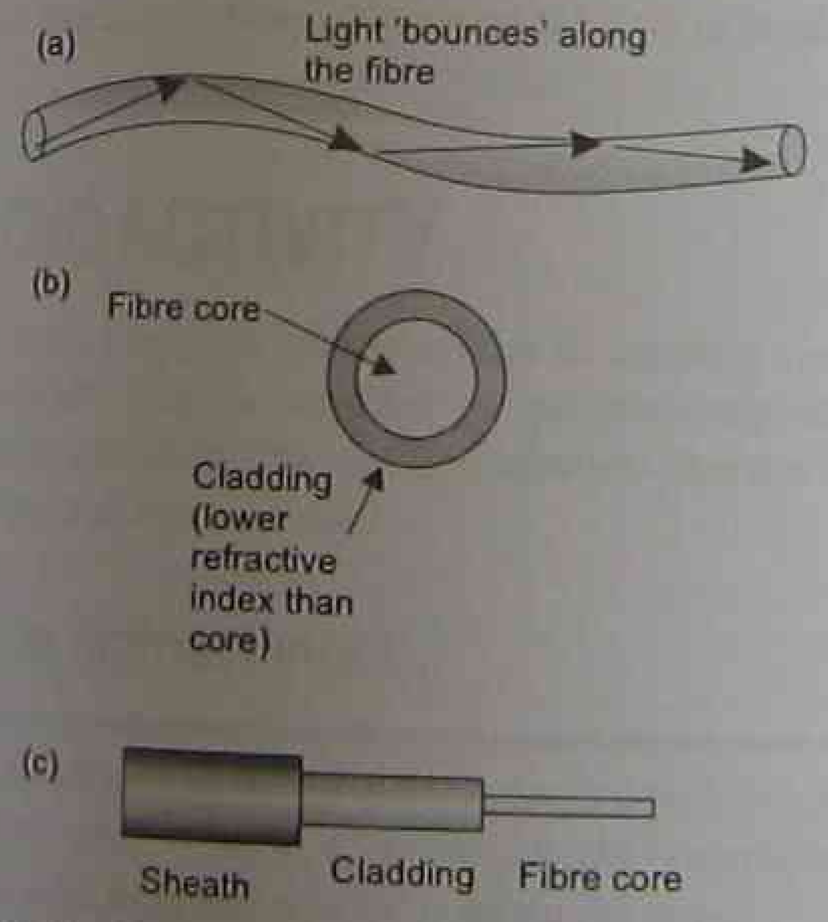

Figure 4. 14 Optic fibre

Each one of the fibres contributes light to part of the image. To transmit the image without any distortion requires a *coherent bundle* (Figure 4.15).

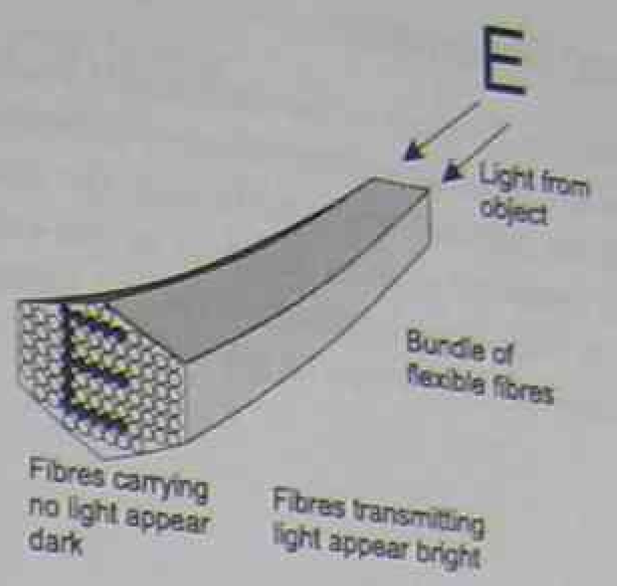

Figure 4.15 A coherent bundle

A **coherent bundle** *is one in which the individual fibres are kept in the same relative positions in the bundle at both ends.*

Resolution

The resolution of the bundle is the amount of detail that can be seen and is determined by the number of fibres, which in turn depends on the individual fibre thickness. (Diffraction effects limit the minimum thickness of the fibres.)

Flexible fibre optic endoscopes contain:

1 A *light guide* to direct light down the endoscope to illuminate the scene. This consists of a concentric bundle of *non-coherent* optic fibres (where the component glass fibres can be arranged in any order).
2 A coherent *image guide* as discussed above.
3 A *water pipe* to wash the end of the endoscope to keep it clear.
4 An *operations channel* to insert surgical instruments.
5 A *channel* for suction of gas exchange.

ENDOSCOPE USES

Endoscopes have two essential uses:

1 to observe internal organs; and
2 to obtain tissue samples of internal organs for analysis (*biopsy*).

Internal Observation

This was the first use of the endoscope. By directing the end of the endoscope to the area to be examined such as the stomach or colon (bowel), the doctor can see any problem such as an ulcer or pre-cancerous polyp. A fibre optic bundle (see earlier) transmits an image that can be viewed on a TV screen.

Obtaining Tissue Samples

A cable running the length of the endoscope con
miniature surgical instruments such as too
(biopsy) forceps. The biopsy forceps can take a
sample which can then be removed for analy
Wires carrying electric current can also be used
cauterise blood vessels and the like.

SECTION 3: RADIOACTIVITY

BIG IDEA:

Radioactivity can be used as a diagnostic tool.

OUTCOMES:

Students learn to:

1 Outline properties of radioactive isotopes and define their half-lives
2 that are used to obtain scans of organs.
3 Describe how radioactive isotopes may be metabolised by the body to bind or accumulate in the target organ.
4 Understand that during decay of specific radioactive nuclei positrons are given off.
5 Discuss the interaction of electrons and positrons resulting in the production of gamma rays.
6 Describe how the positron emission tomography (PET) technique is used for diagnosis.

Students:

1 *Perform an investigation to compare an image of a bone scan with an X-ray image.*
2 *Gather and process secondary information to compare a scanned image of at least one healthy body part or organ with a scanned image of its diseased counterpart.*

RADIOACTIVITY

Despite its negative connotations as causing cancer, radioactivity has a number of positive aspects in medicine including its use in radiation therapy[8] and its use as a diagnostic tool.

What is radioactivity?

> **Radioactivity** *is the spontaneous breakdown of an element into a new element by the emission of alpha (α), beta (β) and/or gamma (γ) rays.*

The Frenchman Henri Becquerel discovered radioactivity in 1896, a year after the discovery of X-rays.

The Nature of α, β and γ Radiation

In 1899 the New Zealand born physicist Ernest Rutherford, working at Cambridge University in England, commenced work to find the nature of the radiation emitted from radioactive substances. He found two distinct types of radiation from uranium—one that was easily absorbed and another that was relatively more penetrating. He called these rays alpha (α) and beta (β) respectively.

In 1900 the French physicist Villard identified a third very penetrating radiation from radium which he called gamma (γ) radiation.

Table 4.3 compares the properties of alpha, beta and gamma radiation.

Figure 4.16 illustrates the effects of passing alpha, beta and gamma radiation through a magnetic field. The sign of the charge can be deduced from this by application of the right-hand palm rule for charges.

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[8] Radiation therapy (radiotherapy) is used to treat cancer and diseases of the blood such as leukaemia.

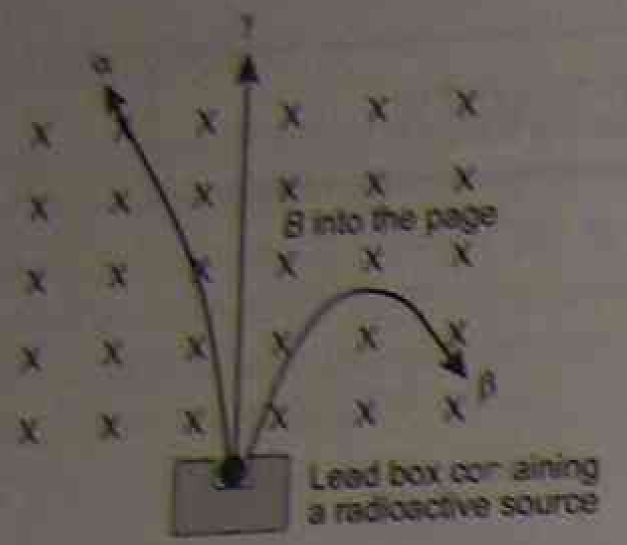

Figure 4.16 Effect of magnetic fields on radiation

RADIOISOTOPES

Natural radioactivity is exhibited by all of the naturally occurring isotopes above bismuth in the periodic table. In addition, radioactive isotopes—*radioisotopes*—exist for many other elements such as ${}^{2}_{1}H$ and ${}^{14}_{6}C$.

In 1933 the first *artificial* radioactive nuclei were synthesised when aluminium was bombarded with alpha particles forming an isotope of phosphorus with a short half-life (a measure of how long it takes to decay, see below).

Enrico Fermi (see p.231) also synthesised a large number of artificially induced radioisotopes *by bombarding elements with neutrons.*

Today, more than 400 artificial radioisotopes are known to exist; many are produced in devices called particle accelerators, for example, a cyclotron.

HALF-LIFE

The time taken for a particular radioactive element to decay is unique to that element and is best described in terms of the element's half-life.

> *The* **half-life** *of an element is defined to be the time it takes for half the given mass of an element to decay into a new element.*

These half-lives may vary from microseconds to millions of years.

When a radioactive element decays it does so in a manner similar to that shown by the graph in Figure 4.17.

If N_o is the number of atoms of a particular radioactive element at time zero, N is the number of atoms remaining after time t, and $T_{1/2}$ is the half-life, then the fraction remaining after time t is given by:

$$\frac{N}{N_o}=\left(\frac{1}{2}\right)^{tT_{1/2}}$$

Table 4.3 The properties of alpha, beta and gamma rays

Type of radiation	Nature and charge	Approximate mass	Ionising effect	Absorbed by	Deflection in electric or magnetic field
alpha	helium nucleus; double positive charge	4 x proton mass	strong	sheet of paper	very small
beta	electron; negative positron; positive	1/1800 proton mass	weak	5 mm aluminium	large
gamma	electromagnetic wave; neutral	zero mass	very weak	never fully absorbed; intensity halved by 25 mm lead	zero

EXAMPLE 4

A radioactive element has a half-life of 2 days, what fraction remains after 8 days?

SOLUTION

$$\frac{N}{N_o}=\left(\frac{1}{2}\right)^{tT_{1/2}}=\left(\frac{1}{2}\right)^{8/2}=\left(\frac{1}{2}\right)^{4}=\frac{1}{16}$$

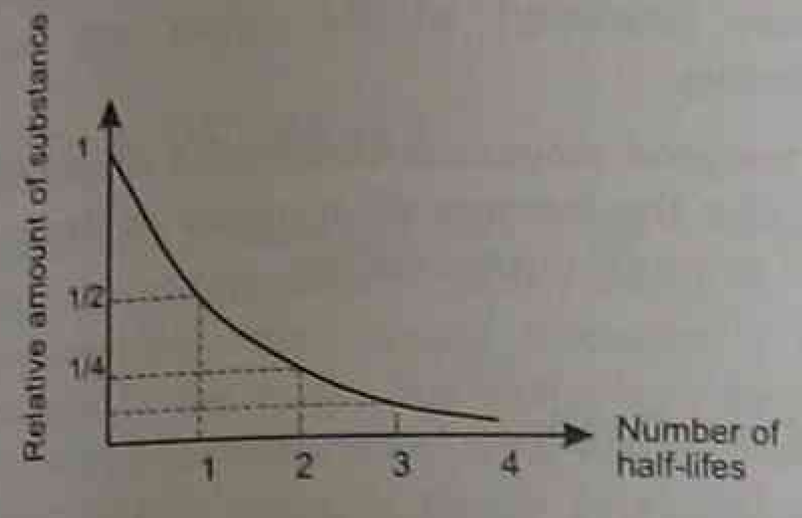

Figure 4.17 Half-life curve

RADIOISOTOPES USED IN SCANNING

As far backs as the 1960s, doctors used radioactive substances to assist in diagnosing certain diseases.

Isotope Scanning

In *isotope scanning* (also called *nuclear imaging* and *nuclear scanning*) a radioisotope is introduced into the body, generally by intravenous injection but sometimes by inhalation. The radioisotope acts identically to its stable isotope (of the same element) and so it can take part in physiological processes. The radioactivity means that it can be easily traced (for example, by *gamma cameras* moving back and forth over the organ being scanned), even in minute quantities. This allows the passage and accumulation of the radioisotope to be pinpointed.

Abnormalities are identified by either a complete or partial lack of uptake (*cold spot*, see Figure 4.18) or excessive uptake (*hot spot*) of the radioisotope. By taking a series of images over time, any irregularities in the movement and concentration of the radioisotope can indicate a damaged or diseased organ.

Figure 4. 18 Scintigram gamma camera scan of a normal human heart. This image is an example of a 'cold spot' scan using the radioisotope Thallium-201 and was taken after its injection into the blood circulation. The dark horseshoe shape in the centre indicates normal radioactive uptake by the exercising heart muscle. The lighter grey and white indicates below average radioactive uptake and hence abnormal blood flow and/or damaged heart muscle.

Nuclear imaging works well with both bone and soft tissue.

What About the Half-Life?

It is important that any radioisotope used in medical diagnosis has a short half-life (preferably in the order of hours or days at most). A long half-life would mean that the radioisotope would continue to emit potentially dangerous radiation for an extended period of time. Short half-lives mean that the radiation is reduced to harmless levels quickly.

Commonly Used Medical Radioisotopes

Over many years, doctors and chemists have identified many *organ specific chemicals* (that is, chemicals that are utilised by specific organs). For example, iodine accumulates in the thyroid. By attaching radioisotopes to these chemicals, the radioisotope can be directed to the organ of interest. Since *chemically* an element is identical to its radioisotope[9], the *labelled* substance is utilised by the body in its normal metabolic processes and is excreted normally.

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[9] Isotopes differ in the number of neutrons, not the number of electrons. The electrons determine the chemistry.

Most radioisotopes used in medical work are pure gamma emitters or gamma and beta emitters. Technetium-99m[10] is often used because it has a short half-life (see Table 4.4) and is a pure gamma emitter. Gamma emission is preferable for diagnostic work because the gamma rays pass through the body and are detected. (Alpha and beta emitters do not pass far enough through the body to be easily detected but still cause damage.)

Technetium is also useful since its parent nuclide is molybdenum-99 with a half-life of 66 h. (This means it can produce Tc-99 for a week or so before it needs replenishing.)

Table 4.4 shows some radioisotopes used for medical imaging.

Table 4.4 Radioisotopes used in medical scanning

Radioisotope	½-Life	Use
Au-198	2.7 d	Liver imaging
I-131	8 d	Thyroid imaging
Sr-85	64 d	Bone imaging
Tc-99m	6 h	Imaging of brain, thyroid, lungs, liver, spleen, kidney, gall bladder, skeleton, bone marrow, and salivary and lachrymal glands.
Ga-67	72 h	Detects soft-tissue tumours
Th-201	74 h	Diagnosis of coronary artery disease and damaged heart muscle

POSITRON EMISSION TOMOGRAPHY (PET)

A particular form of isotope scanning is *positron emission tomography* whereby a radioisotope emits positrons (positive electrons).

Positron emission tomography *is a non-invasive technique used to produce images of internally active parts of the human body by the use of short-lived radioisotopes produced in accelerators.*

In particular, PET is used to produce images of brain activity and the metabolic activity of other tissues. *PET provides functional information.* This is the main advantage of PET over other imaging methods such as X-radiography, CT and MRI which show the structure (anatomy) of the organ but not its functioning.

PET has good diagnostic capabilities since diseases often alter the function of an organ or tissue even before structural changes occur.

What is a Positron?

A *positron* is a positive electron (the electron's antiparticle). Positrons are emitted from specific radioisotopes as follows:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + \nu$$

where *X* and *Y* are the 'parent' and 'daughter' nuclei respectively, *A* is the mass number, *Z* is the atomic number and ν is a neutrino. In this process a proton decays into a neutron, a positron and a neutrino as follows: $^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + \nu$

An example of such a reaction is: $^{11}_{6}C \rightarrow {}^{11}_{5}B + {}^{0}_{+1}e$

Pair Annihilation

When a positron interacts with an electron in a reaction called *pair annihilation*, gamma rays are produced as follows:

$$^{0}_{+1}e + {}^{0}_{-1}e \rightarrow 2\gamma$$

These gamma rays have the same energy (511 keV) but travel in opposite directions (Figure 4.19).

A scanner can detect these gamma rays and the information is then fed into a computer to be converted into an image.

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[10] The 'm' stands for a metastable state.

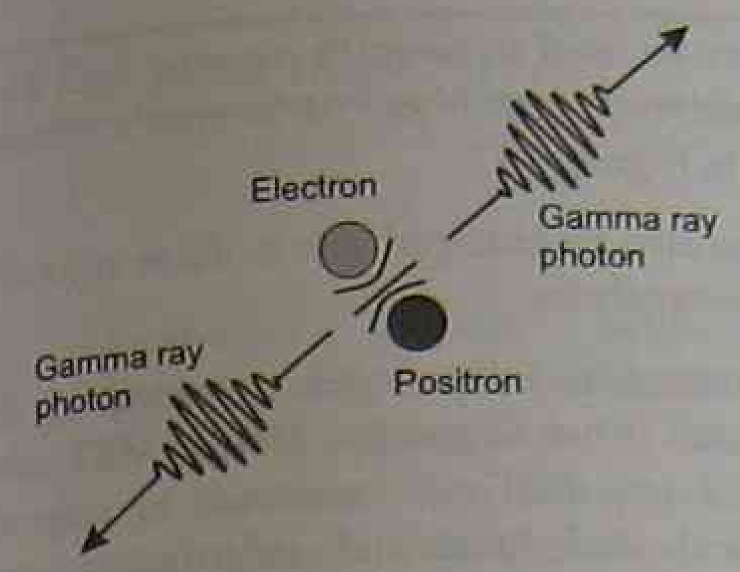

Figure 4. 19 Pair annihilation

How Does PET Work?[11]

The first step in making a PET image is to give the patient a radioisotope[12] (also called a *radio-pharmaceutical*) that closely resembles a natural substance in the body. For example, a commonly used radiopharmaceutical is 2-fluoro-2-deoxy-D-glucose (FDG), which is similar to natural glucose but is labelled with the radioisotope fluorine-18. F-18 has a half-life ~2 hours (see Table 4.5) and is readily produced in a particle accelerator called a cyclotron.

Glucose is a biological energy source and when it is injected into the patient it enters the brain and other tissues. Its rate of 'consumption' indicates the metabolic activity of a structure or part of a structure. The more active a particular part of the brain (or other organ) is, the faster the FDG is absorbed.

How are the Short Lived Radioisotopes Produced?

PET uses short half-life radioisotopes in its operation. Table 4.5 shows some of the common radioisotopes used in PET scanning. These are produced in a cyclotron. (A cyclotron is a particle accelerator that produces a large number of protons. These protons are accelerated in a circular path using strong alternating electromagnetic fields. The protons are allowed to hit a target leading to the positron-emitting radioisotopes as in Table 4.5.) For example: $^{10}_{5}B + {}^{1}_{1}H \rightarrow {}^{11}_{6}C$

The short half-life means that the cyclotron has to be in close proximity to where the scanning is being done, often within a hospital complex itself (see p.155).

Table 4.5 Radioisotopes used in PET

Radioisotope	½-Life
carbon-11	20.3 m
oxygen-15	2.03 m
fluorine-18	109.8 m
bromine-75	98.0 m

The radioisotope is subsequently incorporated into a chemical compound similar to that used in the body[13] to make a *radiopharmaceutical*.

The radiopharmaceutical releases positrons, which interact with electrons in the patient's body, and the subsequent gamma rays are detected.

How is a Scan Done?

During a scan, the patient's head, or part being scanned, is placed inside a large doughnut-shaped ring (a gantry) of gamma ray detectors which consist of special crystals (sodium iodide—NaI) which absorb gamma rays and convert them into light (Figure 4.20). These light pulses are amplified by a photomultiplier.

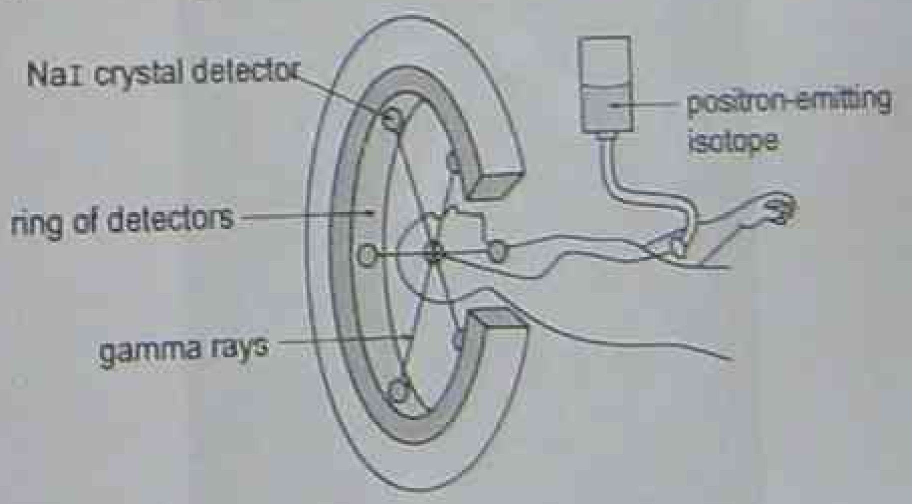

Figure 4. 20 PET scan

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[11] http://www.epub.org.br/cm/n01/pet/petworks.htm An excellent site that discusses how PET works. Good pictures available, with links to other sites. Another good site is http://www.triumf.ca/welcome/petscan.html

[12] The radioisotope can be administered by injection or by inhalation depending on the isotope used.

[13] PET has the advantage that the atoms which can be turned into positron emitters, are the same atoms found in organic molecules including oxygen, nitrogen, carbon and fluorine. The labelled molecules act chemically and biologically identical to the unlabelled molecule.

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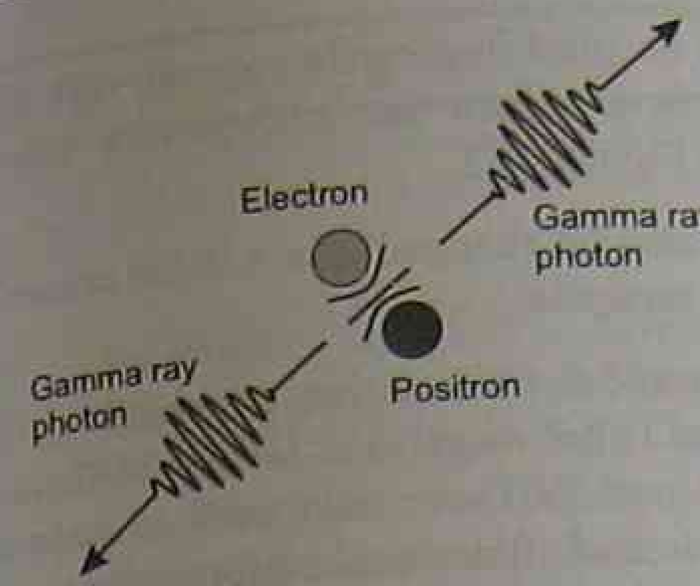

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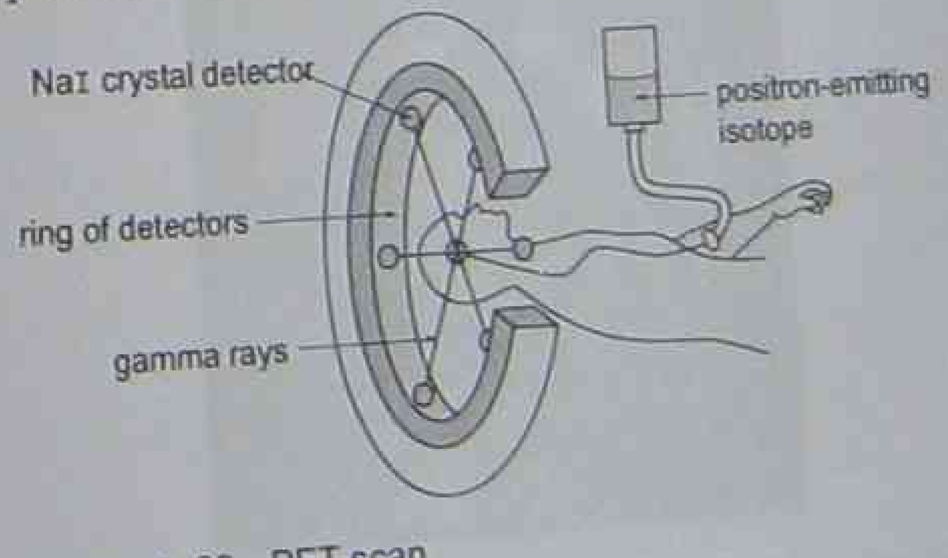

Figure 4. 20 PET scan

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[13] PET has the advantage that the atoms which can be turned into positron emitters, are the same atoms found in organic molecules including oxygen, nitrogen, carbon and fluorine. The labelled molecules act chemically and biologically identical to the unlabelled molecule.

Since the gamma rays are emitted with the same energy and in opposite directions, a pair of detectors placed at 180° to each other will detect the two rays. Computers calculate the point from which they emerged by comparing the arrival times of the two photons (Figure 4.20). (If the point were an equal distance from both detectors they would arrive at the same time; if closer to one detector than the other, the gamma ray would arrive at the closest detector first.)

This data is analysed by powerful computers (in the same manner in which CAT is analysed) and is displayed as a series of 'slices' or 'sections' on a video screen. (The whole process is called *scintigraphy*, from *scintillation* meaning a pulse of light.) By taking several adjacent slices at the one time, a *three-dimensional image* can be produced.

Interpreting a PET Scan

Not only does the detector detect where the gamma rays are being emitted from, but they also measure how many gamma rays are coming from a particular point. This is displayed on a video screen in *grey scale* (where black is zero count and white is maximum count). Differences in the degree of 'greyness', enables the activity of the organ to be mapped (Figure 4.21).

Figure 4. 21 PET scan of the brain of a normal person. Different shades of grey show brain activity from low (light grey) to high (white). Normal brain metabolic activity produces a roughly symmetrical pattern in the white areas of left and right cerebral hemispheres.

PET can be used to identify patients with abnormal brain activity (such as Alzheimer's disease) as shown in Figure 4.22.

This can also be changed into a 'false colour' image for easier analysis.

The anatomical information provided by PET is limited and is not as good as CT (or MRI, see later). Often CT and PET are combined to gain detailed anatomical *and* functional information about an organ.

Figure 4. 22 The brain scan of a patient with Alzheimer's disease. Note the patchy appearance. Compare this with Figure 4.21.

What Does a PET Scan Show?

PET is used primarily for investigations of the brain including detection of tumours and strokes, for measuring cerebral blood flow and other neurological diseases such as multiple sclerosis and epilepsy. It can even detect the early onset of *Alzheimer's* disease. Currently PET research includes investigating the brains of people with brain diseases including Parkinson's disease and schizophrenia in an attempt to learn more about these debilitating diseases.

PET is also used to measure brain activity related to various tasks such as thinking, moving an arm... and can also detect heart disease and cancer (especially lung, breast and colon).

The very high cost of PET scanners limits their number in Australian hospitals.

E x t e n s i o n

ANSTO

ANSTO (*Australian Nuclear Science and Technology Organisation*), located at Lucas Heights in Sydney's suburbs is the main source of radioisotopes in Australia. The radioisotopes used for research and industrial and medical uses are produced in either ANSTO's research nuclear reactor—*HIFAR* (High Flux Australian Reactor)—for the neutron-rich isotopes, or at the *National Medical Cyclotron (NMC)* in Camperdown, Sydney (near the Royal Prince Alfred Hospital), for the neutron-deficient isotopes.

It is important that the short half-life isotopes are produced locally so that they remain effective for use. This is why the cyclotron is near the hospital. The hospital and the NMC are connected by a $500,000 pneumatic rapid transfer system.

Public debate continues to rage about the nuclear reactor (the *HIFAR* reactor) at Lucas Heights in Sydney. Couldn't a cyclotron make all the radioisotopes we require? The answer is no! Nuclear reactors make neutron-rich radioisotopes (by effectively adding a neutron to the atom). Cyclotrons, on the other hand, make neutron-deficient radioisotopes. In general, a cyclotron cannot make the radioisotopes made in a reactor. The most important of these is technetium-99m which accounts for ~80% of nuclear medicine usage worldwide.

SECTION 4: MAGNETIC RESONANCE IMAGING

BIG IDEA:

The magnetic field produced by nuclear particles can be used as a diagnostic tool.

Students learn to:

1 Identify that the nuclei of certain atoms and molecules behave as small magnets.

2 Identify that protons and neutrons in the nucleus have properties of spin and describe how net spin is obtained.

3 Explain that the behaviour of nuclei with a net spin, particularly hydrogen, is related to the magnetic field they produce.

4 Describe the changes that occur in the orientation of the magnetic axis of nuclei before and after the application of a strong magnetic field.

5 Define precessing and relate the frequency of the precessing to the composition of the nuclei and the strength of the applied external magnetic field.

6 Discuss the effect of subjecting precessing nuclei to pulses of radio waves.

7 Explain that the amplitude of the signal given out when precessing nuclei relax is related to the number of nuclei present.

8 Explain that large differences would occur in the relaxation time between tissue containing hydrogen-bonded water molecules and tissues containing other molecules.

Students:

1 *Perform an investigation to observe images from magnetic resonance image (MRI) scans, including a comparison of healthy and damaged tissue.*

2 *Identify data sources, gather, process and present information using available evidence to explain why MRI scans can be used to:*

- *detect cancerous tissues*
- *identify areas of high blood flow*
- *distinguish between grey and white matter in the brain.*

3 *Gather and process secondary information to identify the function of the electromagnet, radio frequency oscillator, radio receiver and computer in the MRI equipment.*

4 *Identify data sources, gather and process information to compare the advantages and disadvantages of X-rays, CAT scans, PET scans and MRI scans.*

5 *Gather, analyse information and use available evidence to assess the impact of medical applications of physics on society.*

CURRENT LOOPS AND MAGNETISM

We know from the Preliminary Course *Electricity in the Home*, that a straight current-carrying wire is surrounded by a circular magnetic field (Figure 4.23(a)). If the wire is a circle (a 'current loop'), the field produced is similar to that of a simple bar magnet, with a north and a south pole (Figure 4.23(b)).

A charged particle, such as a proton or electron, acts like a tiny current loop (Figure 4.23(c)). So too, the nuclei of certain atoms and molecules behave as small magnets.

This phenomenon is related to the *spin* of the charge.

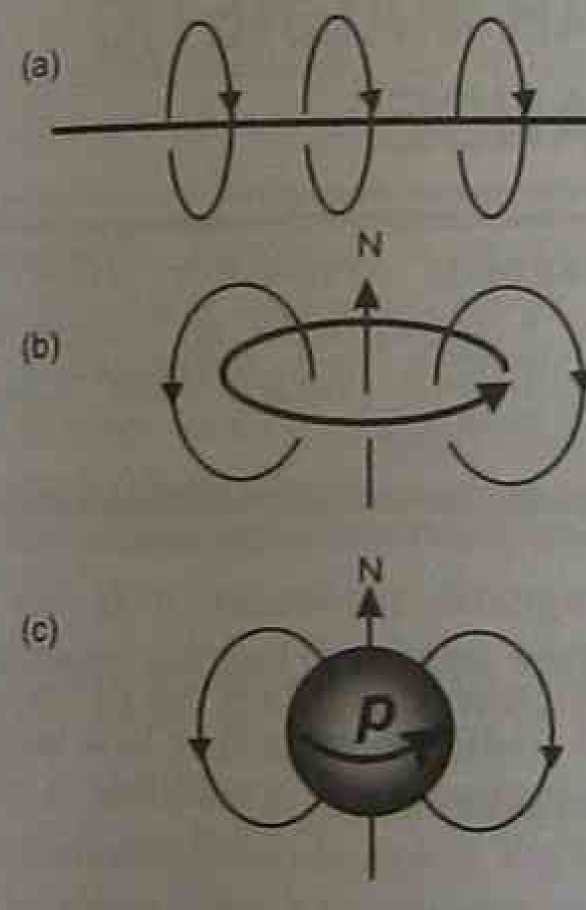

Figure 4.23 Magnetic fields associated with electric currents. (a) Field around a straight current-carrying wire. (b) Field associated with a tiny current loop. (c) Field of a spinning charge (proton).

SPIN

> **Spin,** *like mass and charge, is a fundamental property of all elementary particles. It comes in multiples of ½ and can be + or –*

Before we can understand the concept of spin, we need to introduce the concept of *angular momentum*.

Angular Momentum

We all know that when a body of mass m travels in a straight line with velocity $\vec{v}$ it has a *linear momentum* given by $\vec{p}=m\vec{v}$. Similarly a body of mass m moving in a circle of radius r with a speed v has *angular momentum* given by $\vec{L}=\vec{p}\times\vec{r}$

A spinning object, such as an elementary particle (for example, an electron) also possesses angular momentum. The direction of the angular momentum is found from the right hand grip rule, that is: if the fingers of the right hand point in the direction of rotation, the thumb points in the direction of the angular momentum. This direction is along the axis of rotation.

Spin and Angular Momentum

> **Spin** *is a measure of the intrinsic angular momentum of an elementary particle.*

For a particle spinning (*rotating*) on its axis and *revolving* about an axis, the total angular momentum equals the *spin* angular momentum plus the *orbital* angular momentum. This is the case, for example, for an electron in an atom as it spins on its axis and revolves around the nucleus.

Extension

Electron Spin

In 1925 Samuel Goudsmit and George Uhlenbeck introduced the concept of spin angular momentum for electrons to explain certain atomic measurements. In addition, the concept helped explain the splitting of spectral lines in a magnetic field—the *Zeeman* effect—the doubling of lines in the spectrum of alkali elements and the hyperfine structure in the hydrogen spectrum. The spin concept was ultimately extended to all subatomic particles including protons and neutrons and their antiparticles.

Quantum theory allows spin angular momentum to have discrete values only. These values are expressed as integer or odd half-integer multiples of the *fundamental angular momentum* $\frac{h}{2\pi}$ or $\hbar$ (h

bar), where h is Planck's constant. *Fermions*, elementary particles that include protons, neutrons and electrons have spin $\frac{1}{2}, \frac{3}{2}$... *Bosons*, for example, photons and mesons have integer spin 0, 1... (the $\frac{h}{2\pi}$ or $\hbar$ is understood).

Spin can be 'up' or 'down' (see Figure 4.26).

Nuclear Spin

Groups of particles also have a spin as a result of the spin of their individual particles. A nucleus, for example, has a spin determined by the spin of the nucleons that make it up. (In fact, the nuclear spin is the sum of the orbital angular momentum and the intrinsic spin of the nucleons.)

For even mass number nuclei, the spin is an integer; for odd mass number nuclei, the spin is a half integer ($\frac{1}{2}, \frac{3}{2}$...). All nuclei with an even number of protons and neutrons have zero spin in their ground state.

Consider the deuterium atom (^2_1H). This has one unpaired electron, one unpaired proton and one unpaired neutron. It has an electronic spin of ½ and a nuclear spin = 1. The helium atom (^4_2He), however, has two paired electrons, two paired[14] protons and two paired neutrons and has no net spin.

Nuclei with Spin

Most elements in the periodic table have an isotope with a non-zero nuclear spin. Table 4.6 indicates the spin of a number of nuclei routinely used in nuclear magnetic resonance (see later).

> *An electron (or proton) with spin acts like a tiny magnet. So too, nuclei with spin also act like tiny magnets.*

This characteristic is put to good use in *nuclear magnetic resonance*.

Table 4.6 Nuclear spin

Nucleus	Unpaired protons	Unpaired neutrons	Net spin
^1H	1	0	½
^2H	1	1	1
^{31}P	0	1	½
^{23}Na	2	1	3/2
^{14}N	1	1	1
^{13}C	0	1	½
^{19}F	0	1	½

NUCLEAR MAGNETIC RESONANCE[15]

> **Nuclear magnetic resonance** (NMR) is t *emission or absorption of electromagn radiation by atomic nuclei when subjected certain magnetic fields.*

In nuclear magnetic resonance it is the unpa nuclear spins (see previous) that are important.

To understand NMR we must first look briefly at phenomenon of *precession*.

Precession and Gyroscopes

Most of us have watched a spinning top. Rather th fall over, as it would do if it were not spinning, t top moves about a vertical axis with the axis of s tracing out a cone shape (Figure 4.24).

> *When set spinning about one axis—the axis symmetry—the top will also rotate around second axis. This change in the direction of original axis of rotation is called* precession[16]

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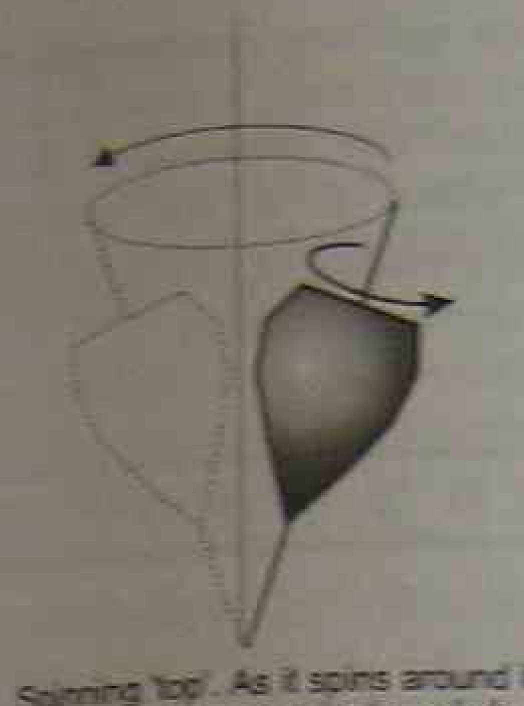
[14] If paired, then one spin up and one spin down add to zero; if two are unpaired they add to one.

[15] http://www.simplyphysics.com/page2_1.html Good introduction to NMR and MRI.

[16] Although beyond the requirements of the syllabus, precession is a result of the conservation of angular momentum.



Spinning 'top'. As it spins around its axis it also traces out a 'cone' about a vertical axis.

Figure 4. 24 Precession of a spinning top

Magnetic Moment

A spinning electric charge has associated with it a characteristic called *magnetic moment*.

> *The* **magnetic moment** *is a measure of the turning effect of a spinning charge in a magnetic field. It determines how difficult it is for the charge to align its axis of rotation in the direction of an external magnetic field.*

Alignment in an External Magnetic Field

Consider a stationary bar magnet placed in an external magnetic field (B_o) as in Figure 4.25(a). If it is free to rotate, the bar magnet will align itself parallel to the field as shown in Figure 4.25(b).

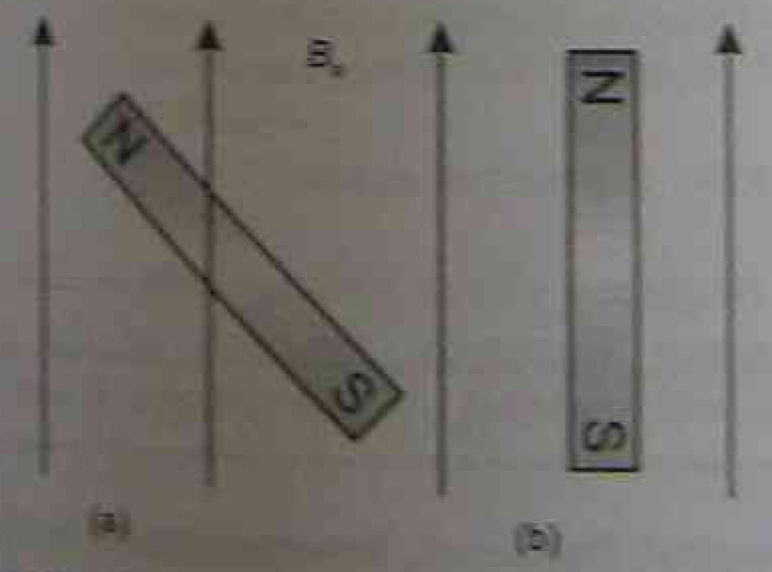


Figure 4.25 Bar magnet in a magnetic field

The magnetic moment of a spinning charge lies along the axis of rotation. If placed in an external magnetic field (B_o), the spinning charge will experience forces tending to align the magnetic moment in one of two directions: parallel to the field (Figure 4.26(a)), as we saw for the bar magnet or antiparallel to the field (Figure 4.26(b)).

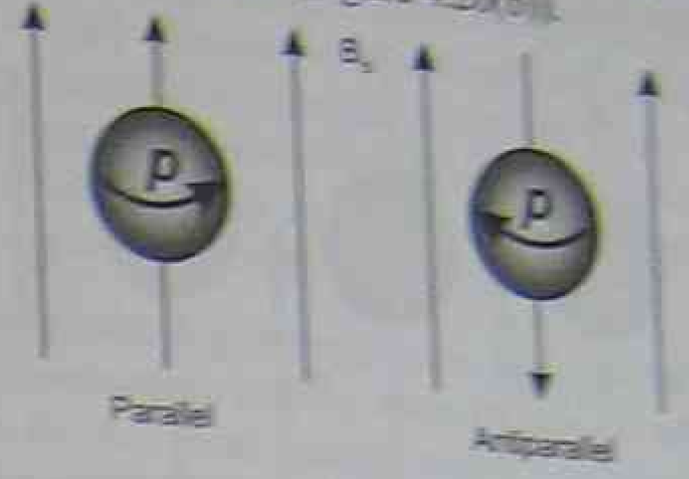


Figure 4.26 Orientation of spinning charge in a magnetic field (a) parallel to the field ('spin up') and (b) antiparallel to the field ('spin down').

The parallel state corresponds to the low-energy state and the antiparallel orientation to the high-energy state.[17]

Quantum mechanics dictates that a nucleus with spin I will have $2I + 1$ possible orientations. A nucleus of spin ½ such as hydrogen will hence have $2(½) + 1 = 2$ possible orientations. In the absence of an external magnetic field these two orientations have the same energy; in the presence of a magnetic field the energy levels split as in Figure 4.27.

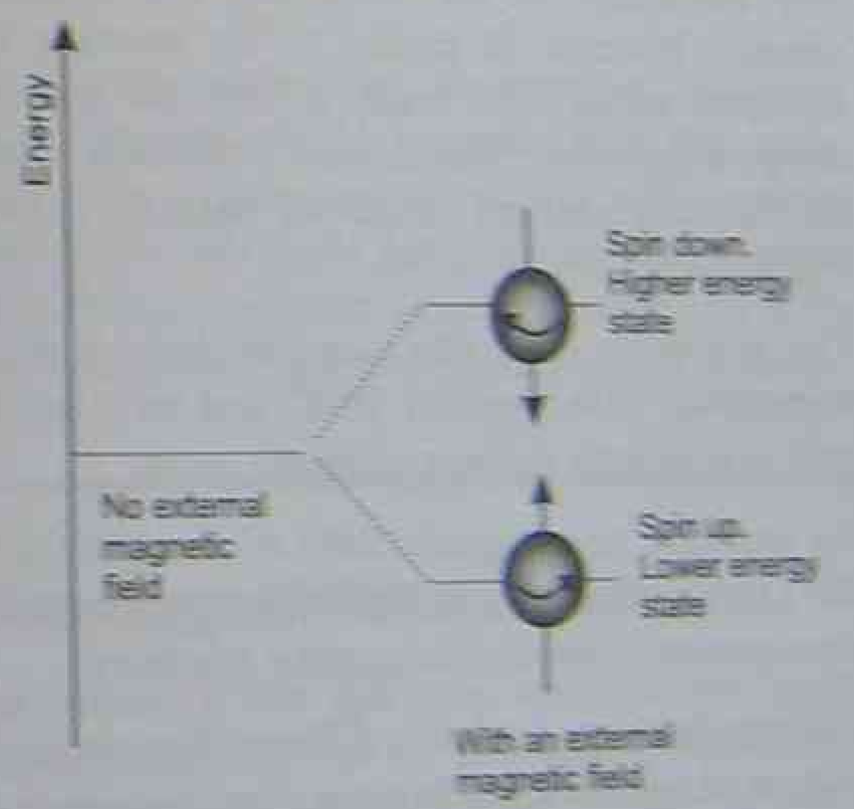


Figure 4. 27 Energy differences in a magnetic field

A slight excess of protons align parallel with the external field (Figure 4.28). (At a B field of 1.5 T, for every 2 million protons, nine more are spinning 'up' than 'down'.) The net macroscopic result is alignment with the external field.

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[17] This requires quantum mechanics for its explanation.

The stronger the external field, the greater the energy level difference and the more excess protons are aligned with the field.

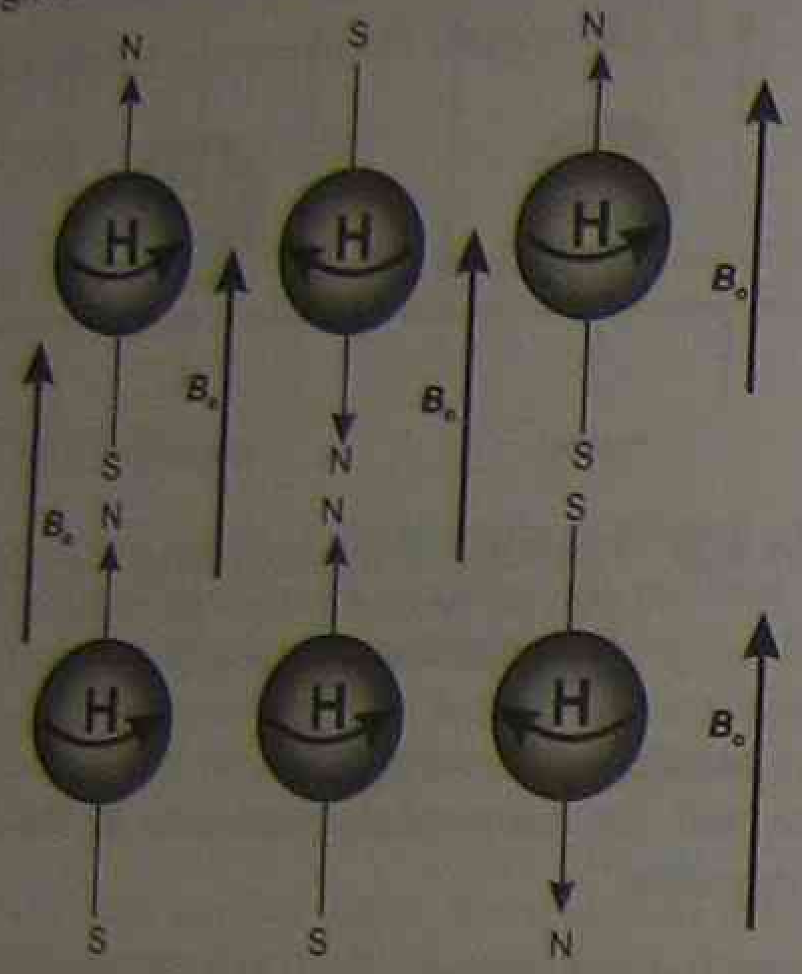

Figure 4.28 Excess of protons with spin up compared to spin down

Larmor Frequency

The interaction of the field and the magnetic moment, however, is similar to the spinning top discussed earlier. The result is that the spinning charge will *precess*. This *Larmor precession* causes the magnetic moment vector to describe a cone (Figure 4.29).

The precession rate (the *Larmor frequency*) is proportional to the applied field[18] and so it can be used to accurately measure magnetic fields.

For example, in a magnetic field of strength 0.2 T, the Larmor frequency is 8.5 MHz—in the radio-wave portion of the electromagnetic spectrum.

Different nuclei precess with different frequencies in a given magnetic field. Measure the frequency of precession and you can identify the element.

Just like electrons can absorb a photon of energy to move from a lower energy state to a higher energy state, so too the spinning protons in the low-energy state (spin up) can absorb a photon to move to the high-energy state. The frequency to do this is found from $E = hf$ where E is the energy difference between the two states and f is called the resonance frequency or *Larmor* frequency.

Extension

The Larmor frequency (ω_o) is related to the magnetic field strength (B_o) by $\omega_o = \gamma B_o$ where γ is the *gyromagnetic ratio*. This is unique to each type of nuclei.

Resonance

In standard nuclear magnetic resonance, a weak oscillating magnetic field in the form of pulses of radio waves is superimposed on a strong steady field (Figure 4.29). This oscillating field rotates in a plane at right angles to that of the strong field.

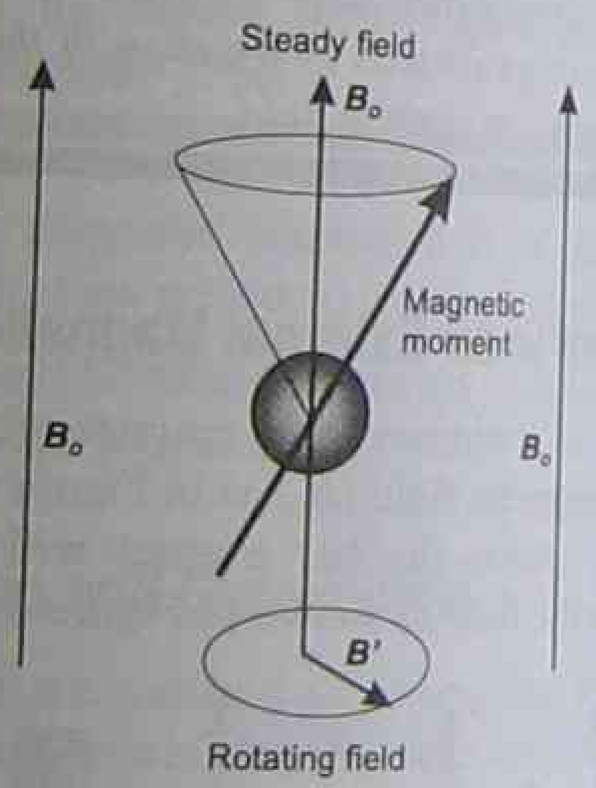

Figure 4.29 Larmor precession

If the frequency of the rotating field is different to the Larmor frequency, the axis of the rotating particle will 'wobble' (*precess*), that is, it describes a cone.

If the applied frequency, however, equals the Larmor frequency of precession, *resonance* occurs and the system absorbs energy from the varying field—the atoms are 'knocked over' (Figure 4.30).

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[18] http://web.chem.queensu.ca/FACILITIES/NMR/nmr/webcourse/precess.htm Excellent applet showing precession in a magnetic field and the effect of the field strength on the Larmor frequency. Another good site is http://physics.rug.ac.be/watersofatoom/applets/nmt/NMR_net.html

Using a RF Signal

Consider Figure 4.30. In the absence of a magnetic field the spins are randomly oriented (Figure 4.30(a)). When a magnetic field is applied they align with the field (Figure 4.30(b)).

If the correct amount of radio frequency energy is now supplied, the nucleus can be made to flip from the low energy state (spin up) to the higher energy state (spin down) as in Figure 4.30(c). The nuclei are forced to rotate in phase with the pulse and hence with each other. As they relax, that is return to the low energy state, they releases energy that can be detected (Figure 4.30(d)).

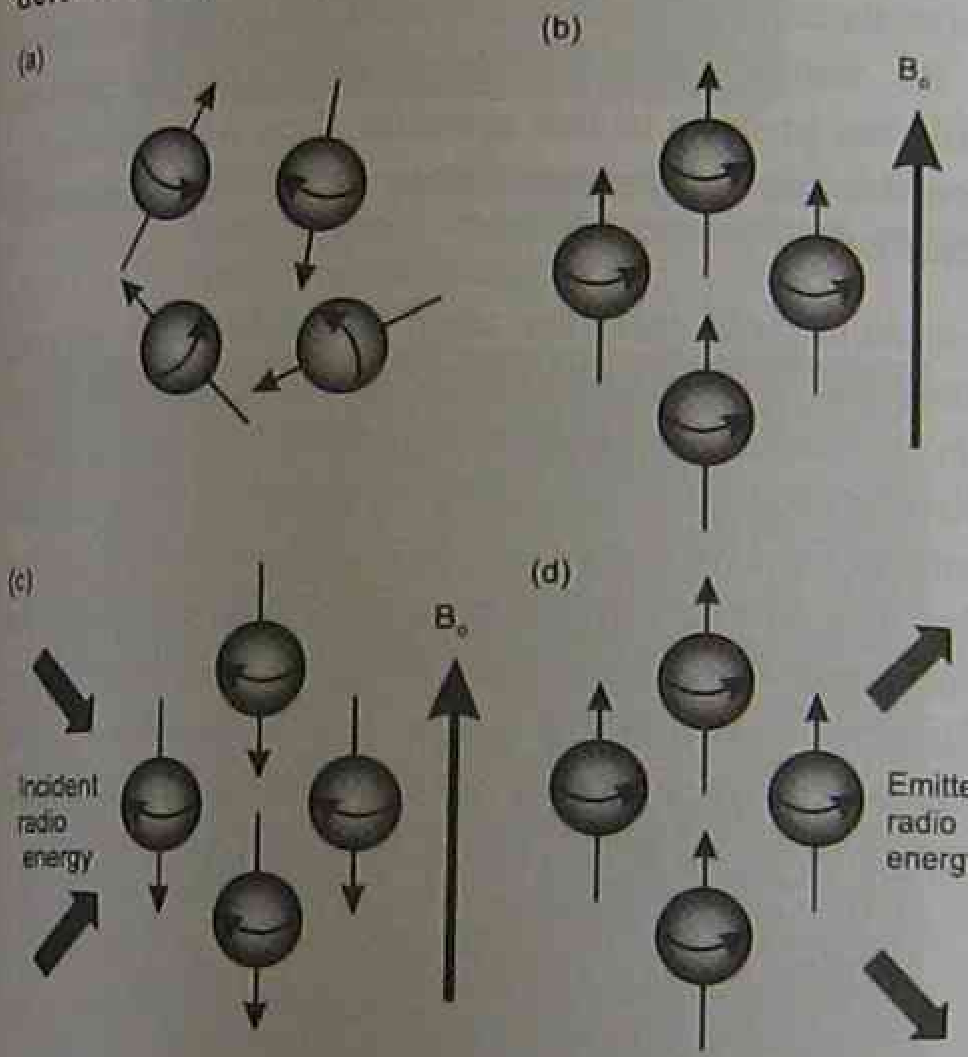

Figure 4. 30 Nuclear magnetic resonance. In (a) the spins are randomly oriented. In (b) they align in an external magnetic field. They can be made to flip to the higher energy state when the correct energy is supplied (c) and when they relax the emit energy (d) that can be detected.

Extension

Relaxation Processes

Nuclei in the high-energy state return to the lower energy state in two ways:

1 spin-lattice relaxation
2 spin-spin relaxation.

Spin-Lattice Relaxation (T_1 decay)

The nuclei in NMR do not exist in isolation—they are part of a large sample called the lattice. In this lattice nuclei experience vibrational and rotational motion creating a complex magnetic field—the lattice field. This lattice field has many components some of which will be equal to the Larmor frequency of the nuclei being examined.

Nuclei in the high-energy state can interact with those components causing them to lose energy and return to the lower energy state. This results in increased vibrational and rotational energy within the lattice (causing a small temperature increase).

The relaxation time (T_1) depends on the mobility of the lattice and the type of nucleus. Different tissue types have different relaxation times.

Spin-Spin Relaxation (T_2 decay)

Spin-spin relaxation is the interaction between neighbouring nuclei with the same precessional frequency but different quantum states.

When the precessing nuclei are first 'knocked over' they are all in phase. Over time they get out of phase with the result that the signal fades away—it decays. How does this happen?

As we saw earlier, the frequency of precessing nuclei depends on the magnetic field that nuclei experience. For isolated nuclei, this is the external field B_o. As the nuclei move around their magnetic fields begin to interact—this causes the precession frequency to vary and so the nuclei get out of phase.

Proton Magnetic Moment

The proton in the hydrogen atom has the largest magnetic moment for its spin and is the nucleus most commonly used, providing the strongest resonance signals. Other commonly used nuclei are those of the atoms phosphorus and fluorine.

In the early 1970s, the principles of nuclear magnetic resonance were applied to produce images for medical diagnosis.

MAGNETIC RESONANCE IMAGING[19]

Magnetic resonance imaging (MRI) *is a non-invasive technique used to produce images of tissues inside the body using radio-frequency energy and strong magnetic fields.*

MRI differs from X-radiography, PET and CT in that it does not use ionising radiation and hence is safer.

How Does MRI Work?

MRI uses a powerful cylindrical magnet (~30,000 times stronger than the Earth's magnetic field) which surrounds the patient (Figure 4.31.)

Figure 4. 31 Woman patient having a magnetic resonance imaging brain scan. A radiologist examines the scan on a monitor in real time.

The intense magnetic field forces nuclei in the tissue being scanned (notably hydrogen) to 'line up'. As we have seen, the nuclei do not line up exactly with the field; rather they precess around it. Pulses of radio-frequency electromagnetic waves are then directed at the body and, if their frequency equals that of the nuclei—the *Larmor frequency*—*resonance* occurs as discussed earlier. At resonance the nuclei absorb the radio wave's energy.

When the radio wave is 'turned off' the nuclei return to their original orientation in the field. In doing so they release the absorbed energy as weak radio signals of the same frequency as the incident wave. A receiving coil detects this energy and a computer reconstructs an image.

Locating Specific Nuclei

Selecting a 'slice' or plane of interest in the patient is done by taking advantage of the fact that the Larmor frequency is proportional to the strength of the external magnetic field B_0. By varying B_0 for different sections of the patient, each section will have its own unique Larmor frequency. By directing a RF wave of specific frequency into the patient only the protons in that specific slice will resonate—protons in adjacent slices will be relatively unaffected.

Gradient field coils are used to produce the varying magnetic field. In addition to the main magnet, three *shim coils* set up a magnetic gradient in the x, y and z directions (Figure 4.32). The z-direction is along the patient's body from head to toe—B_0 increases from the feet to the head; the x-direction is across the body and the y-direction is down the body (from front to back). Each point in the patient's body therefore, has a unique set of x, y and z 'magnetic coordinates'.)

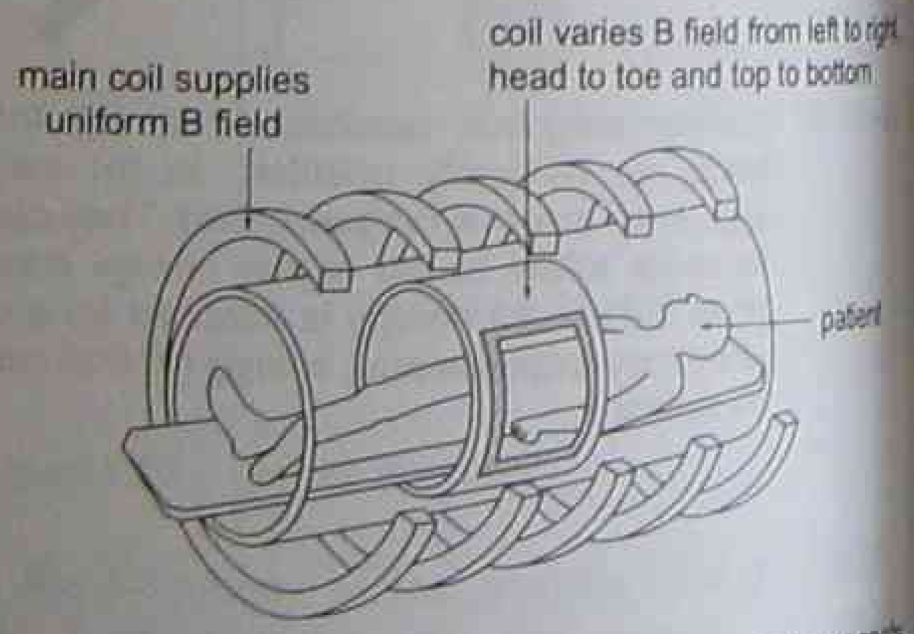

Figure 4. 32 MRI scanner showing the various magnets

The strength and duration of the signals is dependent on the properties of the tissue from which they are emerging. The higher the spin density is, the greater the concentration of hydrogen nuclei in the site being imaged. Hydrogen has its greatest density in body fluids. Next comes soft tissue followed by cartilage and membranes. (Bones show no MRI signal.)

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[19] http://www.howstuffworks.com/mri.htm is an excellent site on how magnetic resonance imaging works.

A computer decodes the signals into a visual image in a similar manner as for CT and PET scans (see Figures 4.33 and 4.34).

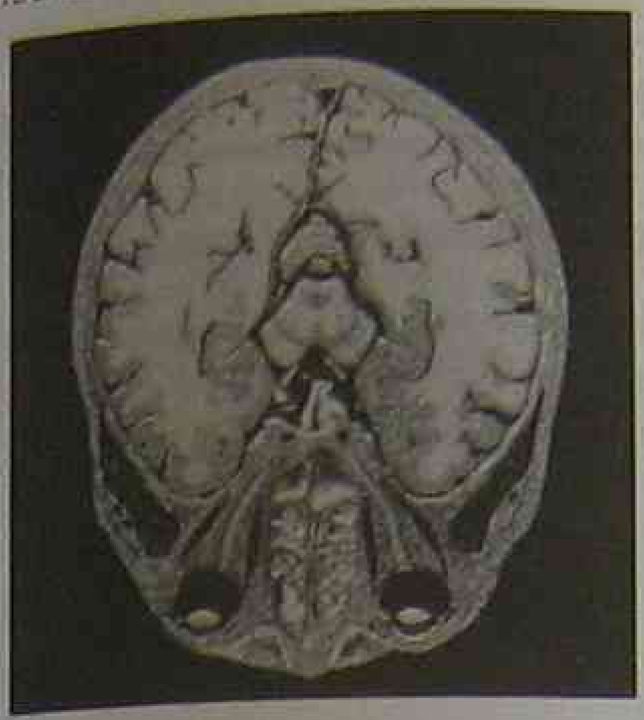

Figure 4. 33 MRI scan of a human head containing a healthy brain. Note the eye sockets at the bottom of the image.

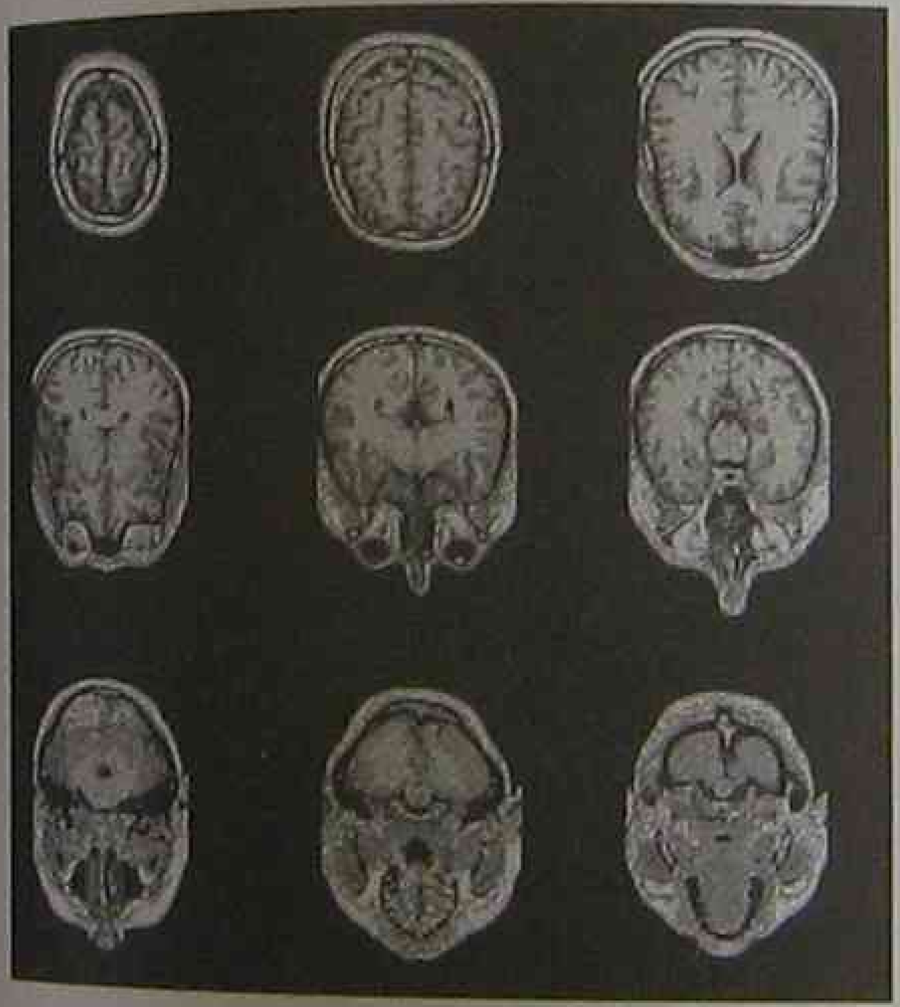

Figure 4. 34 A series of MRI scans taken from the top of the head (top left) down to the level of the teeth (lower right). At top are the two cerebral hemispheres of the brain consisting of white matter (white shading) and grey matter (dark grey). In the middle, the face is seen with rounded eyeballs and nasal cavity.

Essentially, MRI works by measuring the nuclear magnetic moments of hydrogen nuclei (protons) that reside in the body's water and fats. Proton density mapping makes it possible to produce images of tissues that are comparable to, or better than those obtained from CT scanning.

MRI has the advantage that it can image in any plane simply by activating the three gradient magnets appropriately. (In CT and PET the patient needs to be positioned appropriately for different image planes to be obtained.)

Figure 4.35 summarises the basic steps in MRI.

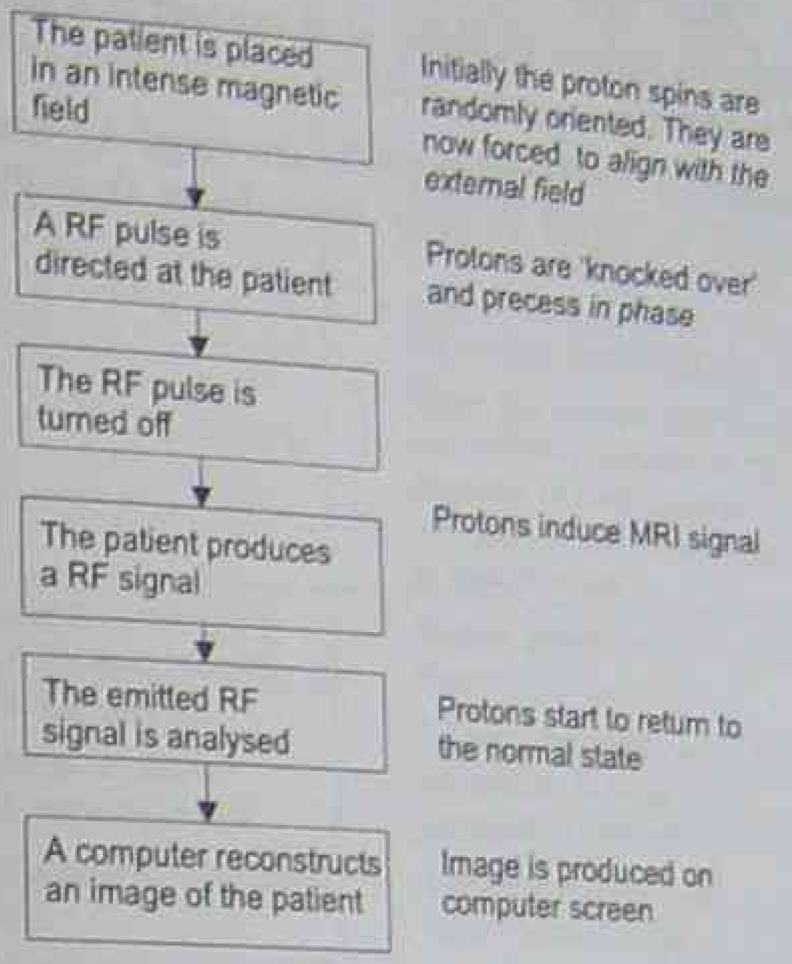

Figure 4. 35 Basic steps in MRI scan

What is MRI Used For?

MRI images are able to accurately differentiate between normal and diseased tissues and provide the most detailed anatomical information. MRI is the number one choice for studying the *brain* and *central nervous system*. For example, it ideal for:

1 diagnosing multiple sclerosis (MS)
2 detecting brain and pituitary gland tumours
3 diagnosing stroke (in the early stages) and
4 diagnosing infections in the brain, spine and joints.

In is also used to examine the chest, abdomen and joints including ligament damage and degeneration of discs in the spine. MRI is especially good at detecting cancerous tumours.

MRI is considered to be the best of the diagnostic imaging techniques.

What is Functional MRI (fMRI)?

In recent years scientists have developed techniques to show the structure and the function of organs such as the brain. Using the magnetic properties of blood, scientists have been able to see the flow of blood in the brain and the heart as they are working. Changes in blood flow can be recorded as the patient performs various functions or is exposed to a range of stimuli.

Functional MRI can produce an image of brain activity as much as forty times faster than PET allowing greater precision in determining when a particular area of the brain becomes active and its duration.

Secondary Source Investigation

Comparison of Imaging Techniques

Table 4.7 compares the various types of imaging techniques that we have looked at, including their advantages and disadvantages.

Table 4.7 Comparison of Imaging Techniques

Imaging Technique	Procedure	Advantages	Disadvantages
X-rays	A beam of X-rays is directed through the patient. Bone and different tissue types allow the X-rays to pass through to varying degrees. An image is formed on a photographic plate as a series of 'shadows'. Bones absorb more X-rays than soft tissue. On radiograms, bones show up as white against a darker background.	▪ Relatively simple to use. ▪ The cheapest imaging technique. ▪ Lots of simple X-ray machines are available.	▪ Shows structure but not the function of the organ being scanned. ▪ Shows all structures, for example, the ribs over the lungs making it more difficult to diagnose lung diseases. ▪ Resolution not as good as the other imaging techniques. ▪ Ionising radiation used and so exposure must be accurately controlled. ▪ Often the patient may have to fast before the X-ray or be required to take special 'contrast' substances such as a 'barium meal'.
CT Scan	A series of X-ray beams is directed through the patient from various angles in a plane. Computers take the information and build up a picture of a 'slice' of the particular organ. This can be displayed on a TV screen or on a photographic plate.	▪ Resolution much better than conventional X-rays (allowing finer detail to be seen). ▪ Creates a cross-sectional image of the viewed organ. ▪ Three-dimensional images can be generated. ▪ Good for diagnosing tumours and other space-filling lesions. ▪ Preferred for evaluating stroke.	▪ Shows structure but not the function of the organ. ▪ Ionising radiation used and so exposure must be accurately controlled. ▪ More expensive than conventional X-ray.
PET	A radiopharmaceutical is injected or inhaled by the patient. The radioisotope emits positrons which annihilate with electrons in the patient and emit gamma rays. A special camera detects these radioactive emissions.	▪ Provides an image of the *activity* of the particular organ, not just its structure. ▪ Good for diagnosing stroke and other neurological diseases.	▪ Ionising radiation used. ▪ Expensive to use (a cyclotron must be 'nearby' to provide the short-lived radioisotope).
MRI	The patient is placed in a strong magnetic field which tends to align some of the 'atomic magnets' in the molecules within the patient. Pulses of radio-frequency (RF) electromagnetic waves bombard the patient and at particular frequencies RF energy is absorbed and emitted. A computer decodes this information and an image (2D or 3D) is produced.	▪ No ionising radiation (that is, X-rays or radioactive emissions) is used. ▪ Provides the clearest pictures of organs such as the brain. (MRI hardly 'sees' bone.) ▪ Can be used to scan the chest, abdomen and joints. ▪ The technique of choice for imaging the brain and central nervous system. ▪ With *functional magnetic resonance imaging* (fMRI) it can provide both anatomical and functional views of the brain.	▪ Most expensive imaging technique. The machine itself costs ~$1M. ▪ Some people experience claustrophobia from the closeness of lying in the long tube. (2-3% cannot complete the examination.) ▪ MRI requires a long time for a scan (~40 min) compared to ~5 min for a CT scan. This impacts on operating costs. ▪ Aneurism clips may 'toggle' and tear the artery they are supposed to repair. ▪ People with pacemakers or metal prothesis (for example artificial hips) cannot be scanned (due to the intense steady magnetic fields used).

SUMMARY:

- Ultrasound is sound with frequencies greater than 20 kHz.
- Piezoelectric crystals convert mechanical oscillations into an oscillating potential difference and vice versa
- The acoustic impedance is a measure of how easy it is to transmit sound through a medium.
- Different media have different acoustic impedances and reflect sound differently.
- Ultrasonography is the use of ultrasound in medical (and industrial) applications.
- Ultrasound imaging is a non-invasive method that uses ultrasound to 'see inside' the human body.
- Imaging modes include *A*-, *B*-, sector and phase scans and each has its advantages.
- The Doppler effect is the apparent change in frequency when there is relative motion between a source of sound and the observer.
- Doppler echocardiography is used to detect abnormalities of the heart.
- Bombarding a tungsten target with electrons in an evacuated chamber produces X-rays.
- Hard X-rays have short wavelengths (~0.01 nm); soft X-rays have longer wavelengths (~1 nm)
- X-rays can be used to 'see inside' the human body.
- Computerised axial tomography (CAT or CT) is a method that uses X-rays and computers to make a detailed picture of the inside of the human body.
- An endoscope is a tube that uses optical fibres to look inside the body.
- Endoscopes assist in observing internal organs and in obtaining tissue samples for biopsy.
- Radioisotopes can be used for body scanning.
- Radioisotopes vary in their half-life (the time for half the given mass to decay into a new element).
- Positron emission tomography (PET) is a non-invasive technique that uses positron-emitting radiopharmaceuticals to image the internal organs and tissues.
- Pair annihilation produces gamma rays that can be used to determine the characteristics of the organ or tissue.
- Protons, electrons and certain atoms and molecules act as tiny magnets.
- Nuclei with spin tend to align themselves in an external magnetic field and precess about the field direction.
- When bombarded with radio-frequency waves at the Larmor frequency, the nuclei absorb energy. As they 'relax' they emit energy that is detected and measured.
- Different tissues contain different concentrations of hydrogen atoms and this is what MRI detects.
- Different scanning techniques have different advantages and disadvantages.

Key Terms

acoustic impedance
A-scan
biopsy
B-scan
CAT (CT)
coherent
current loop
Doppler effect
echocardiography
electromagnet
endoscope
gamma rays
half-life
imaging
Larmor frequency
magnetic gradient
MRI
PET
piezoelectric
precession
radio frequency
radioactivity
radioisotope
radiopharmaceutical
relaxation time
resonance
technetium
scanning
sector scan
spin
tomography
total internal reflection
transducer
ultrasonography
ultrasound
X-rays

QUESTIONS AND PROBLEMS ON *MEDICAL PHYSICS*

SECTION 1: ULTRASOUND

1 Define the following terms:
  (a) ultrasound
  (b) transducer
  (c) piezoelectric
  (d) acoustic impedance.

2 The acoustic impedance of fat and muscle is 1.38×10^6 kg.m^{-2}.s^{-1} and 1.70×10^6 kg.m^{-2}.s^{-1} respectively. What is the ratio of the reflected to incident intensity for a fat/muscle interface?

3 Explain the difference between *A*-scans and *B*-scans.

4 What is a sector scan?

5 What are the limitations of ultrasound scans?

6 Short ultrasound pulses are directed through a patient's body with echoes detected from two interfaces *X* and *Y*. The echoes are detected from *X* and *Y* after 0.025 ms and 0.040 ms respectively. How far away are the two interfaces from the transducer? (The speed of sound in soft tissue is 1540 m.s^{-1})

7 What is the Doppler effect?

8 How is the Doppler effect used in echocardiography?

SECTION 2: ELECTROMAGNETIC RADIATION

1 Briefly describe how X-rays are produced.

2 What are the differences between 'hard' and 'soft' X-rays?

3 Briefly describe how CAT (or CT) scans are produced.

4 Compare a standard radiograph with a CT scan. What advantages does CT have?

5 Define the following terms:
  (a) endoscope
  (b) coherent bundle
  (c) incoherent bundle.

6 What are endoscopes used for?

SECTION 3: RADIOACTIVITY

1 Define the following terms:
  (a) radioactivity
  (b) alpha radiation
  (c) beta radiation
  (d) gamma radiation
  (e) half-life

(f) radioisotope

(g) radiopharmaceutical.

2 Describe four common radioisotopes used in medicine and their uses.

3 Define the following terms:

(a) positron

(b) pair annihilation

(c) gamma camera.

4 Briefly describe how positron emission tomography (PET) is used in medical imaging.

5 Compare PET with CT for medical imaging.

SECTION 4: MAGNETIC RESONANCE IMAGING

1 Define the following terms:

(a) spin

(b) magnetic moment

(c) precession

(d) nuclear magnetic resonance (NMR)

(e) Larmor frequency.

2 Explain how magnetic resonance imaging (MRI) is used in medicine.

3 Describe the advantages and disadvantages of MRI scans compared with CT scans.

TEST QUESTIONS ON MEDICAL PHYSICS

QUESTION 1

(a) Ultrasound is an important method for imaging the interior of a human body.

(i) Define the term ultrasound. (1 mark)

(ii) Describe how ultrasound is produced in medical scanning. (2 marks)

(iii) Explain why a coupling medium (usually a gel) is required between the ultrasonic transducer and the patient's skin. (2 marks)

(b) Recall three advantages of ultrasound for medical imaging. (3 marks)

(c) The speed of sound in water, in human soft tissue and in the brain is all very similar. Explain why this is so. (1 mark)

(d) Briefly describe how X-rays are currently produced for medical diagnosis. (3 marks)

(e) Technetium-99m has a half-life of 6 h.

(i) Define the meaning of 'half-life'. (1 mark)

(ii) Calculate what fraction of technetium remains after 18 h. (2 marks)

(iii) Recall the advantage in medical diagnosis of such a short half-life. (1 mark)

(iv) Recall a disadvantage of the short half-life. (1 mark)

(f) The *National Medical Cyclotron* is situated in Camperdown, a Sydney suburb, near the Royal Alexandra Hospital for Children.

(i) What is the role of the cyclotron? (1 mark)

(ii) Recall one example of what is produced in the cyclotron. (1 mark)

(iii) Explain why it is placed near to the hospital. (1 mark)

(g) Clearly describe how an MRI scan is obtained. (5 marks)

QUESTION 2

(a) Ultrasound is a useful imaging technique in medical diagnosis.

(i) The resolution of ultrasound imaging can be improved by using higher frequency waves. Explain what limits the use of higher and higher frequencies. (2 marks)

(ii) Recall two disadvantages of ultrasound. Explain your answer. (2 marks)

(b) The speed of sound in brain tissue is ~1541 $m.s^{-1}$ and brain tissue has an acoustic impedance of 1.68×10^6 $kg.m^{-2}.s^{-1}$. Calculate the approximate density of brain tissue. (2 marks)

(c) Explain how X-rays are used in simple (not CT) imaging. (3 marks)

(d) Technetium-99m is the most widely used radioisotope in nuclear medicine. It is used to scan organs such as the brain, thyroid, lungs and liver. Briefly explain how Tc-99m is able to provide an image of these organs. (4 marks)

(e) In radioisotope scanning, pure gamma emitters are the preferred radiation source. Explain why this is so. (2 marks)

(f) PET is the acronym for *Positron Emission Tomography*.

(i) Define the meaning of 'positron'. (1 mark)

(ii) Explain where they come from in medical imaging. (1 mark)

(g) MRI scans rely on measuring the 'spin' of hydrogen atoms.

(i) Define what is meant by the spin of an atom. (1 mark)

(ii) Describe what happens when atoms with spin are placed in a magnetic field. (2 marks)

(iii) Explain how this is used to produce a scan of a patient. (3 marks)

(iv) Explain why MRI is the preferred scanning technique for brain injury. (2 marks)

QUESTION 3

(a) Ultrasonography is a scanning technique commonly used in medical diagnosis. Two scan modes used are called *A*-scan and *B*-scan. Clearly distinguish between these two scan types. (4 marks).

(b) An X-ray tube consists of an evacuated tube, a cathode, a copper anode and a tungsten target.

(i) What is the purpose of the cathode? (1 mark)

(ii) Recall the purpose of the anode. (1 mark)

(iii) Recall the purpose of the tungsten target. (1 mark)

(iv) Explain how the X-rays could be made 'harder'. (2 marks)

(v) Describe how X-rays are used in simple (not CAT) medical diagnosis. (2 marks)

(c) Clearly explain how a CAT (CT) scan is produced. (5 marks)

(d) Radioisotope scanning relies on giving the patient a radiopharmaceutical.

(i) Define a 'radiopharmaceutical'. (2 marks)

(ii) Describe how they are administered to a patient. (1 mark)

(iii) Describe how they are used in the diagnosis of disease. (2 marks)

(e) Recall four advantages and four disadvantages of MRI scans over other diagnostic scans such as CT and PET. (4 marks)

QUESTION 4

(a) Ultrasound is extensively used to monitor the development of the foetus in the mother's womb.

(i) Explain what makes ultrasound useful for this task. (2 marks)

(ii) The scan we generally see of the foetus is a 'sector scan'. Describe how this is produced. (2 marks)

(b) The acoustic impedance of water and kidney is 1.34×10^6 $kg.m^{-2}s^{-1}$ and 1.62×10^6 $kg.m^{-2}s^{-1}$ respectively.

(i) Describe the significance of 'acoustic impedance'. (2 marks)

(ii) Calculate what fraction of incident ultrasound is reflected from a water/kidney interface. (2 marks)

(c) Describe one advantage of a CAT scan that makes it a better diagnostic tool than ultrasound or conventional X-rays. (2 marks)

(d) An endoscope is a device used to assist in medical diagnosis.

(i) What is an endoscope? (1 mark)

(ii) Explain what the coherent bundle of fibres in the endoscope is used for. (2 marks)

(iii) Briefly explain how an endoscope is used to assist in a biopsy. (3 marks)

(e) Describe one medical radioisotope you have studied and explain how it is used in medical diagnosis. (4 marks)

(f) Clearly explain how a PET scan is produced. (5 marks)

Chapter Five

Astrophysics

SECTION 1: MAKING OBSERVATIONS

BIG IDEA:

Our understanding of celestial objects depends upon observations made from Earth or from space near the Earth.

OUTCOMES:

Students learn to:

1 Discuss Galileo's utilisation of the telescope to identify features of the Moon.
2 Discuss why some wavebands can be more easily detected from space.
3 Define the terms resolution and sensitivity of telescopes.
4 Discuss the problems associated with ground-based astronomy in terms of resolution, absorption of radiation and atmospheric distortion.
5 Outline methods by which the resolution and/or sensitivity of ground-based systems can be improved including:
  - adaptive optics
  - interferometry
  - active optics.

Students:

1 Identify data sources, plan, choose equipment or resources for, and perform an investigation to demonstrate why it is desirable for telescopes to have a large diameter objective lens or mirror in terms of both sensitivity and resolution.
2 *Gather, process and present information on new generation optical telescopes.*

Physics Stage 6 Syllabus Outcomes © Board of Studies NSW, 1999 (Amended 2000, 2001, 2002, 2003)

CONTEXTUAL OUTLINE

Since the beginning of humankind, people have strained their eyes skywards and marvelled at the beauty and mystery of the heavens. With the technological advance provided by the invention of the telescope, it was realised that there are many more stars than people first thought existed. It was also realised that stars, like humans, are born, mature and eventually die.

To explain how the universe works, we use scientific models, theories and laws to make sense of our observations (using different components of the electromagnetic spectrum).

A range of techniques such as *photometry, astrometry, imaging* and *spectroscopy* allow us to discover much about the nature of celestial objects.

Advancements in technology have led to advancements in the means of obtaining information from space. These include Earth-bound optical and radio telescopes, as well as orbiting telescopes such as the *Hubble Space Telescope*.

Scientists continue to seek explanations for celestial phenomena (such as stellar evolution and the working of 'exotic' objects such as *neutron stars* and *black holes*) based on our knowledge and understanding of the electromagnetic spectrum.

High-energy radiation emitted by objects are studied to increase our understanding of *supernova* and *Einstein's General Relativity*.

We begin this chapter with a revision of the electromagnetic spectrum followed by how we determine the positions of celestial objects (astrometry). Next we look at how information from spectra allows us to infer much about celestial objects. Binary stars are then studied and we conclude with a look at stellar evolution[1].

GALILEO

In 1609, after hearing of an instrument that made things look closer, Galileo worked out the principles upon which it worked and constructed one of the earliest telescopes. He used it to gather new evidence for the Copernican Theory of the universe and Kepler's Law of periods (see *The Cosmic Engine*).

This evidence included the discovery of :

1 the moons of Jupiter;
2 the phases of Venus;
3 the rough features of the moon;
4 sunspots on the Sun; and
5 thousands of 'new' stars now became visible that could not be seen with the unaided eye.

This provided Galileo with evidence to refute the geocentric model of Ptolemy. The moons of Jupiter, for example, looked just like a 'Copernican system'; the phases of Venus showed that Venus must orbit the Sun as Copernicus had suggested.

The rough features of the moon, the sunspots and the 'new' stars all conflicted with the Ptolemaic belief that heavenly objects were *perfect* and the heavens were *unchanging*.

THE ELECTROMAGNETIC SPECTRUM

As we saw in the Preliminary Course *The World Communicates*, all electromagnetic waves travel at the same speed: 3 x 10^8 m.s^{-1} in a vacuum. (In different media, however, such as glass, they travel at different speeds resulting in *refraction*.)

Visible light is only a small part of the range of electromagnetic waves called the *electromagnetic spectrum*. The wavelength of visible light ranges from ~350 nm (1 nm = 10^{-9} m) for violet, to ~700 nm for red.

The wave types of this spectrum differ only in frequency (and hence wavelength). Figure 5.1 illustrates the electromagnetic spectrum.

As the diagram suggests, there is no sharp division between the various types—they gradually merge into one another. What we call them often depends on the manner of their production. X-rays for example, could be produced with wavelengths

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[1] Astrophysics has among the best sites on the World Wide Web, including:

http://csep10.phys.utk.edu/astr162/lect/index.html is the site of an excellent series of lectures on astrophysics. It is definitely worth a visit. It covers the entire topic (and more).

http://www.pbs.org/wnet/hawking/html/home.html is another excellent site for all things cosmological from the renowned cosmologist, Stephen Hawking.

http://observe.arc.nasa.gov/nasa/space/stellardeath/stellardeath_contents.html this excellent NASA site contains all you need to know about stellar evolution.

Other recommended sites include:

http://map.gsfc.nasa.gov/index.html

http://mrcohen1.keel.physics.ship.edu/108/evol.htm

http://zebu.uoregon.edu/textbook/se.html

http://www.public.iastate.edu/~astro_580/IbenTutST/iben1.html

http://cassfos02.ucsd.edu/public/tutorial/StevII.html

http://amazing-space.stsci.edu/

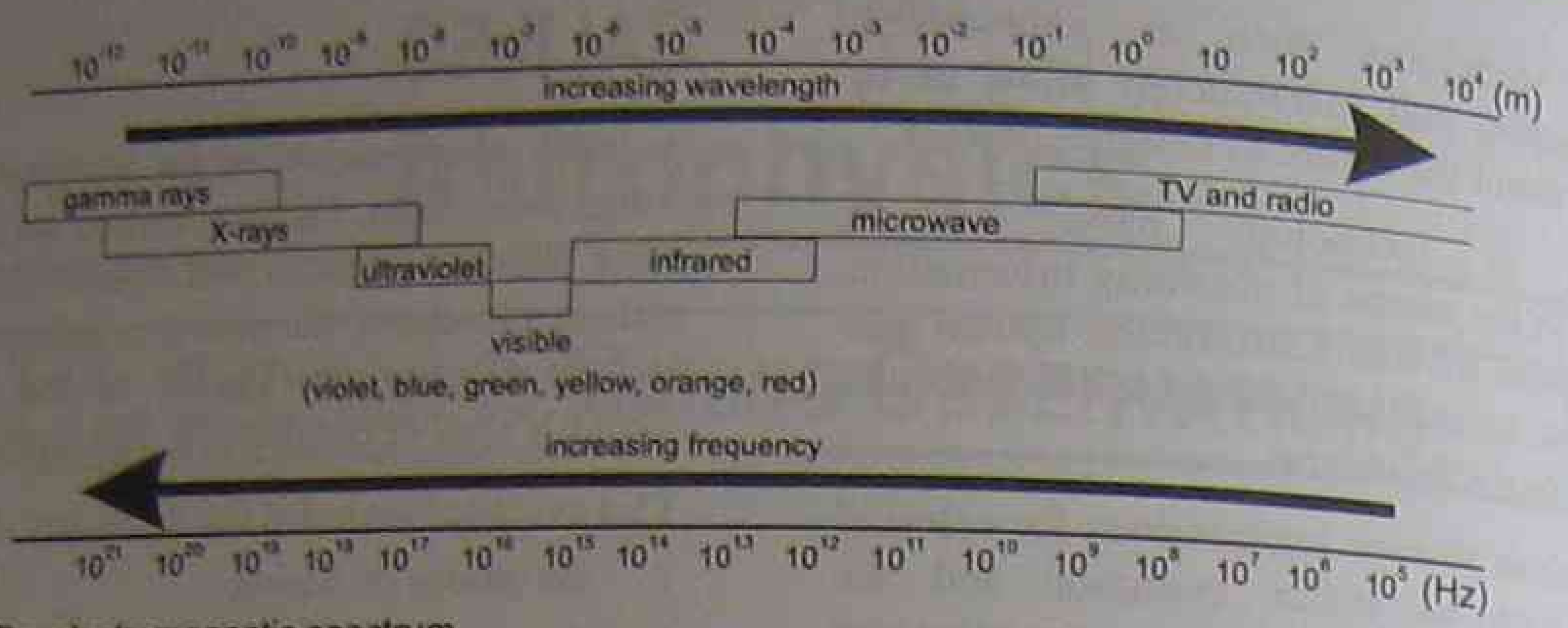

Figure 5. 1 The electromagnetic spectrum

similar to gamma radiation emitted by radioactive substances, but they are still referred to as X-rays because of how they are made (by allowing electrons to hit a metal target).

Table 5.1 indicates the *approximate* wavelengths of the members of the spectrum.

Table 5. 1 Approximate wavelengths of members of the electromagnetic spectrum. The boundaries between the different forms are approximate.

Wave Type	**Wavelength**
radio	kilometres to fractions of a metre
microwave	$10^{-2} - 10^{-4}$ m
infrared	$10^{-4} - 10^{-6}$ m
visible	7×10^{-7} m – 3×10^{-7} m
ultraviolet	3×10^{-7} m – 10^{-9} m
X-rays	$10^{-9} - 10^{-12}$ m
gamma rays	10^{-10} – ? m

ABSORPTION BY THE ATMOSPHERE

Selective absorption by the Earth's atmosphere of some bands of wavelengths, have implications for how and where we study electromagnetic radiations coming from objects in space.

High-energy gamma rays, ultraviolet and X-ray radiation are absorbed by the upper atmosphere; water vapour and gases in the atmosphere reflect much of the infrared radiation. As a result:

> **Ground-based astronomy** *is restricted primarily to the visible and radio-wave regions of the electromagnetic spectrum with some narrow 'windows' in the near infrared.*

The effects of the atmosphere are summarised in Table 5.2.

Table 5. 2 Effect of the atmosphere on members of the electromagnetic spectrum

Wave Type	**Wavelength**	**Effect of Atmosphere**
Radio	kilometres to fractions of a metre	Not absorbed. Wave-lengths >100m are reflected by the ionosphere.
Micro-wave	10^{-2}—10^{-4} m	Not absorbed.
Infrared	10^{-4}—10^{-6} m	Partly absorbed by water vapour and carbon dioxide.
Visible	7×10^{-7} m—3×10^{-7} m	Not absorbed.
Ultra-violet	3×10^{-7} m—10^{-9} m	Mostly absorbed by molecules in the atmosphere.
X-rays	10^{-9}—10^{-12} m	Absorbed by atoms in the atmosphere.
Gamma rays	10^{-10}—? m	Absorbed by nuclei in the atmosphere.

It is clear that there are 'transparent windows' for electromagnetic waves in the visible and radio wave sections. This has implications for astronomers as they attempt to investigate the structure and composition of the universe (see HSC Option Topic *Astrophysics*.)

It follows that to use these other radiations effectively (the ultraviolet and far infrared), we need to 'get above' the atmosphere. Orbiting telescopes and space probes travelling to distant objects are used to examine information in these bands.

E x t e n s i o n

Telescopes

Telescopes can be classified according to the wavelengths they detect. For example, there are *optical telescopes, ultraviolet telescopes, radio telescopes*… Optical telescopes can be further classified as either:

1 refracting; or
2 reflecting.

Refracting Telescopes

Refracting telescopes use lenses to focus the light from distant objects. They are limited by the size of the lens that can be accurately ground and supported. Too large and they distort under their own weight. They also absorb a significant part of the incident light (already extremely feeble from distant objects). Refractors are also larger than reflectors (see below) requiring bigger 'housing'.

The world's largest refractor is the 102 cm refractor in Yerkes Observatory in Wisconsin USA.

Reflecting Telescopes

Optical reflecting telescopes use mirrors to collect and focus the incident light. They too are limited in their size by engineering difficulties of mirror manufacture[2]. They are smaller than the equivalent refractor. The largest optical reflecting telescope today is the 10 m *Keck Telescope* in Hawaii.

Radio reflecting telescopes are used extensively to detect radio waves from space. They use either a wire mesh bowl-shaped 'dish' or straight 'dipole' to collect and focus the incoming radiation.

The largest radio reflector is the 305 m diameter dish in Puerto Rico.

GROUND-BASED TELESCOPES

We have seen that it is possible to avoid the absorption of certain wavelengths by 'getting above' the atmosphere. What about ground-based telescopes? In addition to the limit on the wavelengths than can be used[3], their effectiveness in observing distant stars and galaxies also depends on other factors including the telescope's:

1 *sensitivity*; and
2 *resolution* (resolving power).

SENSITIVITY

> *The* **sensitivity** *of a telescope is a measure of its light-gathering power.*

This depends upon the size of the aperture of the telescope (effectively the diameter of the lens or mirror for optical telescopes, or the dish for radio telescopes). The more light (or other form of electromagnetic radiation) than can be detected, the fainter the star (or galaxy) that can be 'seen'.

The larger the aperture, the more sensitive is the telescope. In astronomy, *big is better*. This is one reason why astronomers are always looking for larger telescopes.

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[2] For information on new ways of manufacturing reflecting telescopes, see *New Generation Optical Telescopes* p.178

[3] As a result, ground-based telescopes are often placed on high mountaintops and in regions of low humidity. Decide on a telescope site using Mountain Quest at: http://btc.montana.edu/ceres/html/mountainquest.htm

RESOLUTION (RESOLVING POWER)

> **Resolution** *is the ability of a telescope to clearly distinguish between two very close objects.*

(This may be because they are physically close together or because they are a long distance away.)

The resolution of a telescope is limited by two factors:

1. *aberrations*, that is, faults or imperfections in the lens or mirror; and
2. *diffraction*, that is, the bending of light (or other waves) around objects or through gaps.

Aberrations

Lenses and mirrors suffer from a number of aberrations that prevent a point object appearing as such but rather as a 'blob'. Good telescope design can limit these faults but not eliminate them.

Diffraction

Diffraction cannot be eliminated since it is a consequence of the wave nature of light. Light passing through an aperture causes *diffraction patterns* to be produced (Figure 5.2(a)). If two objects are so close that their diffraction patterns overlap, they cannot be distinguished as two separate sources (Figure 5.2(b)). When they can be distinguished, they are said to be *resolved*.

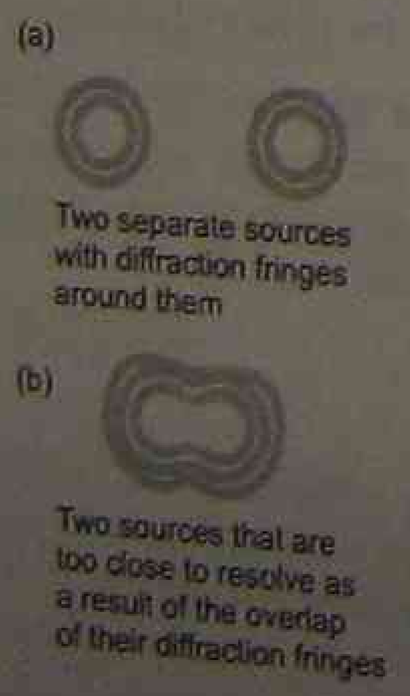

Figure 5.2 Diffraction effects on resolution

Angular Resolution

Resolution is measured in terms of the angle that is subtended by the object at the telescope and is hence called the *angular resolution*. It is measured in *radians*, but more commonly in *seconds of arc*[4] (arc seconds).

The resolution of a telescope is limited by:

1. The wavelength of the electromagnetic radiation that is detected. The smaller the wavelength, the better the resolution. As mentioned earlier, this radiation can be in the visible wavelengths, the ultraviolet wavelengths or even the radio wavelengths; and
2. The size of the aperture (that is, the diameter of the lens, mirror or dish). This is another reason why astronomers want larger telescopes.

Extension

Theoretical Resolution of Optical and Radio Telescopes

It can be shown that the theoretical resolution of a telescope is given by $\theta = 1.22\frac{\lambda}{D}$ where θ is the angular separation (the resolution) in radians, λ is the wavelength of the electromagnetic radiation detected and D is the effective diameter of the lens or mirror. (The smaller the value of θ, the higher the resolution.)

EXAMPLE 1

What is the theoretical resolution of the 5.1 m (200 inch) *Hale Telescope* at Mt Palomar in the USA? (Assume the visible light has a mean wavelength of 550 nm.)

SOLUTION

$$\theta = 1.22\frac{\lambda}{D}$$
$$= 1.22 \times \frac{550 \times 10^{-9}}{5.1}$$
$$= 1.3 \times 10^{-7} \text{ rad}$$
$$= 1.3 \times 10^{-7} \times \frac{360}{2\pi} \text{ degrees}$$
$$= 1.3 \times 10^{-7} \times \frac{360}{2\pi} \times 60 \times 60 \text{ arc seconds}$$
$$= 0.027 \text{ arc seconds}$$

Turbulence in the air ensures that this theoretical value is not achieved. (Large diameter objectives are not justified by the increased resolution but by their light-gathering ability.)

EXAMPLE 2

What is the theoretical resolution for the 300 m radio telescope in Puerto Rico if it uses 4 cm radio waves?

SOLUTION

$$\theta = 1.22\frac{\lambda}{D}$$
$$= 1.22 \times \frac{4 \times 10^{-2}}{300}$$
$$= 1.6 \times 10^{-4} \text{ rad}$$
$$= 1.6 \times 10^{-4} \times \frac{360}{2\pi} \text{ degrees}$$
$$= 1.6 \times 10^{-4} \times \frac{360}{2\pi} \times 60 \times 60 \text{ arc seconds}$$
$$= 33 \text{ arc seconds}$$

GROUND-BASED ASTRONOMY

As we have seen in Example 1, in theory optical telescopes have high resolving powers; atmospheric effects, however, limit the resolution to approximately one second of arc. The Earth's atmosphere not only *selectively absorbs* certain wavelengths of electromagnetic radiation (see p.172), but also *distorts the image* of distant light sources.

Seeing

When we look at a star on a clear night with our unaided eye, the star 'twinkles'. That is, it does not appear as a steady *point* of light but appears to 'wiggle about'. This is an example of an optical phenomenon called *'seeing'*.

> **'Seeing'** *is the distortion of the image of a distant light source by the Earth's atmosphere.*

Ground-based telescopes look through kilometres of atmosphere[5]. 'Seeing' results from variations in the Earth's refractive index over areas smaller than the aperture of typical telescopes. These variations typically cause the image of an unresolved star to break up into a number of distorted images called *'speckles'*. (This effect is equivalent to a distortion of the telescope.) Constant atmospheric movement causes these speckles to dissolve, reform and move about randomly.

To improve on the angular resolution scientists can:

1. move the telescope above the atmosphere (for example, the *Hubble Space Telescope*[6]); or
2. use *adaptive optics;*
3. use *interferometry;* or
4. use *active optics.*

Extension

It should be obvious that the 'seeing' effects of the Earth's atmosphere can be eliminated, by placing the telescope in space. This also allows wavelengths to be received that would otherwise be absorbed, in particular the ultraviolet and parts of the infrared. It also eliminates the so-called 'background noise' due to city lights. The cost, however, is prohibitive in all

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[4] In one complete revolution there are 360 degrees of arc. Each degree is made up of 60 minutes of arc and each minute is made up of 60 seconds of arc.

[5] It is the first 30 km or so of atmosphere that most affects seeing. Placing telescopes on high mountains tends to lessen the effect.

[6] The *Hubble Space Telescope* was launched in 1990 and became fully operational in late 1993.

but a few cases. (The *Hubble Space Telescope* cost over a billion dollars to build and put into orbit.)

Earth-orbiting satellites have been utilized to carry telescopes for all wavelengths from gamma to infrared.

ADAPTIVE OPTICS

> **Adaptive optics** *is a technique that involves measuring and compensating (in real-time) for the atmospheric effects.*

Adaptive optics of telescopes involves sampling part of the incident light (for example, from a star), and measuring the amount of atmospheric distortion (bending) in a *wavefront sensor*. Any distortions in the wavefront sensor correspond to distortions in the atmosphere above the telescope. By sampling the light up to 1000 times per second and feeding the information back to a tilt-tip mirror (which can adjust for small changes in the light's position) and an adjustable 'flexible mirror', astronomers can effectively 'straighten out' the light that has been bent by the atmosphere. Ideally this allows the part of the light used to create the image to pass through the telescope undistorted, dramatically improving image resolution.

Most adaptive optic systems have three elements (Figure 5.3):

1 the *wavefront sensor*;

2 the *wavefront correction device* (usually a tilt-tip mirror and a flexible mirror); and

3 a *computer* to analyse the information from the sensor and control the correction device.

The mirror can be a single thin piece or it can consist of individual segments (see p.178). In either case, *piezoelectric actuators* adjust the mirror by applying tiny pushes or pulls. (The amount of adjustment is miniscule, as little as $\frac{1}{240\,000}$ mm!)

Adaptive optics requires a bright reference star for detection of the wavefront distortion. Unfortunately not all objects of interest have such a star nearby! One solution is to create an artificial 'star' by scattering a laser pulse off sodium atoms in the upper atmosphere. While not perfect, this is a good compromise when real reference stars are absent.

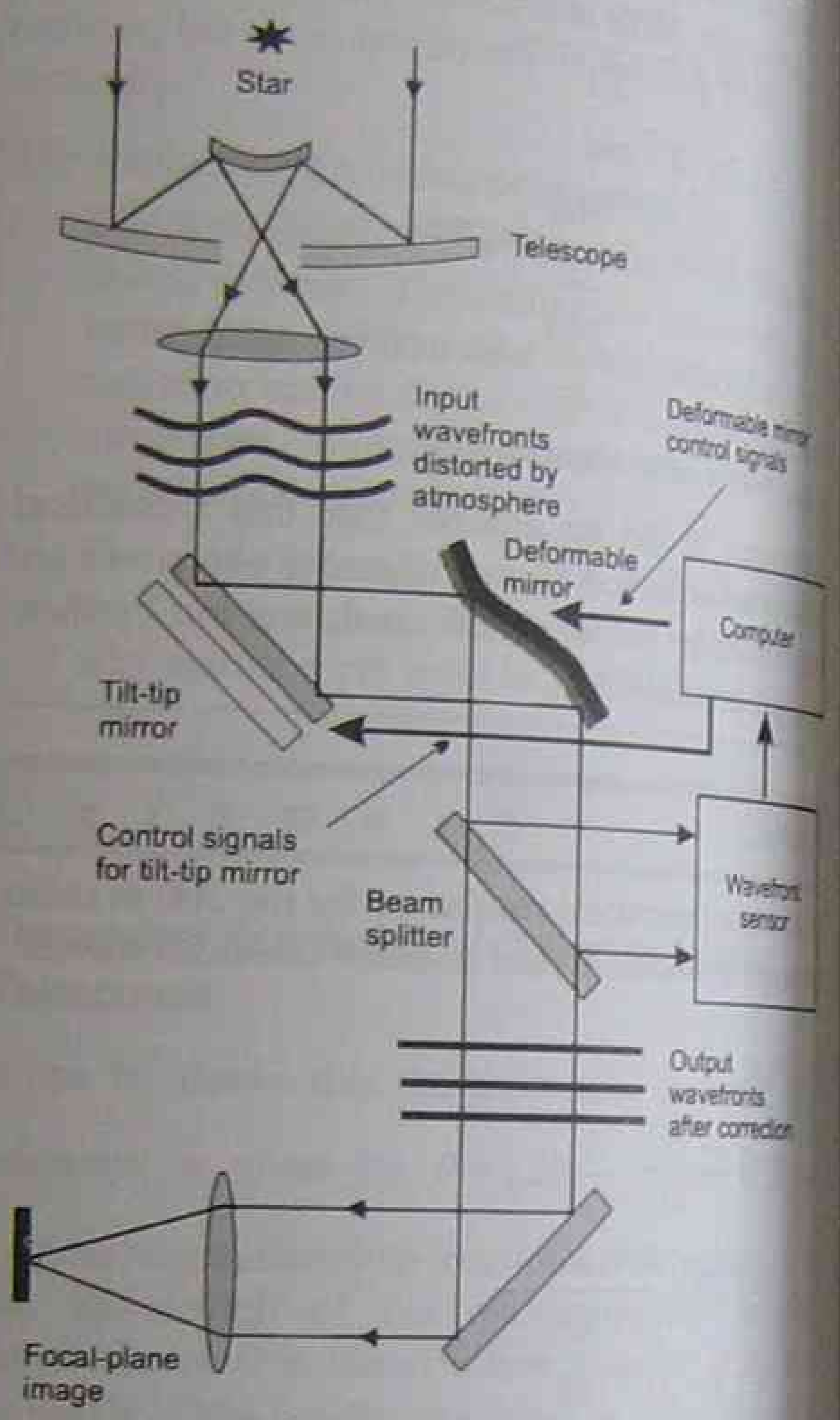

Figure 5. 3 The principle of adaptive optics

Adaptive optics is designed for telescopes of at least 2 m diameter. In Australia this includes the 3.9 m *Anglo-Australian Telescope* and the Australian National University's 2.3 m telescope, both at Siding Springs in NSW. These telescopes have adaptive optics and use a *bimorph* mirror. This is made from two plates of piezoelectric material bonded together. Voltages applied to the mirror cause it to flex. In this way the shape can be adjusted to compensate for imperfections.

INTERFEROMETRY

The sensitivity of a telescope depends on the surface area of the mirror used (and on its diameter). The resolution, however, depends on the diameter only and not the surface area. Hence, two mirrors separated by the diameter of one large mirror *will* have the same resolution. This idea is put to use in the *interferometer*.

Theoretically, two *appropriately connected* telescopes separated by a distance of 50 m will have the same resolving power as one mirror with a 50 m diameter.

It follows that the angular resolution in optical and radio telescopes can be improved by using several telescopes connected in an array and by using the phenomenon of *interference*.

> **Interferometry** *is a technique used to study optical or radio-wave interference. The device in which it occurs is called an* **interferometer**.

Optical Interferometers

In the simplest optical interferometer, two optical telescopes observe the same star (Figure 5.4). The two light beams are superimposed and interference occurs between the waves. The star's brightness will vary according to the delay in the arrival time of the beams at the two telescopes (which is determined by the extra distance—the *path difference* that the light has to travel to the furthest telescope). If they arrive at the same time then the waves 'add up'. This is called *constructive interference*.

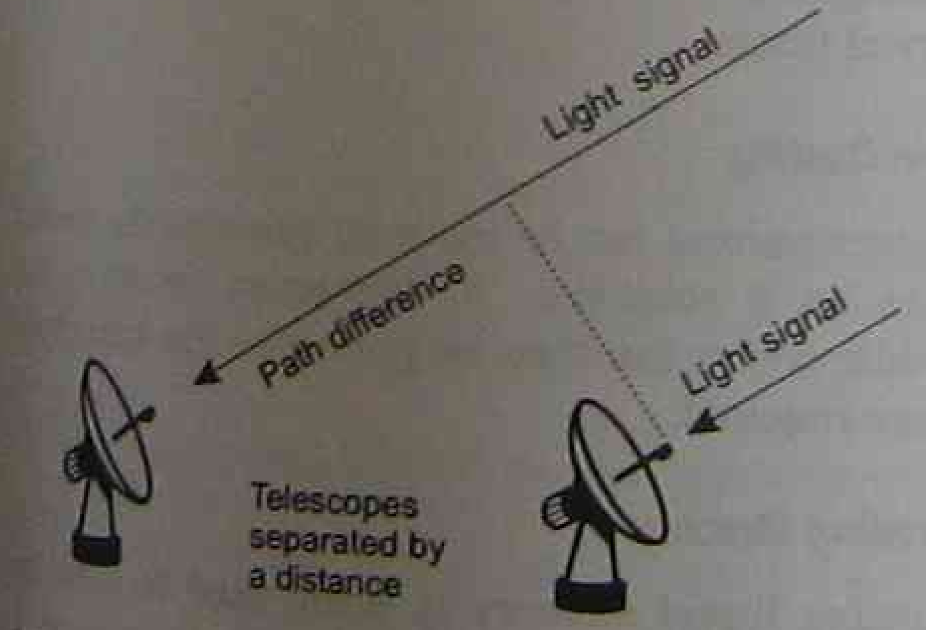

Figure 5. 4 Michelson interferometer

As the Earth rotates on its axis, one telescope comes closer to the star than does the other. If it is closer by half a wavelength, a crest from one coincides with a trough from another and *destructive interference* occurs—the star 'disappears'. As rotation proceeds, the star successively reappears and disappears. The further apart the two telescopes, the narrower the interference fringes and the greater the angular resolution.

A Michelson interferometer doesn't measure an image directly. One can, however, be reconstructed from the data of interference fringes.

In 1920, Albert A. Michelson and Francis Pease measured the apparent diameter of the largest star, Betelgeuse, using the phenomenon of interference (although they used two apertures of the same telescope rather than two separate ones). To measure smaller star diameters requires the telescopes to be separated more, which presents significant engineering problems. 'Seeing' also presents problems.

It was not until 1975 that Antoine Labeyrie observed interference fringes with separate telescopes. Today, distances of less than 100 m separate most telescopes in optical interferometers.

Optical interferometers are best used for astrometric purposes, that is, for accurate determination of stellar distances and diameters.

Radio Interferometers

The difficulties of using separate optical telescopes meant that interferometry is most commonly used for radio telescopes. The *Very Large Array (VLA)* in New Mexico USA uses 27 movable radio dishes to simulate one large radio telescope. The signals from each dish are sent via coaxial cable or fibre optic link to a central laboratory where they are combined to form the high-resolution image.

Very Large Baseline Interferometry (VLBI)

By setting the components of the interferometer thousands of kilometres apart, the resolution of radio telescopes can be increased significantly.

Coaxial cable and fibre optic links, however, become impractical due to cost. Recording the information from each element of the interferometer on broadband videotape and sending the tapes to a central location allows high-resolution images to be obtained.

To ensure that the individual recordings are synchronised, atomic clocks are used at each telescope (accurate to better than one millionth of a second). Angular resolutions as high as 1 arc second can be achieved by this method.

ACTIVE OPTICS

Whereas *adaptive optics* attempts to compensate for the turbulence in the atmosphere (see p.176), *active optics* attempts to compensate for imperfections in the actual mirror (which means they can be made bigger).

> **Active optics** *is a technique that involves measuring and compensating (in real-time) for imperfections in the telescope mirror.*

New telescopes like the 8 m *European Southern Observation (ESO)* use thin plates only 20 cm thick. One hundred and fifty actuators push and pull on the back surface of the mirror 'actively' controlling the mirror's shape. The active optics mirrors work in a similar manner to the adaptive optics discussed previously, except they need only work much slower (every minute or so).

Active control ensures that even if the mirror's shape is not perfect, large-scale errors can be controlled by the actuators; so too, distortions due to temperature variations can be compensated for.

The best examples of such active control telescopes are the two *Keck Telescopes*[7] on Mauna Kea[8] in Hawaii. These telescopes each comprise 36 separate, 1.8 m long hexagonal mirrors, ~7 cm thick and each pre-stressed into the desired shape. Each segment is computer controlled to $\frac{1}{240,000}$ mm to maintain image quality!

Keck I was commissioned in 1992 and *Keck II* in 1999. They represent the world's largest telescopes for optical and near-infrared astronomy. With an 85 m baseline, the two telescopes can act as a two-element interferometer with a predicted resolution of 5 milliarc seconds (mas) at 2.2 μm wavelength.

It is planned that by 2002 these two telescopes will be combined with four 'outrigger' telescopes to act as a larger optical interferometer with the resolution rising to 30 microarc seconds (μas)!

Secondary Source Investigation

New Generation Optical Telescopes

As we have seen, scientists want bigger and bigger mirrors for their telescopes. This is because bigger mirrors mean greater light-gathering ability, which in turn means that fainter objects can be seen.

The cost of mirrors for telescopes, however, increases at approximately the cube of the diameter. That is, doubling the mirror's diameter increases its cost approximately eight-fold. New, cheaper methods of increasing mirror size are required.

Lightweight Mirrors

Lightweight glass mirrors are being developed to create a new generation of optical telescopes. Until recently, large reflecting telescopes had primary mirrors with thicknesses approximately one-sixth the mirror's diameter. This ensures stability in the shape as it is moved to examine different parts of the sky.

Mirrors can be made lighter in a number of ways. The mirror's weight can be lessened by 'digging out' a significant amount of the mirror's back or by casting mirrors with a honeycomb back structure and curved fronts.

Spin Casting

Lighter mirrors can be made by spinning the molten glass as it solidifies. A depression forms in the middle which can then be ground to the hyperbolic shape required.

Rotating Mercury

Rotating liquid mercury is being used to form the surface in a new generation of parabolic mirrors. A successful 2.7 m 'liquid mirror' has been built in Canada. With the mercury only 2 mm thick, the mirror is capable of diffraction-limited performance. Already other metals such as gallium and its alloys are being investigated for use in 'liquid mirrors'.

Thin Mirrors

An exciting new development is the production of *thin mirrors* (~1 mm thick) made from curved glass face-sheet attached to a honeycomb composite backing structure.

Already a 2 m prototype has been fabricated for the *New Generation Space Telescope (NGST)* being developed by NASA with mirrors up to 4 m being considered.

Replica Mirrors

Another new development has seen weight and cost further reduced by replicating already existing mirrors. A graphite reinforced composite (GRFC honeycomb material is applied to the mirror which acts as a template. After it cures, the GRFC forms a shell with the shape of the template. After separation from the template and coating with a reflecting material, the new mirror is ready for use. It needs only to be thick enough to maintain its optical shape, typically a few mm.

Gemini Telescopes

Mauna Kea in Hawaii is also home to the *Gemini telescopes*[9] to which Australia is a partner.

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[7] http://huey.jpl.nasa.gov/keck/ is the web site of the *Keck Telescopes*.

[8] This is one of the best observing sites in the world. It is approximately twice as high as the next highest major observatory and is above 40% of the atmosphere. Nights are calm and clear and it remains above clouds for most of the time.

[9] http://www.gemini.anu.edu.au/public/public.html is the Gemini web site. Allows the viewer to go on a virtual tour.

SECTION 2: ASTROMETRY

BIG IDEA:

Careful measurement of a celestial object's position, in the sky, (astrometry) may be used to determine its distance.

OUTCOMES:

Students learn to:

1 Define the terms parallax, parsec and light-year.
2 Explain how trigonometric parallax can be used to determine the distances to stars.
3 Discuss the limitations of trigonometric parallax measurements.

Students:

1 *Solve problems and analyse information to calculate the distance to a star given its trigonometric paralla using* $d = \frac{1}{p}$.
2 *Gather and process information to determine the relative limits to trigonometric parallax distanc determinations using recent ground-based and space-based telescopes.*

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ASTROMETRY

Of major interest to astronomers is the measurement of a celestial object's position, as this can be used along with other measurements, to determine the distance to that object.

> **Astrometry** *is the measurement of the positions and motions of the stars.*

PARALLAX

Place the first finger of your right hand approximately 30 cm in front of your nose. Now close your left eye, keeping your right eye open. Quickly open your left eye and close your right eye. Repeat a few times, swapping your open eye with your closed eye. You will notice that your fing *appears to move relative to the background.*

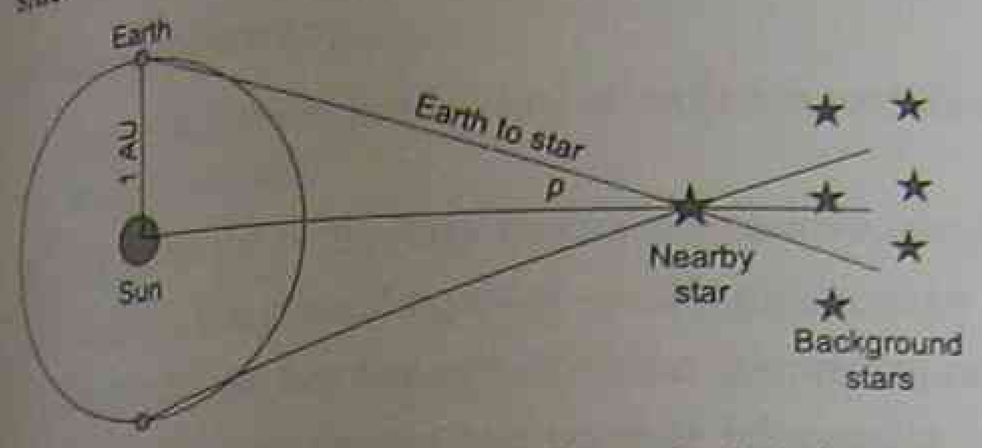
> *When an object is viewed from two differe positions it appears to move in relation to it background. This apparent movement is terme* **parallax**.

In astronomy parallax refers to the difference i direction of a celestial object when viewed by a observer from two widely separated points.

TRIGONOMETRIC PARALLAX

Parallax can be used directly to determine the distance of nearby stars (within a few hundred ligh years! For more distant stars, other methods must be used since the amount of parallax is negligible.)

Consider the Earth as it rotates about the Sun as in Figure 5.5[10]. By observing a nearby star against the background of more distant stars on two separate occasions when the Earth is at the opposite end of its orbit, we can measure the parallax (the angle labelled p in the diagram). From trigonometry, if we know one angle and one side of a right-angled triangle, we can calculate the length of the other side.



If p = 1 arc second, the distance to the nearby star is 1 parsec

Figure 5. 5 Trigonometric Parallax

These distances are generally measured in units called *parsecs* (and in some cases in *light-years*.)

PARSEC

The parsec is a standard astronomical distance.

> *One* **parsec** *is the distance at which the radius of the Earth's orbit subtends an angle of one second of arc.*

If the parallax of a star (p) is measured in *seconds of arc*[11] *(arc seconds)*, then the distance (d) in parsecs is given by:

$$\boxed{d = \frac{1}{p}}$$

EXAMPLE 3

The nearest star, Proxima Centauri, has the largest measured parallax of 0.772 seconds of arc. (The smallest that can be directly measured is about 25 times smaller than this.) How far away is Proxima Centauri?

SOLUTION

$$d = \frac{1}{p}$$
$$= \frac{1}{0.772}$$
$$= 1.30 \text{ parsecs}$$

EXAMPLE 4

The smallest parallax that can be measured from the Earth is ~0.03 arc seconds. What distance does this correspond to?

SOLUTION

$$d = \frac{1}{p}$$
$$= \frac{1}{0.03}$$
$$= 33 \text{ parsecs}$$

Distances within our galaxy (the Milky Way), are generally measure in *kiloparsecs* (where 1 kiloparsec = 1000 parsecs). For distances to other galaxies, we use megaparsecs. (1 megaparsec = 1,000,000 parsecs).

Light-Year

This is another unit of astronomical distance.

> *One* **light-year** *is the distance travelled by light in one year.*

EXAMPLE 5

How long is one light-year in metres?

SOLUTION

$$s = vt$$
$$= 3.0 \times 10^8 \times 365.25 \times 24 \times 60 \times 60 \text{ m}$$
$$= 9.47 \times 10^{15} \text{ m}$$

---

[10] http://instruct1.cit.cornell.edu/courses/astro101/java/parallax/parallax.html Java applet demonstrating trigonometric parallax

[11] There are 3600 arc seconds in 1 degree. The ball of a ballpoint pen subtends 1 arc second at a distance of approximately 100 m!

Parsecs and Light-years

One parsec is equal to 3.26 light-years.

EXAMPLE 6

How far away is Proxima Centauri in light-years given that it is a distance of 1.29 parsecs?

SOLUTION

$$d = 1.30 \times 3.26$$
$$= 4.24 \text{ light years}$$

Problems of Trigonometric Parallax

The errors in measuring parallax mean that it is only useful for the nearest stars, that is, stars within a few hundred light-years. This accounts for approximately 700 stars only of the estimated billions of stars.

SECTION 3: SPECTROSCOPY

BIG IDEA:

Spectroscopy is a vital tool for astronomers and provides a wealth of information.

Students learn to:

1. Account for the production of emission and absorption spectra and compare these with a continuous black body spectrum.
2. Describe the technology needed to measure astronomical spectra.
3. Identify the general types of spectra produced by stars, emission nebulae, galaxies and quasars.
4. Describe the key features of stellar spectra and describe how this is used to classify stars.
5. Describe how spectra can provide information on surface temperature, rotational and translational velocity, density, and chemical composition of stars.

Students:

1. *Perform a first-hand investigation to examine a variety of spectra produced by discharge tubes, reflected sunlight or incandescent filaments.*
2. *Analyse information to predict the surface temperature of a star from its intensity/wavelength graph.*

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SPECTRA

Everything we know about stellar objects has been deduced from the electromagnetic radiation (visible light, infrared, ultraviolet, radio...) that comes to us from these objects. The range of wavelengths that we observe is the *spectrum* of the source.

From a stellar object's spectrum we can determine characteristics including:

1. surface temperature;
2. speed of translation and rotation;
3. density; and
4. chemical composition.

Spectral analysis (*spectroscopy*) is an extremely important aid to the astronomer because spectra are an element's 'fingerprints' in that these spectra are as unique to each element as a person's fingerprints are unique to that person.

Spectra can be either emission or absorption spectra.

Emission Spectra

Emission spectra can be either 'continuous' or 'line' or 'band' spectra.

Continuous Spectra

When a piece of metal is heated it changes colour from red to white, passing through orange, yellow and white-yellow as it gets hotter. When viewed through a spectroscope (see p.186), a *continuous spectrum* is seen. This means 'all of the colours of the rainbow' are present.

This spectrum is in agreement with Planck's *black body radiation* as discussed in *The Cosmic Engine.*

Solids, liquids or very dense gases produce continuous spectra where interactions take place between adjacent atoms. All wavelengths are produced.

Line Emission Spectra[12]

> *When an element is excited by heating it to incandescence or passing an electrical discharge through it, the element emits light of definite wavelengths, giving a* **line emission spectrum** *when viewed through a spectroscope (Figure 5.6).*

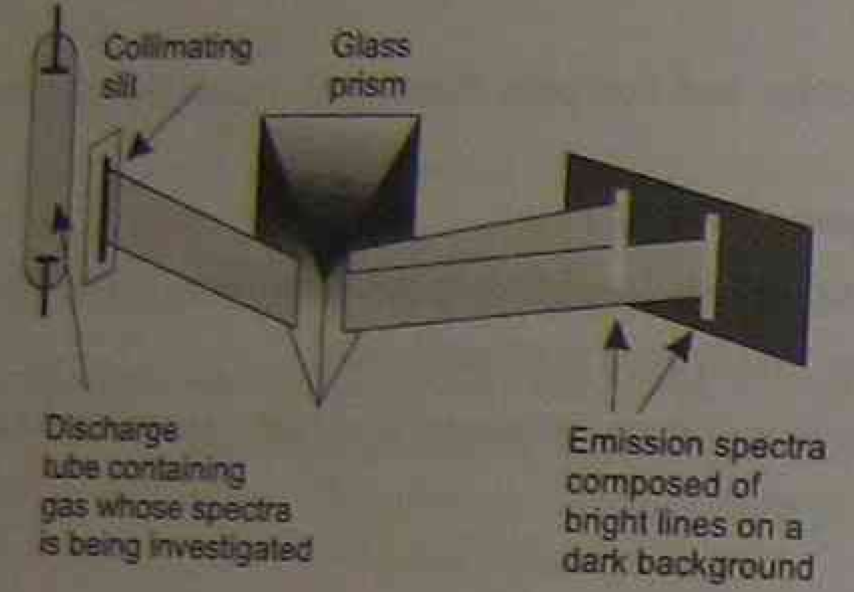

Figure 5. 6 Production of a line emission spectrum

Each element has a characteristic line spectrum (the lines being images of the spectroscope's slit in specific wavelengths) and this can be used to identify that element. Figure 5.7 shows the line emission spectrum of hydrogen (in the visible portion of the spectrum known as the Balmer series).

Low-density monatomic gases and vapours at high temperatures produce line spectra.

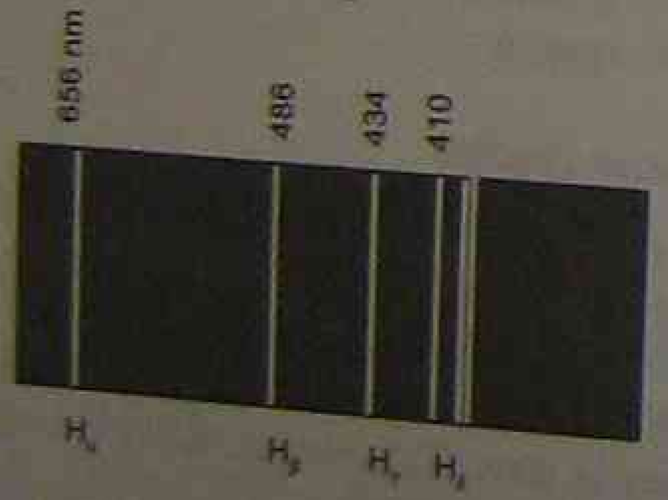

Figure 5. 7 Line emission spectrum of hydrogen

Band Emission Spectra

When molecules are excited they tend to emit 'bands' rather than discrete lines. In particular the molecules O_2, CO_2 and $H_2O_{(g)}$ produce such spectra due to interactions between the atoms of the molecule.

How Are Line Emission Spectra Formed?

According to the Bohr model, atoms consist of a dense positive nucleus surrounded by negatively charged electrons. These electrons are arranged in *discrete energy levels*. Electrons can exist in these levels only. Each energy level can only contain a certain number of electrons: two in the first level, eight in the second level, eighteen in the third level…

The simplest atom, hydrogen, consists of a nucleus of one proton with one electron moving about the electron is normally in the lowest energy level (the *ground state*). When an atom of hydrogen is excited, for example, by an incoming photon, the electron can absorb sufficient energy to 'jump' to the next (higher) energy level. The electron then 'falls back' almost immediately and releases the energy as a quantum or photon of energy (Figure 5.8(a)).

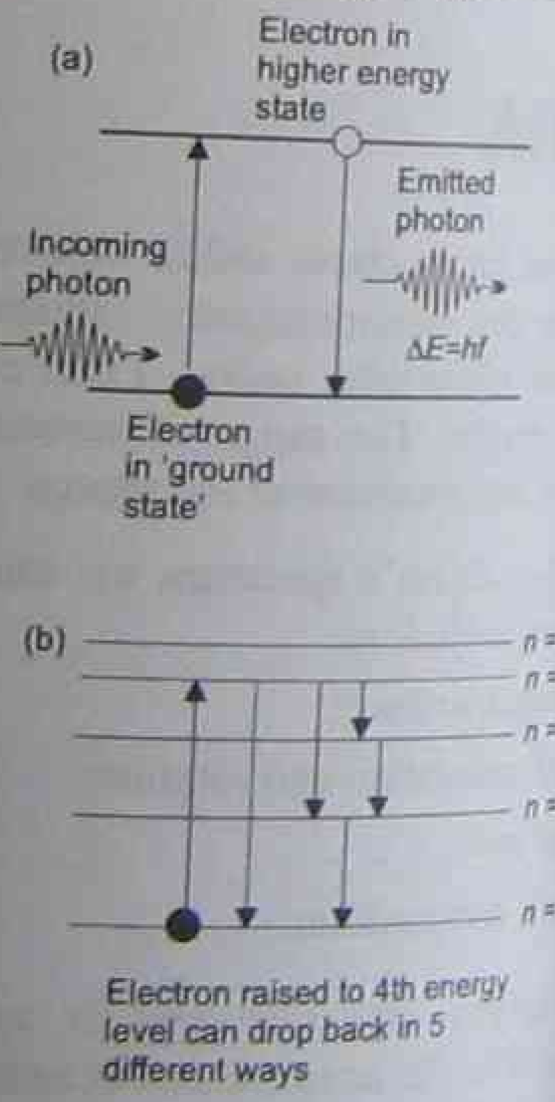

Figure 5. 8 Formation of line spectra at the atomic level

The energy is quantised by the relationship $\Delta E = hf$ where ΔE is the energy difference, h is Planck's constant and f is frequency. It follows that

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[12] http://jersey.uoregon.edu/elements/Elements.html Spectra of all the elements. Just click and its emission or absorption spectra is displayed. Another excellent site is http://phys.educ.ksu.edu/vqm/html/emission.html simulates emission and absorption spectra. Requires Shockwave.

there are only certain energy levels, only discrete frequencies are possible and these correspond to discrete wavelengths or colours (in the visible portion of the electromagnetic spectrum).

With millions of atoms in any sample, there is a range of discrete wavelengths corresponding to transitions between different energy levels (Figure 5.8(b)). (To be part of the visible spectrum, the electrons must fall back to the second energy level.)

Absorption Spectra

> *Just as an element is capable of emitting certain frequencies of light, so too it is capable of absorbing these same frequencies, giving an* **absorption spectrum.**

When light, for example, passes through the cooler layers of gas (such as the photosphere of a star), certain *absorption lines* are observed when the light is viewed through a spectroscope (Figure 5.9). (In the solar spectrum these lines are referred to as *Fraunhofer lines*.)

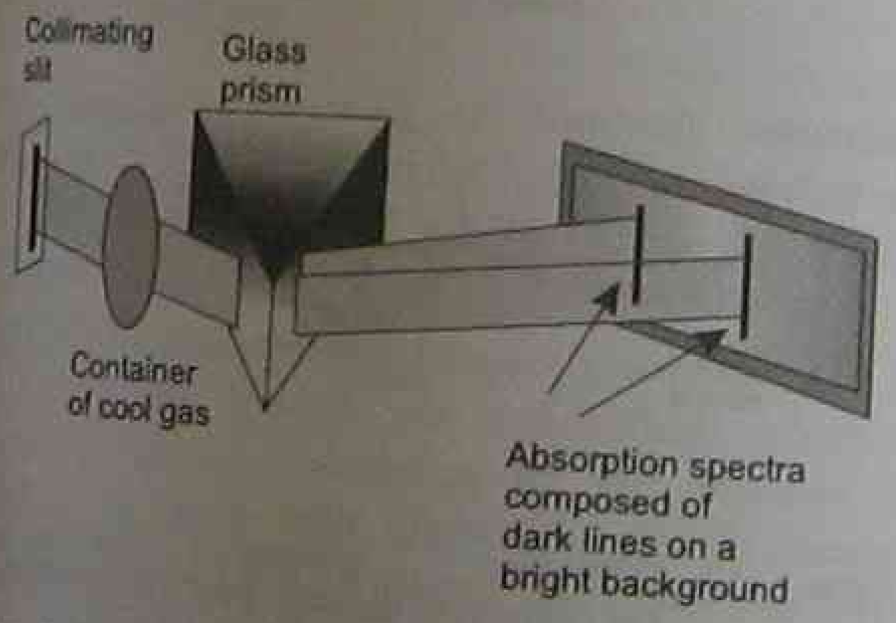

Figure 5. 9 Production of an absorption spectrum

By comparing the positions of these absorption lines with the positions of the emission lines from known elements on Earth, the composition of the star can be deduced. Figure 5.10 compares the line emission and line absorption spectra of hydrogen. Note that the lines correspond.

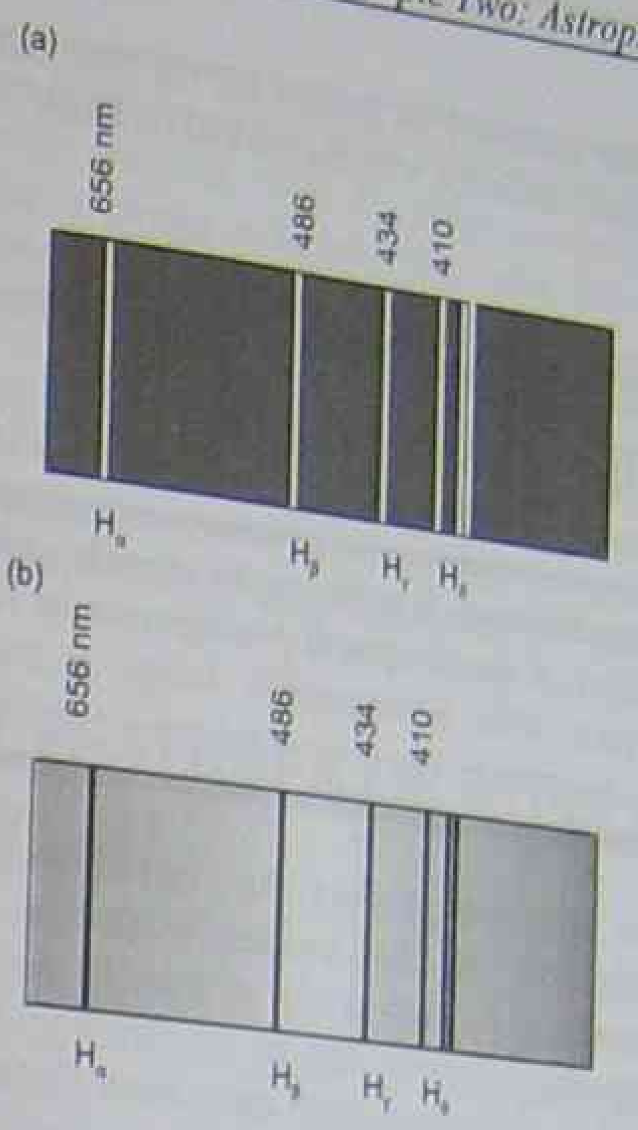

Figure 5. 10 Emission and absorption spectra of hydrogen

How are Line Absorption Spectra Formed?

Consider what happens if a continuous spectrum of light passes through cooler hydrogen gas. Electrons in the hydrogen absorb energy from the continuous spectrum at particular frequencies, corresponding to the discrete energy required to raise the electron to a higher energy level. This 'removes' these particular frequencies (wavelengths) from the continuous spectrum giving rise to an absorption spectrum. (Although the electron 'relaxes' almost immediately and falls back to a lower energy level and releases the energy, it does so in all directions. Relative to the direction of the incident light, the intensity is much less and so appears dark.)

Contributions of Spectroscopy

Spectroscopy has made many contributions to astronomy, among them being:

1 The identification of the elements in the atmosphere of stars and galaxies.

2 The detection of an invisible member of a binary star by Doppler shift (see p.198).

3 The detection of the expansion of the universe (see *The Cosmic Engine*).

4 The discovery of helium (in the Sun and other stars), before it was discovered on Earth.

SPECTROSCOPE (SPECTROMETER)

A **spectroscope** *is a device for visually observing spectra. A* **spectrograph** *photographs or records spectra. (The photographic image is called a spectrogram.)*

There are two devices for spreading out the wavelengths of the incident radiation into a spectrum:

1 a prism; and
2 a diffraction grating.

A Prism Spectroscope

In a prism spectroscope (Figure 5.11), light from a source passes through a slit and is collimated (made into a parallel beam) and is then dispersed by the prism. An eyepiece then examines the 'spread out' light. Rotation of the eyepiece allows different wavelengths to be measured.

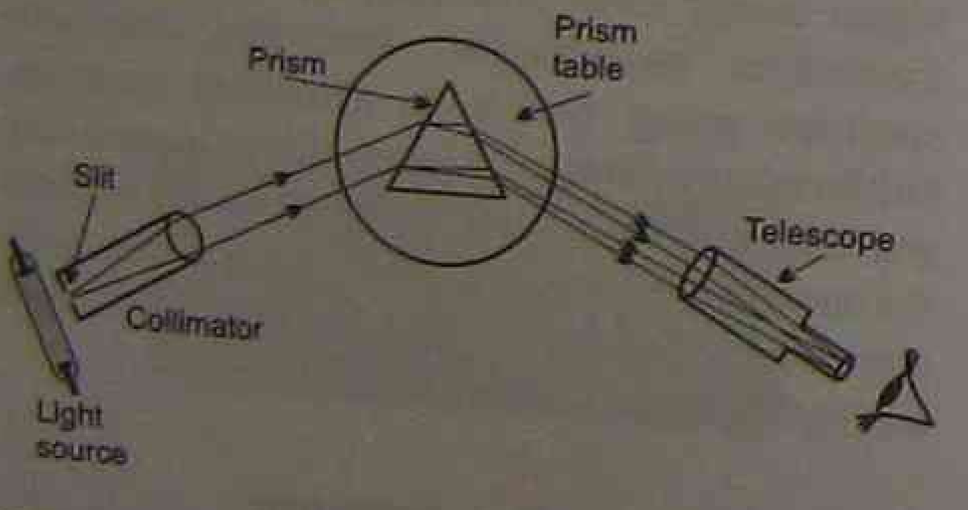

Figure 5.11 A prism spectroscope

When analysing starlight, the collimator can be dispensed with as the light arrives parallel from the distant star because it has travelled so far.

A limitation of prisms is that they absorb some of the radiation. Glass in particular absorbs the ultraviolet and infrared.

A Diffraction Spectroscope

The majority of modern spectroscopes use diffraction gratings[13]. These can be either *reflection gratings* (Figure 5.12(a)) or *transmission gratings* (Figure 5.12(b)).

Concave reflection gratings both disperse and focus the light which falls onto a detector such as a telescope (or more commonly a photomultiplier). The grating is rotated resulting in radiation of a particular wavelength falling onto the detector.

Diffraction gratings have better *resolving power* than prisms.

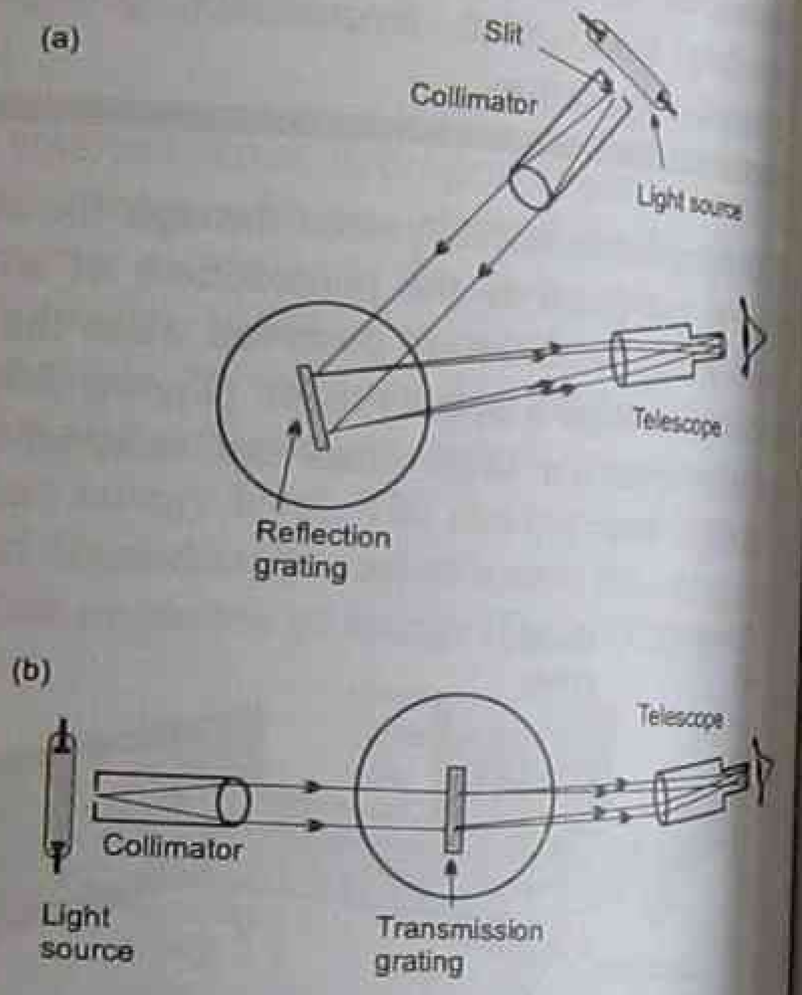

Figure 5. 12 Diffraction grating spectroscopes (a) Reflection grating and (b) Transmission grating

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[13] A diffraction grating consists of a large number of lines (thousands per cm) of parallel 'slits'. Interference between the light from each slit causes the different wavelengths to be spread out into a spectrum. They can be transmission gratings or reflection gratings.

STELLAR SPECTRA[14]

There is a range of stellar spectra. They can be produced by:

1 stars
2 emission nebulae
3 galaxies and
4 quasars.

Star Spectra

Stars produce spectra that depend directly on the star's temperature according to Planck's *black body radiation*. The spectrum of a star is an absorption spectrum (see p.185).

Emission Nebulae Spectra

Emission nebulae spectra result when the interstellar gas clouds surrounding hot stars are excited by UV radiation from the star. The gas is mainly hydrogen and the light is mainly hydrogen emission spectra although other elements (for example, nitrogen and oxygen) are also present and give off their own characteristic emission lines.

Galaxy Spectra

A galaxy is composed of hundreds sometimes millions of stars gravitationally bound together and circling about a common centre. The Milky Way is our galaxy.

Tens of thousands of galaxies are known to exist. In all cases, the spectra are red-shifted, which is explained by the expansion of the universe. In addition to stars and planets, galaxies contain hydrogen gas in both its atomic and molecular forms and complex molecules containing hydrogen nitrogen, carbon and silicon.

Galaxies not only emit visible light but emissions across almost the entire electromagnetic spectrum, in particular, radio waves and infrared.

Quasar Spectra

Although the earliest quasars to be discovered were strong radio-wave sources, the definition has been extended as follows:

Quasars *(quasi-stellar radio sources) are distant 'starlike' sources, that is, point sources, that exhibit a strong red-shift. They emit enormous amounts of energy.*

Quasars are only 1–2 light-years in size and it is thought that an object of this size can only produce the enormous amounts of energy they do is by gas being 'swallowed up' by a black hole.

KEY FEATURES OF STELLAR SPECTRA

Absorption spectra of stars vary in terms of the strength and pattern of the individual absorption lines. While some stars have strong hydrogen lines (dark lines, since absorption), others have no hydrogen lines but may contain calcium or sodium lines. The temperature of the star's photosphere determines the pattern. Measure the pattern and you can determine the temperature!

This is usually done first for the hydrogen lines. As discussed earlier, an absorption line occurs when an electron absorbs a quantum of energy and jumps to a higher energy level in an atom. To produce a line in the visible portion of the electromagnetic spectrum, the electron must be in the *second energy level* when it absorbs a photon.

If the temperature is too low, the electrons may be in the first energy level (the *ground state*) and will not produce a strong absorption line. Conversely, too high a temperature will result in complete ionisation of the atoms, stripping them bare of their electrons. Again, no absorption can occur.

To produce strong hydrogen absorption lines, the star's temperature must be within a certain range (4,000 K to 12,000 K).

Helium atoms, on the other hand, cling tightly to their electrons and temperatures in the range of 15,000 K to 30,000 K are needed for strong helium absorption lines in the visible portion of the spectrum.

Different atoms are sensitive to different temperatures. By comparing their spectra, it is possible to accurately determine any star's temperature.

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[14] http://amazing-space.stsci.edu/ Learn about stellar colours and temperatures at the Star Light, Star Bright java applet at the Space Telescope Science Institute.

CLASSIFYING STARS BY THEIR SPECTRA

Stars can be classified on the basis of information deduced from stellar spectra[15]. One way is to group stars whose spectra indicate that they have the same or very nearly the same surface temperature. As we have just discussed, this is based on the strength of the hydrogen absorption lines.

Different *spectral classes* result from this grouping. The A class have the strongest (darkest) hydrogen absorption line; B class is the next strongest. Originally, almost all the letters of the alphabet were used but over a period of time, astronomers have consolidated the various types into *seven* classes. They are referred to as O, B, A, F, G, K, M (*O Be A Fine Girl Kiss Me*). Within each spectral class there are a further 10 subdivisions (types) labelled A0, A1... A9, with temperature decreasing from A0 to A9. Table 5.3 shows the spectral classes for some common stars.

Table 5.4 shows the relationship between spectral class, colour, colour index (see p.194), surface temperature and the special spectral features.

Table 5. 4 Spectral classes of some common stars

Star	Spectral class
Arcturus	K2
Betelgeuse	M2
Hadar	B1
Sirius	A1
Vega	A0
Sun	G2

EXAMPLE 7

By referring to Tables 5.2 and 5.3, determine:

(a) the hottest star;

(b) the likely colour of Sirius;

(b) the likely temperature of the Sun.

Table 5. 3 Important characteristics of spectral classes

Spectral class	Colour	Colour Index	Surface temperature	Spectral features
O	Blue	–0.30	30 000 K	Strong lines of ionised helium. Lines of doubly ionised oxygen, nitrogen and carbon.
B	Blue-white	–0.15	30 000 to 15 000 K	Lines of neutral helium are most prominent. Hydrogen lines stronger than in O class.
A	White	0.00	15 000 to 10 000 K	Hydrogen lines are most prominent. Singly ionised magnesium, silicon, iron, calcium and titanium appear.
F	White-yellow	+0.40	10 000 to 7 000 K	Hydrogen lines are weaker than in A stars and neutral metals are stronger.
G	Yellow	+0.80	7 000 to 5 000 K	Lines of ionised calcium are the strongest feature. Hydrogen lines are weak. Lines of many neutral and singly ionised metals are present.
K	Orange	+1.20	5 000 to 4 000 K	Neutral metal lines are most prominent. Hydrogen lines are almost non-existent. Molecular bands are becoming more important.
M	Red	+1.80	4 000 to 3 000 K	Molecular bands are the most prominent feature. Titanium oxide bands are very prominent.

---

[15] http://zebu.uoregon.edu/nsf/spectra.html Java applet that allows you to download various stellar spectra. Well worth a visit.

SOLUTION

(a) Hadar is the hottest, with a spectral class of B1. Remember O is the hottest, followed by B, A ...

(b) Sirius is white since it is an A spectral class.

(c) The Sun's temperature is between 5000 K and 7000 K.

INFORMATION DEDUCED FROM STELLAR SPECTRA

Stellar spectra enable astronomers to deduce a lot of information about stars including their:

1 structure
2 chemical composition
3 velocity
4 temperature and
5 density.

Star Structure

The fact that stellar spectra are primarily absorption spectra, indicates that stars consist of a hot dense inner part producing a continuous spectrum, and a cooler, less dense outer layer.

Star Composition

As discussed previously, by comparing stellar spectra with the spectra of elements on the Earth, it is possible to deduce the composition of the stellar object (Figure 5.10, p.185).

Star Velocity

The stellar translational velocity can be determined from the *Doppler effect*. Motion of the star away from us results in a *red-shift*; motion towards us results in a *blue-shift*. The faster the velocity, the greater is the shift.

Similarly, the stellar rotational velocity can be measured. By taking a spectrogram of either the approaching or receding edge of the Sun for example, and comparing it with a spectrogram of the Sun's centre, the *period* of the Sun's rotation can be measured. From this, the rotational speed can be computed.

Star Density

The spectra of stars are primarily dependent on their temperature and are also affected by the density of the outer absorbing layer. Density, in turn, depends on the star's surface gravity.

An undisturbed atom normally radiates a narrow line. Charged particles passing nearby can disturb the energy level such that in a hot gas, the spectral lines can be 'spread out'. This spreading out depends on the density. Dwarf stars, with high density, produce broad lines; supergiants with less dense atmospheres have narrow spectral lines.

COLOUR AND TEMPERATURE

As we can see in Table 5.3, there is a link between the colour of a star and its surface temperature. A star approximates to a *black body* and so there is a relationship between the dominant wavelength emitted and the temperature as shown in Figure 5.13[16].

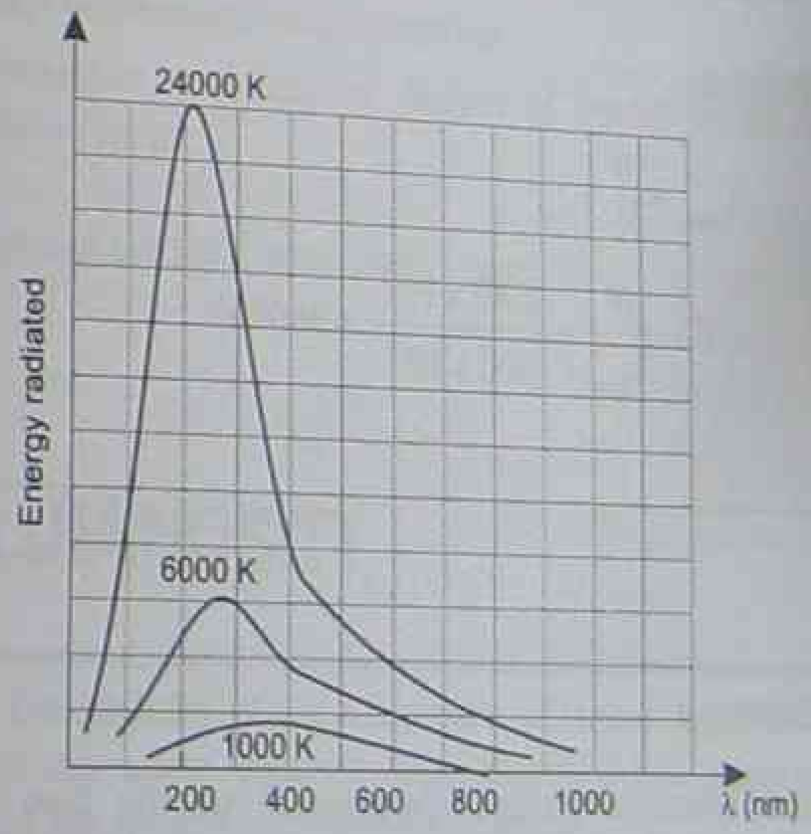

Figure 5. 13 Black body radiation curves

From the black body curve, astronomers can determine the temperature of a star. They do this using Wien's Law.

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[16] http://plabpc.csustan.edu/astro/VirtualAstronomyLab/SpectralLightCurve/index.htm http://plabpc.csustan.edu/astro/VirtualAstronomyLab/SpectralLightCurve/Blackbody.htm is a Java applet that allows you to graph black body radiation curves.

Extension

Wien's Law

Wien's Law *states that the wavelength (λ_{max}) carrying the maximum intensity of radiation in a spectrum emitted by a hot body at a certain absolute temperature* T, *is inversely proportional to that temperature.*

That is:

$$\boxed{\lambda_{max} = \frac{W}{T}}$$

where $W = 2.89 \times 10^{-3}$ m.K

EXAMPLE 8

A star radiates light with the wavelength of the most intense radiation equal to 300 nm. What is the temperature of the star?

SOLUTION

$$\lambda_{max} = \frac{W}{T}$$

$$\therefore T = \frac{W}{\lambda_{max}} = \frac{2.89 \times 10^{-3}}{300 \times 10^{-9}} = 9600\,\text{K}$$

EXAMPLE 9

The effective surface temperature of the Sun is 5800 K. What is the peak wavelength from the Sun?

SOLUTION

$$\lambda_{max} = \frac{W}{T} = \frac{2.89 \times 10^{-3}}{5800 \times 10^{-9}} = 500\,\text{nm}$$

SECTION 4: PHOTOMETRY

BIG IDEA:

Photometric measurements can be used for determining distance and comparing objects.

OUTCOMES:

Students learn to:

1 Define absolute and apparent magnitude.
2 Explain how the concept of magnitude can be used to determine the distance to a celestial object.
3 Outline spectroscopic parallax.
4 Explain how two-colour values (that is, colour index, *B-V*) are obtained and why they are useful.
5 Describe the advantages of photoelectric technologies over photographic methods for photometry.

Students:

1 *Solve problems and analyse information using* $M = m - 5\log(d/10)$ *and* $\frac{I_A}{I_B} = 100^{\frac{(M_B - M_A)}{5}}$ *to calculate the absolute or apparent magnitude of stars using data and a reference star.*
2 *Perform an investigation to demonstrate the use of filters for photometric measurements.*
3 *Identify data sources, gather, process and present information to assess the impact of improvements in measurement technologies on our understanding of celestial objects.*

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PHOTOMETRY

Photometry *is the measurement of the brightness of stars and other celestial objects.*

From such measurements a large amount of information can be deduced about a stellar object's characteristics including temperature, composition, age...

When we look up at the stars on a clear night it is obvious that not all appear equally bright; some stars are brighter than others. This variation may be due to the stars being at different distances from us and/or having different *intrinsic brightness.*

LUMINOSITY

Luminosity *(L) is a measure of the rate at which a star emits radiant energy, that is, it is a measure of the total power emitted by a star.*

Luminosity depends upon:

1 the size (radius) of the star and
2 the surface temperature of the star.

Large stars are more luminous than smaller stars (of the same temperature) and hotter stars are more luminous that cooler stars (of the same radius).

BRIGHTNESS

The **brightness** *(I) of a star is a measure of the intensity of radiation arriving at the Earth from a star.*

This is dependent upon:

1 the intrinsic luminosity (L) of the star and

2 the distance (d) to the star.

Mathematically:

$$\boxed{I = \frac{L}{4\pi d^2}}$$

Hipparchus

In the second century BC the Greek philosopher Hipparchus listed 1080 stars with their latitude, longitude and their brightness on a scale of six *magnitudes*.

MAGNITUDES

A first-magnitude star is *defined* to be 100 times brighter than a sixth-magnitude star. Certain stars are used as standards for the absolute values of magnitude.

It follows from this definition that:

1 The brighter the star, the smaller the magnitude.

2 A difference of one magnitude always corresponds to the same brightness ratio, that is, $\sqrt[5]{100} = 2.512$. A star of magnitude 3 is 2.512 times brighter than a star of magnitude 4. Similarly a star of magnitude 2 is 2.512 x 2.512 = 6.31 times brighter than a star of magnitude 4.

Apparent Magnitude (Apparent Brightness)

The **apparent magnitude (m)** *of a celestial body is its magnitude as measured by an observer (usually on the Earth).*

The apparent magnitude is governed by:

1 the intrinsic luminosity and

2 the distance from the source.

The Inverse Square Law for Light

The intensity of light from a source decreases as the square of the distance (Figure 5.14), that is:

$$I \propto \frac{1}{d^2}$$

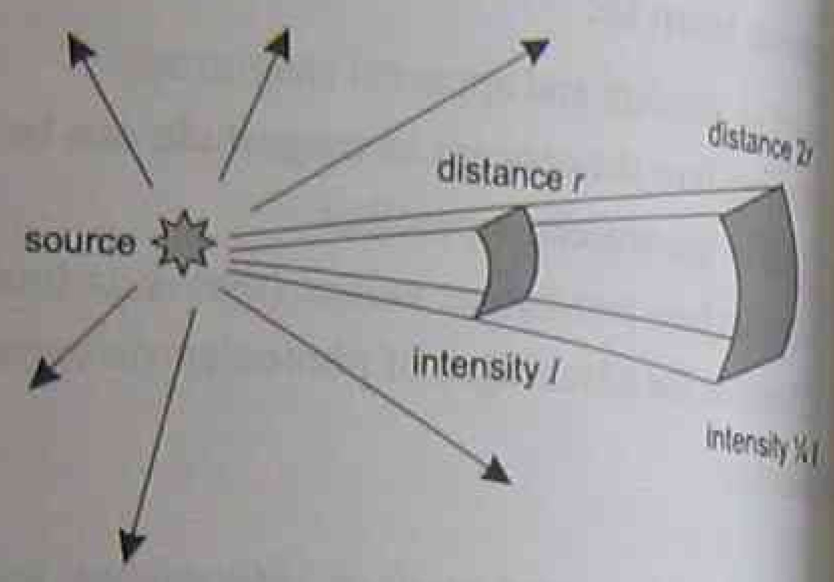

Figure 5. 14 Inverse square law of light

For example, if the distance between the source and the observer is doubled, the intensity is reduced to ¼ of its original value; if the distance is tripled the brightness decreases to $\frac{1}{9}$ of its original value. Conversely if the distance is halved, the intensity increases 4 times.

It follows that if two identical stars *alpha* and *beta* exist with *beta* twice as far away as *alpha*, then *beta* will have an apparent magnitude ¼ that of *alpha*.

For two stars with apparent magnitudes m_A and m_B respectively and intensities I_A and I_B we have:

$$\boxed{m_A - m_B = 2.5\log_{10}\frac{I_B}{I_A}}$$

This is equivalent to:

$$\frac{I_A}{I_B} = 2.512^{(m_B - m_A)}$$

EXAMPLE 12

Two stars, Delta and Epsilon, have apparent magnitudes of −1 and +3 respectively. How much brighter does Delta appear than Epsilon?

SOLUTION

The ratio of the brightness of Delta to Epsilon is:

$$\frac{I_A}{I_B} = 2.512^{(3--1)} = 2.512^4 = 40$$

That is, Delta is 40 times brighter than Epsilon.

Absolute Magnitude (Absolute Brightness)

The **absolute magnitude** *(M) is defined as the brightness the star would have if it were a standard distance from us—this distance is 10 parsecs (see p.181).*

For two stars with absolute magnitudes M_A and M_B and apparent brightness I_A and I_B respectively, we have:

$$\boxed{\frac{I_A}{I_B} = 100^{\left(\frac{M_B - M_A}{5}\right)}}$$

EXAMPLE 13

By reference to Table 5.5 opposite, compare the brightness of the stars Arcturus and Sirius.

SOLUTION

$$\frac{I_{Arcturus}}{I_{Sirius}} = 100^{\left(\frac{M_{Sirius} - M_{Arcturus}}{5}\right)}$$

$$= 100^{\left(\frac{1.4--0.3}{5}\right)} = 4.8$$

MAGNITUDE AND DISTANCE

It is possible to determine the distance to a stellar object from its absolute and apparent magnitudes. For a star with an apparent magnitude m at a distance d and absolute magnitude M at a distance of 10 parsecs it is found that:

$$\boxed{m - M = 5\log_{10}\frac{d}{10}}$$

$m - M$ is called the *distance modulus*.

Table 5. 5 Magnitude of stars for Example 13

Star	Apparent visual magnitude	Absolute visual magnitude
Arcturus	0.00	-0.3
Betelgeuse	+0.41	-5.6
Hadar	+0.63	-5.2
Sirius	-1.51	+1.4
Vega	+0.04	+0.5

EXAMPLE 14

Canopus has an apparent magnitude of −0.72 and an absolute magnitude of −3.1

(a) How far away is Canopus in parsecs?

(b) What is the parallax of Canopus?

SOLUTION

(a) $$m - M = 5\log_{10}\frac{d}{10}$$

$$-0.72 - (-3.1) = 5\log_{10}\frac{d}{10}$$

$$5\log_{10}\frac{d}{10} = 2.38$$

$$\frac{d}{10} = 2.99$$

ie. $d = 29.9$ parsecs

(b) $$d = \frac{1}{p}$$

ie. $$p = \frac{1}{d}$$

$$= \frac{1}{29.9}$$

$= 0.033$ seconds of arc

EXAMPLE 15

Table 5.5 shows the absolute and apparent magnitudes for a number of stars. Use it to answer the following questions.

(a) Which star is brightest to an observer on the Earth? Explain your answer.

(b) How far away is Vega?

(c) How much brighter does Betelgeuse appear than Hadar?

(d) How much brighter is Betelgeuse than Hadar?

SOLUTION

(a) The smaller the apparent visual magnitude, the brighter the star. Hence Sirius ($m = -1.51$) is the brightest star.

(b)
$$m - M = 5\log_{10}\frac{d}{10}$$
$$0.04 - 0.5 = 5\log_{10}\frac{d}{10}$$
$$5\log_{10}\frac{d}{10} = -0.46$$
$$\frac{d}{10} = 0.81$$
i.e. $d = 8.1$ parsecs

(c) The difference in brightness of Betelgeuse to Hadar is 0.63 – 0.41 = 0.22. Hence brightness ratio is $2.512^{0.22} = 1.22$; that is, Betelgeuse appears to be 1.22 times brighter than Hadar.

(d)
$$\frac{I_A}{I_B} = 100^{\frac{(M_B - M_A)}{5}}$$
$$= 100^{\frac{-5.2+5.6}{5}}$$
$$= 100^{0.08}$$
$$= 1.45$$

SPECTROSCOPIC PARALLAX

This is a misnomer since it doesn't use parallax, but it is a method for determining distances to stellar objects.

Spectroscopic parallax *is a method using spectra to determine distances to stellar objects.*

From an object's observed spectrum, astronomers can deduce its spectral class and luminosity. This allows them to determine its location on the *Hertzsprung-Russell diagram* (see p.203) and from this, its absolute magnitude. This, in conjunction with its apparent magnitude measured by photometry, allows the distance to be calculated.

EXAMPLE 16

Spica is a main sequence star of spectral class B1 and with an apparent magnitude $m = 1.0$. How far away is Spica?

SOLUTION

From the H-R diagram (p.203) absolute magnitude can be estimated at approximately $M = -2.5$.

$$m - M = 5\log\frac{d}{10}$$
$$1.0 - (-2.5) = 5\log\frac{d}{10}$$
$$\frac{3.5}{5} = \log\frac{d}{10}$$
$$d = 50 \text{ parsecs}$$

Spectroscopic parallax is a method that yields an approximate value only. It is used when there is no alternative method and at best yields a 'ball park' figure.

MEASURING MAGNITUDES

A star can have three different kinds of magnitudes depending on whether it is seen by:

1 the human eye
2 a photographic emulsion or
3 a photocell.

These three detectors differ in their *sensitivity* to all the different colours of light radiated by a star:

1 The eye is most sensitive in the *yellow-green* portion of the spectrum ($\lambda \sim 570$ nm).

2 Photographic emulsions are commonly more sensitive in the *blue-violet* portion of the spectrum ($\lambda \sim 400$ nm). It follows that:
   (a) a blue star will hence appear brighter on a photograph than in the eye; and
   (b) a red star will appear duller in a photograph.

3 Photocells respond equally well to all wavelengths.

To improve precision, the magnitude of a star is actually measured in some preselected colour such as blue or yellow by the use of appropriate filters.

COLOUR INDEX

Stellar brightness is generally measured in three 'colours':

1 ultraviolet (U);
2 blue (B)—which approximates to the photographic response; and
3 yellow (V)—which approximates to the visual response.

If U, B and V are the magnitudes of a star in the three colours, with B and V, the photographic and visual magnitudes respectively, then the difference ($B - V$) is called the *colour index* of the star. That is:

$$\boxed{CI = B - V}$$

Imagine that an astronomer is measuring the colour index of a blue star. Since it is blue, it will appear bright through a blue filter. Thus it would have a small magnitude (remember, magnitude decreases as brightness increases).

On the other hand, when viewed through a yellow filter it will be dull since the yellow filter would absorb the blue light. Hence it would have a large magnitude. A calculation of $B - V$ would then have a large number subtracted from a smaller number; the result would be negative.

It thus follows that $CI = B - V$ has negative values for blue stars and positive values for red stars.

EXAMPLE 17

Three stars have the following photographic and visual magnitudes shown in Table 5.6.

Table 5.6 Example 17

Star	B	V
α	3.1	2.4
β	4.1	4.4
γ	5.9	7.5

(a) What is the colour index of each star?

(b) Which star is the reddest?

(c) Which star is the bluest?

SOLUTION

(a)

Star	B	V	B-V
α	3.1	2.4	+0.7
β	4.1	4.4	-0.3
γ	5.9	7.5	-1.6

(b) α is the reddest (most positive value of B–V).

(c) γ is the bluest (most negative B-V)

PHOTOELECTRIC PHOTOMETRY

In this method, light from a stellar object passes into either a *photomultiplier* or a *Charge Coupled Device* (*CCD*).

A photomultiplier is a device that converts weak light into a stronger electric current (Figure 5.15). It consists of an evacuated tube in which photons enter through a thin glass window at the top. The thin window allows some of the photons (~1 in 10) to pass through and hit a *photocathode* with a *photoemissive surface* (generally antimony-caesium).

Secondary electrons are accelerated to the first *dynode* by an accelerating voltage. (Generally a photomultiplier has 9–14 dynodes with each one having an additional 100 V.) Secondary emission from each of the dynodes results in an increasing number of photoelectrons (the *gain* can be as high as 10^9 times) which creates a measurable current.

This current is easily read and since it is *proportional to the light input*, weak light intensities can be accurately measured (down to magnitude 24).

In addition, the time to pass through the tube is ~ 10^{-8} to 10^{-9} s. This fast response coupled with the proportional response of the current, makes it an effective detector of starlight.

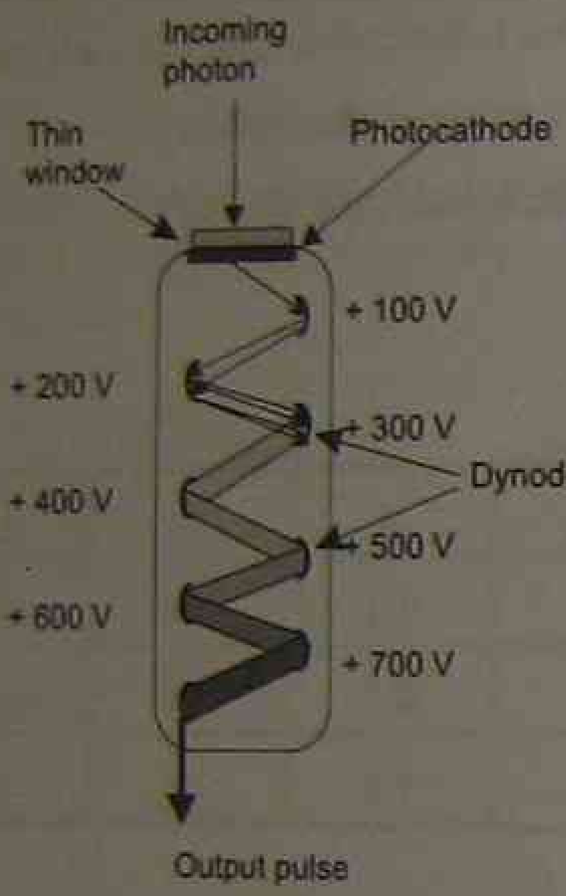

Figure 5. 15 Photomultiplier

A charge-coupled device utilizes a light-sensitive material on a silicon chip to detect individual photons. Unlike a photomultiplier, a CCD contains circuitry to transfer the signal along a row of pixels (*picture elements*) allowing it to rapidly scan celestial objects. Individual pixels can be arranged in a straight line—a *linear array*—or in rows and columns—a *two-dimensional array*. For example the *Hubble Space Telescope* has a CCD detector with a 1600 x 1600 pixel array.

Most large observatories throughout the world use CCDs to record photometric data because they have the following advantages:

1. they can quickly scan celestial objects and record the data
2. their sensitivity is ~100 times that of a photographic plate (see below)
3. they can be altered to provide increased sensitivity for different wavelengths.

PHOTOGRAPHIC PHOTOMETRY

This is not as 'accurate' as photoelectric photometry since it relies on *visual* comparisons of star images on photographic plates. The brighter a star, the bigger and denser is its image on the plate. However because of the complex relationship between the size and density of the image and the star's brightness, it is not able to calibrate them accurately.

Although not as sensitive as photoelectric devices photographic methods do provide higher resolution.

SECTION 5: BINARY AND VARIABLE STARS

BIG IDEA:

The study of binary and variable stars reveals vital information about stars.

OUTCOMES:

Students learn to:

1. Describe binary stars in terms of the means of their detection: visual, eclipsing, spectroscopic and astrometric.
2. Explain the importance of binary stars in determining stellar masses.
3. Classify variable stars as either intrinsic or extrinsic and periodic or non-periodic.
4. Explain the importance of the period-luminosity relationship for determining the distance of Cepheids.

Students:

1. *Perform an investigation to model the light curves of eclipsing binaries using computer simulation.*
2. *Solve problems and analyse information by applying:* $m_1 + m_2 = \dfrac{4\pi^2 r^3}{GT^2}$

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BINARY STARS

Binary stars *consist of two stars orbiting about their common centre of mass and obeying the Law of Universal Gravitation.*

About half of all known star systems are binary or multiple systems.

Binary stars are of various types, including:

1. *visual*
2. *eclipsing*
3. *spectroscopic* and
4. *astrometric.*

Visual Binaries

These have orbits which can be *observed directly* as *ellipses* traced out relative to the background stars as shown in Figure 5.16. The centre of mass of the system is closer to the more massive star.

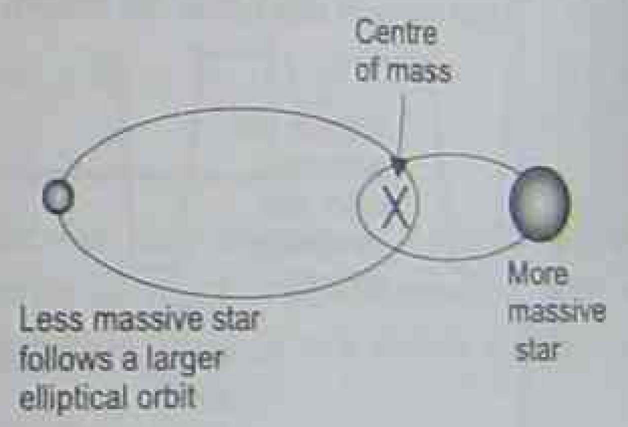

Figure 5. 16 The elliptical orbits of visual binary stars

Eclipsing Binaries[17]

As the name suggests, one star of the pair *eclipses* the other at regular intervals, leading to variations in the brightness of the light from the other star. Such stars are said to be *extrinsic variables* (see p.200).

Consider Figure 5.17. For convenience we will consider the larger duller star to be 'stationary' with

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[17] http://instruct1.cit.cornell.edu/courses/astro101/java/eclipse/eclipse.htm Java applet demonstrating eclipsing binary stars

the smaller brighter star revolving around it. When situated as shown in Figure 5.17(a), the light from both stars reaches the Earth and gives a certain combined light intensity.

As the brighter star eclipses (moves in front of) the duller star, as in Figure 5.17(b), the combined intensity dips slightly. This is a *secondary eclipse*. When the brighter star is behind the duller star (Figure 5.17(c)) the combined intensity changes more. This is a *primary eclipse*.

The result is a light curve similar to that in Figure 5.17(d) if the eclipse is total or like that in Figure 5.17(e) if it is a partial eclipse.

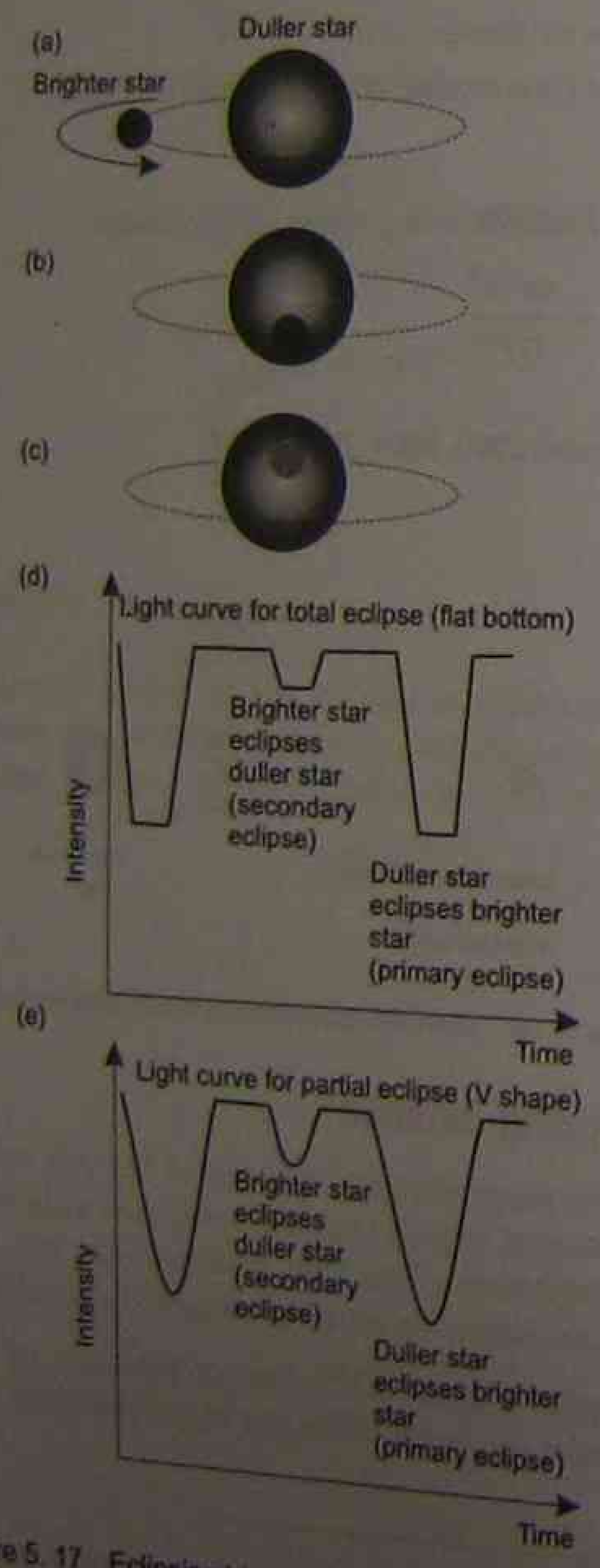

Figure 5. 17 Eclipsing binary and resulting light curve

Spectroscopic Binaries[18]

These cannot be resolved by optical telescopes but instead are detected by the Doppler shift of their spectral lines. When a source of light is receding from Earth, its wavelengths are shifted towards the red end of the spectrum—a *red shift*. Conversely, if the source of light is approaching Earth then the wavelengths of light undergo a *blue shift*.

Consider Figure 5.18. In Figure 5.18(a) the stars *A* and *B* are both moving perpendicularly to the line of sight of an observer on Earth. As a result no spectral shift is observed (the stars are neither approaching nor receding from the Earth). The spectra will resemble that in Figure 5.18(c).

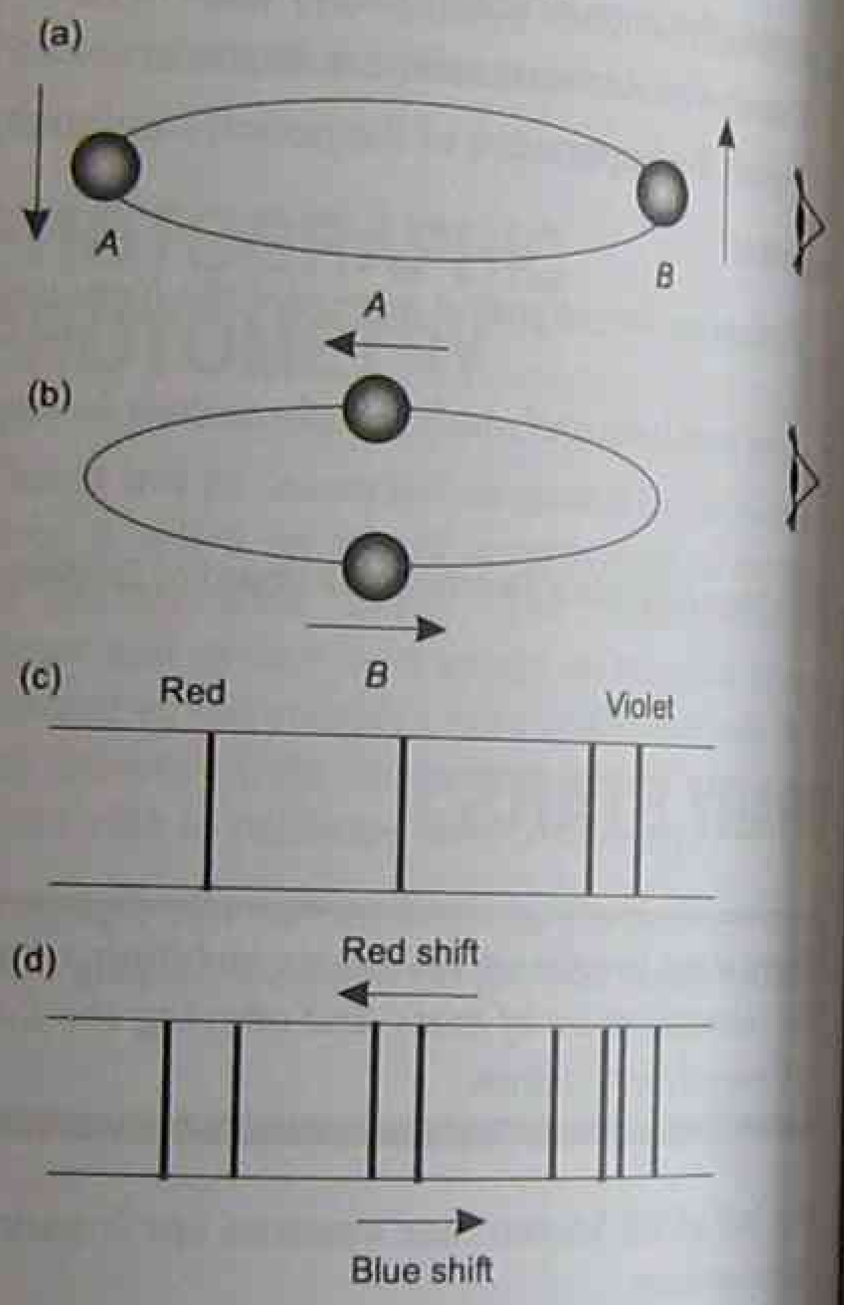

Figure 5. 18 Spectroscopic binaries and their resulting spectra

In Figure 5.18(b), however, the stars are moving such that *A* is receding from the observer while *B* is approaching. Light from *A* will suffer a red shift and that from *B* a blue shift. The spectrum observed on Earth will hence show a doubling of the spectral lines, as shown in Figure 5.18(d).

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[18] http://instruct1.cit.cornell.edu/courses/astro101/java/binary/binary.htm Java applet demonstrating spectroscopic binary stars

As the stars continue to rotate about their common centre of mass they will return to the situation in Figure 5.18(a) (although with *A* and *B* reversed). The spectrum will again resemble Figure 5.18(c).

Periodic doubling of the spectral lines is an indication of a spectroscopic binary.

Astrometric Binaries

These are, strictly speaking, not visual binaries since both stars cannot be resolved (separated) in a telescope. Only one component is bright enough to see. The presence of the faint companion star is inferred from the perturbation of the path of the visible star.

The bright star Sirius is an example of an astrometric binary (its two components being Sirius A and Sirius B).

USING BINARIES TO DETERMINE MASSES OF STARS

Binary stars are important in determining the masses of stars (the mass of an isolated star cannot be directly measured). The two components of a binary star revolve in ellipses about a *common centre of mass* (Figure 5.19), with the centre of mass being closer to the more massive star.

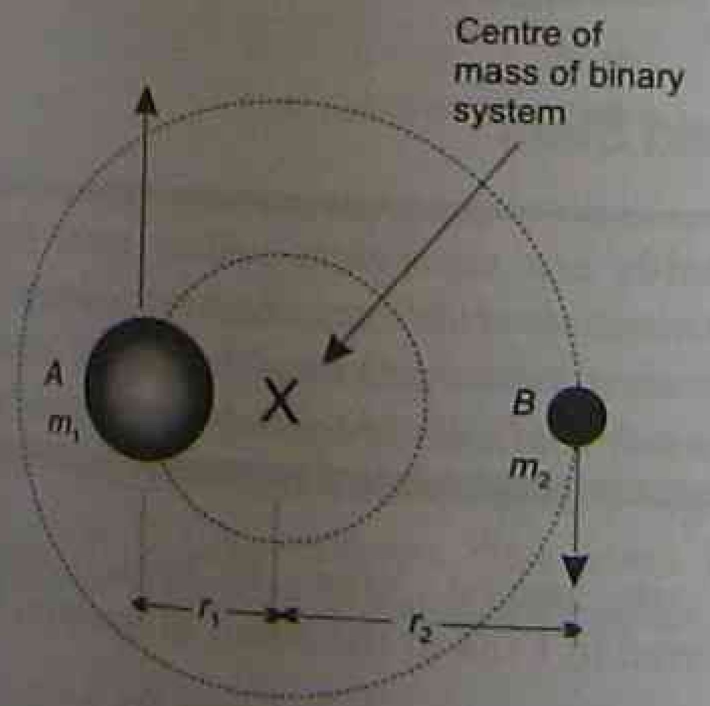

Figure 5. 19 Binary stars rotating about their common centre of mass.

Spectroscopic binary stars are preferred over visual binaries for mass determination because:

1 there are many more distant stars than near stars and
2 their speeds can be easily measured by their Doppler shift.

If the two stars have masses m_1 and m_2 (in units of solar masses) and are separated by distances r_1 and r_2 respectively from the centre of mass (Figure 5.19), then: $m_1r_1 = m_2r_2$

It follows that:

$$\frac{r_1}{r_2} = \frac{m_2}{m_1}$$

The massive star also moves slower than does the low-mass star *and its spectral lines have a smaller Doppler shift.*

From Kepler's Law of periods we also have:

$$\frac{a^3}{T^2} = \frac{4\pi^2}{G(m_1 + m_2)}$$

where a is the distance separating the two stars in astronomical units (AU), T is the period of each component (in years) and the masses are in kg.

If the masses are in terms of solar masses, this equation reduces to:

$$\boxed{m_1 + m_2 = \frac{a^3}{T^2}}$$

Consider the stars moving in a circular orbit about the centre of mass with a period T. For star 1, moving with a speed of v_1 it moves a distance given by:

$$s_1 = v_1T = 2\pi\ r_1$$

Similarly:

$$s_2 = v_2T = 2\pi\ r_2$$

Hence:

$$\frac{r_1}{r_2} = \frac{v_1}{v_2} = \frac{m_2}{m_1}$$

Since the velocities can be measured by the star's Doppler shift, the ratio of the masses can be calculated. Since the total mass can be found from Kepler's Law, the individual masses can be calculated!

EXAMPLE 18

Find the combined mass of the two stars in a binary system with a period of revolution around their common centre of mass of 2 years and an average separation of 2 AU.

SOLUTION

$$m_1+m_2=\frac{a^3}{T^2}$$
$$=\frac{2^3}{2^2}\text{ solar masses}$$
$$=2\text{ solar masses}$$

That is, the combined mass is twice the mass of the Sun.

EXAMPLE 19

Two stars in a spectroscopic binary have a period of 1.5 years and a separation of 5 AU. If the low-mass star has a radial velocity of 300 km.h^{-1} and the massive star a radial velocity of 100 km.h^{-1}, what is each star's mass?

SOLUTION

The total mass is found from:

$$m_1+m_2=\frac{a^3}{T^2}$$
$$=\frac{5^3}{1.5^2}$$
$$=55.6\text{ solar masses}$$

The ratio of the masses is found from:

$$\frac{m_2}{m_1}=\frac{v_1}{v_2}$$
$$=\frac{300}{100}$$
$$=3$$

$$\text{Total mass}=4m_1=55.6$$
$$m_1=13.9\text{ solar masses}$$
$$m_2=41.7\text{ solar masses}$$

VARIABLE STARS

An eclipsing binary is an example of a variable star. Variable stars can be classified as either:

1 intrinsic or
2 extrinsic.

These can be further classified as either:

1 periodic or
2 non-periodic.

Intrinsic Variable Stars

Intrinsic variable stars *are stars that vary in brightness or other respects.*

The most basic property of a variable star is its *light curve*—a graph of brightness versus time. Variables are classified according to whether this light curve is *periodic* (that is, it repeats itself at regular intervals) or *non-periodic*. Periodic variables include *pulsating stars*.

PULSATING STARS

A star is a sphere of gas and as such it can *vibrate* in various harmonic modes just like air in an organ pipe. This causes the star to brighten and fade due to cyclic contraction and expansion. The most common type of pulsating stars are *Cepheids*.

Cepheid Stars

Cepheids *are supergiant yellow stars (of which approximately 1000 are known) which vary in brightness with an amplitude of about one magnitude and with absolutely regular periods.*

They are named after δ-Cephei, which was discovered in 1784 in the Small Magellanic Cloud.

Figure 5.20 shows the light curve for δ-Cephei.

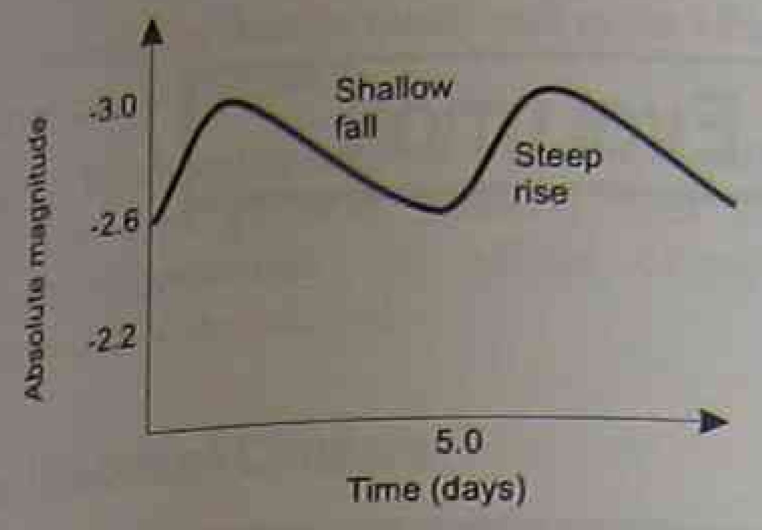

Figure 5.20 Light curve for δ-Cephei

In 1912 Henrietta Leavitt of Harvard College Observatory discovered a relationship between the period and luminosity of δ-Cephei that can be used to determine distances to far away galaxies[19]. It is this relationship that makes Cepheids so useful.

Period-Luminosity Curve

A definite relationship exists between the period of pulsation of a Cepheid and its luminosity, as illustrated in Figure 5.21. The longer the period, the greater is the luminosity.

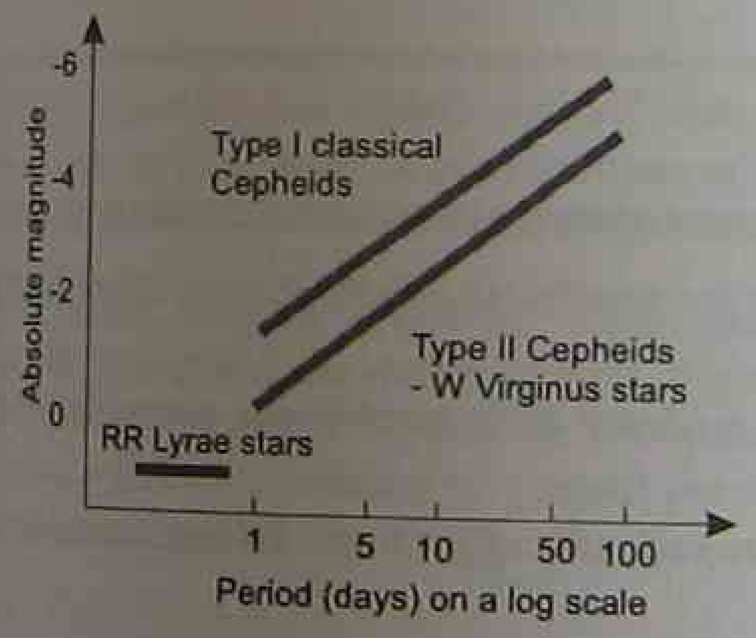

Figure 5.21 Period-luminosity curve

Cepheids are now known to come in two varieties: Type I and Type II. Type I Cepheids are the classical Cepheids (such as δ-Cephei) and are Population I stars, that is older stars with relatively high metal content; Type II Cepheids are Population II stars, that is younger stars with lower metal content.

Distance Measurements using Cepheids

Cepheids have provided astronomers with a powerful distance-measuring tool. By observing the period of pulsation, the absolute luminosity can be found directly from the period-luminosity graph. Comparison of the absolute luminosity with the apparent luminosity and application of the inverse square law for light enables distances to the Cepheids to be calculated (and by inference the distance to the galaxy in which the Cepheid exists).

EXAMPLE 20

A Type I Cepheid is observed to have a period of 50 days and an apparent magnitude of 10. How far is it away?

SOLUTION

From the graph, a period of 50 days is approximately equivalent to an absolute magnitude of –5. Therefore:

$$m-M=5\log\frac{d}{10}$$
$$10--5=5\log\frac{d}{10}$$
$$\log\frac{d}{10}=3$$
$$d=10^4\text{ parsecs}$$

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[19] http://plabpc.csustan.edu/astro/VirtualAstronomyLab/Cepheid2/index.htm is a java applet that shows the use of Cepheid variable stars to measure distances. Trace the light curve of a Cepheid variable at http://hoa.aavso.org/zetagem.htm

SECTION 6: STELLAR EVOLUTION

BIG IDEA:

Stars evolve and eventually die.

OUTCOMES:

Students learn to:

1. Describe the processes involved in star formation.
2. Outline the key stages in a star's life in terms of the physical processes involved.
3. Describe the types of nuclear reactions involved in main sequence and post-main sequence stars.
4. Discuss the synthesis of elements in stars by fusion.
5. Explain how the age of a globular cluster can be determined from its zero-age-main sequence plot for a H-R diagram.
6. Explain the concept of star death in relation to:
   - planetary nebulae
   - supernovae
   - white dwarfs
   - neutron stars/pulsars
   - black holes.

Students:

1. *Present information by plotting Hertzsprung-Russell diagrams for nearby or brightest stars, stars in a young open cluster and stars in a globular cluster.*
2. *Analyse information from a H-R diagram and use available evidence to determine the characteristics of a star and its evolutionary stage.*
3. *Present information by plotting on a H-R diagram the pathways of stars of 1, 5 and 10 solar masses during their life cycle.*

STELLAR EVOLUTION[20]

As mentioned earlier, stars, like humans, are born, mature and ultimately die. As they mature, their chemical composition changes, resulting in a change in the star's physical properties such as luminosity and size. By examining closely linked groups of stars known as *clusters*, the evolution of stars can be determined.

This is possible because:

1. the stars in a typical cluster are all at nearly the same distance from Earth;
2. the stars would have similar initial chemical compositions; and
3. the stars were born at about the same time.

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[20] http://observe.arc.nasa.gov/nasa/space/stellardeath/stellardeath_contents.html an excellent NASA site. Contains all you need to know about stellar evolution. Another excellent site is http://map.gsfc.nasa.gov/html/web_site.html

The only variable then is mass, and so its effect on evolution can be followed.

Similarly, by choosing different clusters of different ages (*open* and *globular* clusters) with similar chemical compositions, the effects of age on evolution can be determined.

Open (Galactic) Clusters

Open (galactic) clusters *consist of loose irregular aggregations of stars.*

Open clusters contain a few hundred to a few thousand stars; individual stars in the cluster are easily distinguished. Most open clusters are found situated close to the equatorial plane of the Milky Way.

They are young clusters, containing Population I stars that is, young stars containing relatively high percentages of metals.

Globular Clusters

Globular clusters *are tightly packed collections of hundreds of thousands or even millions of stars.*

These clusters have a spherical shape and are distributed throughout the entire galaxy in a sphere called the *halo*. They are Population II objects, that is, relatively old stars containing a small percentage of several metals; they have high velocities relative to the Sun.

Globular clusters contain large numbers of faint evolved stars like *white dwarfs*. They also contain as their brightest stars, *red giants*.

Unlike open clusters, globular clusters contain little or no gas or dust and are the precursors of new stars.

HERTZSPRUNG-RUSSELL DIAGRAM

In *The Cosmic Engine* we were introduced to the Hertzsprung-Russell (H-R) diagram[21]. It is so vital to an understanding of stellar evolution that we will further study it in some detail.

A **Hertzsprung-Russell diagram** *is a graph that plots two stellar properties on its axes.*

Previously we considered luminosity and temperature. From what we have seen in this chapter, we could equally well plot absolute magnitude against stellar class (or colour index). When this is done for the stars nearest to us, a graph like Figure 5.22 results.

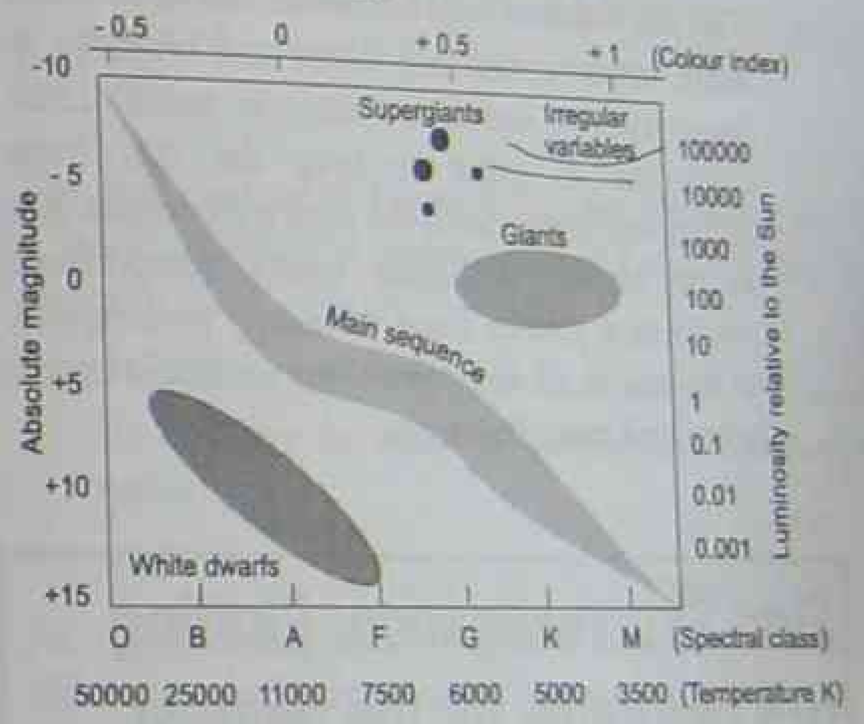

Figure 5. 22 Hertzsprung-Russell diagram for the stars in our galaxy

Features of the H-R Diagram

The essential features of a H-R diagram are:

1. Stars are not randomly distributed but fall within certain distinct regions. Each region corresponds to a particular evolutionary stage.
2. The great majority of stars (~90%) including our Sun, lie on the *main sequence*. This is a

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[21] http://plabpc.csustan.edu/astro/VirtualAstronomyLab/Spectral/HR/index.htm is a Java applet that allows you to plot a H-R diagram.

narrow band going from top left to bottom right. Main sequence stars tend to be very stable.

3 Moving along the main sequence from bottom right to the top left, the stars are hotter, larger, bluer and more luminous.

4 Above the main sequence and to the right on the graph lie a group of stars known as *giants*. These stars are about 100 times brighter and have diameters up to 100 times greater than our Sun. Above the giants are a group of *supergiants* which are bigger still; more than 100 times our Sun. The giant's branch is separated from the main sequence by the *Hertzsprung gap*.

5 Below the main sequence lie the *white dwarfs*. The rare types of stars—white dwarfs, red giants and supergiants—represent various stages of stellar evolution.

6 The less massive stars are cooler and duller. The more massive stars are hotter and brighter. A more massive star has a stronger gravitational field and in order to keep the star from collapsing in on itself, the core temperature has to be higher. A higher central temperature produces a greater flood of energy pouring out of the star in all directions—the surface is hence hotter and more luminous.

First Investigation: Plotting H-R Diagrams for the Nearest and Brightest Stars

Nearest Stars

This investigation assumes you are familiar with a spreadsheet such as *Microsoft Excel*. Open a new spreadsheet and enter the following headings and data shown in Table 5.7.

Note: In the H-R diagram, the luminosity is plotted as a logarithmic scale. In the cell under the heading *log(luminosity)*, type '=log10(C3)' (using the address of whatever cell you have placed luminosity in. In my case it is cell C3). This converts the luminosity to a log scale. Highlight this cell and drag the *handle* down to fill in the values for the other data. Alternatively use the *Fill down* command in the *Edit Menu*.

Table 5. 7 Temperature and luminosity for the nearest stars

Nearest Stars			
Name	Temp (K)	Luminosity	log Luminosity
Sun	5860	1	=log10(C3)
Proxima Centauri	3240	0.00006	
Alpha Centauri B	5860	1.6	
Alpha Centauri A	5250	0.45	
Barnards Star	3240	0.00045	
Wolf 359	2640	0.00002	
BD+362147	3580	0.0055	
L726-8A	3050	0.00006	
UV Ceti	3050	0.00004	
Sirius A	9230	23.5	
Sirius B	9000	0.003	
Ross 154	3240	0.00048	
Ross 248	3050	0.00011	
Epsilon Eridani	4900	0.3	

To plot a chart, highlight the temperature and log(luminosity) data. Note that you will have to hold CTRL after highlighting temperature to then highlight log(luminosity). Open *Chart Wizard* and select the X-Y scatter graph and graph the data. Add the appropriate labels and titles. Because astronomers historically have temperature decreasing to the right, you will need to reverse this axis. To do so click the X-axis and from the *Scale* page, click *Reverse the order* of the X-axis. When this is all done, a graph like Figure 5.23 results.

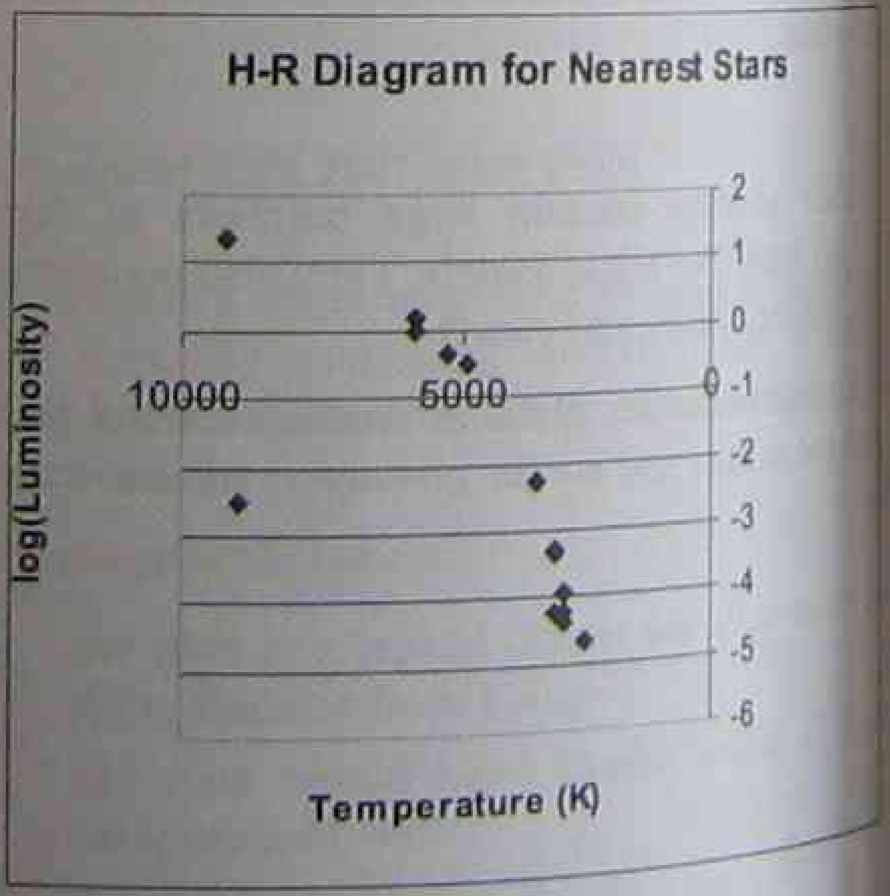

Figure 5. 23 H-R diagram for the nearest stars

Print your diagram and identify the different star types, that is, *main sequence*, *red giants* and *white dwarfs*.

The Brightest Stars

Repeat the process just done for the nearest stars using the following data for the brightest stars.

Table 5. 8 The brightest stars

Brightest Stars			
Name	Temp (K)	Luminosity	log Luminosity
Sun	5860	1	0
Sirius A	9230	23.5	
Canopus	7700	1400	
Alpha Centauri B	5860	1.6	
Arcturus	4420	110	
Vega	9520	50	
Capella	5200	150	
Rigel	11200	42000	
Procyon	6440	7.2	
Betelgeuse	3450	12600	
Achenar	15400	200	
Beta Centauri	24000	3500	
Altair	7850	10	
Alpha Crucis	25400	3200	
Aldebaran	15400	95	

Composite of the Nearest and Brightest

By combining the two data tables it is possible to get a composite graph (remembering to delete one of the replicated data, such as that for the Sun before graphing). When completed a diagram like Figure 5.24 results. It quite clearly shows the predominance of main sequence stars and fewer red giants and a single white dwarf!

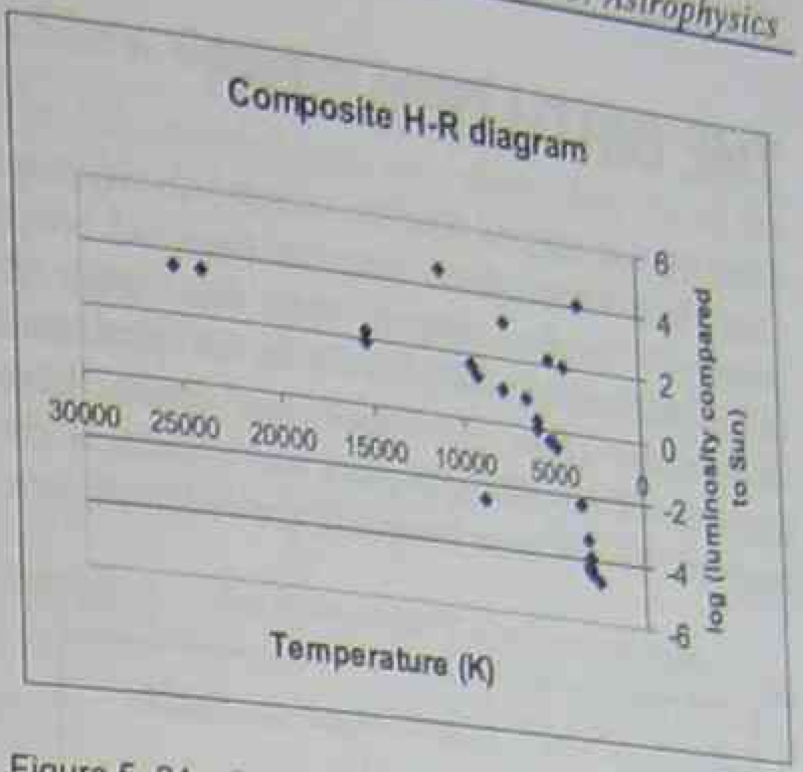

Figure 5. 24 Composite H-R diagram for the nearest and brightest stars

KEY STAGES IN A STAR'S LIFE[22]

The H-R diagram of Figure 5.22 gives cosmologists a 'track' to follow in the evolution of a star. The key stages in a star's life are:

1 its birth

2 its life-time in which it evolves and reaches maturity and

3 its death.

As we shall see, after its birth, a star, whatever its life span, usually remains on the main sequence in a steady state for about 90 per cent of its lifetime. The remaining 10 per cent is spent in various forms. These include *red giant*, *supergiant* and so on until the star's demise as a *white dwarf* (if the initial mass is less than 8 solar masses) or a *neutron star* or *black hole* (if the initial mass exceeded 8 solar masses).

We will now look at these different stages, beginning with a star's 'birth'.

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[22] http://instruct1.cit.cornell.edu/courses/astro101/java/evolve/evolve.htm Java applet demonstrating stellar evolution. Another good site is found at: http://plabpc.csustan.edu/astro/stars/stars.htm

THE BIRTH OF A STAR

The birth of stars is literally clouded in mystery. Stars form from local condensations of cold, extremely rarefied gases and dust globules (*proto-galaxies*) located primarily in the spiral arms of galaxies. These giant molecular clouds have diameters of 60–300 light-years and masses in the range of 10^5—10^6 solar masses (Figure 5.25(a)).

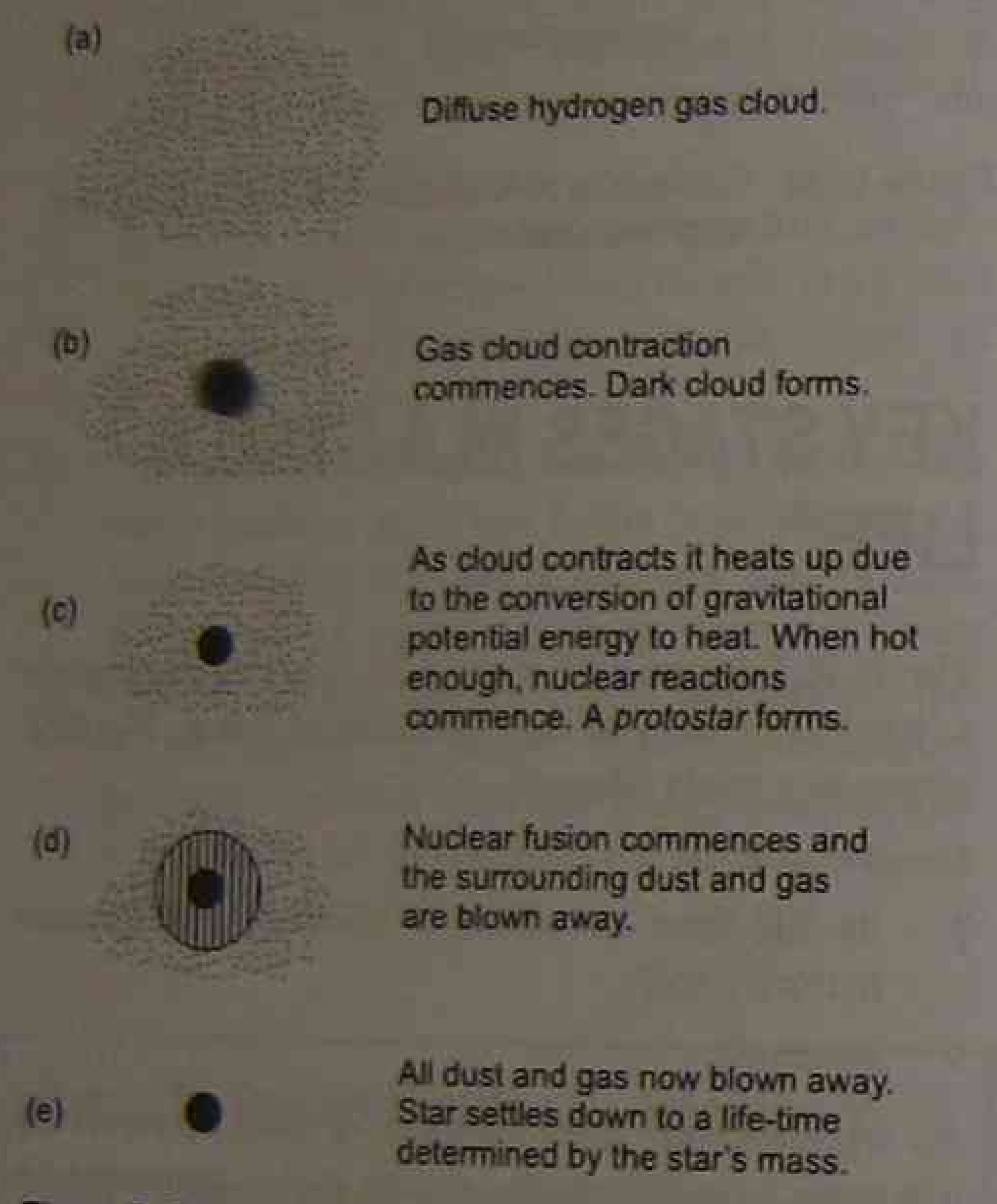

Figure 5. 25 The birth of a star

Protostars

A chance eddy (disturbance)[23] in these moving gas particles can cause an even larger mass of gas to form, which in turn attracts even more gas (Figure 5.25(b)). As the gas condenses the temperature of the gas cloud rises as a result of the conversion of *gravitational potential energy* into heat[24]: a *protostar* is formed (Figure 5.25(c)). These protostars have masses of 10^3–10^5 solar masses and may form in a period of a few years.

As the core temperature increases, the protostar reaches a point where it begins to emit a faint visible red glow in addition to infrared. (Nuclear fusion has *not* yet begun. The energy comes from gravitational potential energy.) Although relatively cool, the star is so large that it has high luminosity. This places it in the top right-hand side of the H-R diagram. At this point (*A* in Figure 5.26) the protostar is also called a T-Tauri star (after the first object of this type discovered).

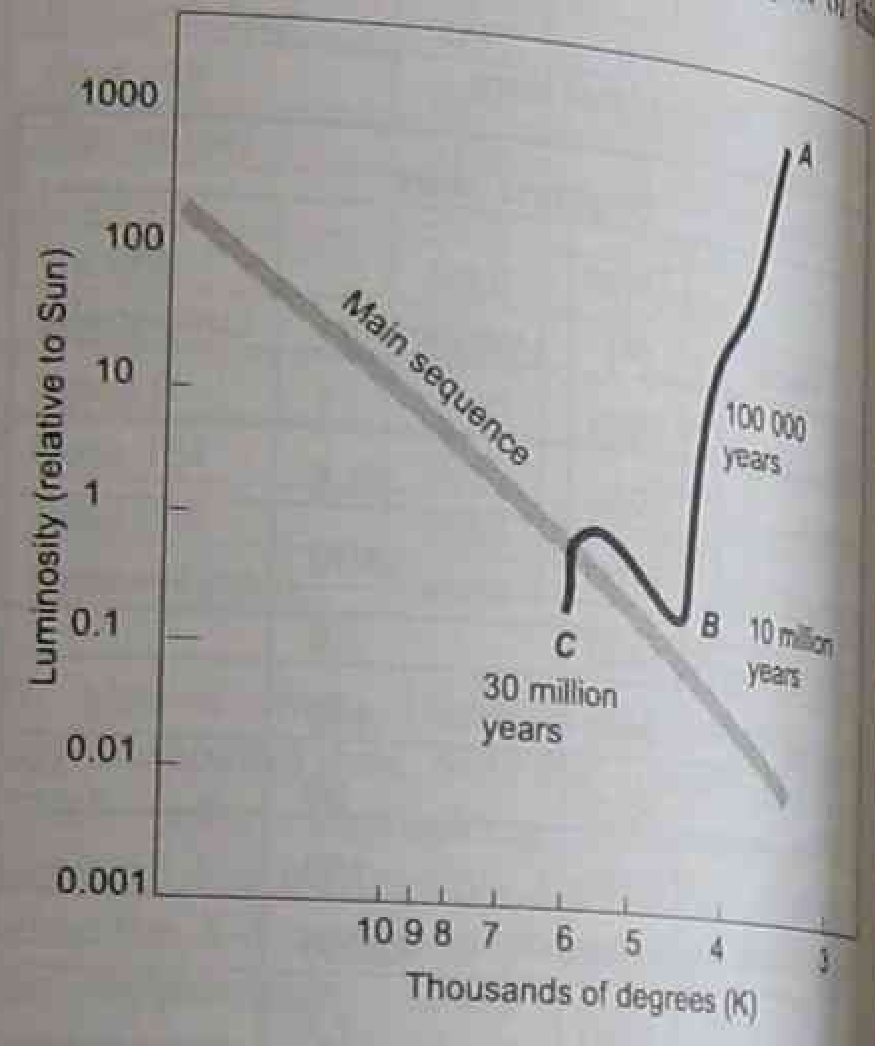

Figure 5. 26 A track to the main sequence for a star of mass approximately one solar mass

Pre-Main Sequence

As the protostar continues to contract, it moves down and to the left approaching the main sequence. Contraction slows down as the 'pre-main sequence star' approaches equilibrium between the forces trying to 'blow it apart' and the force of gravity causing it to contract (see *Stellar Equilibrium*).

The star continues to contract until the core temperature is high enough for *nuclear fusion* reactions to commence (Figure 5.25(d)). The 'star' now lies just above the main sequence (*B* in Figure 5.26). It may take some 10 million years to get to this point (or longer for smaller mass stars).

As the spinning gas cloud contracts, not only does it heat up but it also speeds up (just like a spinning ice skater does by bringing their arms closer to their body). This causes fragmentation of the cloud resulting in additional stars being formed.

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[23] This may result from the shock waves from a supernova explosion.

[24] Theory predicts that 50% of the gravitational potential energy is radiated away; the other 50% heats the gas.

Stellar Equilibrium

The evolution of a star is a struggle of opposing forces—the force of gravity pulling material in and the force due to the pressure of the hot *plasma* (completely ionised gas) pushing outwards (Figure 5.27). The two forces must be in equilibrium if the star is to be stable. Since energy is continually being radiated away from the star, it needs to be replaced. A fuel is needed to provide this energy (see later).

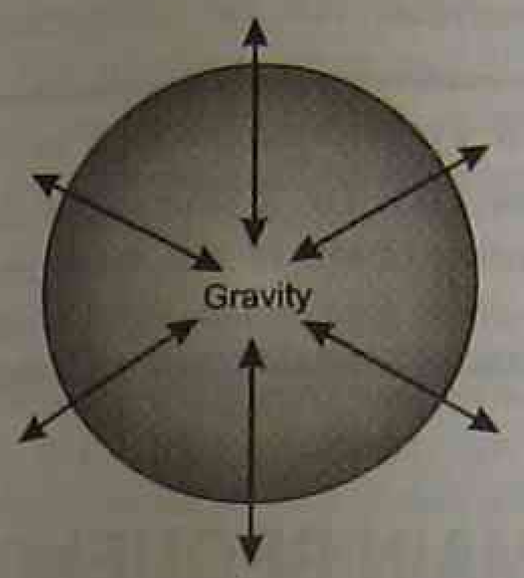

Figure 5. 27 The opposing forces inside a star

Zero-Age-Main-Sequence

It may take several million more years to settle down on the main sequence as a fully-fledged *star*. The main sequence is a band and not a line. The thickness is the result of slight differences in the stars. Because stars commence their life at the lower border, it is called the *Zero-Age-Main-Sequence (ZAMS)*.

Exactly where the star joins the main sequence is determined solely by its mass. The more massive the star, the further to the upper left-hand side it joins as shown in Figure 5.28.

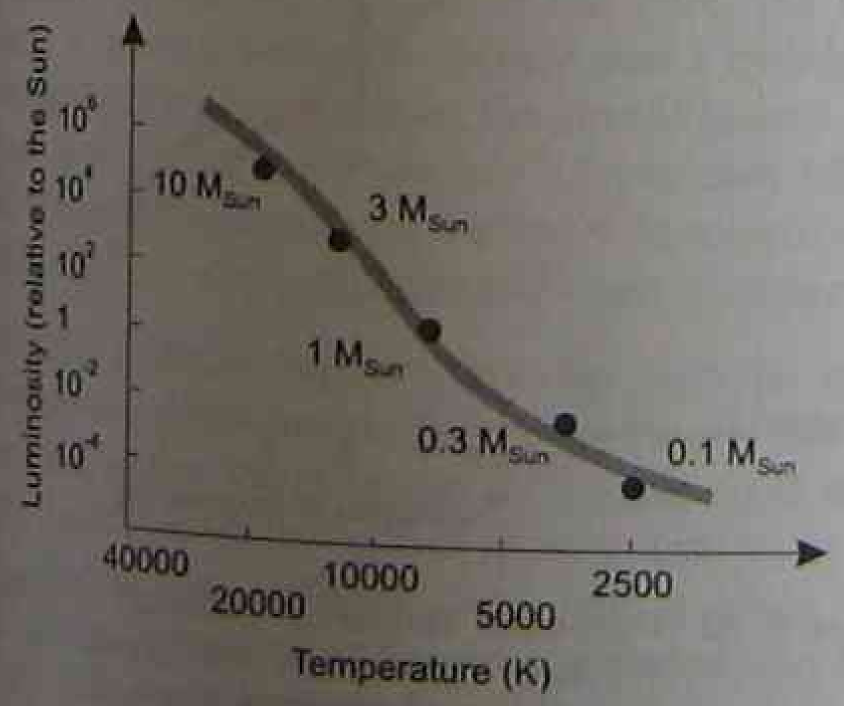

Figure 5. 28 The effect of mass on where a star commences its life

A Star's 'Gestation Period'

The time to reach true star 'status' depends on the mass. The lower the mass, the longer the times spent in the 'star birth' process; the more massive the star, the shorter the 'gestation period'. A star of ~1 solar mass requires ~30 million years to reach the ZAMS; a star of much greater mass (say 10 times the mass of the Sun) may only require three hundred thousand years (see Table 5.9).

Table 5. 9 Pre-main sequence contraction times

Mass ($M_{sun} = 1$)	Spectral Type	Time to Reach ZAMS (10^6 years)
30	O6	0.03
10	B3	0.3
4	B8	1.0
2	A4	8.0
1	G2	30
0.5	K8	100
0.2	M5	1000

If the mass of a protostar is less than 0.08 solar masses, the core temperature never reaches a high enough temperature to initiate nuclear fusion. These 'brown dwarfs' are not real stars.

MAIN SEQUENCE STARS

> *A* **main sequence star** *is one in which hydrogen is burnt to form helium in its core.*

How Long Will a Star Stay on the Main Sequence?

A star can remain on the main sequence for a long time. This time is proportional to the mass and inversely proportional to the luminosity.

A star more massive than the Sun for example, will spend a shorter time (than the Sun) on the main sequence. This happens because to counter its increased gravitational pull, the larger star will consume its hydrogen fuel at a much faster rate, causing it to evolve faster. (The increased rate of fuel consumption is greater than the increase in fuel supply.)

Our Sun may remain on the main sequence for a total period of about 10 billion years. It has been shining as it is now for about 4.5 billion years so it will continue to shine for some time yet!

Energy Sources In Main Sequence Stars

As we saw in *The Cosmic Engine,* in 1939 Hans Bethe proposed that at the high temperatures in the interiors of stars, *nuclear fusion* of hydrogen nuclei into helium was possible, with the *release of energy*.

Bethe and Critchfield then proposed that there are two possible *thermonuclear* reactions involving hydrogen:

1 the proton-proton chain; and
2 the carbon cycle.

Proton-Proton Chain

The reactions proposed for this chain were

$$^{1}_{1}H+{}^{1}_{1}H\rightarrow {}^{2}_{1}H+{}^{0}_{+1}e+\nu+\text{energy}$$
$$^{2}_{1}H+{}^{1}_{1}H\rightarrow {}^{3}_{2}He+\gamma+\text{energy}$$
$$^{3}_{2}He+{}^{3}_{2}He\rightarrow 2{}^{1}_{1}H+{}^{4}_{2}He+\text{energy}$$

where ${}^{1}_{1}H$, ${}^{2}_{1}H$, ${}^{0}_{+1}e$, ν, ${}^{3}_{2}He$, γ and ${}^{4}_{2}He$ represent hydrogen, deuterium, a positron, a neutrino, helium-3, gamma rays and helium-4 respectively.

The net result is to convert four protons into one helium nucleus.

The energy released is tiny for each helium-4 nucleus produced, but with billions of nuclei, the total energy released is enormous, sufficient to explain the radiation from the stars.

The proton-proton chain is the nuclear fusion process in cooler main sequence stars.

The Carbon Cycle (also called the CNO cycle)

In this cycle, carbon, nitrogen and oxygen (from the initial dust and gas material of the protostar) act as *catalysts* for the following reactions:

$$^{12}_{6}C+{}^{1}_{1}H\rightarrow {}^{13}_{7}N+\gamma$$
$$^{13}_{7}N\rightarrow {}^{13}_{6}C+{}^{0}_{+1}e+\nu$$
$$^{13}_{6}C+{}^{1}_{1}H\rightarrow {}^{14}_{7}N+\gamma$$
$$^{14}_{7}N+{}^{1}_{1}H\rightarrow {}^{15}_{8}O+\gamma$$
$$^{15}_{8}O\rightarrow {}^{15}_{7}N+{}^{0}_{+1}e+\nu$$
$$^{15}_{7}N+{}^{1}_{1}H\rightarrow {}^{12}_{6}C+{}^{4}_{2}He$$

The net result (again) is to convert four protons into one helium nucleus.

The **carbon cycle** *predominates at temperatures greater than 1.8 x 10^{7} K (the hotter stars) and the* **proton-proton chain** *is the main process below this temperature (the cooler main sequence stars).*

POST-MAIN SEQUENCE STARS

Having reached the end of its time on the main sequence, that is, its *hydrogen-burning* phase, the star leaves and moves off the main sequence along a line like *CDEF* (Figure 5.29)—the star has become a *red giant.*

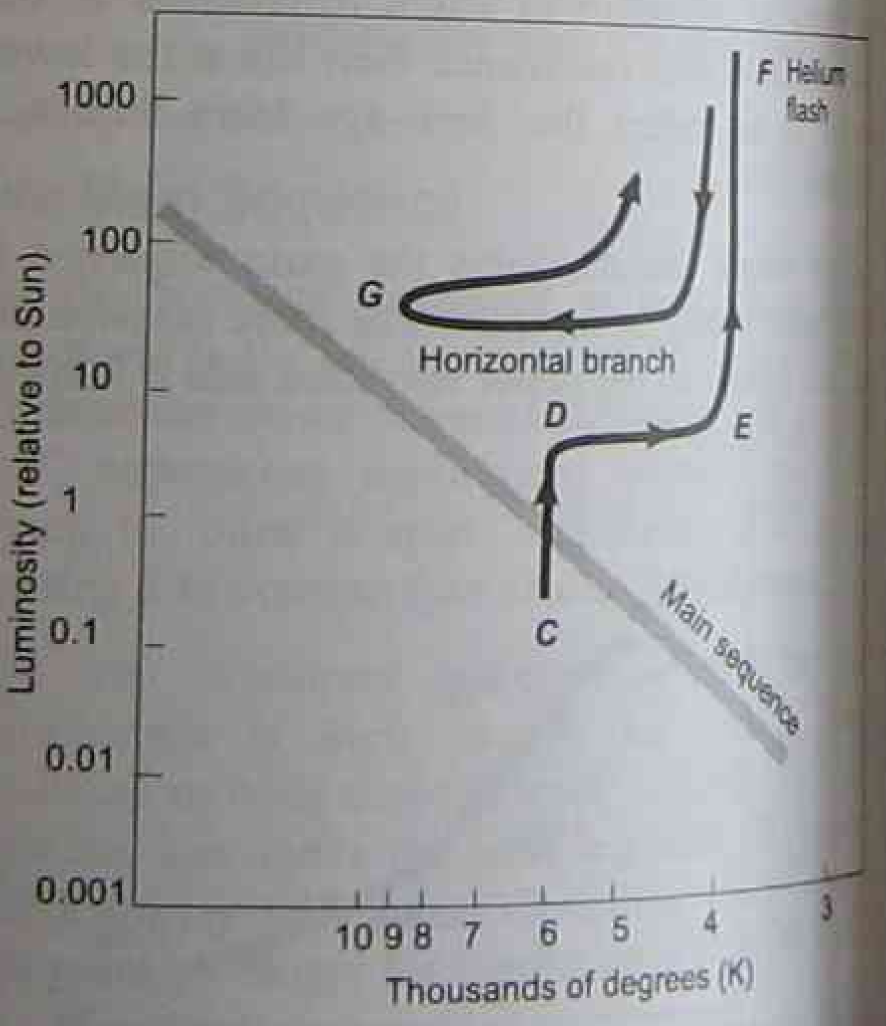

Figure 5. 29 Post-main sequence evolution of a star of ~ 1 solar mass. The star leaves the main sequence and becomes a red giant.

Nucleosynthesis

Nucleosynthesis *is the creation of the chemical elements by nuclear reactions.*

In the 1940s a team of scientists used Einstein's equations to calculate that the Big Bang would have produced a mixture of 25% helium and 75% hydrogen in the universe. This is in close agreement with the observations of the composition of the oldest stars. The question remains, *'Where did the other elements come from?'* This question will be answered as we consider post main sequence stars.

Red Giants

Red giants *are large diameter, very luminous stars but their surfaces are relatively cool and consequently they emit light mostly in the red section of the visible spectrum.*

Their dimensions are enormous—if the Sun were to change into a red giant, for example, the Earth would lie within its volume! The enormous size results in an extremely low density—lower than a good vacuum obtainable on Earth.

Calculations show that red giants result from the evolution of stars with initial masses less than 8 solar masses.

Red Giants and Helium Burning

As we have seen, in a main sequence star, hydrogen is 'burnt' producing helium in the core. As time passes, a core of helium is formed and a hydrogen-burning shell moves out from the core (Figure 5.30). When this helium core reaches 12 per cent of the total mass, it collapses and increases in temperature as the outer envelope expands and cools quickly.

This core collapse happens because with no more hydrogen to burn in the core, no more heat is generated at the star's centre by fusion, so it is no longer held against the pull of gravity. Inevitably the core begins to collapse and as it does, so gravitational potential energy is converted into heat energy. This extra heat from the centre is what causes the outer layers of the star to expand dramatically. It may take up to a few hundred million years to swell up to 100 times the size of our Sun's present diameter. Gradually the brightness decreases and the light becomes redder as the surface area increases at a faster rate than the energy being generated can increase.

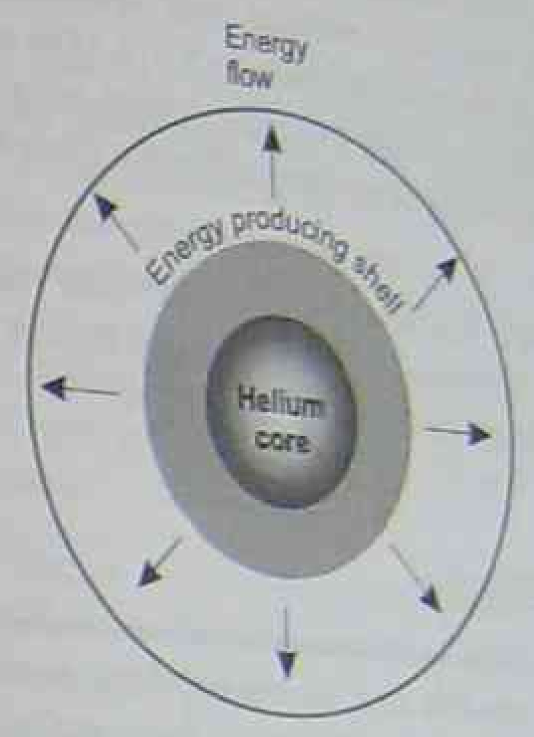

Figure 5. 30 Helium burning in the core of a red giant surrounded by a shell in which hydrogen is burning.

As the surface cools, the light becomes redder and the star becomes a *red giant* such as Betelgeuse in the constellation of Orion.

Helium Flash and The Triple Alpha Process

Initially the core temperature of the red giant is too low for helium fusion but core-contraction results in further conversion of gravitational potential energy into heat which raises the temperature of the core and the surrounding hydrogen burning shell. In a star like our Sun, helium burning begins explosively in the *helium flash* (*F* in Figure 5.29). This effectively reduces the rate of hydrogen burning in the shell around the core. This leads to a contraction and the star 'dips down' and to the left along the *horizontal branch.*

Helium burns to form carbon in the *triple alpha process*. Essentially this is: $3{}^{4}_{2}He\rightarrow{}^{12}_{6}C+\text{energy}$. Fusion of helium to carbon results in a non-burning carbon core. This in turn shrinks and heats the outer layers and the star moves back along the *asymptotic giant branch* forming an extremely bright red supergiant (*G* Figure 5.29).

STELLAR DEATH

As with all aspects of stellar evolution, the path followed depends upon the star's mass. For stars that start their lives with a mass *less* than eight solar masses (such as our Sun), nuclear reactions stop with 'helium burning'. These stars end their lives by ejecting *planetary nebulae* (see opposite), leaving behind a white dwarf (Figure 5.31). (The mass of a white dwarf cannot exceed a critical value equal to ~1.4 solar masses—a limit called the *Chandrasekhar mass*.)

Stars with initial masses greater than eight solar masses explode as *supernovae* leaving behind *neutron stars* or *black holes* (see p. 211).

White Dwarfs

White dwarfs *are low mass, high-density very faint stars in the last stage of stellar evolution.*

A typical *white dwarf* has a radius similar to that of the Earth (~5000 km), an average density of 10^9 kg.m^{-3} and a surface temperature of 10^4 K. At such high densities the stellar material is *degenerate*.

Degeneracy

As a consequence, of one of the basic tenets of quantum mechanics—the *uncertainty principle*—an electron restricted to a small volume of space has a large momentum and so exerts a pressure (*electron degeneracy pressure*) which stabilises the white dwarf against collapse.

As a white dwarf's mass increases, its radius decreases, resulting in increased degeneracy pressure preventing further collapse.

Planetary Nebulae

The core of a low-mass star never reaches the temperature required for fusion of carbon. In Figure 5.31 the star has followed the path *GHI*. In the process of collapse, up to one-fifth of the mass of the collapsing star is left behind as a cloud of gas—a *planetary nebula*—surrounding the white dwarf.

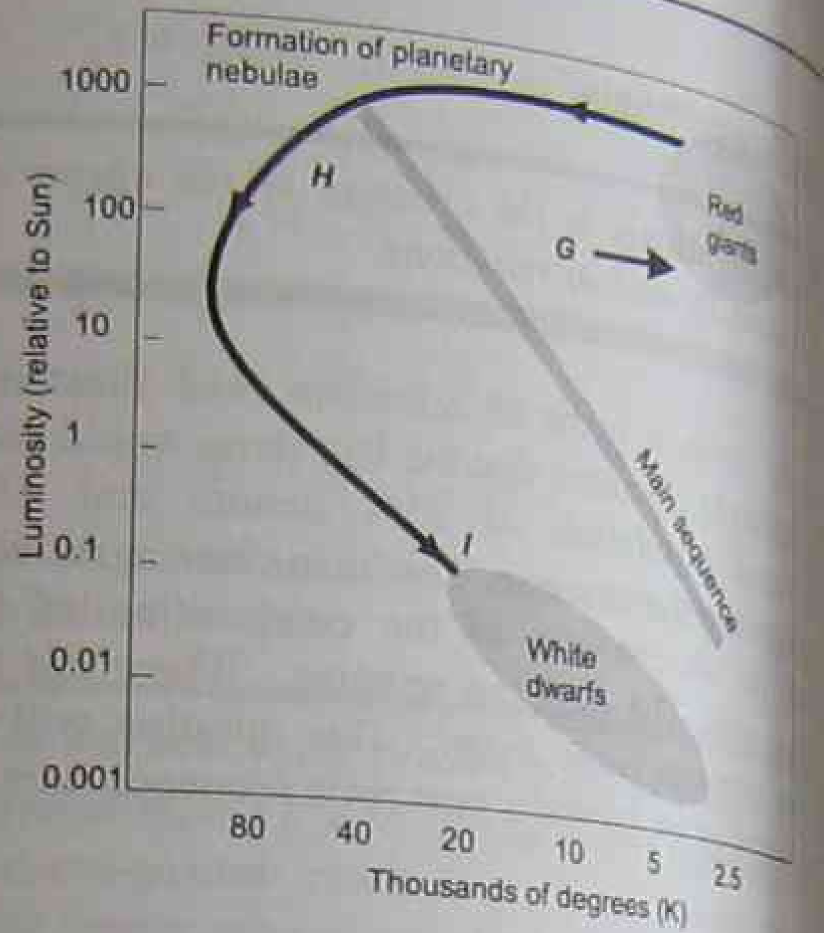

Figure 5. 31 Final stages of evolution for a sta ~1 solar mass

This expanding shell of gas slowly spreads thro space until it becomes too rarefied to detect visua the core left behind is a bare white dwarf.

A white dwarf has no nuclear reactions occurr that is, it has no energy source. It begins extremely hot (~100,000 K), with the residual he from its time spent as a star's core. As time goes it loses this heat by radiation into space and ends eventually as a cold dark 'brown (or black) dwarf

Secondary Source Investigation

Evolution of Stars of Varying Mass

Figure 5.32 shows a simplified track of the overa evolution of a star of ~1 solar mass (combining th earlier) diagrams.

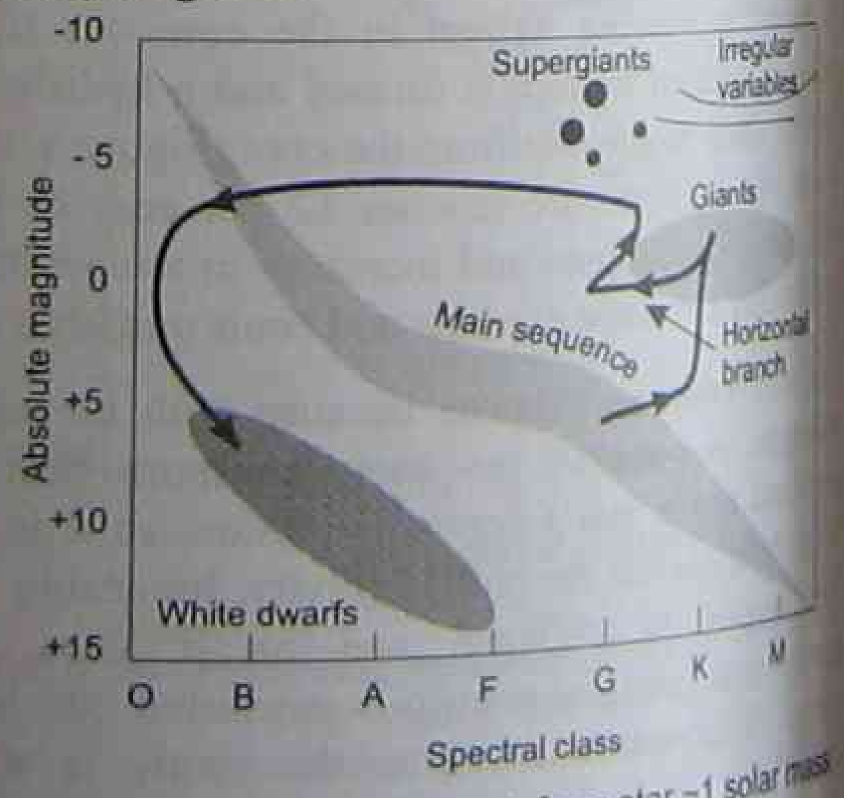

Figure 5. 32 Evolutionary track for a star ~1 solar mas

Similarly Figure 5.33 shows a simplified evolutionary pathway for stars more massive than our Sun.

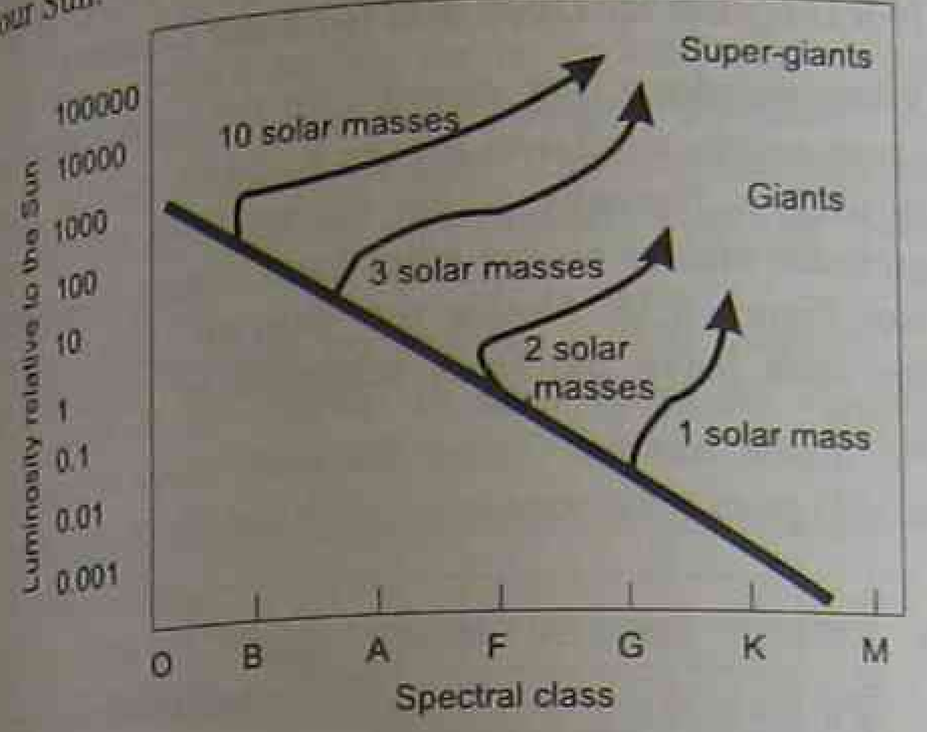

Figure 5. 33 Evolutionary tracks for stars of mass greater than 1 solar mass

As we have seen, stars with initial mass less than eight solar masses stop at helium burning to form a white dwarf. They are prevented from collapsing further by the electron degeneracy pressure (Figure 5.35(a) over the page).

However, for stars with an initial mass greater than eight solar masses, nuclear fusion continues beyond helium burning. The helium core itself begins to react to form carbon and oxygen.

When the helium is exhausted, carbon and oxygen unite. Their burning produces elements such as neon, magnesium, silicon and sulfur. Still later, the silicon and sulfur ignite to form nickel and iron. The result is an 'onion' structure to the star (Figure 5.34).

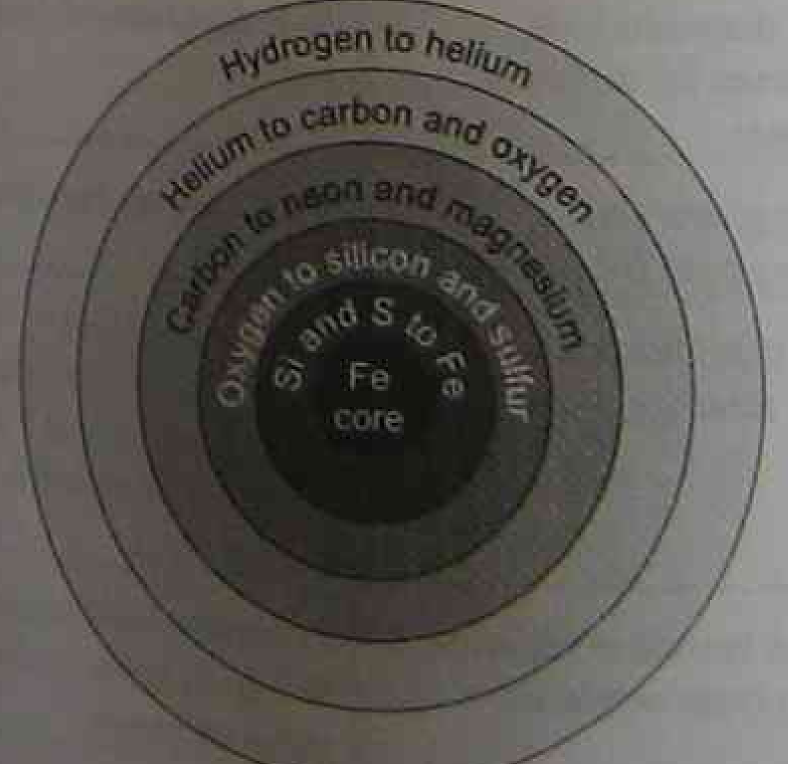

Figure 5. 34 The evolved structure of a star of 20 solar masses

Supernovae

Supernovae *are stars that explode as a result of instabilities produced following exhaustion of the nuclear fuel.*

Iron Core Collapse

When the iron core mass (being added to from the surrounding shell) approaches the Chandrasekhar limit of 1.4 solar masses for the formation of a white dwarf, dramatic consequences ensue. The iron core does not ignite to form heavier elements since this requires an energy input (iron is the most stabl nucleus). With no more energy being produced i the star's core, gravity overwhelms the star and th core collapses.

In less than a second the core shrinks from diameter of about 8000 km to one of about 20 km At this high density (see below), the core resis further collapse and the in-falling matter 'bounce off. This *core bounce* results in enormous amoun of energy being released (mainly as neutrinos) in violent explosion which *blows away the surroundi envelope.*

A single supernova explosion may result in a sing star shining brighter than a billion stars (if only fo short time of ~1 month).

It is during this explosion that elements higher th iron are synthesised by *neutron capture*. Th elements are ejected into space where they beco incorporated into future generations of stars.

Neutron Star (Pulsar)

For core masses >1.4 solar masses but <3 s masses, as the core is squeezed to this diamete about 20 km, electrons are forced into prot forming neutrons (Figure 5.35(b)). The result *neutron star* of incredible density. A pinhea neutron mass would weigh a million kilogr Such great density stops further collapse. (neutrons literally run out of space to move ar creating a *neutron degeneracy pressure*.)

As a neutron star rotates it gives out pulse X-radiation—hence the name *pulsar* as alternative to neutron star.

Black Holes

When extremely heavy stars explode their collapsing core may exceed 3 solar masses. In such cases the collapse does not stop with a neutron star. The shrinking core continues to shrink until its diameter is only a few kilometres or less across!

At these dimensions, the gravity near the surface is so large that even light cannot escape—a *black hole* has formed (Figure 5.35(c)).

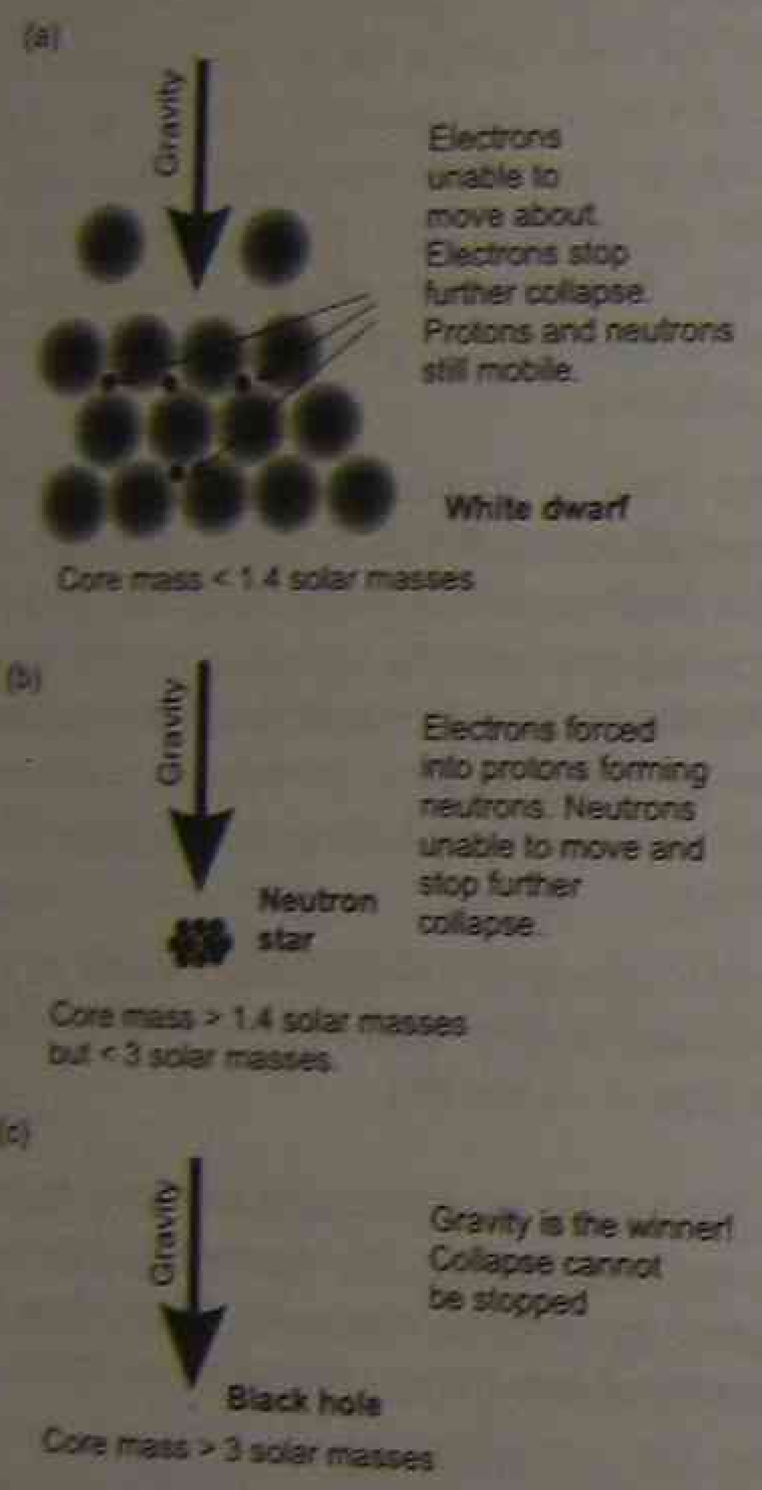

Figure 5. 35 The evolutionary end product depends on the mass of the star.

Table 5.10 shows the energy sources of various star types.

Table 5. 10 Energy sources in various stellar objects

Star type	Energy Source
Main sequence	hydrogen 'burning'
Red giant	helium 'burning'
White dwarf	no energy source
Supernova	'burning' of heavier elements up to iron

Secondary Source Investigation

H-R Diagram for Open and Globular Clusters

When we plot a H-R diagram for the nearby stars a graph results similar to Figure 5.22 (see p.203). This is what is typically found for an *open cluster*. A *globular cluster* on the other hand results in a graph like Figure 5.36. Notice the 'turn-off' point where the stars leave the main sequence to become red giants.

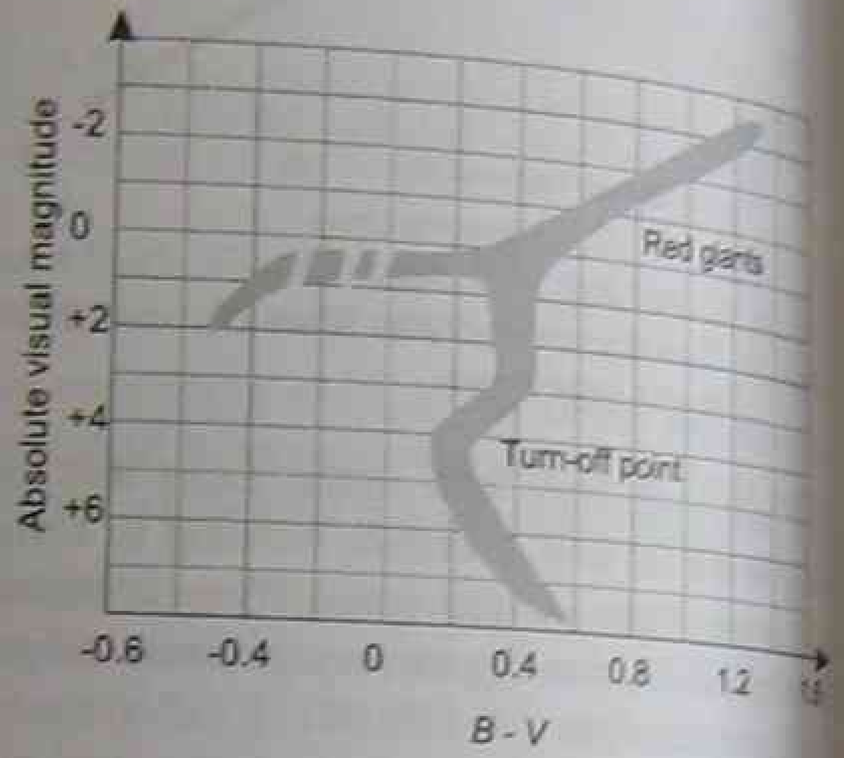

Figure 5. 36 H-R diagram for the Globular Cluster M

Immediately some obvious differences appear between the H-R diagrams of open and globular clusters as indicated in Table 5.11.

Table 5. 11 Comparisons of H-R diagrams for open and globular clusters.

Open Cluster	Globular cluster
H-R diagrams look different for different clusters	H-R diagrams all look similar
Both giants and supergiants are present	There are no supergiants
The giant branch occurs at zero absolute magnitude	The giant branch commences at absolute magnitude of ~-3.5 and proceeds downwards to fainter stars
Giant branch is separate from main sequence	A narrow band connects the giant branch with the main sequence
Some are young; some are old	All have low 'turn-off' points indicating they are old clusters

DETERMINING THE AGE OF A CLUSTER

As we discussed earlier, the more luminous a main sequence star, the faster it consumes its nuclear fuel and hence the quicker it ages. Knowing this, the age of a cluster can be determined from its main sequence plot.

Astronomers begin by plotting a H-R diagram for the stars in the cluster. In most cases the diagram shows a clear 'turn-off point' beyond which few massive, luminous main sequence stars exist (Figure 5.36).

The turn-off point varies between clusters as indicated in Figure 5.37.

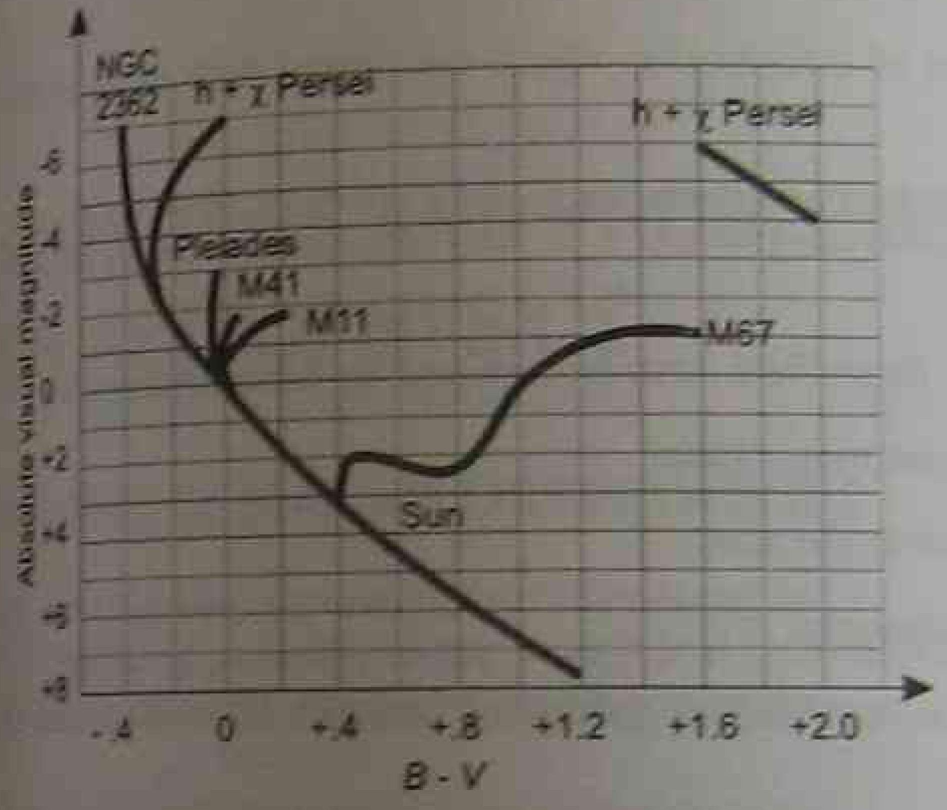

Figure 5. 37 Various H-R diagrams

The turn-off occurs where the main sequence star 'leaves' the H-R diagram on its evolutionary path to form a *red giant*. It follows that the hottest, more massive stars (O-type) leave first, followed by the next coolest stars (B-type and A-type).

The age of the cluster is determined as follows:

1 If the main sequence for that cluster contains O-type stars, the cluster is less than 10 million years old. Why? Because that's how long it takes for an O-type star to use up its core of nuclear fuel of hydrogen.

2 If A-type or B-type main sequence stars are present, the cluster is much older than 10 million years.

> *In general: the lower the* ***cut-off point*** *on the H-R diagram, the older the cluster.*

In Figure 5.37 the oldest cluster is M67 (lowest cut-off point) and the youngest is NGC 2362 (highest cut-off point).

SUMMARY

- The electromagnetic spectrum ranges from the high frequency (small wavelength) gamma rays through to the low frequency radio waves. These waves are selectively absorbed by the Earth's atmosphere.
- Ground-based astronomy is restricted to the visible and radio-wave regions of the electromagnetic spectrum with some narrow windows in the near infrared.
- The sensitivity of a telescope is a measure of its light-gathering power; its resolution is a measure of its ability to distinguish between two very close objects.
- The sensitivity and resolution of a telescope can be improved by using adaptive optics and interferometry.
- New generation telescopes use techniques including lightweight mirrors and active optics.
- The distances to the stars can are measured in parsecs and light-years.
- Trigonometric parallax is used to determine the distance to the nearest stars. It is limited by the size of the baseline that is set by the diameter of the Earth's orbit around the Sun.
- The spectra of stellar objects allow us to determine a lot of information about the object such as its surface temperature and chemical composition.
- Spectra can be emission or absorption spectra and are detected by spectroscopes.
- Stars can be classified according to their spectra.
- The brightness of a star is determined by its size (radius), its surface temperature and its distance from us.
- The brightness of a star determines its absolute and apparent magnitude.
- The magnitude of a star can be used to deduce the distance to the star.
- Spectroscopic parallax uses stellar spectra to determine distances.
- The colour index of a star is the difference between the magnitudes measured using a blue filter and the magnitude using a yellow filter, that is, $CI = B\text{-}V$
- Photomultiplier tubes provide faster measurements of magnitude than photographic plates.
- Binary stars can be visual, eclipsing, spectroscopic or astrometric.
- Binary stars can be used to determine stellar masses.
- Variable stars can be intrinsic variables or extrinsic variables.
- The period-luminosity relationship of Cepheid variables can be used to deduce the distance to distant galaxies.
- Stars are born, mature and eventually die.
- The way in which stars evolve is determined by their mass. The greater the mass, the faster they evolve.
- The evolution of stars can be tracked on a Hertzsprung-Russell (H-R) diagram.
- The H-R diagrams for open and globular clusters allow the age of a cluster to be deduced.

Key Terms

absolute magnitude
adaptive optics
apparent magnitude
arc seconds
astrometry
astrophysics
binary stars
black hole
Cepheid variables
CNO cycle
colour index
electromagnetic spectrum
globular cluster
helium burning
Hertzsprung-Russell diagram
Hubble Space Telescope
interferometry
Keck Telescopes
light-year
luminosity
main sequence
neutron star
nuclear fusion
open cluster
parallax
parsec
photometry
proton-proton cycle
pulsar
red giant
resolution
sensitivity
spectra
spectral class
spectroscope
spectroscopic parallax
stellar evolution
supernova
variable stars
white dwarf
zero-age-main-sequence

QUESTIONS AND PROBLEMS ON *ASTROPHYSICS*

SECTION 1: MAKING OBSERVATIONS

1 Explain why ground-based astronomy is restricted primarily to the visible and radio wave regions of the electromagnetic spectrum.

2 Define the meaning of the following terms:
   (a) sensitivity of a telescope
   (b) resolution of a telescope
   (c) 'seeing'.

3 Explain briefly how adaptive optics and interferometry can be used to improve the sensitivity and resolution of ground-based telescopes.

4 Briefly describe some of the techniques used for the new generation of optical telescopes.

SECTION 2: ASTROMETRY

1 Define the following terms:
   (a) astrometry
   (b) parallax
   (c) parsec
   (d) light-year.

2 How can trigonometric parallax be used to determine the distances to stars?

3 The star 40-Eridini is 5 pc away. What is its parallax?

SECTION 3: SPECTROSCOPY

1 Define the following terms:
   (a) spectrum
   (b) continuous spectrum
   (c) emission spectrum
   (d) absorption spectrum
   (e) spectroscope.

2 State two stellar characteristics that can be deduced from a star's spectra.

3 Explain why some stars have strong (dark) hydrogen lines while others have only weak hydrogen lines.

4 What is the basis on which stars are classified in different spectral classes?

5 How can spectra be used to determine an object's velocity?

6 How is the density of a star related to its spectrum?

7 Explain how Wien's Law relates temperature and spectra.

8 A red giant radiates light with the maximum wavelength at 600 nm. What is the temperature of this giant?

SECTION 4: PHOTOMETRY

1 Define the following terms:
  - (a) photometry
  - (b) absolute magnitude
  - (c) apparent magnitude
  - (d) spectroscopic parallax
  - (e) colour index.

2 Our Sun has an apparent visual magnitude of -26.5 and an absolute visual magnitude of +4.83. Explain why these magnitudes are different.

3 A star of the sixth magnitude is located 40 pc from the Sun. What is its absolute magnitude?

4 A star has an apparent magnitude of 8 and an absolute magnitude of 0. How far away is it?

5 A particular star has a colour index of +0.9. Describe its colour and temperature.

SECTION 5: BINARY AND VARIABLE STARS

1 Define the following terms;
  - (a) binary stars
  - (b) visual binary
  - (c) eclipsing binary
  - (d) spectroscopic binary
  - (e) astrometric binary.

2 Explain how binary stars can be used to determine stellar masses.

3 The period of a binary star is 40 years. If 22 AU separates the stars, what is their combined mass?

4 An eclipsing binary star is an extrinsic variable star. What does this mean?

5 What is the period-luminosity relationship for Cepheid variables?

6 Explain how Cepheid variables are used to determine distances to galaxies.

SECTION 6: STELLAR EVOLUTION

1 Briefly describe the formation of a star from the interstellar medium.

2 What nuclear reactions are occurring in:
  - (a) main sequence stars?
  - (b) red giants?
  - (c) white dwarfs?
  - (d) supernova?

3 Red giants are relatively cool (~3000 K) but highly luminous. Explain.

4 Briefly explain how the elements, other than hydrogen and helium, are formed.

5 Define the following terms:
  - (a) planetary nebulae
  - (b) white dwarf
  - (c) supernova
  - (d) neutron star
  - (e) black hole.

6 Explain how the size of a star determines how quickly it evolves.

7 Clearly describe the probable evolution of a star of mass ~10 solar masses.

8 Why don't black holes appear on the Hertzsprung-Russell diagram?

9 Explain how the zero-age main sequence can be used to determine the age of a cluster.

TEST QUESTIONS ON ASTROPHYSICS

Each QUESTION *is composed of a number of parts. Suggested marks for each part are indicated. In keeping with the format of the HSC Examination, each question totals 25 marks.*

QUESTION 1

(a) The world's largest optical telescopes, the 10 m *Keck Telescopes* are situated at Mauna Kea in Hawaii at an altitude of 4200 m. Identify two reasons why they were placed here. (2 marks)

(b) The *European Space Agency* placed the *Hipparcos* satellite into orbit in 1989. Its role was to survey the nearby stars and determine their distances as accurately as possible.

  - (i) Identify the basic principle used to determine these distances. (1 mark)
  - (ii) One result was that the distances to remote galaxies were found to be ~10% further away than previously believed. Identify what implication this has for the age of the universe. (1 mark)

(c) Proxima Centauri is the closest star (other than our Sun) to us and it is 4.3 light-years away. Proxima Centauri has an apparent visual magnitude of 0.06.

  - (i) Calculate the parallax of Proxima Centauri. (1 mark)
  - (ii) Calculate its absolute visual magnitude. (1 mark)

(The following data may be required: 1 parsec equals approximately 3.26 light-years.)

(d) Helium was discovered in the Sun (from the Greek *Helios*) before it was discovered on Earth. The technique used was spectroscopy.

  - (i) Account for the basic principle that underlies spectroscopy. (2 marks)
  - (ii) Explain the advantage of using a photomultiplier instead of photographic film in analysing the light from a star. (2 marks)

(e) Colour index is a useful property for astronomers.

  - (i) Explain what is meant by the colour index of a star. (1 mark)
  - (ii) Identify its use to astronomers. (1 mark)

(f) The light curve for the classical Cepheid variable δ-Cephei is shown in Figure 5.38.

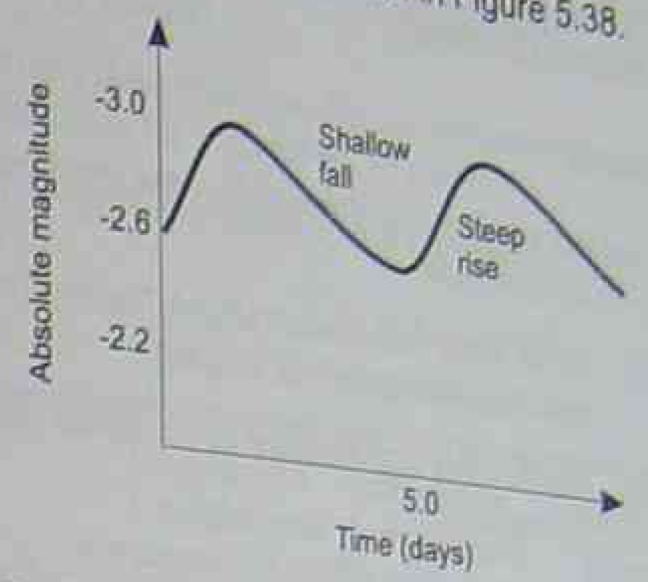

Figure 5. 38

  - (i) Calculate the approximate period of oscillation of δ-Cephei. (1 mark)
  - (ii) Account for the variation of light intensity of δ-Cephei with time. (2 marks)

(g) A white dwarf is a rare stellar object.

  - (i) What is a white dwarf? (1 mark)
  - (ii) Describe how it is formed. (2 marks)

(h) Figure 5.39 is a Hertzsprung-Russell diagram.

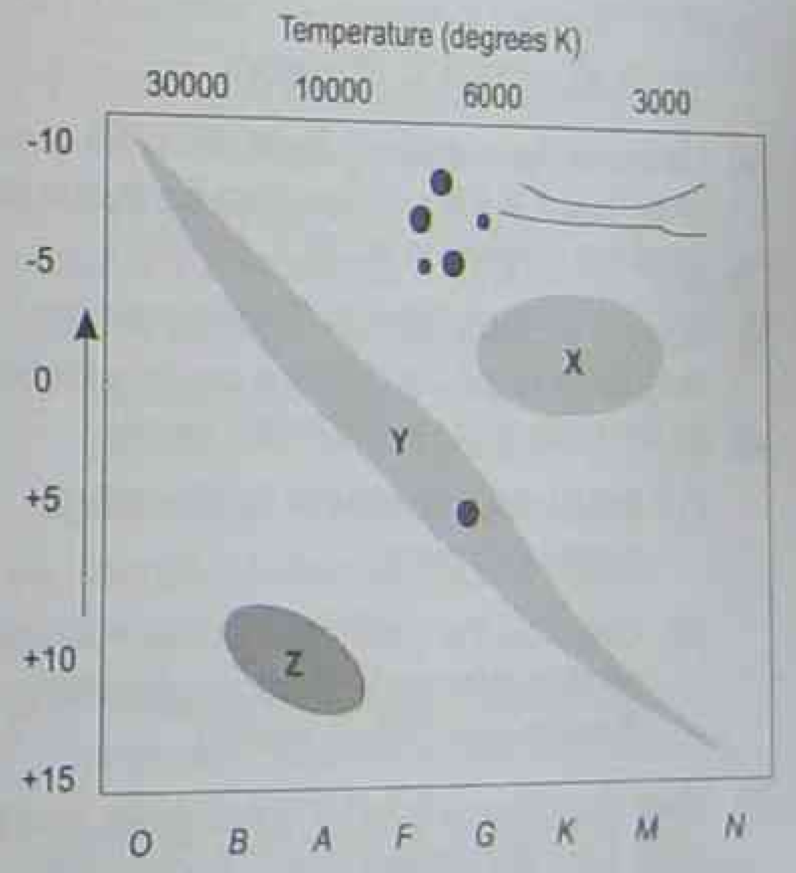

Figure 5. 39

  - (i) Identify what is plotted on the vertical axis. (1 mark)
  - (ii) Identify the regions labelled X, Y and Z. (2 marks)
  - (iii) As you move from bottom right to top left along the region marked Y, recall what changes occur in the characteristics of the star. (1 mark)

(i) Explain why the turn-off point for a cluster in an H-R diagram is an indication of the age of the cluster. (3 marks)

QUESTION 2

(a) Galileo was among the first to view the heavens with a telescope.

- (i) What were *two* observations Galileo made with his telescope? (2 marks)
- (ii) Identify the significance of his observations. (2 marks)

(b) Recall what factors affect the apparent brightness of a star as viewed from the Earth. (1 mark)

(c) The star Proxima Centauri has a stellar parallax of 0.772 seconds of arc (the largest recorded, indicating this is the closest star to us; it is in fact one of the three stars that constitutes the brightest pointer to the Southern Cross). Calculate the distance to Proxima Centauri in parsecs. (1 mark)

(d) The Sun has a temperature of ~6000 K. Calculate which wavelength is most intense in the solar spectrum. The following data may be required:

$W = 2.89 \times 10^{-3}$ m.K. (2 marks)

(e) Calculate the absolute magnitude of the Sun given that it is 4.8×10^{-6} pc from Earth and its apparent magnitude is –26.7. (1 mark)

(f) Spica is a B1 star with an apparent visual magnitude of 1.0. Its distance can be estimated by the method of spectroscopic parallax.

- (i) Explain the meaning of spectroscopic parallax. (1 mark)
- (ii) Calculate the distance to Spica. You will need to refer the Hertzsprung-Russell diagram on p.203. (2 marks)

(g) *'Red stars have a positive colour index and blue stars a negative colour index'.* Explain this statement. (2 marks)

(h) A star is observed over a period of time and is found to produce a light curve as shown in Figure 5.40.

- (i) Identify what type of star produces such a light curve. (1 mark)
- (ii) Describe what is happening at the regions labelled X, Y and Z on the light curve. (2 marks)

(i) Stellar objects include red giants, binary stars, open clusters, globular clusters and dust clouds. Select any *three* of these and briefly describe or define them. (5 marks)

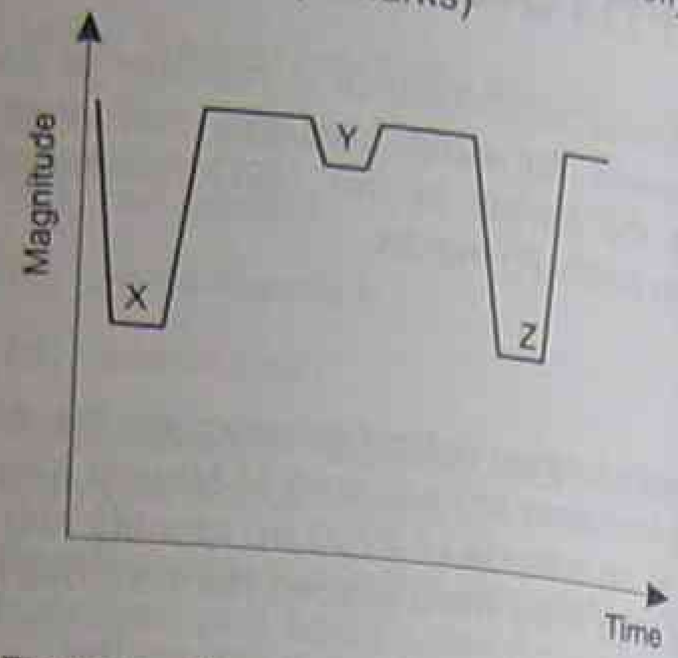

Figure 5. 40

(j) Briefly describe the birth of a star of ~1 solar mass up to its reaching the main sequence on a Hertzsprung-Russell diagram. (3 marks)

QUESTION 3

(a) Adaptive optics is a method used to improve the resolution of ground-based telescopes. Briefly explain how this technique works. (3 marks)

(b) Trigonometric parallax is a method used to determine a star's distance from the Earth. This distance is usually measure in parsecs (pc).

- (i) Draw a simple diagram to illustrate the meaning of trigonometric parallax in relation to astronomy. (1 mark)
- (ii) Use this diagram to show how one parsec (1 pc) is defined. (1 mark)
- (iii) Recall the limitations of trigonometric parallax. (1 mark)
- (iv) Recall another method that can be used to determine stellar distances. (1 mark)

(c) A star is observed to have an apparent visual magnitude of 6.0 and is 20 parsecs from Earth. Calculate its absolute magnitude. (2 marks)

(d) Some stars are found to produce 'spread out' spectral lines. Identify what can be deduced from this. (1 mark)

(e) The Hertzsprung-Russell diagram is a plot of magnitude versus temperature or spectral class or colour index. The basic graphs are the same in all cases. Explain why temperature, spectral class and colour index are related. (2 marks)

(f) The discovery of Cepheid variables provided scientists with a convenient method for determining distances to stellar objects. Briefly outline the steps involved in this method. (3 marks)

(g) The Sun is a G2 star with a surface temperature of ~6000 K. The solar constant, that is, the power received on the Earth per second, is 1400 $J.s^{-1}.m^{-2}$. The Sun lies 1.5×10^{11} m from the Earth.

- (i) Calculate the energy that is being radiated from the Sun per m^2. (Hint: The energy is radiated outwards as a sphere.) (2 marks)
- (ii) Recall where this energy comes from. (1 mark)
- (iii) The production of this energy causes the composition of the Sun to change. Copy the outline of the Hertzsprung-Russell diagram in Figure 5.20 and draw the likely steps in the evolutionary path of the Sun. Explain each step. (3 marks)

(h) Account for the gap in the H-R diagram ('the H-R gap') between the main sequence and the red giant stage. (2 marks)

(i) Figure 5.41 shows the H-R diagram for a range of clusters.

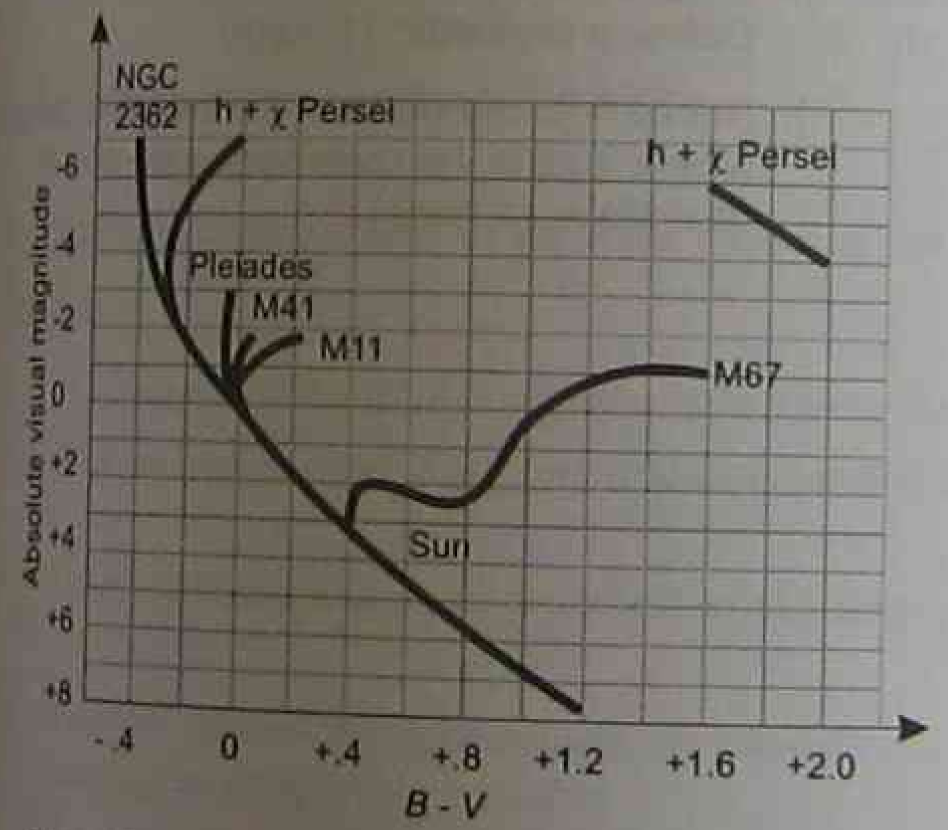

Figure 5. 41

- (i) Identify which cluster shown is the oldest. (1 mark)
- (ii) Explain your reasoning for your answer in (i) above. (1 mark)

QUESTION 4

(a) The largest optical telescopes in the world, the two 10 m *Keck Telescopes* are to be used as a two-element optical interferometer.

- (i) Identify what an interferometer is. (1 mark)
- (ii) Recall what is/are its advantage(s). (2 marks)

(b) Briefly describe how the surface temperature of stars can be measured. (1 mark)

(c) This question refers to the information in Table 5.12.

Table 5. 12

Star	Apparent brightness	Absolute brightness	Colour index (B – V)
Sirius	–1.45	+1.41	0
Canopus	–0.73	–4.70	+0.16
Betelgeuse	+0.41	–5.50	+1.5

- (i) Which star appears brightest to us? Explain your answer. (1 mark)
- (ii) Which star has the highest temperature? Explain your answer. (1 mark)
- (iii) Calculate the distance to Canopus. (1 mark)
- (iv) Calculate the parallax of Canopus. (1 mark)
- (v) Predict the likely spectral class for Betelgeuse. (1 mark)

(d) In 1939 Bethe proposed that the energy radiated from stars was a result of the fusion of light elements into heavier ones.

- (i) Identify what energy conversion was postulated to allow stars to shine before the proposal of fusion reactions. (1 mark)
- (ii) Identify what problem led to Bethe's proposal. (1 mark)
- (iii) Recall the basic fusion reaction Bethe proposed. (Word equation only) (1 mark)

(e) A particular Cepheid type variable star has a period of approximately 5 days and an average apparent magnitude of +4. Using the period-luminosity curve of Figure 5.42 calculate the distance to the galaxy containing this star. (2 marks)

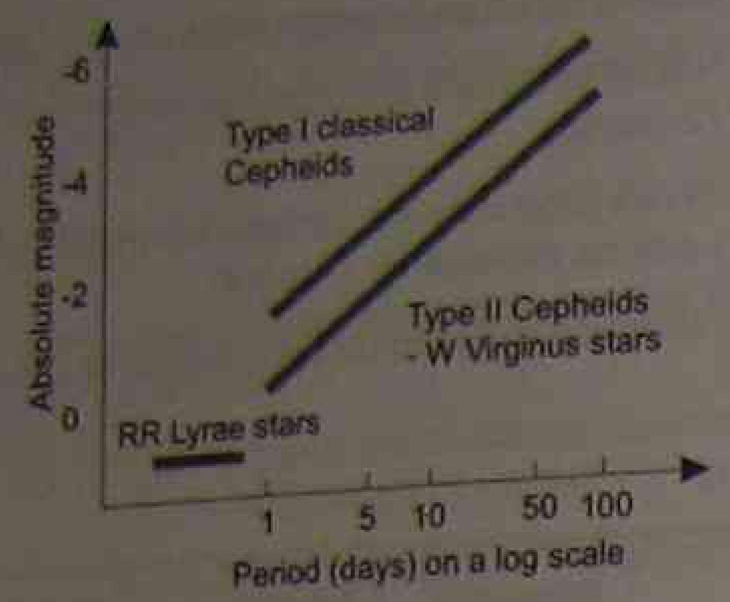

Figure 5. 42

(f) This question refers to the information in Table 5.13.

Table 5. 13

Star	Absolute magnitude	Spectral class
Sun	+4.83	G2
Antares	–4.50	M1
Sirius	+1.41	A1
Betelgeuse	–5.50	M2
Barnard's star	+13.25	M5

(i) Plot the position of each star on the Hertzsprung-Russell diagram in Figure 5.43 and predict its probable evolutionary state. (3 marks)

(ii) Which star is hottest? Explain your reasoning. (1 mark)

(iii) Identify the nuclear fuel in Betelgeuse. (1 mark)

(iv) Predict the colour of Antares. (1 mark)

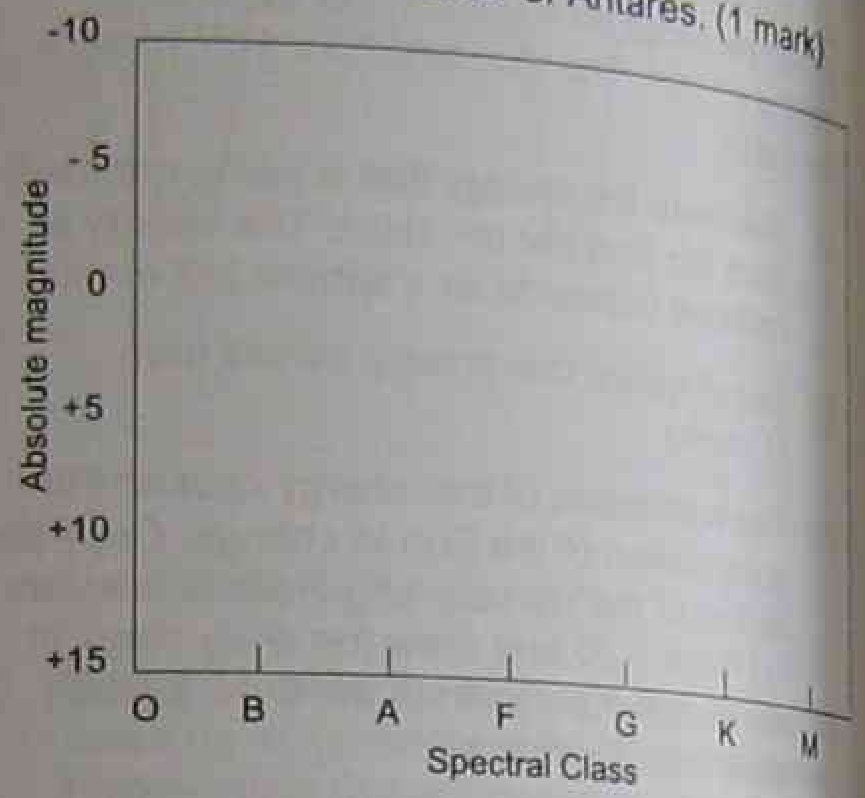

Figure 5. 43

(g) Compare the H-R diagram of a globular cluster with that for an open (galactic) cluster, stating three major differences. (3 marks)

(h) (i) Define a protostar. (1 mark)

(ii) Recall how the mass of the protostar affects where it joins the main sequence and its final state. (1 mark)

Chapter Six

Quanta to Quarks

SECTION 1: MODELS OF THE ATOM

BIG IDEA:

Problems with the Rutherford model of the atom led to the search for a model that would better explain the observed phenomena.

OUTCOMES:

Students learn to:

1 Discuss the structure of the Rutherford model of the atom, the existence of the nucleus and electron orbits.
2 Analyse the significance of the hydrogen spectrum in the development of Bohr's model of the atom.
3 Discuss Planck's contribution to the concept of quantised energy.
4 Define Bohr's postulates.
5 Describe how Bohr's postulates led to the development of a mathematical model to account for the existence of the hydrogen spectrum for which $\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$
6 Discuss the limitations of the Bohr model of the hydrogen atom.

Students:

1 *Perform a first-hand investigation to observe the visible components of the hydrogen spectrum.*
2 *Process and present diagrammatic information to illustrate Bohr's explanation of the Balmer series.*
3 *Solve problems and analyse information using* $\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$
4 *Analyse secondary information to identify the difficulties with the Rutherford-Bohr model, including its inability to completely explain:*
   - *the spectra of larger atoms;*
   - *the relative intensity of spectral lines;*
   - *the existence of hyperfine spectral lines;*
   - *the Zeeman effect.*

CONTEXTUAL OUTLINE

As we enter the twenty-first century it is of interest to reflect on the state of physics at the beginning of the twentieth century. Following the work of Newton in the seventeenth century on mechanics and gravity and the work of Maxwell in light and other electromagnetic waves in the nineteenth century, it was initially believed that physicists 'knew' all the laws of nature and that any changes would '... be in the fifth decimal place'. Classical physics—physics prior to 1900—was, however, unable to explain the behaviour of matter on the subatomic scale. *Black body radiation* (see p.112), the *photoelectric effect* (see p.113) and *line emission spectra* (see p. 186) defied explanation.

The first three decades of the twentieth century saw a change as revolutionary as the work of Newton some two centuries before. *Quantum mechanics* and *relativity* evolved to give a more accurate description of the behaviour of matter on the atomic and subatomic scale. This scientific revolution led to significant changes, both in the way we view the world around us and in our ability to manipulate matter for the benefit (and otherwise) of the human race.

This chapter commences with the *Rutherford model* of the atom. We then look at the *Bohr model*, both its successes and its failings. We then look at the wave nature of matter and its use in explaining the atomic model. Next we look at some practical applications of this new knowledge. We conclude with the current *standard model of matter* consisting of quarks, leptons and bosons.

THE ATOMIC THEORY

Today we believe that all matter is composed of tiny particles—*atoms*—and that these atoms are made up of even smaller *fundamental* particles—*protons*, *neutrons* and *electrons*[1]. The atomic theory is one of humankind's greatest intellectual achievements.

The Beginnings

Democritus

Over 2000 years ago the Greek philosopher Democritus proposed that there was a limit to how small one could divide matter—this smallest indivisible particle was called an atom.

Aristotle (~340 BC)

The atomic theory of Democritus was criticised by Aristotle who proposed an alternative model based on four basic 'elements'—*earth, air, fire* and *water*. Aristotle's view held prominence for the next two thousand years as it better fitted with the religious beliefs of the time.

Dalton

In 1801, as a result of his studies in chemistry, James Dalton, a Scottish teacher proposed his atomic theory which stated that:

1 Matter is composed of small *indivisible* atoms.
2 Elements contain only one type of atom. Different elements contain different atoms.
3 Compounds contain more than one type of atom.

Thomson's 'Plum Pudding' Model

As discussed in the HSC Core Topic *From Ideas to Implementation* we saw how the British physicist J.J. Thomson and others showed that cathode rays—*electrons*—were present in all matter.

In 1904, Thomson proposed that the atom was a sphere of positive charge in which were embedded rings of negative charges (electrons), like 'plums in a pudding' (Figure 6.1).

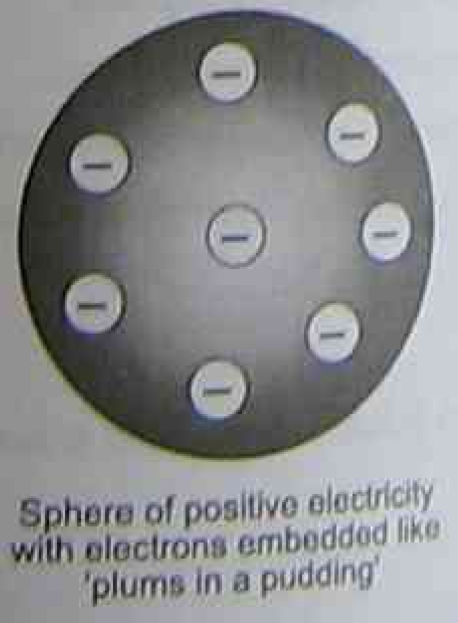

Figure 6. 1 Thomson's 'plum pudding' model

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[1] We will see later that protons and neutrons are not truly fundamental as they are themselves made up of other particles—*quarks*.

Radiation and the Atom

The discovery of radiation in the late nineteenth century by Henri Becquerel proved vital in the progress of physics in at least two areas:

1 The fact that certain elements were known to emit radiation (that is α, β and γ rays) suggested that the atom was divisible and not indestructible, as proposed in Dalton's atomic model; and
2 Radiation provided an important tool for the study of matter. Rutherford first suggested the use of alpha particles to probe the internal structure of the atom in 1911. As a result of this experiment the nucleus and its protons were discovered.

RUTHERFORD'S SCATTERING EXPERIMENT[2]

In 1911 Geiger and Marsden, at the instigation of Ernest Rutherford, performed an experiment in which the newly discovered alpha particles were fired at a thin gold foil (Figure 6.2). Most of the alpha particles passed through with only small deflections, as would have been expected on the Thomson model of the atom current at the time. About 1 in 8,000, however, were deflected through angles greater than 90°.

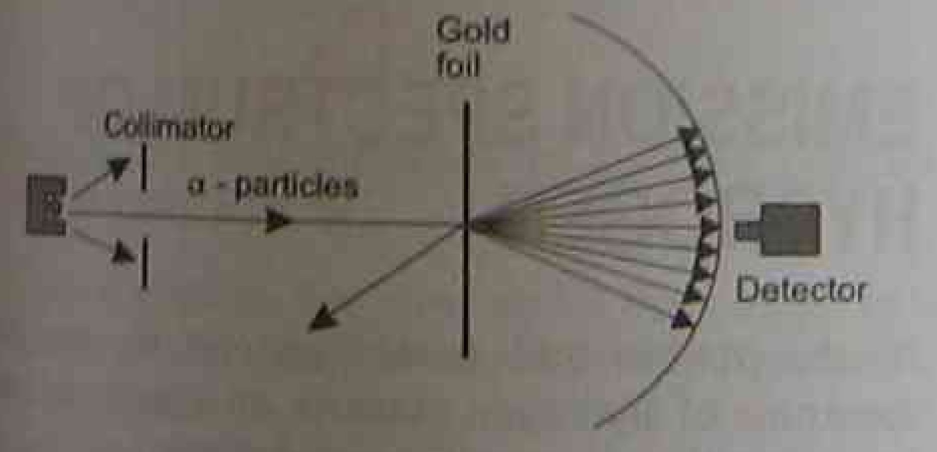

Figure 6. 2 Rutherford's scattering experiment

The results obtained by Geiger and Marsden were so unexpected that Rutherford was prompted to write '*... it was almost as incredible as if you fired a 15 inch shell at a piece of tissue paper and it came back and hit you ...*'.

Rutherford proposed that the only way that the alpha particles could be deflected through large angles was if *all* the atom's positive charge and nearly all its mass was concentrated in a small dense *nucleus* with the electrons some distance away, as indicated in Figure 6.3. Most of the atom is empty space.

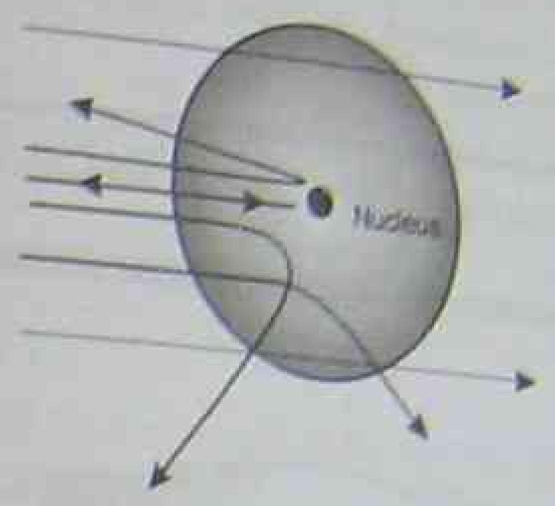

Figure 6.3 The Rutherford atom (not to scale)

The Nucleus

From the results of the alpha particle scattering experiment, Rutherford was able to estimate the size of the atom and its nucleus. He estimated the atom to have a diameter of ~10^{-10} m and the nucleus a diameter of ~10^{-14} m.

Inadequacies of Rutherford's Atom

For all of its success in explaining alpha particle scattering, Rutherford's interpretation still left many questions unanswered. These included:

1 What is the nucleus made up of?
2 What keeps the negative electrons from being attracted into the positive nucleus?
3 How are the electrons arranged around the nucleus?

If the electrons circled the atom like planets around the Sun (which could explain why they did not fall into the nucleus), they would be accelerating. Accelerated charges, however, are known to emit electromagnetic radiation, so the electrons should *continuously* lose energy and spiral into the nucleus and hence the atom should collapse.

The fact that atoms are stable and elements emit *line spectra* (see p.224), rather than *continuous spectra*, showed that electrons had none of these characteristics.

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[2] http://micro.magnet.fsu.edu/electromag/java/rutherford/ A Virtual Rutherford experiment.

SPECTRA

When white light is passed through a triangular prism as in Figure 6.4, the light is broken up into its constituent colours—*red, orange, yellow, green, blue and violet*. There is a continuous spread of colours and hence wavelengths. Such a spectrum is called a *continuous spectrum*. It can be viewed with a *spectroscope*.

> *A* **spectroscope**[3] *is a device used to examine spectra.*

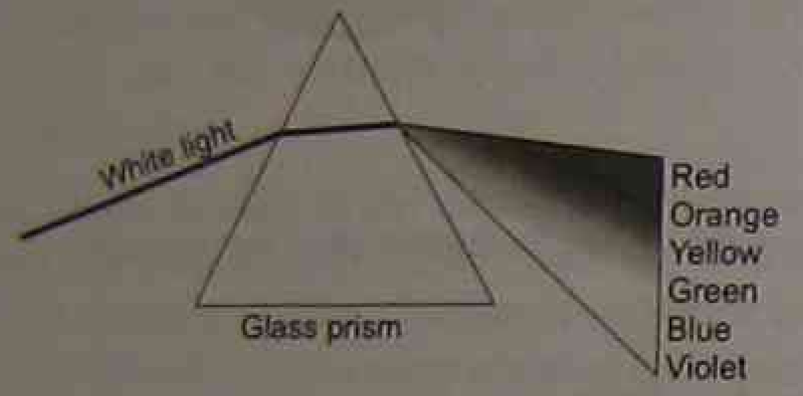

Figure 6.4 Continuous spectra

Essentially a spectroscope consists of a tube with a slit in one end and a prism or diffraction grating which splits the light into its constituent parts.

Spectra can be either:

1 emission or
2 absorption.

Emission Spectra[4]

It had long been known that most gases *emit* light when excited. This excitation could occur by:

1 heating the gas to a high temperature; or
2 passing an electric current through the gas at low pressure (see p.99).

As far back as 1752 the Scottish physicist Thomas Melville showed that the *emission spectra* of different gases were different. He showed that:

> *When an element is excited, the element emits light of definite wavelengths giving rise to a line* **emission spectrum** *when viewed through a spectroscope (Figure 6.5).*

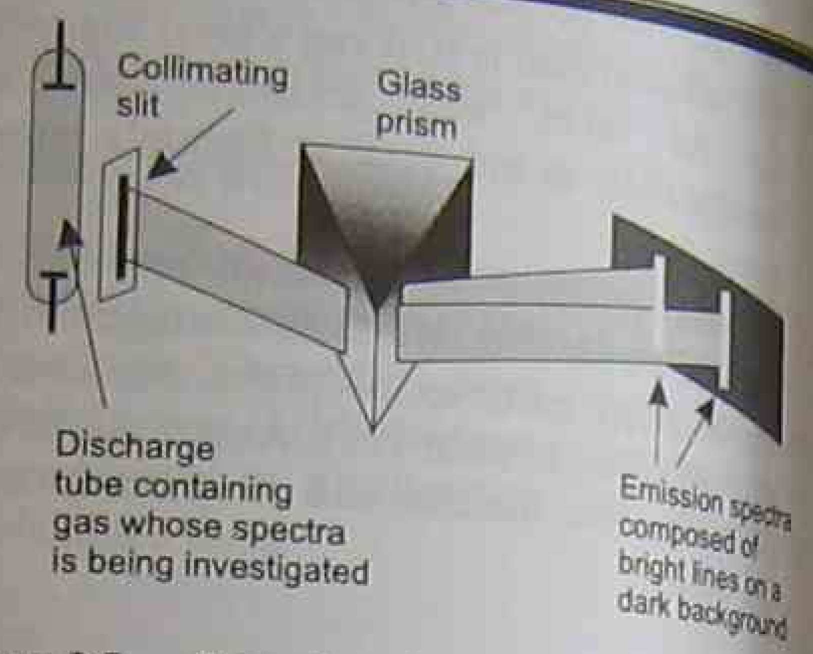

Figure 6.5 Formation of line emission spectra

Each element has a characteristic *line emission spectrum* (the lines being images of the spectroscope slit in specific wavelengths). In 1823 the British astronomer John Herschel made the suggestion that each gas could be identified from its unique line spectrum.

Spectra are an element's 'fingerprints' in that they are unique to each element, just as a person's fingerprints are unique to that person.

The spectrum of a gas to be extensively studied was that of the lightest gas, hydrogen.

EMISSION SPECTRUM OF HYDROGEN

In the visible and near-ultraviolet the emission spectrum of hydrogen consists of a series of lines corresponding to specific wavelengths (colours), as in Figure 6.6.

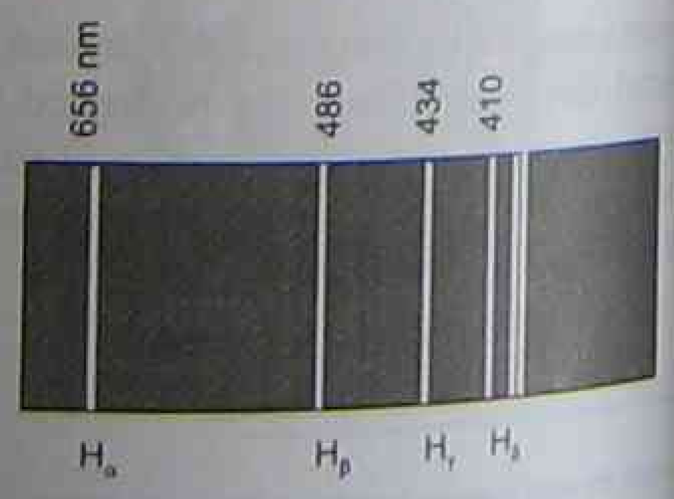

Figure 6.6 Hydrogen emission spectrum

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[3] If the light to be analysed falls on a photographic plate it is called a *spectrometer*.

[4] http://jersey.uoregon.edu/elements/Elements.html displays the emission and absorption spectra of all the elements of the Periodic Table. Just click on an element and its spectrum is displayed. Another excellent site is http://phys.educ.ksu.edu/vqm/html/emission.html for a simulation of emission and absorption spectra. Requires Shockwave.

In 1885 a Swiss schoolteacher, Johan Balmer, found an *empirical formula,* (that is, a formula derived purely from experiments with no theoretical basis), which gave the wavelengths of the emission lines for hydrogen. The wavelength of each line could be found from:

$$\lambda = b\left(\frac{n^2}{n^2 - 2^2}\right)$$

where *b* is a constant and *n* is an integer (which is different for each line) as indicated in Table 6.1.

Table 6.1 The Balmer series for hydrogen

Name of line	n	λ	Colour
H_α	3	656.2	red
H_β	4	486.1	green
H_γ	5	434.0	blue
H_δ	6	410.13	violet

Written in its modern form, Balmer's formula is:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

where R_H is a constant called the Rydberg constant, equal to 1.097 x 10^7 m^{-1}.

Balmer speculated that other series lines might exist which prompted others to search for (and succeed in finding) them.

In general we can write:

$$\boxed{\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)}$$

where n_f can have the values 1, 2, 3, 4… and $n_i = n_f + 1, n_f + 2, n_f + 3$ … as shown in Table 6.2.

Table 6. 2 The spectral lines of hydrogen

Series name	Discovered	Spectral region	Values in Balmer's equation	
			n_f	n_i
Lyman	1906-14	ultraviolet	1	2, 3, 4…
Balmer	1885	UV–visible	2	3, 4, 5…
Paschen	1908	infrared	3	4, 5, 6…
Brackett	1922	infrared	4	5, 6, 7…
Pfund	1924	infrared	5	6, 7, 8…

EXAMPLE 1

Calculate the wavelength of the first two lines of the Lyman series.

SOLUTION

From Table 6.2 we have $n_f = 1$ for the Lyman series and the first two lines will correspond to $n_i = 2$ and $n_i = 3$. Hence:

Similarly:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$= R_H\left(\frac{1}{1^2} - \frac{1}{3^2}\right)$$

$$= 1.097 \times 10^7 \times \frac{8}{9}$$

$$\lambda = \frac{9}{8 \times 1.097 \times 10^7}\ \text{m}$$

$$= 1.02 \times 10^{-7}\ \text{m}$$

= 102 nm for the second line

Extension

Absorption Spectra

Just as an element is capable of *emitting* certain frequencies of light, so too, it is capable of *absorbing* these *same* frequencies. In 1859 Kirchoff succeeded in showing that the absorption spectrum produced by passing white light through a cool gas matched exactly the emission lines produced by the same gas when excited (for example, by heating or passing an electric current through the gas—see Figure 6.7).

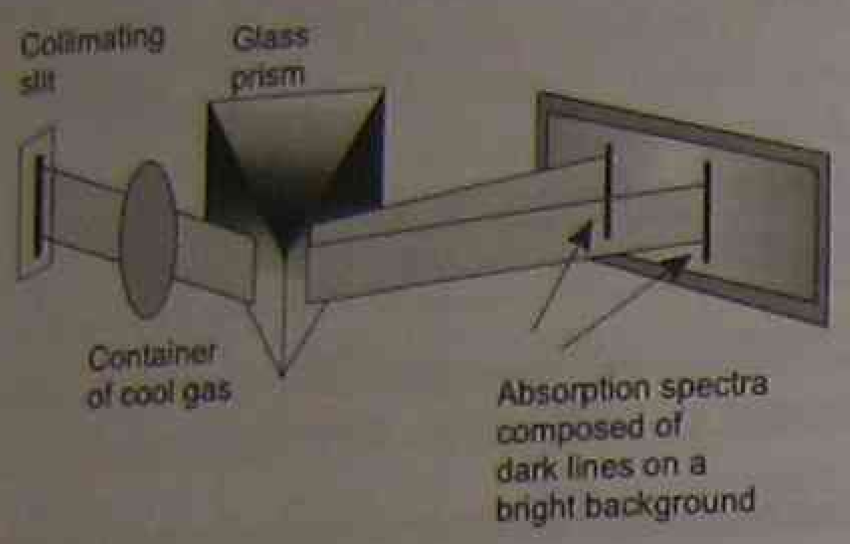

Figure 6.7 Formation of absorption spectrum of a gas

For example, when light passes through cooler layers of gas (for example, the photosphere of a star), certain *absorption lines* are observed when the light is viewed through a spectroscope. (In the solar spectrum these lines are referred to as *Fraunhofer lines.*)

By comparing the positions of these absorption lines with the positions of the emission lines from known elements, the composition of a substance can be deduced.

QUANTUM THEORY

Black Body Radiation

In the Preliminary Course Core Topic *The Cosmic Engine* we were introduced to the concept of a *black body* as a perfect emitter or absorber of energy.

It had long been known that there was a relationship between the dominant wavelength of electromagnetic radiation emitted by a hot object and its temperature. This is illustrated in Figure 6.8. We then saw in *From Ideas to Implementation* that, try as they might, physicists, using classical physics (the physics of Newton and Maxwell), could not get agreement between theory and experiment to explain the black body radiation curve[5]. A radical change in approach was needed. This was the *quantum theory* of physics.

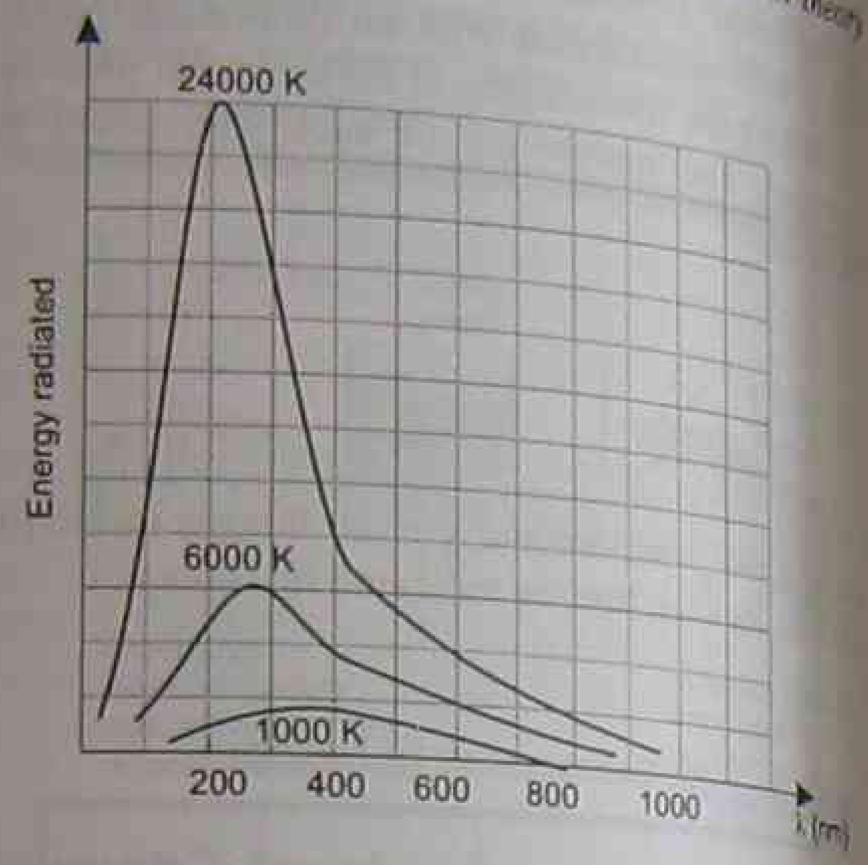

Figure 6.8 Black body radiation curve

Quantum physics began in 1900 with the German physicist Max Planck. Planck found that he could only get agreement between theory and experiment for black body radiation by making a fundamental change to the laws of physics! He proposed that:

> *Energy is not emitted by a hot object continuously as classical physics said it should, but rather it is emitted in little 'bursts' or 'packets of energy'*—**quanta** *(photons) of energy.*

Mathematically we write:

$$\boxed{E = hf}$$

where h is a constant called Planck's constant ($= 6.626 \times 10^{-34}$ J.s) and f is the frequency.

After it was used successfully to explain black body radiation, quantum theory's next big triumph was in explaining Bohr's model of the atom.

BOHR'S ATOM

In 1913 to account for the discrepancies between Rutherford's model of the atom and the available experimental evidence in particular, the emission spectrum of hydrogen, the Danish physicist Niels Bohr put forward some radical propositions. He postulated that:

1. Electrons can revolve in certain allowed orbits[6]—*stationary states (energy states)*—without radiating energy.
2. When an electron falls from a higher energy level to a lower energy level, it emits energy that is *quantised* by the Planck relationship $E_2 - E_1 = \Delta E = hf$
3. Angular momentum (mvr) is quantised and can only take values of $\frac{nh}{2\pi}$ where n is the *principal quantum number.*

---

[5] Classical physics predicted that as the wavelength of the radiant energy decreased (say from the visible to the ultraviolet), the intensity of the radiation would increase without limit. This would violate the law of conservation of energy. This effect became known as the 'ultraviolet catastrophe'.

The first postulate accounts for the *observed stability* of atoms. Why these stationary states existed was unknown. That they did exist was a fact.

The second postulate explains the line emission spectra. Emission (or absorption) of energy is discontinuous and corresponds to a transition between two stationary states. Since the energy is quantised, the frequency of the emitted (or absorbed) radiation is predetermined. A transition between different states will lead to different frequencies—colours (Figure 6.9). This postulate effectively sets limits on the allowed orbits (see below).

Using this mixture of classical and quantum physics, Bohr was able to derive the equation for the spectral lines of hydrogen (see p.229). He didn't know why the electrons obeyed his rules, only that they did! These were purely empirical results.

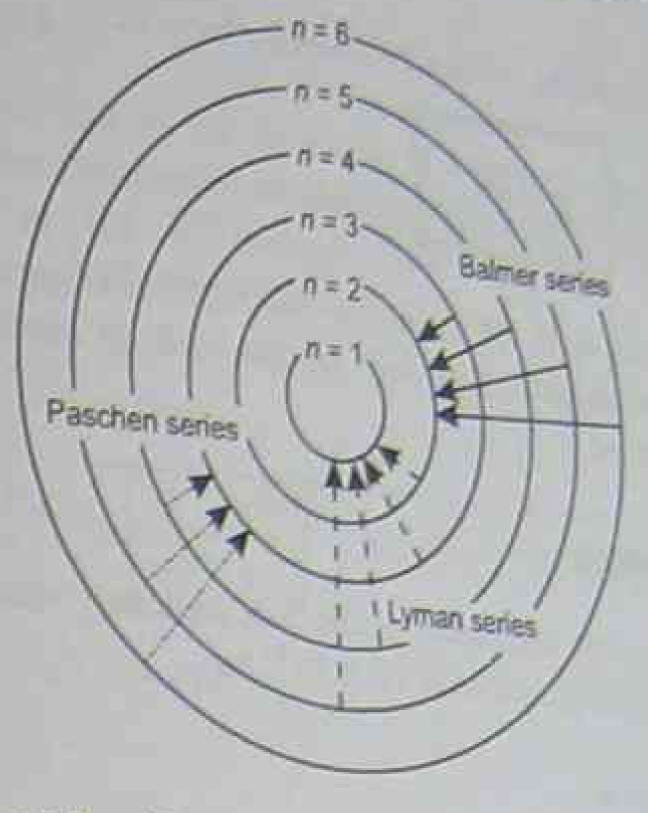

Figure 6.9 The cause of line emission spectra

Extension

Successes of the Bohr Model

Bohr was able to derive two expressions from his model. The first relates the radius of the electron orbit to the quantum number n and the second expression relates the energy of the orbit to the quantum number.

The Bohr Radii

By equating the electrostatic force of attraction between the nucleus and the electron in its orbit to the centripetal force required allowed Bohr to derive the following equation[7]:

$$\boxed{r_n = \frac{h^2 n^2}{4\pi^2 kme^2}}$$

where:

$n = 1, 2, 3\ldots$

$h = 6.626 \times 10^{-34}$ J.s (Planck's constant)

r_n = radius of the n^{th} stationary state ('orbit')

m = mass of the electron = 9.109×10^{-31} kg

$k = 9.0 \times 10^{9}$ N.m^2.C^{-2}

e = charge on the electron = -1.602×10^{-19} C

---

[6] These orbits were interpreted as the path the electrons followed as they revolved around the nucleus (somewhat like the orbits of the planets around the Sun).

[7] NB: The derivation of this formula is beyond the syllabus requirements.

This can be written in a simpler form as:

$$\boxed{r_n = n^2 r_1}$$

where r_1 is the radius of the first stationary state. This suggests that *only certain radii of orbits are allowed.*

EXAMPLE 2

Show that the radius of the first stationary state for the hydrogen atom is 5.3 x 10^{-11} m.

SOLUTION

We have the expression: $r_n = \dfrac{h^2 n^2}{4\pi^2 kme^2}$. The radius of the first stationary state has $n = 1$ and substituting the data we get:

$$r_n = \frac{(6.626\times10^{-34})^2\times1^2}{4\pi^2\times9.109\times10^{-31}\times9\times10^9\times(-1.602\times10^{-19})^2}$$
$$=5.3\times10^{-11}\text{ m}$$

EXAMPLE 3

What is the radius of the second stationary state?

SOLUTION

$$r_n = n^2 r_1$$
$$r_2 = 2^2 r_1$$
$$=4\times5.3\times10^{-11}=2.1\times10^{-10}\text{ m}$$

Energy of the Orbits

Bohr was also able, by combining the expression for the potential energy of the electron-nucleus system to its kinetic energy, to derive an expression for the total electron energy in the stationary states. This expression is:

$$\boxed{E_n = -\frac{2\pi^2 k^2 e^4 m}{h^2 n^2}}$$

where: $n = 1, 2, 3\ldots$ and the other symbols are as discussed for the Bohr radius.

The negative sign indicates the electron is bound to the nucleus. It comes about because we define the zero of potential as being infinity. (Energy must be supplied to the electron to remove it from the nucleus, a process called *ionisation.*)

This expression can also be written as:

$$\boxed{E_n = \frac{1}{n^2}E_1}$$

where E_1 is the energy of the electron in the first stationary state which is equal to −13.6 eV

EXAMPLE 4

What is the energy (in electron volts) of the electron in the second orbit?

SOLUTION:

$$E_n = \frac{1}{n^2}E_1$$
$$E_2 = \frac{1}{2^2}\times(-13.6)\text{ eV}$$
$$=-3.4\text{ eV}$$

It is possible to determine the energy of each orbit in this manner and from this construct an energy level diagram for hydrogen (Figure 6.10).

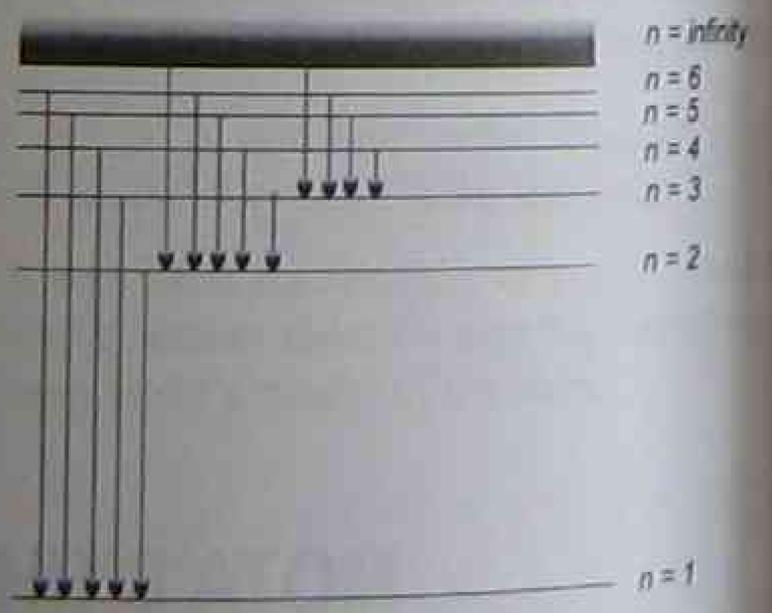

Figure 6.10 The energy levels for hydrogen

THE BOHR MODEL AND THE BALMER SERIES

One of the greatest successes of the Bohr model[8] was that it was able to provide a physical basis for the Balmer series formula (which up until that point was purely an empirical formula). Bohr's reasoning was as follows:

From Bohr's second postulate we have:

$$hf = E_f - E_i$$

From the expression for energy we have:

$E_i = \dfrac{1}{n_i^2}E_1$ and $E_f = \dfrac{1}{n_f^2}E_1$ hence:

$$hf = \frac{1}{n_f^2}E_1 - \frac{1}{n_i^2}E_1 = \left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)E_1$$

and since: $c = f\lambda \Rightarrow f = \dfrac{c}{\lambda}$ the expression reduces to:

$$\frac{1}{\lambda} = \frac{E_1}{hc}\times\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$$
$$\text{ie.}\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$$

which is the Balmer formula!

Extension

Franck-Hertz Experiment

In 1914 the Germans Franck and Gustav Hertz provided direct experimental evidence of energy levels. They bombarded mercury atoms with electrons and observed that the atoms would only absorb energy in *discrete amounts.*

EXAMPLE 5

The red line in the spectrum of hydrogen results from the transition of an electron from the 3rd energy level to the 2nd energy level. Calculate the wavelength of the red light.

SOLUTION

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$$
$$=1.097\times10^7\times\left(\frac{1}{2^2}-\frac{1}{3^2}\right)$$
$$=1.097\times10^7\times\left(\frac{1}{4}-\frac{1}{9}\right)$$
$$\lambda = 6.56\times10^{-7}\text{ m}$$
$$=656\text{ nm}$$

LIMITATIONS OF THE BOHR MODEL

For all of its success, the Bohr model of the atom had serious limitations:

1. It was an *ad hoc* mixture of classical and quantum physics. It assumed that some laws of classical physics held and others did not.
2. It did not work for multi-electron atoms (hydrogen has only one electron).
3. It could not explain the *relative intensities* of the spectral lines. Some lines were more intense than others. Why this should occur was unknown.
4. Certain spectral lines were found to consist of a number of very fine and close lines. The cause of these *hyperfine spectral lines* could not be explained.
5. The splitting of spectral lines when the sample was placed in a magnetic field—the *Zeeman effect*—could also not be explained.

It was clear that a new model was required to explain the way that matter was structured. This began with the work of de Broglie.

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[8] http://www.walter-fendt.de/ph11e/bohrh.htm http://suzy.phys.nwu.edu/~anderson/java/vpl/atomic/hydrogen.html Both sites look at the Bohr model of the atom.

SECTION 2: QUANTUM PHYSICS

BIG IDEA:

The limitations of classical physics gave birth to quantum physics.

OUTCOMES:

Students learn to:

1 Describe the impact of de Broglie's proposal that any kind of particle has both wave and particle properties.
2 Define diffraction and identify that interference occurs between waves that have been diffracted.
3 Describe the confirmation of de Broglie's proposal by Davisson and Germer.
4 Explain the stability of the electron orbits in the Bohr atom using de Broglie's hypothesis.

Students:

1 *Solve problems and analyse information using* $\lambda = h/mv$
2 *Gather, process, analyse and present information and use available evidence to assess the contributions made by Heisenberg and Pauli to the development of atomic theory.*

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WAVE-PARTICLE DUALITY OF LIGHT

In the Preliminary Course, *The World Communicates*, we saw that light exhibits properties that we normally say are *wave-like*, for example, interference[9] and polarisation. Then in the HSC Course, *From Ideas to Implementation*, we saw that in some situations light behaves as if it were a particle, for example, the photoelectric effect. The question is: *Is light a wave or is it a particle?*

This question has two answers—*light is both*. Which one of its identities it shows to the experimenter is dependent upon the particular situation being investigated. In some situations light acts as if it were a wave; in other situations it acts like a particle. This is the *wave-particle duality* of light.

Light, however, does not display both identities at the same time and at the same place. Light diffracts around an obstacle (wave property) and then falls onto a metal plate and cause photoemission (particle property) but it does not exhibit both properties at the same time.

To illustrate the duality of light, the diagram in Figure 6.11 is often used. This '*wave packet*' is particle-like in its finite size but wave-like in its varying amplitude. This amplitude is now viewed as a measure of the *probability* of finding a photon at a particular place.

1 Where the amplitude is large, so too is the probability of finding the photon.
2 Where the amplitude is small, so too is the probability of finding the photon.

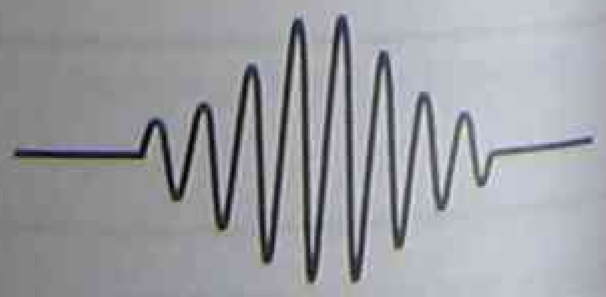

Figure 6.11 A *wave packet* or photon

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[9] In *The World Communicates* we were introduced to the idea of the superposition of sound. This is an example of interference. All waves exhibit the phenomenon of interference.

Photon Momentum

Consider a photon of light. Using Einstein's mass-energy equivalence formula and Planck's equation, we have:

$$E = mc^2 = hf = h\frac{c}{\lambda}$$

The momentum of a particle is hence:

$$p = mc = \frac{h}{\lambda} \Rightarrow \lambda = \frac{h}{p}$$

That is, a photon of light has its momentum (p) related to its wavelength (λ) by the equation

$$\boxed{\lambda = \frac{h}{p}}$$

This equation relates the wave characteristic wavelength (λ) with the particle property of momentum (p).

Extension

Compton Scattering

In 1923 Arthur Compton investigated the effect of bombarding matter with X-rays. He found that some electrons were ejected and the bombarding X-rays were either transmitted or scattered. Some of the scattered X-rays had a frequency that was less than that of the initial rays.

Compton found that he could get a simple explanation of this effect by assigning to the X-rays a photon momentum of $p = \frac{h}{\lambda}$ and considered the interaction with the electrons as being a collision between two particles (Figure 6.12). He thus proved that X-rays interact with matter as if they had *a photon momentum of p and hence provide further confirmation of their particle nature.*

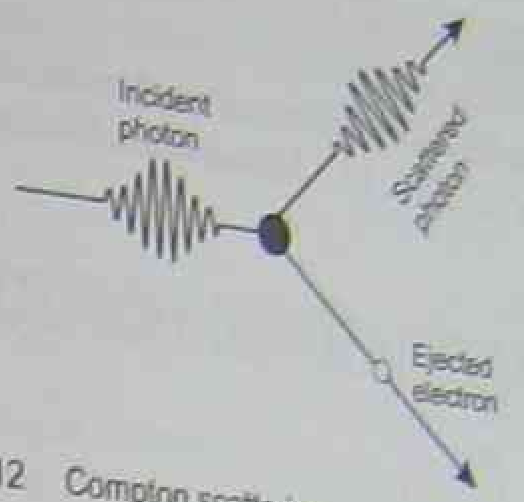

Figure 6.12 Compton scattering

MATTER WAVES

In 1924 the Frenchman Louis de Broglie generalised the equation already derived for a photon to include *anything* with momentum.

De Broglie proposed that if a physical phenomenon such as light, which was once considered to have a wave nature, was subsequently found to have a particle nature as well, then other phenomena, such as electrons, previously considered to have only a particle nature, could conversely, have a wave nature, as described by the expression:

$$\boxed{\lambda = \frac{h}{mv}}$$

De Broglie referred to these waves as *matter waves*.

EXAMPLE 6

What is the de Broglie wavelength of an object of mass $m = 1.0$ kg moving at a speed $v = 1.0\ \text{m.s}^{-1}$?

SOLUTION

$$\lambda = \frac{h}{mv} = \frac{6.626\times10^{-34}}{1.0\times1.0} = 6.626\times10^{-34}\ \text{m}$$

This is much less than atomic dimensions and is undetectable.

EXAMPLE 7

What is the de Broglie wavelength of an electron of mass $m = 9.109 \times 10^{-31}$ kg moving at 1.0×10^{6} m.s^{-1}?

SOLUTION

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.626\times10^{-34}}{9.109\times10^{-31}\times1.0\times10^{6}} \text{ m}$$

$$= 7.3\times10^{-10} \text{ m}$$

This wavelength is comparable to atomic dimensions (in particular the atomic spacing in crystals). Hence it should be possible to prove the wave nature of matter (for example, electrons) by observing some characteristic wave property such as *interference* or *diffraction*.

DIFFRACTION

Diffraction *is the bending of waves around obstacles or through barriers.*

From Figure 6.13 we can see that the amount of diffraction depends on the ratio of the wavelength to the size of the gap or obstacle. It can also be seen that the waves bend into the geometrical shadow region.

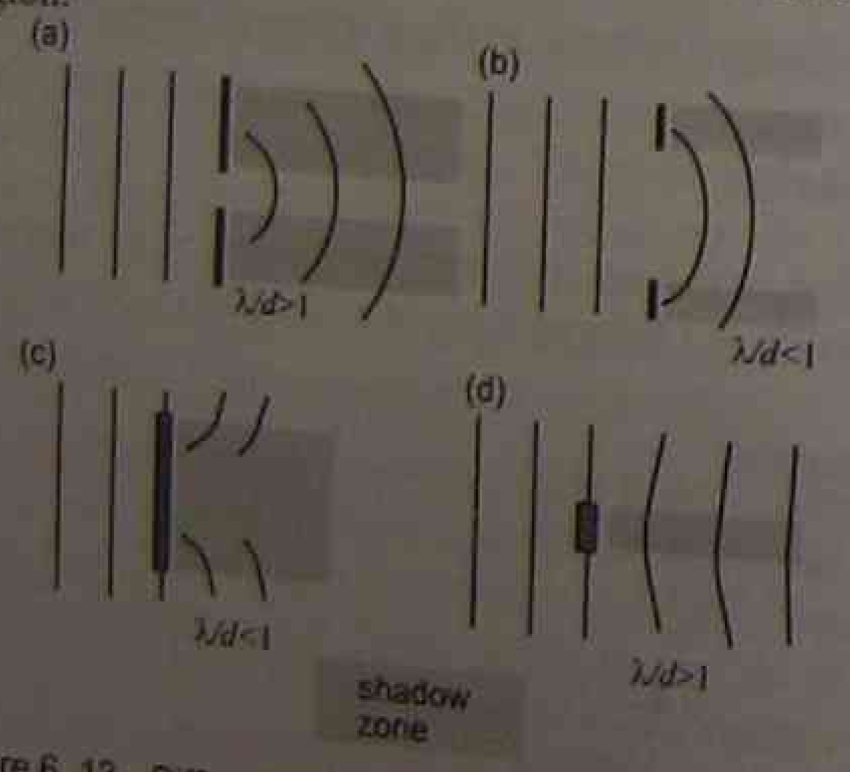

Figure 6. 13 Diffraction of waves

Interference

In the *Preliminary Course* we were introduced to the phenomenon of wave superposition.

The **principle of superposition** states: *If two or more waves of the same type pass through the same medium at the same time, the displacement of any point is the sum of the individual displacements.*

Another way of explaining superposition is that waves interact with each other when they meet.

The effect of one wave on another is called **interference** *and is only exhibited by waves.*

If two waves arrive at the same point in phase such that a crest meets a crest and a trough meets a trough, they reinforce each other. This interference is called *constructive interference* (Figure 6.14(a)).

If the two waves arrive at the same point π radians out of phase such that a crest meets a trough, they 'cancel each other out'. This is called *destructive interference* (Figure 6.14(b)).

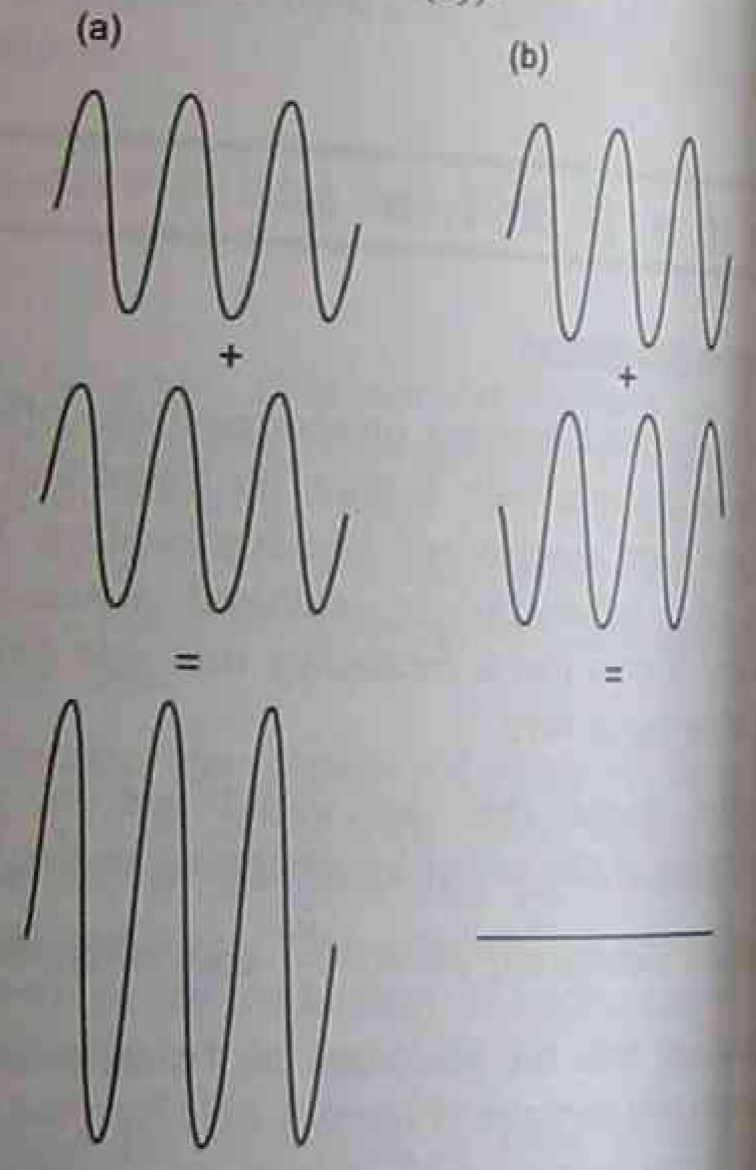

Figure 6. 14 Interference (a) constructive and (b) destructive

Two Source Interference

Consider Figure 6.15(a). Waves falling on a small opening emerge as circular waves. If there are two such sources as in Figure 6.15, the waves emerging from the two sources overlap and interfere. It follows that:

Interference occurs between waves that have diffracted.

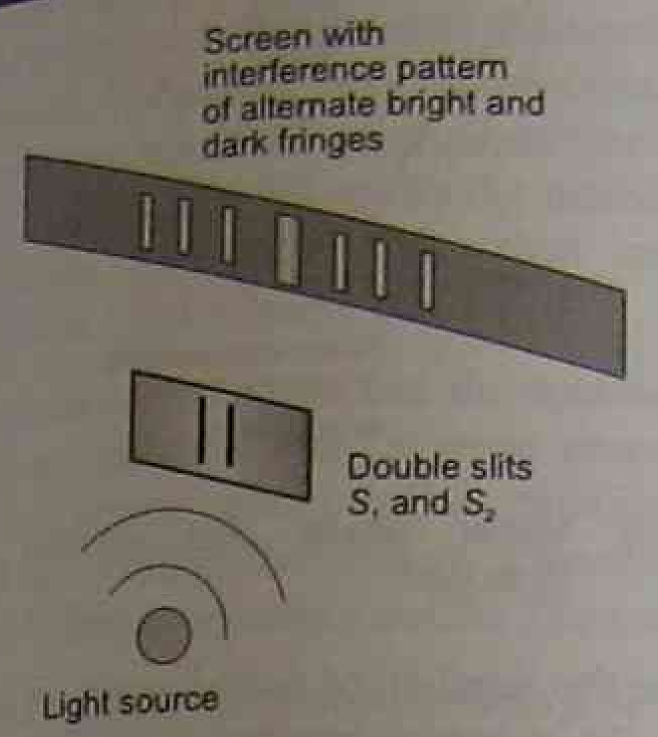

Figure 6. 15 Diffraction at a slit and subsequent interference of waves

The interference results in a series of bright and dark fringes. Bright fringes result when the two waves arrive at a point in phase and dark fringes when they arrive at a point with a π radian phase difference.

Consider Figure 6.16(a).

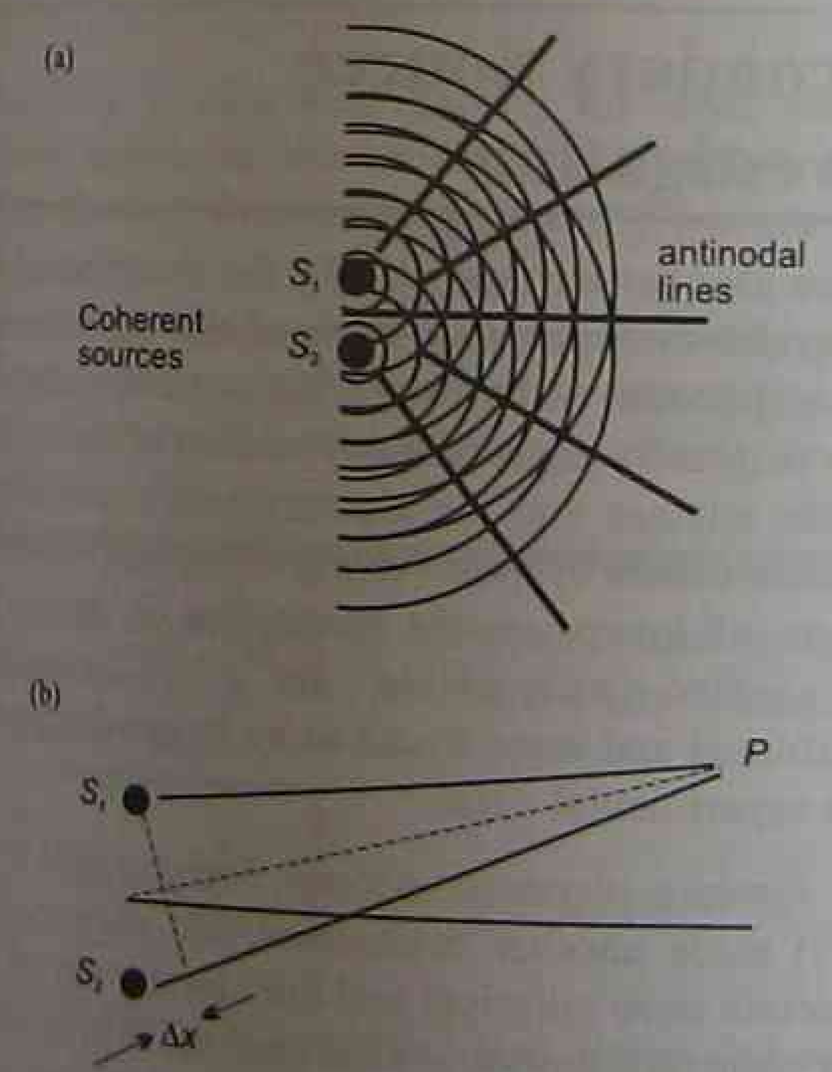

Figure 6. 16 Diffraction and interference between two sources

Waves from the two sources S_1 and S_2 overlap and interfere forming *anti-nodal* lines where crest meets crest and *nodal* lines where crests meet troughs. Whether a point such as *P* is a point of constructive interference or destructive interference depends on the extra distance, Δ*x*, travelled by the waves from S_2 compared to those from S_1.

ELECTRON DIFFRACTION

In a series of experiments commencing in 1923 the Americans Clinton J. Davisson and Lester H. Germer scattered electrons from the surface of a nickel crystal (Figure 6.17) and obtained an intensity pattern of the reflected electrons that showed *diffraction* effects like those for light discussed above. The electrons were exhibiting *wave characteristics*.

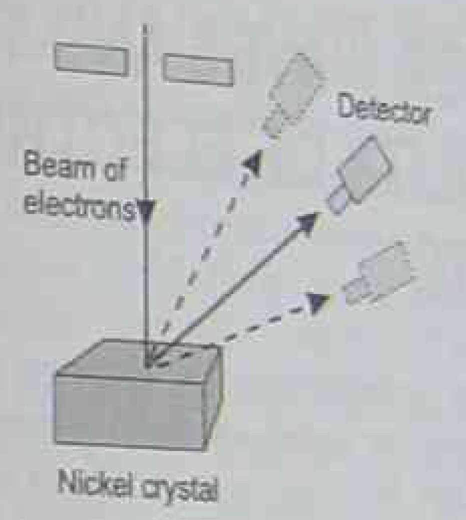

Figure 6.17 The Davisson and Germer experiment

In 1928 the British physicist G.P. Thomson[10] passed an electron beam through a thin sheet of gold foil and obtained diffraction patterns similar to that obtained by passing light through certain materials (Figure 6.18).

The wave nature of electrons is put to practical use in the *electron microscope* which uses electrons instead of light to view tiny objects. These devices are capable of magnifying many millions of times.

---

[10] Thomson succeeded in proving the wave nature of electrons some 28 years after his father J.J. Thomson first demonstrated their particle properties in his discovery of cathode rays.

Figure 6.18 Electron diffraction pattern formed when a beam of electrons is passed through a thin metal foil

MATTER WAVES AND THE STABILITY OF ELECTRON ORBITS

Bohr's first postulate said that electrons could rotate in their orbits or stationary states without radiating energy. Bohr, however, was unable to explain why this happened.

The concept of matter waves made it possible to show how the electrons could be stable in their orbits around the nucleus. If an integral number of electron wavelengths fitted into the circumference of the electron orbit, *standing waves*[11] would be possible and no energy would be lost (Figure 6.19). That is:

$$n\lambda = 2\pi r$$

But $\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$ which leads to:

$$\frac{nh}{mv} = 2\pi r$$

$$mvr = \frac{nh}{2\pi}$$

But this is Bohr's third postulate! Hence the relationship that Bohr had to *assume* is a direct consequence of the wave nature of matter and the quantisation of energy.

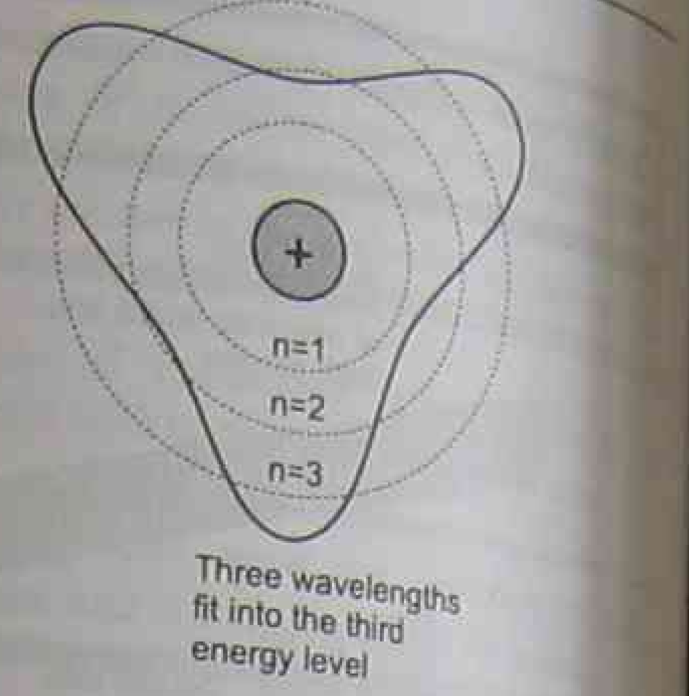

Figure 6.19 Matter waves and electron orbits of hydrogen

Note that the number of wavelengths in an orbit is equal to the quantum number *n*. In Figure 6.19, in the third energy level there are three wavelengths. (It should not be thought that the electron follows the wavy line. The wave represents the amplitude of the electron matter wave. Where the amplitude is greatest, so too is the probability of finding the electron. The wave is shown drawn on the Bohr orbit for convenience.)

Secondary Source Investigation

As we saw earlier (see p.227), the Bohr model was successful in explaining some of the characteristics of the spectrum of hydrogen but not other elements. Bohr originally neglected any motion of the nucleus, but the nucleus and the electron rotate around their common centre of mass. Using this modification, the spectra of *hydrogen-like* atoms that is, atoms with one electron (such as He^+, Be^{2+}, Li^{3+}...) could be determined and were found to be in good agreement with experimental data.

The German physicist Arnold Sommerfield (1868-1951) made another refinement. He suggested that the orbits were elliptical and not circular (by analogy with planetary motion). This enabled him to explain the fine structure of the hydrogen spectrum, that is, that each line was really made up of a number of closely spaced lines. Even better agreement was obtained when it was suggested that each electron was *spinning* on its own axis.

---

[11] In a standing wave, energy is continually transferred between kinetic energy and potential energy but is not lost.

Heisenberg

The Bohr model, with these modifications, was the pre-eminent theory of the atom by 1920. In this year, the German born Werner Heisenberg (1901-1976) commenced his study at Munich University under Sommerfield. Following the completion of his doctorate he moved to the prestigious University of Gottingen and started work under the mathematician and physicist, Max Born. He then moved to Copenhagen in 1924 to study under Bohr.

By 1924 physicists accepted that the quantum theory needed to be replaced with a more encompassing *quantum mechanics* theory. (The modified theory could still not explain the relative intensities of the lines in the hydrogen spectrum and the Zeeman effect.)

In 1925 Heisenberg introduced a theory of quantum mechanics using complex mathematical constructs called *matrices*.

In 1926 the Austrian physicist Erwin Schrödinger proposed an alternative theory—wave mechanics. His theory was based on the matter wave idea introduced by de Broglie in 1924 (see p.231). At first the two theories appeared to be unrelated, but in May 1926, Schrödinger proved that Heisenberg's *matrix quantum mechanics* and his own *wave mechanics* were equivalent.

Heisenberg is also well known for what was to become known as the *uncertainty principle*. This effectively says that for an elementary particle such as an electron:

> *The more precisely the position is determined, the less precisely the momentum is known in the instant and vice versa.*

If Δp is the uncertainty in the momentum and Δx is the uncertainty in the position, then Heisenberg showed that:

$$\boxed{\Delta p \Delta x \geq \frac{h}{2\pi}}$$

where h is Planck's constant. This shows that as Δx decreases, Δp increases.

This relationship has profound implications for the way we view matter. Classical mechanics assumed that, given the position and momentum of an object such as a planet, it is possible to determine the position and momentum at any time in the future. (Classical physics is referred to as deterministic physics.) Quantum mechanics on the other hand, is non-deterministic as we can illustrate by Figure 6.20.

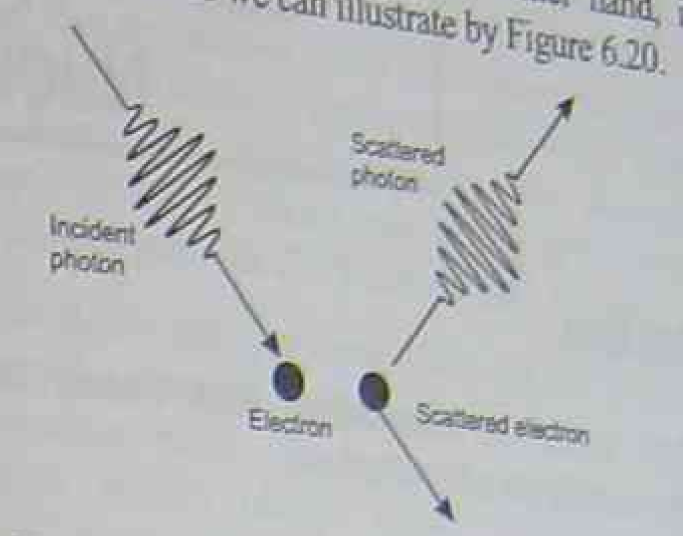

Figure 6.20 'Seeing' an electron

Suppose we wish to measure the position and velocity of an electron moving in an evacuated tube such as a cathode ray tube. To 'see' the electron we first have to interact with it by bouncing a photon off it. The small size of an electron means we have to use light of small wavelength (diffraction of waves means that large waves bend around small objects as if they were not there). Such waves, however, have high frequencies and hence energy ($E = hf$). The photon will hence give a large and random 'kick' to the electron, changing its momentum in a non-predetermined manner! (Conversely, if we lower the momentum of the photon to lessen its effect, the longer wavelength means we cannot know the position accurately.)

The uncertainty principle showed that we cannot speak with certainty about events on the atomic scale but must rather speak in terms of the *probability* of something occurring. (Max Born was the first to understand the probability interpretation of atomic behaviour.) This 'probability' interpretation underpins all of quantum mechanics.

Pauli

In 1925 the Austrian theoretical physicist, Wolfgang Pauli (1900-1958), a friend of Heisenberg, put forward the *exclusion principle* which states that no two electrons can occupy the same quantum state (energy state) of an atom. This principle led to an explanation of the regularity of elements in the periodic table.

The exclusion principle was subsequently found to be a consequence of the solution to Schrödinger's wave equation.

Pauli was also responsible for the prediction of the existence of the neutrino (see p.240).

SECTION 3: APPLICATIONS OF NUCLEAR PHYSICS

BIG IDEA:

The work of Chadwick and Fermi in producing artificial transmutations led to practical applications of radiation.

OUTCOMES:

Students learn to:

3 Define the components of the nucleus (protons and neutrons) as nucleons and contrast their properties.
1 Discuss the importance of conservation laws to Chadwick's discovery of the neutron.
2 Define the term 'transmutation'.
3 Describe nuclear transmutations due to natural radioactivity.
4 Describe Fermi's initial experimental observation of nuclear fission.
5 Discuss Pauli's suggestion of the existence of the neutrino and relate it to the need to account for the energy distribution of electrons emitted in β-decay.
6 Evaluate the relative contributions of electrostatic and gravitational forces between nucleons.
7 Account for the need for the strong nuclear force and describe its properties.
8 Explain the concept of a mass defect using Einstein's equivalence between mass and energy.
9 Describe Fermi's demonstration of a nuclear chain reaction in 1942.
10 Compare requirements for controlled and uncontrolled nuclear chain reactions.

Students:

1 Perform a first-hand investigation or gather secondary information to observe radiation emitted form a nucleus using a Wilson Cloud Chamber or similar detection device.
2 *Solve problems and analyse information to calculate the mass defect and energy released in natural transmutation and fission reactions.*
3 *Analyse information and use available evidence to assess how Chadwick's and Fermi's work changed understanding of the atom.*

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DISCOVERY OF THE NEUTRON

> *Protons and neutrons are collectively called* ***nucleons***.

Table 6.3 compares these two particles.

Table 6. 3 The proton and neutron

Property	Proton	Neutron
mass	1.673×10^{-27} kg	1.675×10^{-27} kg
charge	$+1.6\ 10^{-19}$ C	neutral

Symbolically the nucleus of an element (X say) is represented as $^{A}_{Z}X$ where:

> *The number of protons in the nucleus is referred to as the* **atomic number** *Z. The sum of the protons and neutrons is the* **mass number** *A.*

The number of neutrons is found from $N = A - Z$

EXAMPLE 8

In the reaction $^{9}_{4}\text{Be} + ^{4}_{2}\text{He} \rightarrow ^{12}_{6}\text{C} + ^{1}_{0}n$, give the composition of each element.

SOLUTION

Beryllium (Be) has 4 protons and 5 neutrons; helium (He) has 2 protons and 2 neutrons and carbon has 6 protons and 6 neutrons.

The Proton-Electron Hypothesis

Following Rutherford's discovery of the nucleus (see p.223) it was proposed that it contains A protons and A-Z electrons (where A is the mass number and Z is the atomic number). This would:

1 Result in a charge of Ze on the nucleus (which was in agreement with Rutherford's experimental results).
2 'Explain' the results of β^- emission—the emission of electrons from atoms. The electrons *had* to come from somewhere in the nucleus.

Progress in knowledge about the nucleus, however, showed this hypothesis to be incorrect. For example, application of the *uncertainty principle*[12] (see p.235) showed that the nucleus could not contain electrons. In addition, the mass of the nucleus was found to be about twice the atomic number, for example, hydrogen with Z = 1 had a mass of ~ 2 *atomic mass units* (u); oxygen with Z = 8 had a mass of ~16 u.

In 1920 Rutherford proposed that a neutral particle with similar mass to the proton—which he termed the *neutron*—might exist in the nucleus. The neutron's neutral charge would not affect the nucleus' charge and the extra mass would account for the measured mass of the nucleus.

Chadwick and the Neutron

In 1930, the Germans Walther Bothe and Becker discovered that bombarding beryllium with alpha particles resulted in the emission of a penetrating type of radiation. The radiation proved not to be gamma rays even though these were the *expected* penetrating radiation.

In 1932 the Englishman James Chadwick suggested that this radiation consisted of Rutherford's *neutrons*. These neutrons were ultimately found to have approximately the same mass as a proton.

A schematic diagram of the apparatus used by Chadwick to discover the neutron is shown in Figure 6.21.

1 Since ionisation is the principal method of detecting radiation, the uncharged neutrons would be hard to detect, as they would cause little or no ionisation.
2 The addition of proton-rich paraffin (containing lots of hydrogen atoms), enhances the detection. The neutrons eject protons as a result of elastic collisions and as these cause ionisation they are readily detected. (Joliot and Curie first did this experiment.)
3 By applying the laws of *conservation of momentum and energy*, Chadwick was able to prove the existence of the neutron. The equation for the reaction is

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[12] This says that the more we know about the position of a particle such as an electron, the less we know about its energy. If an electron were confined in a space the size of a nucleus, its energy would be too great to stay there!

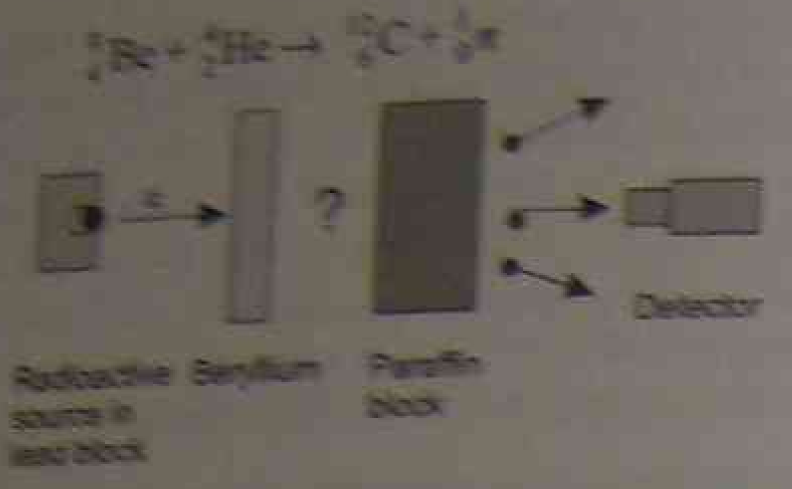

Figure 6.21 Chadwick's experiment

As a result of the work of Rutherford and Chadwick the nucleus was shown to consist of protons and neutrons.

RADIOACTIVITY

Radioactivity *is the spontaneous breakdown of an element into a new element by the emission of α, β and/or γ rays.*

Natural and Artificial Radioactivity

Natural radioactivity is exhibited by all of the naturally occurring isotopes above bismuth in the periodic table. In addition, radioactive isotopes (radioisotopes) exist for many other elements such as $^{3}_{1}H$ and $^{14}_{6}C$.

In 1933 Irene and Frederick Joliot-Curie (Marie Curie's daughter and her husband) produced the first artificial radioactive nuclei when they bombarded aluminium with alpha particles forming an isotope of phosphorus with a short half-life (a measure of how long it takes to decay).

Fermi (see p.239), also synthesised a large number of artificial radioisotopes by bombarding elements with neutrons.

Today, more than 400 artificial radioisotopes are known to exist; many are produced in particle accelerators (see p.251).

TRANSMUTATION AND NUCLEAR REACTIONS

Transmutation *occurs when one element changes into another element. Natural transmutations occur in radioactive decay such as alpha and beta decay.*

In all transmutations (as in all nuclear reactions), the mass number and atomic number are conserved, that is, the sum of the mass numbers on the left-hand side equals the sum of the mass numbers on the right-hand side and the sum of the atomic numbers on the left-hand side equals the sum of the atomic numbers on the right-hand side.

Alpha Decay

In alpha decay, a nucleus of element X (say) changes into the nucleus of another element Y according to the *nuclear equation:*

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$$

where $^{4}_{2}He$ is the *alpha particle.*

Beta Decay

There are two types of beta decay:

1 β^- decay and

2 β^+ decay.

β^- Decay

This is illustrated by the equation:

$$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}e + \bar{\nu}$$

where $\bar{\nu}$ is a particle called an *antineutrino* (see later) and $^{0}_{-1}e$ is the beta minus particle (an electron).

Where does the electron come from? A neutron decays into a proton, an electron and an antineutrino—the electron and antineutrino are emitted but the proton stays behind, thus increasing the atomic number by 1. This is indicated as follows:

$$^{1}_{0}n \rightarrow ^{1}_{1}p + ^{0}_{-1}e + \bar{\nu}$$

β^+ Decay

A positron (positive electron) is emitted after a proton decays into a neutron, a positron and a neutrino as follows:

$$^{A}_{Z}X \rightarrow ^{A}_{Z-1}Y + ^{0}_{+1}e + \nu$$

where ν is a neutrino. In this process a proton decays into a neutron and a positron as follows:

$$^{1}_{1}p \rightarrow ^{1}_{0}n + ^{0}_{+1}e + \nu$$

Gamma Decay

Gamma decay usually accompanies alpha and beta decay. A nucleus de-excites (loses energy) by emitting high-energy electromagnetic radiation without changing *Z* or *A*. As such this is *not* an example of transmutation.

$$^{A}_{Z}X^{*} \rightarrow ^{A}_{Z}X + \gamma$$

where * denotes an excited nucleus.

Artificial Transmutations

Rutherford achieved the first artificial transmutation in 1919 when he bombarded nitrogen gas with alpha particles and found that oxygen gas was produced!

The equation for this reaction is

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

ENRICO FERMI

As noted, Rutherford used an alpha particle to induce a transmutation. The neutron, however, because of its neutral nature, proved to be a better 'bullet' to cause a transmutation. (Alpha particles, because of their positive charge are repelled by the positive nucleus and find it more difficult to penetrate.)

The Italian Enrico Fermi was the first to realise the neutron's potential. With a group of co-workers in Rome between 1934 and 1938, Fermi bombarded as many of the known elements as possible with neutrons. In the majority of cases *new isotopes were formed.* Occasionally this new nucleus was radioactive and emitted a beta particle. For example, bombarding copper produced the following reactions:

$$^{65}_{29}Cu + ^{1}_{0}n \rightarrow ^{66}_{29}Cu$$

$$^{66}_{29}Cu \rightarrow ^{66}_{30}Zn + ^{0}_{-1}e$$

When Fermi and his group reached uranium, the heaviest known element, the results were confusing. They believed that they had created the isotope $^{239}_{92}U$ which they believed would undergo beta decay to form an isotope of the element with atomic number 93—the first transuranic element, that is,

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U$$

$$^{239}_{92}U \rightarrow ^{239}_{93}? + ^{0}_{-1}e$$

where "?" represents the unknown new element.

NUCLEAR FISSION

Fermi and his group just failed to discover nuclear fission in their experiments with uranium. In 1938 however, the German physicists Otto Hahn and Fritz Strassmann repeated Fermi's experiments and bombarded $^{238}_{92}U$ with neutrons. In addition to the isotope $^{239}_{92}U$ found by Fermi, Hahn and Strassmann detected the nucleus of the element barium $^{141}_{56}Ba$. This, they believed, must be a product of the *splitting of the nucleus* of another isotope of uranium, $^{235}_{92}U$ present in the original sample. They had discovered *nuclear fission* but were reticent to state the conclusion that the uranium nucleus could be split.

On 16 January 1939 the Austrian physicists, Lise Meitner and Otto Frisch took the step, and stated that the neutron led to the breakdown of the uranium nucleus into *two nuclei of roughly equal size*—a process they called *nuclear fission* (because of its similarity to the fission of bacteria when they reproduce by 'splitting in half').

Chain Reaction

The reaction that Hahn and Strassmann had produced was $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$ + energy

An alternative reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{148}_{57}La + ^{85}_{35}Br + 3^{1}_{0}n + \text{energy}$$

In both reactions, in addition to the two large fragments, three neutrons are produced. Since only one is required to initiate a nuclear reaction, the possibility of a chain reaction presented itself.

Critical Mass

The reason that Fermi had not detected fission is that neutron capture leads to fission in some cases and at other times to beta decay. Why is this?

For a chain reaction to continue there needs to be a balance between the production and loss of neutrons. Neutrons are lost from the reaction in three main ways:

1 capture by uranium without fission;
2 capture by other atoms in the sample or in the containing material; and
3 escape without capture.

There is a critical mass (critical size) where the production of neutrons just equals the loss of neutrons.

Moderators

U-235 is fissionable (undergoes fission) with thermal (slow) neutrons but not as readily with *fast* neutrons. The neutrons liberated by a chain reaction have high initial speeds and need to be slowed down to thermal energies. This slowing down can be achieved by collisions with atoms that won't readily absorb the neutrons in materials termed *moderators*.

Moderators include

1 ordinary water (H_2O)
2 'heavy' water (deuterium oxide, D_2O)
3 graphite (as used in the first atomic 'pile', see below) and
4 beryllium.

THE NEUTRINO

In 1930 the Austrian physicist Wolfgang Pauli (see p.235), proposed the existence of a particle with properties unlike anything known at the time. It would be a particle with no electric charge, no mass, and no magnetic properties and would have almost no interaction with matter. It would, however, have energy, linear momentum and angular momentum (the momentum associated with a rotating body). As such, it was 'something' rather than 'nothing'.

Pauli called the particle a 'neutron' but confusion with the particle discovered by Chadwick in 1932, also called the neutron, led to Fermi labelling it the neutrino—'little neutral one' in Fermi's native Italian.

What led Pauli to predict the existence of such a particle? It came from experimental investigations of beta decay, for example

$$^{234}_{90}Th \rightarrow ^{234}_{91}Pa + ^{0}_{-1}e$$

When the masses before and after were measured and the difference in mass was converted to energy according to Einstein's $E=mc^2$ equation, a discrepancy arose. The electron was found to have less energy than expected from the mass-defect—on average one-third of the energy that should be associated with the electron disappeared and nothing could be found to make up the deficit. (Gamma rays were predicted to account for the difference but they could not be detected.) Pauli suggested that the energy that appeared to be 'lost' was carried away by the neutrino.

Without Pauli's postulated particle, the well-established laws of conservation of energy, mass and angular momentum would have to be abandoned, an idea that did not sit well with Pauli.

The experimental discovery of the neutrino did not occur until 1956, but by then physicists had long accepted its existence to preserve the conservation laws.

As it turns out, the neutrino associated with beta-minus (β^-) decay is actually an anti-neutrino represented as $\bar{\nu}$[13].

THE NUCLEAR FORCE

As we have seen, the nucleus contains positive protons and neutral neutrons. Since positive charges repel, it might be expected that the nucleus should 'blow itself apart' (see Example 9). The only known attractive force was that of gravity but it was too small (see Example 10) to account for the stability of the nucleus. Obviously another attractive force is required.

---

[13] A horizontal 'bar' above a symbol denotes the antiparticle.

Example 9

Calculate the electric force of repulsion between two protons placed 1.0×10^{-15} m apart. NB: The force is given by $F = 9\times10^9 \frac{q_1 q_2}{d^2}$

Solution

$$F = 9\times10^9 \frac{q_1 q_2}{d^2}$$

$$= 9\times10^9 \frac{(1.602\times10^{-19})^2}{(1.0\times10^{-15})^2} \text{ N}$$

$$= 230.9 \text{ N}$$

Example 10

Calculate the gravitational force of attraction between two protons separated by 1.0×10^{-15} m. ($G = 6.67\times10^{-11}$ kg.m^2.s^{-2})

Solution

The gravitational force of attraction between two masses m_1 and m_2 is given by:

$$F = 6.67\times10^{-11}\times\frac{m_1 m_2}{d^2}$$

$$= 6.67\times10^{-11}\times\frac{(1.673\times10^{-27})^2}{(1.0\times10^{-15})^2} \text{ N}$$

$$= 1.87\times10^{-34} \text{ N}$$

Obviously this force is too small to hold the protons together!

Experiments indicate that an extremely powerful but short-range force acts equally between the following combinations: proton-neutron, proton-proton and neutron-neutron. This *nuclear force* is brought about by an exchange of particles called *mesons* (just like the electromagnetic force is due to an exchange of photons).

A graph of the nuclear force versus the separation between two nucleons is shown in Figure 6.22.

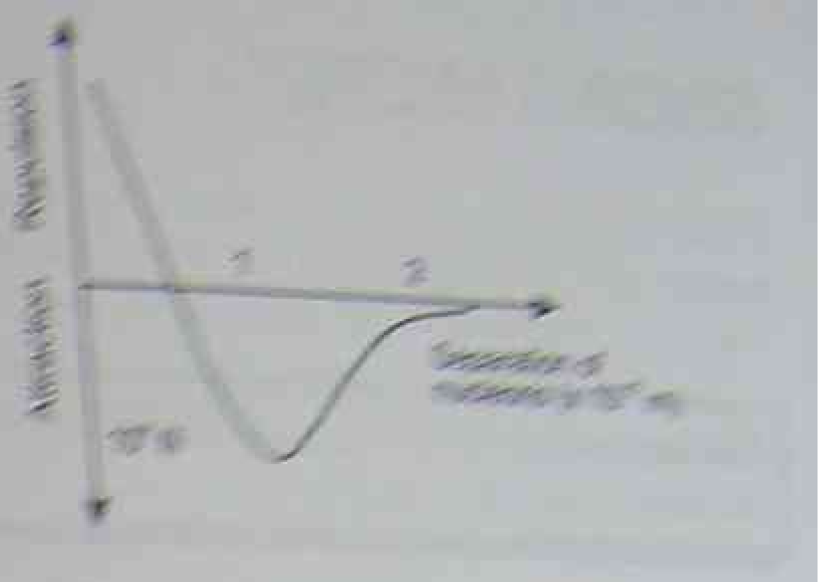

Figure 6.22 Nuclear force versus separation between nucleons

This graph shows that:

1 On average, two nucleons are separated by 1.3×10^{-15} m.
2 At distances greater than $\sim 2 \times 10^{-15}$ m, the nuclear force is effectively zero.
3 If the nucleons come closer than $\sim 0.5 \times 10^{-15}$ m, the nuclear force becomes a force of repulsion.
4 Should the nucleons move within a range of $\sim 0.5 \times 10^{-15}$ m to $\sim 2.2 \times 10^{-15}$ m, the nuclear force is attractive.
5 The force is much stronger than the Coulomb force between two protons (about 140 N at the mean separation compared to ~10,000 N for the nuclear force).

What gives rise to this force? To answer this we must consider the work of Einstein.

MASS DEFECT

Using a device called a mass spectrograph it is possible to measure the masses of atoms[14] and their components. When this is done it is found that:

The mass of the atom is less than the sum of the masses of its components (protons, neutrons and electrons)! This difference is called the **mass defect**.

---

[14] The masses of atoms are relative masses. They are compared to the mass of one carbon atom and are measured in atomic mass units (u). One atomic mass unit is defined as one twelfth of the mass of the carbon-12 atom (which, by definition, has a mass of 12.000000 u exactly). 1 u is equal to 1.661×10^{-27} kg. 1 u is also equal to 931.5 MeV (mega electron volts).

In both reactions, in addition to the two large fragments, *three* neutrons are produced. Since only one is required to initiate a nuclear reaction, the possibility of a *chain reaction* presented itself.

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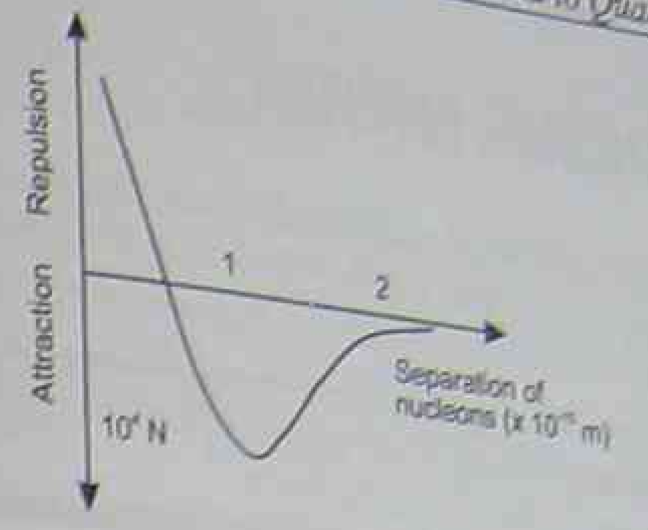

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BINDING ENERGY

Einstein's *Theory of Relativity* states that mass and energy are equivalent. The mass defect is 'converted' into the *binding energy* of the nucleus.

> **Binding energy** *is the energy needed to separate the atom into its separate parts.*

It follows, therefore, that since work must be done to overcome the nuclear attractive force, the energy, and hence mass, of the components must increase. Conversely, when electrons and nucleons *form* an atom, energy is *released*.

EXAMPLE 11

Calculate the mass defect for a helium atom and its corresponding binding energy.

SOLUTION

A helium atom consists of two protons, two neutrons and two electrons:

Rest mass of two protons = 2 x 1.007276 u

Rest mass of two neutrons = 2 x 1.008665 u

Rest mass of two electrons = 2 x 0.000549 u

Total mass of constituent particles in free state

= 4.032980 u

Rest mass of helium atom = 4.002602 u

Therefore mass defect = 0.030378 u

Because of the equivalence between binding energy and mass defect, the binding energy is given by:

$BE = 0.030378 \times 931.5$ MeV = 28.3 MeV

Binding Energy Per Nucleon

By taking the total binding energy of a nucleus and dividing it by the number of nucleons (protons and neutrons) we can calculate the *binding energy per nucleon* (*BE/A*). This is a more meaningful quantity that total binding energy since it tells us how tightly each nucleon is *bound* in the system.

For helium $\frac{BE}{A} = \frac{28.3}{4} = 7.1$ MeV per nucleon. This is a relatively high value and accounts for the emission of a helium nucleus in alpha particle radioactivity.

(The binding energy of the electrons is negligible compared to the nucleons which is why the binding energy of the atom is almost the same as the binding energy of the nucleus alone.)

A graph of binding energy per nucleon versus mass number is shown in Figure 6.23.

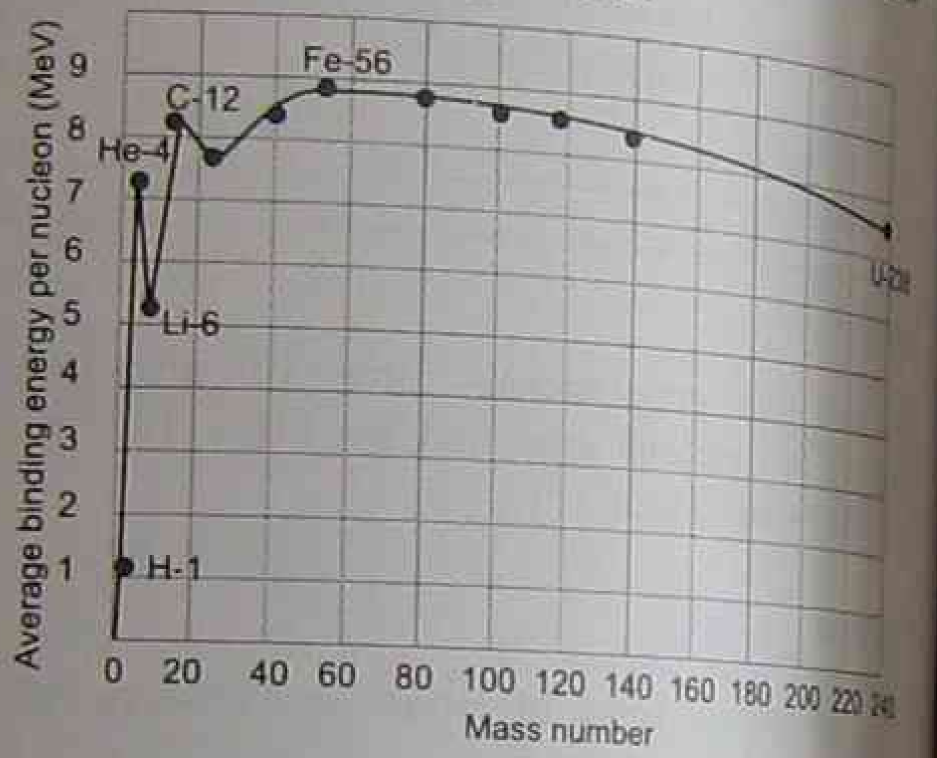

Figure 6.23 Graph of binding energy per nucleon versus mass number

This graph shows:

1 For $A > 60$, the binding energy per nucleon is roughly constant.

2 The most stable nucleus is Fe-56[15]. He-4 is also very stable (accounting for the emission of an alpha particle rather than the individual emission of 2 protons and 2 neutrons).

3 For high values of *A*, *BE/A* decreases. The effects of electrostatic repulsion between the positive protons become more obvious.

4 For low values of *A*, the *BE/A* is low; each nucleon is not uniformly surrounded by other nucleons.

5 The greater the *BE/A* the more stable the nucleus.

---

[15] This explains why iron is the highest nucleus synthesised by fusion in the interior of stars (see *The Cosmic Engine*)

FERMI AND NUCLEAR FISSION

On 2 December 1942 in the squash courts at the University of Chicago, a group of scientists lead by Enrico Fermi, using graphite blocks as a moderator, initiated the first *self-sustaining* nuclear fission reaction.

Prior to this event it was not known with certainty that a chain reaction would occur in uranium and that it could be controlled. The impetus for this work was the *Manhattan Project* (see p.250) set up to build the first atomic bomb.

Fermi and his co-workers used a mixture of 46 tonnes of natural uranium and uranium oxide interspersed in 40,000 graphite blocks. The graphite acted as a moderator which improved the chance of fission in the 0.7% of U-235 in the mixture by slowing down the neutrons. (Slow neutrons are more likely to interact with uranium nuclei than fast neutrons.)

Fermi controlled the reaction by inserting cadmium rods in the 'pile'. These 'control rods' absorb neutrons without reacting.

By slowly withdrawing the cadmium rods Fermi showed that the pile started to heat up—the nuclear fission reaction had begun. This heralded the beginning of the *nuclear age*.

CONTROLLED AND UNCONTROLLED CHAIN REACTIONS

An atom bomb is a good example of a uncontrolled chain reaction; a nuclear reactor on the other hand, is a controlled chain reaction.

In an uncontrolled chain reaction, each neutron released by the uranium atom as it splits is allowed to hit another uranium atom. There is a rapid build-up of atoms undergoing fission and a rapid release of energy (Figure 6.24(a)).

In a controlled chain reaction, however, only one neutron from each fission is available to split another uranium atom (all the others having been absorbed without causing fission, Figure 6.24(b)). These neutrons are absorbed by control rods made of materials such as cadmium (that absorb neutrons without undergoing fission).

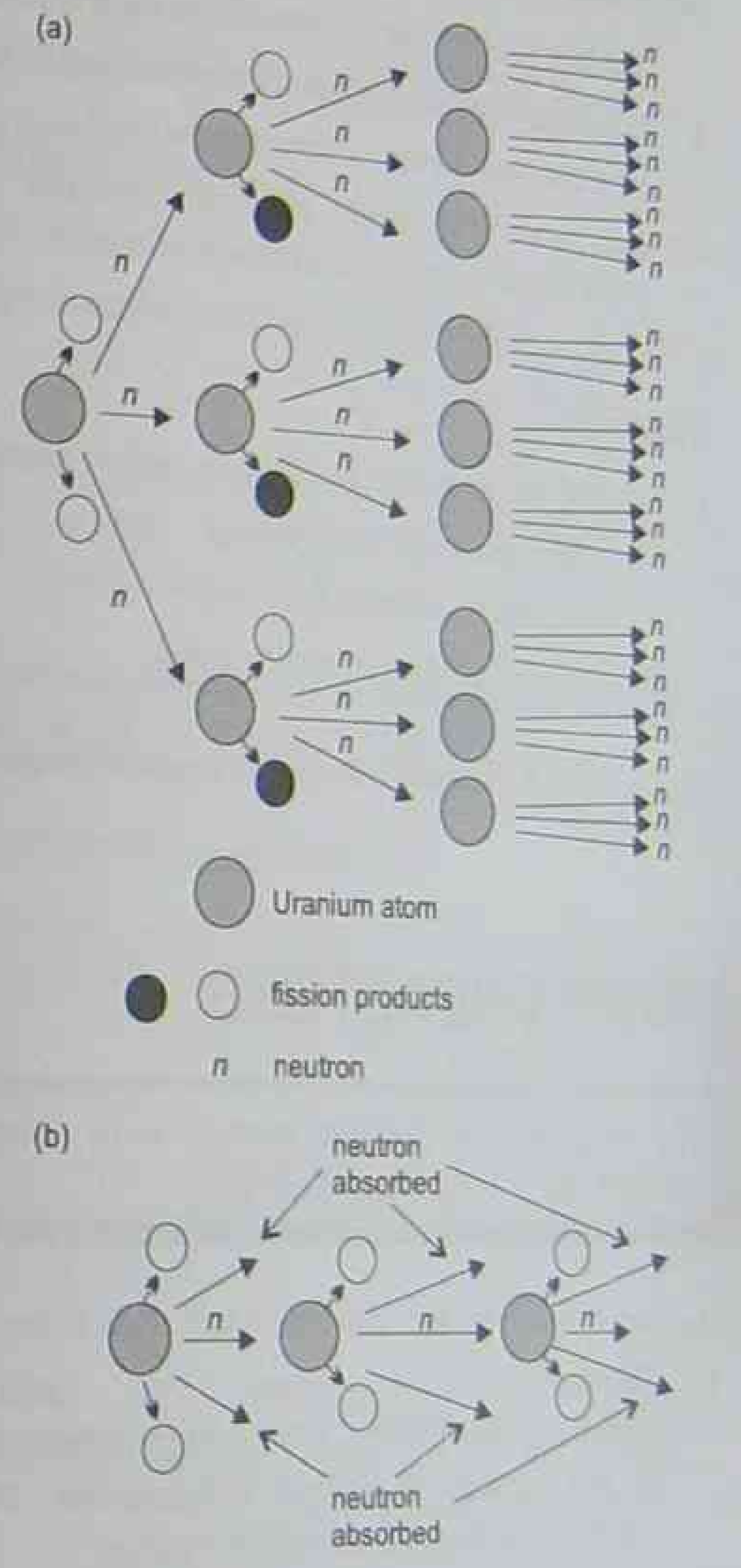

Figure 6.24 (a) Uncontrolled chain reaction (b) controlled chain reaction

SECTION 4: NUCLEAR APPLICATIONS

BIG IDEA:

An understanding of the nucleus has led to large science projects and many applications.

Students learn to:

1 Explain the basic principles of a fission reactor.
2 Describe some medical and industrial applications of radioisotopes.
3 Describe how neutron scattering is used as a probe by referring to the properties of neutrons.
4 Identify ways by which physicists continue to develop their understanding of matter using accelerators as a probe to investigate the structure of matter.
5 Discuss the key features and components of the standard model of matter, including quarks and leptons.

Students:

1 *Identify data sources and gather, process and analyse information to describe the use of:*
  - *a named isotope in medicine*
  - *a named isotope in agriculture*
  - *a named isotope in engineering.*

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FISSION REACTORS

The purpose of a **nuclear reactor** *is to release nuclear energy at a controlled rate.*

Nuclear fission reactors can be classified as either:

1 *Thermal reactors*—where the neutrons producing the fissions have energy comparable to gas particles at normal temperatures. Most commercial reactors are of this type; or
2 *Fast reactors*—where the neutrons producing the fissions have large energies.

Thermal Reactors

The essential features of a thermal fission reactor are:

1 a core of fuel
2 a moderator
3 a means of regulating the number of free neutrons
4 a coolant
5 radiation shielding.

Fuel

The nuclear fuel must contain *fissionable material*. Natural uranium is composed of three isotopes: 99.283% U-238; 0.711% U-235; and 0.006% U-234. U-235 is fissionable with thermal neutrons; U-238 and U-234 are not. U-238 can be converted by ***neutron capture*** into fissionable plutonium-239 (Pu-239). U-238 is a *fertile* material. Most reactor fuel is a mixture of fissionable and fertile material.

In ***enriched uranium*** the proportion of U-235 is increased to improve the probability of fission occurring. Even then, not every lump of U-235 will sustain a chain reaction because:

1 the sample may not be pure and so impurity atoms may accept neutrons without undergoing fission
2 the size may be such that the neutrons can easily escape without hitting further U-235 atoms.

The smallest possible amount of fissionable material that will sustain a chain reaction is the **critical size** (or **critical mass**).

Moderators

As we saw earlier, U-235 is fissionable with thermal (slow) neutrons but not as readily with *fast neutrons*[16]. Since the neutrons liberated by a chain reaction have high initial speeds (energies) they need to be slowed down to thermal energies. This can be achieved by collisions with atoms that won't readily absorb neutrons in *moderators*.

Moderators include:

1 ordinary water
2 'heavy' water (deuterium oxide D_2O)
3 graphite (as used by Fermi in the first atomic *pile*)
4 beryllium.

Control Rods

The chain reaction can be controlled by inserting rods that absorb neutrons in the reactor core. Most reactors have two sets:

1 regulating rods for routine control
2 safety rods (held vertically) for emergency shutdown.

The rods are usually steel, containing *boron* or *cadmium* which readily capture neutrons (they are said to have a high *neutron capture cross-section*).

If the reaction is proceeding too fast, the control rods are pushed further into the reactor core and absorb additional neutrons so causing the reaction to slow down. Conversely, pulling the control rods further out of the reactor core allows more neutrons to initiate fission.

Coolant

Most of the energy in the fission reaction is carried off as kinetic energy by the fission products. These products collide with the surrounding material and produce heat. This heat is removed by a circulating coolant such as:

1 air
2 helium
3 'heavy' water
4 liquid sodium or
5 certain liquid organic compounds.

Radiation Shields

There are usually two shields:

1 A shield designed to protect the walls of the reactor from radiation damage and at the same time reflect neutrons back into the core.
2 A *biological shield* that is used to protect the reactor personnel. This consists of many centimetres of high-density concrete.

Extension

Nuclear Power Stations

Nuclear power stations use the heat produced by nuclear fission to boil water to produce steam to drive turbines that turn generators to make electricity.

The coolant collects the heat from the core. Figure 6.25 illustrates the essential components of a nuclear power station.

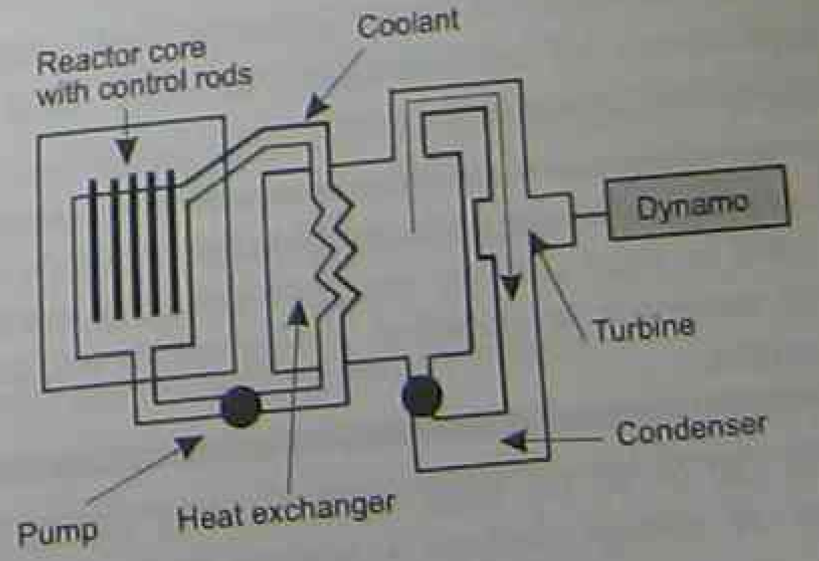

Figure 6.25 Nuclear power station

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[16] Reactors using highly enriched uranium (for example, 75% U-235) need no moderator as they can operate with fast neutrons.

Fast Breeder Reactors

Fast breeder reactors use Pu-239 as a fuel and need no moderator. These reactors produce more fuel than they use. Surrounding the core is a blanket of U-238 which captures neutrons from the core and is converted into Pu-239 in the process as follows:

$$^{238}_{92}\text{U} + ^{1}_{0}n \rightarrow ^{239}_{92}\text{U} + \gamma$$

$$^{239}_{92}\text{U} \rightarrow ^{239}_{93}\text{Np} + ^{0}_{-1}e$$

$$^{239}_{93}\text{Np} \rightarrow ^{239}_{94}\text{Pu} + ^{0}_{-1}e$$

APPLICATIONS OF RADIOISOTOPES

As we saw earlier (p.239), Fermi showed that by bombarding stable elements with neutrons it was possible to produce new isotopes, many of which are radioactive.

Radioisotopes *are radioactive isotopes.*

Radiation[17], despite its negative connotations with genetic mutations, nuclear fallout and nuclear reactor disasters has a number of positive uses for society including:

1 industrial applications
2 medical applications.

Radioactive Tracers

Before we look at some industrial and medical applications of radioisotopes we first need to understand radioactive tracers.

As the name suggests, **radioactive tracers** *are used to trace (follow) the movement and storage of materials in chemical, biological or physical systems.*

This can be on the large scale, such as tracing the flow of sewage through a sewage system, to the molecular or atomic level. For example it is possible to trace the pathways of individual chemicals in complex biological reactions.

INDUSTRIAL APPLICATIONS

Measuring Wear in Machinery

Radioactive tracing can be used to investigate the amount of wear in machine parts by making part of the machine, say the pistons, radioactive (for example, by placing the pistons in a reactor and irradiating with neutrons). After operating the machine for some time, the amount of wear can be determined by measuring the amount of radioactivity in the lubricating oil. The greater the radioactivity, the more wear experienced by the pistons.

Thickness Control

The thickness of metal or plastic as it is manufactured can be monitored using radioisotopes. The amount of radiation passing through the metal or plastic is determined by the thickness. If it becomes too thick (or thin), the detector senses the change in radiation and can be used to adjust the machinery to ensure the correct thickness.

Power Supply

The heat produced by the radioisotope plutonium-238 (Pu-238) can be converted into electricity to power a cardiac pacemaker.

Extension

Radiometric Dating

Radioactivity provides scientists with a 'clock' by which they are able to determine the age of various geological, paleontological and archaeological materials. (This can be important in mineral exploration.) To do this they make use of the concept of the half-life of radioactive materials

Half-Life

The time taken for a particular radioactive element to decay is unique to that element and is best described in terms of the element's half-life.

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[17] We will use *radiation* here to refer to alpha, beta and gamma radiation from radioactive substances.

The **half-life** *of an element is defined as the time it takes for half a given mass of an element to decay into a new element.*

Half-lives may vary from microseconds to millions of years.

When a radioactive element decays it does so in a manner similar to that shown by the graph in Figure 6.26. It follows from the graph that if the half-life of a particular radioactive element is known and the fraction of parent element remaining in a sample can be measured, then the age of the sample can be determined.

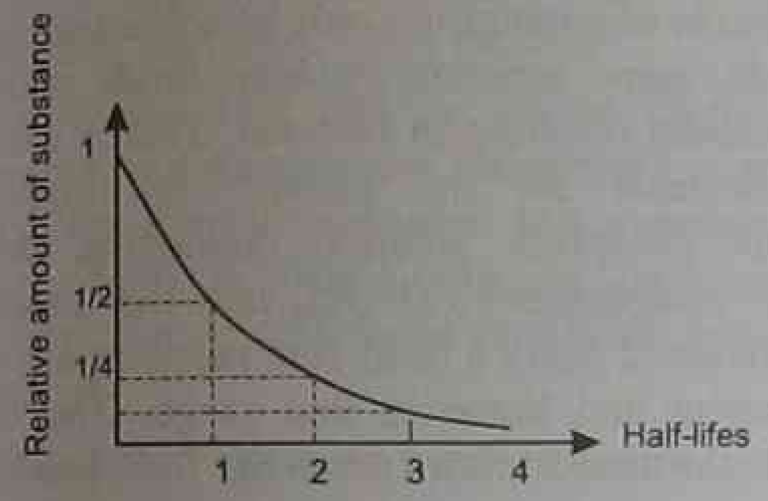

Figure 6.26 Half-life curve

If N_o is the number of atoms of a particular radioactive element at time zero, N is the number of atoms remaining after time t, and $T_{½}$ is the half-life, then the fraction remaining after time t is given by:

$$\frac{N}{N_o} = \left(\frac{1}{2}\right)^{t/T_{½}}$$

For example, if a radioactive element has a half-life of 2 days, what fraction remains after 8 days?

$$\frac{N}{N_o} = \left(\frac{1}{2}\right)^{t/T_{½}} = \left(\frac{1}{2}\right)^{8/2} = \left(\frac{1}{2}\right)^{4} = \frac{1}{16}$$

Radioactivity surrounds us; it is in the earth, in the oceans, in the air we breathe and in our tissues.

Geological Dating

The rocks of the earth's surface contain 5 parts per million (5 ppm) of uranium. Uranium decays over time to lead. The isotope U-238 decays to Pb-206 with a half-life of ~4.5 billion years and the isotope U-235 decays to Pb-207 with a half-life of ~700 million years!

By comparing the ratio of Pb-206 to U-238 and the ratio of Pb-207 to U-235 the age of the rocks can be determined.

Other radioactive substances can also be used. The most favoured methods for geological time keeping (with the *parent nuclide* written first and the *daughter nuclide* written second) are:

1 uranium/lead with a half life of 4500 million years
2 potassium-40/argon-40 with a half-life of 11,800 million years
3 rubidium-87/strontium-87 with a half-life of 50,000 million years
4 carbon-14/carbon-12 with a half-life of only 5,570 years.

Although the theory is well established, the technical difficulties inherent in radiometric determination of age lead to some uncertainties in the dating. Nevertheless, use of these techniques has enabled the Earth to be dated at approximately ~4,600 million years with the oldest rocks being dated at ~3,800 million years.

Radiocarbon Dating

Radiocarbon dating is a method for estimating the age of ancient artefacts. It relies upon the fact that there is a fixed proportion of radioactive C-14 in the atmosphere together with the stable C-12. These proportions are assumed to have remained constant for thousands of years. Plants absorb both the C-14 and C-12 and incorporate them into their structure for as long as they are alive but when they die the proportion of C-14 will decrease since no more is being absorbed. The proportion of C-14 in the sample under test can then be determined to give an estimate of the age of the sample.

Carbon dating is of use for only relatively 'recent' material up to about 70,000 years. In addition, as we have seen, it must be organic (once living) such as charcoal, cloth and plants.

There are many other uses in industry.

MEDICAL APPLICATIONS

The medical applications of radioisotopes include:

1 isotopic tracing/scanning
2 radiation therapy (radiotherapy).

These can all be classed as nuclear medicine.

> **Nuclear medicine** *involves the use of radioisotopes in the diagnosis and treatment of disease.*

Isotopic Tracing/Scanning

By placing radioisotopes in a biological system, its progress through the system and/or its distribution can be investigated.

In this technique, a radioisotope of the same element as one being investigated (chemically they behave in an identical manner) is introduced into the body, usually by intravenous injection. Different organs take up the isotope in different amounts. By detecting the resulting emissions (by using detectors such as *Geiger* counters and *scintillation* counters), the distribution and concentration of the isotopes can be determined. This in turn can lead to the recognition of any abnormalities. The radioisotopes have short half-lives[18] and decay before causing damage to the body.

Iodine-131 is used to look for thyroid abnormalities as it concentrates in the thyroid gland. Similarly carbon-14 is used to scan for abnormalities associated with diabetes and anaemia.

Table 6.4 illustrates some radioisotopes used in scanning and the organs that they work with.

Table 6. 4 Radioisotopes used for scanning

Radioisotope	**Organ to scan**
iodine-131	thyroid, lung
chromium-51	spleen
selenium-75	pancreas
technetium-99m	bone, lung
gallium-67	lymphatics

Radiotherapy

In radiotherapy, radiation is used to destroy abnormal cells inside the body. Gamma-rays from cobalt-60 (as well as X-rays and electrons from particle accelerators) are used in the treatment of cancer. The radiation penetrates the abnormal cells killing them or inhibiting their growth. Nearby healthy cells, affected by the radiation have a greater ability to recover. Nevertheless, the amount of radiation used has to be closely monitored and limited.

Beta Emitters

Sometimes a radiologist will use a *beta emitter*. The short range of penetration will be advantageous. For example, some tumours produce fluids within the body tissues resulting in *oedema*. This is extremely uncomfortable for the patient. By injecting a chromic phosphate solution containing the beta emitter phosphorus-32 (P-32), into the tumour, the short-range (2 mm - 8 mm) beta particles affect only the tumour and tissue in that range. The damage done to the tumour slows down the fluid production.

Cancer Treatment

Cancer radiotherapy relies on gamma emitters such as cobalt-60 (Co-60) with a half-life of 5.26 years. The radiation can be administered by:

1 implanting the actual radioactive material in the tumour; or
2 exposing the body to an external emitter that directs the rays to penetrate the body and the tumour.

The method to be employed depends on factors such as the size and location of the tumour.

Implants of radioactive materials in the form of wires, threads… using radioisotopes of gold, iridium, and caesium (in addition to cobalt) are most effective with small, rapidly growing tumours. They release the radiation over an extended period of time.

External irradiation causes more normal tissue damage but can treat larger tumours. A regime of 10 to 20 sessions over a period of months may be necessary.

Side effects of radiotherapy include nausea, hair loss, vomiting, blood loss, skin disorders and a drop in blood pressure.

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[18] I-131 has a half-life of ~8 days; technetium has a half-life of ~6 hours.

Side effects of radiotherapy include nausea, hair loss, vomiting, blood loss, skin disorders and a drop in blood pressure.

NEUTRON SCATTERING

> **Neutron scattering** *is a powerful method of analysing the internal structure and properties of matter using neutrons.*

A neutron is an uncharged particle with a mass slightly greater than that of the proton. Free neutrons (that is, free of the nucleus) interact with matter in a number of ways depending upon their velocity and the nature of the target. They include:

1 *Scattering*: This can be elastic (both kinetic energy and momentum conserved) or inelastic (kinetic energy conserved but momentum not conserved). In elastic collisions with low-mass nuclei, the neutron loses significant amounts of energy.
2 *Absorption*: These may lead to fission.
3 *Capture*: This may produce new elements, many of which are radioactive.

Neutrons, because of their neutral charge, penetrate matter more easily than do charged particles (for example, protons and electrons).

Neutrons with energies of < 1 eV[19] are termed *slow neutrons*. Those with energies > 1 keV are referred to as *fast neutrons*.

In neutron scattering, an energetic recoil nucleus is produced. The energy of the recoil nucleus varies depending on the type of collision —from zero for a grazing angle to a maximum for a head-on collision. If the neutron collides with a hydrogen nucleus it can transfer almost all its energy in a single collision; for heavier nuclei only a fraction is transferred in each interaction.

Neutron scattering techniques were first developed back in the 1940s and 1950s. Since then the technique has been used to look inside bulk matter to determine its structure and properties. It has been used in the development of magnetic materials for computer data storage, in the determination of the structure of superconductors and even in identifying the structure of viruses.

Neutrons, like all particles, exhibit wave-particle duality. When interacting with matter, the neutron collides with atomic nuclei and scatters in directions determined by the neutron's wavelength and the structure of the irradiated material. From these patterns, scientists can deduce the internal structure of the material. (Neutron scattering—*diffraction*—is analogous to electron diffraction discussed on p.232)

X-rays have been used for many years to probe the interior of materials. Unfortunately X-rays scatter off the electrons. This means they scatter well off high atomic mass atoms (lots of electrons) but they have great difficulty interacting with low mass atoms. They don't detect protons at all! Neutrons, on the other hand, scatter well from protons (the masses are almost the same) and this makes them ideal in determining the structure of solids containing hydrogen bonds (which includes all organic molecules in living things) and many inorganic substances.

NEUTRON ACTIVATION ANALYSIS (NAA)

This is a technique where certain stable elements are made radioactive by bombarding them with a flux of neutrons. These radioactive elements then decay and the emitted particles have energies that allow them to be readily detected. For example, stable sodium atoms can be activated by neutron capture: ${}^{23}_{11}\text{Na} + n \rightarrow {}^{24}_{11}\text{Na} + \gamma$.

The ${}^{24}\text{Na}$ nucleus then decays to give γ-rays, electrons and neutrinos: ${}^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + \gamma + {}^{0}_{-1}e + \overline{\nu}$.

The electrons have a characteristic spread of energies and the γ-rays have energies of 2.75 MeV and 1.37 MeV. Sodium can thus be detected by the presence of lines at these energies in the gamma ray spectrum of the irradiated material. It is particularly useful in the analysis of the rare earth elements, uranium, barium, thorium and hafnium.

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[19] This is a common unit for particles on the atomic scale. One electron volt (1 eV) is the energy gained by an electron accelerated by a potential difference of 1 volt. It is equal to 1.6×10^{-19} J.

Secondary Source Investigation

The Manhattan Project

The Manhattan Project was the code name used for the United States effort to produce the atomic bomb during World War II. It was named after the Manhattan Engineering District of the US Army Corps of Engineers in New York, where much of the early work was done.

In 1938 German scientists discovered nuclear fission (see p.239). Physicists, many of whom were refugees from Nazi persecution, raised the possibility that Nazi Germany might develop an atomic bomb. They included the Hungarian physicists Leo Szilard, Edward Teller (who was to become the 'father' of the H-bomb) and Eugene Wigner. In 1939 Szilard, Teller and Wigner convinced Albert Einstein to write his famous letter to the American President Franklin D. Roosevelt advocating the immediate development of an atomic bomb. As a result, Roosevelt set up an *Advisory Committee on Uranium* in October of that year.

By March 1940 it was confirmed that the isotope uranium-235 (U-235) did in fact undergo fission with slow neutrons.

U-235, however, constitutes only a small percentage of uranium, the majority being U-238 which does not fission with slow neutrons. Two methods were ultimately used to separate U-235 from U-238:

1 *Gaseous diffusion.* By converting the uranium metal to the gas uranium hexafluoride and letting it pass through a series of membranes, it was predicted that the lighter U-235 would more readily diffuse and so its concentration could be increased after each membrane.

2 *Electromagnetic separation:* By bending a current of uranium ions in a magnetic field, the lighter U-235 ions would bend more easily than would the heavier U-238 ions, allowing them to be separated.

Although the two processes were theoretically possible, significant engineering problems had to be overcome before they became successful.

In 1940 the first *transuranic* element, neptunium, ($^{237}_{93}\text{Np}$) was discovered. It was suggested that this would decay into element 94. One of its isotopes with a mass number of 239 was predicted to undergo fission with slow neutrons. In mid 1941, plutonium ($^{239}_{94}\text{Pu}$), was identified and its ability to undergo fission was proven (and at a higher rate that U-235).

On 7 December 1941 the Japanese attacked Pearl Harbour which brought America into the war. This accelerated the race for the atomic bomb.

In May 1942, the army, under the command of Colonel Leslie Groves (soon to be promoted to Brigadier General) was brought into the construction activities necessary for the project to proceed. Groves purchased a site at Oak Ridge Tennessee for the gaseous diffusion plant and appointed the theoretical physicist Robert J. Oppenheimer to direct the actual weapon design and manufacture.

In December 1942 Enrico Fermi (see p.240) created the first chain reaction in a reactor.

By 1945 sufficient bomb-grade U-235 had been produced, (using gaseous diffusion followed by electromagnetic separation), to be fashioned into a bomb. A gun-type bomb was made, consisting of a piece of U-235 in a barrel that could be fired into another piece of U-235, to form a supercritical mass.

Meanwhile the production of Pu-239, produced by bombarding U-238 in a reactor in Hanford Washington, was proceeding in tandem with the U-235 production. Unlike the U-235 bomb, however, the Pu-239 bomb was made by having a sphere of Pu-239, surrounded by explosives. The resulting *implosion* would result in a supercritical mass faster than was possible in a barrel.

The first atom bomb (using Pu-239) was successfully exploded on 16 July 1945 near Alamogordo, New Mexico, with an explosive energy equivalent to 20,000 tonnes of TNT! At this time, the U-235 bomb was on its way to the Pacific.

On 6 August 1945 the U-235 bomb (nicknamed *Little Boy*) was dropped on Hiroshima. Three days later a Pu-239 bomb (*Fat Boy*) was dropped on Nagasaki. The next day, Japan surrendered.

The Manhattan Project was the largest and most costly (~$US2 billion in '1945' dollars) project of the war. It was an engineering feat un-paralleled to that day. The gaseous diffusion plant alone used more electricity than the entire city of Boston!

The 'success' of the project also ensured that humankind had developed the power to destroy itself. The Cold War and the resulting arms race cost us the chance to eradicate disease and hunger.

NUCLEAR STABILITY AND PARTICLE ACCELERATORS[20]

As mentioned earlier (see p.242), the stability of a nucleus is determined by the value of the binding energy per nucleon. The larger this value the more stable the nucleus.

To investigate the nuclear force and the nature of the fundamental particles, the nucleus needs to be disrupted. To do this energy must be put into the nucleus.

This energy input requires *particle accelerators* to accelerate the particles (for example protons) to the required energy. In 1930 John D. Cockroft and Ernest T.S. Walton created the first 'atom smasher' producing the reaction: $^{1}_{1}p+^{7}_{3}\text{Li}\rightarrow^{4}_{2}\text{He}+^{4}_{2}\text{He}$

Particle accelerators include:

1 Van de Graaff generators
2 cyclotrons
3 betatrons
4 synchrotrons
5 linear accelerators.

Extension

Van de Graaff generators

In the early 1930s Van de Graaff devised a continuous high voltage supply that could be used to accelerate protons and other ions to energies of 0.5 MeV. The operation is as shown in Figure 6.27.

1 Charge (either positive or negative) is 'sprayed' on to an endless belt and is carried to the top of the generator.

2 The charge is transferred to the dome and moves to the outside of the sphere.

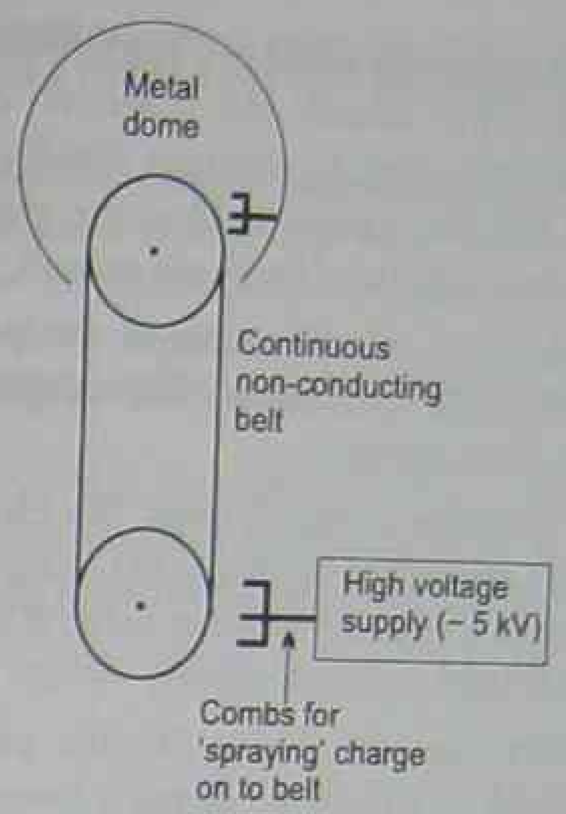

Figure 6. 27 Van der Graaff generator

3 Charge is continually added to the dome to build up a high potential difference which can be used to accelerate particles to high energies. (On small classroom generators, the initial charge is produced by friction with the bottom roller rather than by a high voltage source.)

Cyclotrons

Laurence and Livingston in California invented the cyclotron in 1931. The basic structure of the cyclotron is shown schematically in Figure 6.28. It is used to accelerate ions.

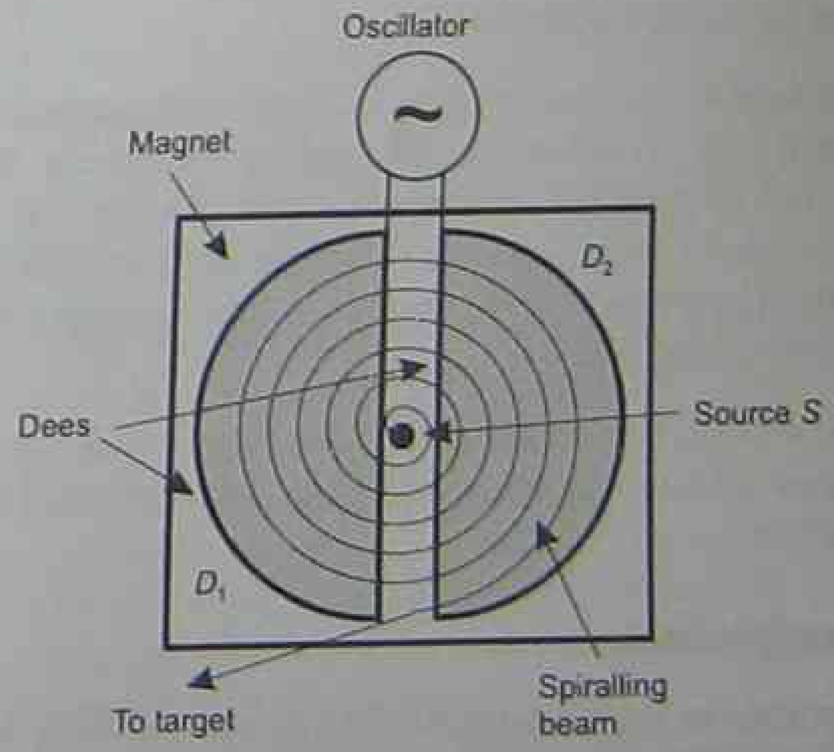

Figure 6. 28 Cyclotron

It works as follows:

1 An ion source is located near the midpoint of the gap between the D-shaped magnets (called dees).

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[20] http://wwwpdg.cern.ch/pdg/cpep/variation.html Website of the world's major particle accelerators.

2 The dees are connected to a high frequency AC source. This causes the potential difference between the dees to alternate rapidly with the result that the electric field in the gap reverses direction millions of times per second.

3 The dees are placed between the poles of a powerful electromagnet. The magnetic field bends the particles.

4 Ions from the source S enter the electric field and are accelerated across it to D_2 (say), where it moves in a circular path due to the *B* field (there is no *E* field within the dees).

5 If when the ion leaves D_2, the polarity has switched, it will be accelerated towards D_1 and will increase in speed. Thus, it will move in a circle of increased radius.

6 By repeated polarity changes, the ion can be continually accelerated until it reaches the required speed and energy when it is then allowed to strike a target.

The Betatron

This device is an *electron* accelerator (hence *betatron*). It differs from a cyclotron in that:

1 the electrons are accelerated by a rapidly changing magnetic field; and
2 the circular orbit has a constant radius.

The Synchro-Cyclotron

Because of relativistic mass increase with increasing speed, the cyclotron is limited in increasing the energy of particles. This results from the fact that as *v* increases, *m* increases and so the angular velocity falls. The particle then arrives too late to receive the accelerating 'kick'.

To overcome this, the accelerating frequency is varied to keep in phase with the orbit times of the particles.

The Synchrotron

Particles at high energies (for example, from a Van de Graaff generator) are injected into a single circular evacuated tube. They pass round the tube under the influence of a large magnet and are 'kicked' along at the right time by a high-frequency supply.

To keep the particles on the same path as their mass increases, the strength of the electromagnet is steadily increased.

A synchrotron has been built in the USA with the ability to accelerate particles to energies of 500 GeV! (1 GeV = ~10^9 eV)

Linear Accelerator

A linear accelerator consists of a series of *drift tubes* connected to an oscillator (Figure 6.29). The oscillator is connected in such a way that each tube has the opposite polarity to the preceding tube.

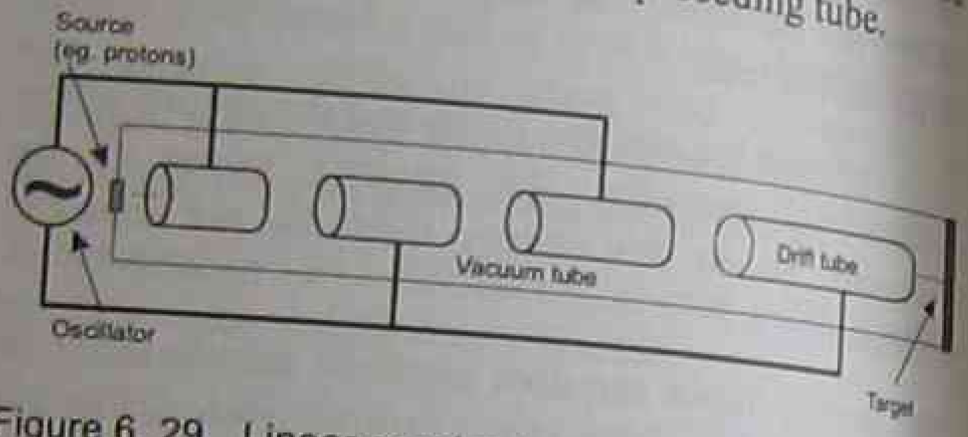

Figure 6. 29 Linear accelerator

1 Charged particles for example protons, emitted from a source are attracted to the first tube which is momentarily negative.

2 The charge accelerates in the electric field that exists in the gap between the tubes and hence gains energy.

3 The electric field inside the drift tube is zero and so the charge drifts along and does not accelerate when inside the tube.

4 The oscillator's frequency is arranged so that by the time the charge gets to the end of one tube, the next tube has changed its polarity. The tube it is leaving now repels the proton and it is attracted to the next tube which, provides additional energy.

5 To compensate for the increased velocity of the particles as they move down the line of tubes, each tube is made progressively longer than the preceding one; this ensures that the charge gets to the end just as the polarity reverses in the tubes.

Linear accelerators are used individually and in conjunction with other accelerators. The most famous linear accelerator is the *Stanford Linear Accelerator Centre (SLAC)* with a three-kilometre-long tube[21].

CERN

CERN is the acronym for ***Conseil Européen pour la Recherche Nucléaire***, now known as the European organization for Nuclear Research, and represents one of the most famous atomic research establishments in the world today. Its establishment was an effort to bring back the European physicists who had emigrated to the United States as a result of World War II. CERN has the most powerful and versatile facilities of its kind in the world. The site covers more than 100 hectares in Switzerland and, since 1965, more than 450 hectares in France. The *Large Electron-Positron Collider* (1989), with a circumference of almost 27 km, has facilitated detailed studies of the Z particle and the standard model of particle physics (see p.253).

Accelerators assist in the investigation of matter in two ways:

1 High energy means high speed and from the de Broglie relationship $\lambda = \frac{h}{mv}$ this means short wavelength. Smaller wavelengths mean greater resolution adding fine detail to the observations.

2 High energy means high mass particles can be produced (from $E = mc^2$). The vast majority of elementary particles[22] can only be 'observed' after their creation in high-energy accelerators; they are not normally 'visible' at typical energies.

As the energy of accelerators was increased, more and more particles were discovered. The quest was on to make sense of this myriad of particles, both old and new.

THE STANDARD MODEL[23]

> *The* **standard model** *is a theory that attempts to describe all interactions of subatomic particles (except those due to gravity).*

Its success lies in its ability to use a small number of particles and interactions to explain the existence of hundreds of particles and their interactions.

We saw earlier that there are four fundamental forces:

1 gravity
2 electromagnetic
3 strong nuclear force and
4 weak nuclear force.

Their relative strengths and range are shown in Table 6.5.

Table 6. 5 The four fundamental forces

Force	**Relative strength**	**Range (m)**
strong nuclear	1	10^{-15}
weak nuclear	10^{-5}	10^{-17}
electromagnetic	$\frac{1}{137}$	infinite
gravity	6×10^{-39}	infinite

The standard model has two main components to explain these forces:

1 *The electroweak theory*—first proposed in 1968 by Steven Werinberg, Sheldon Glashow and Abdus Salam. This describes interactions through the electromagnetic and weak forces. It proposes that the weak nuclear force is mediated by three *bosons* (Figure 6.30) called W^+, W^- and *Z* just as the electromagnetic force is mediated by the *photon*.

2 *Quantum chromodynamics*—the theory of the strong force. Formulated in 1977 it describes a

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[21] www2.slac.stanford.edu/vvc/home.html is an excellent virtual visitor site about SLAC. You can find out about accelerators, particle detectors, a history of SLAC, the theory behind particle physics…

[22] http://wwwpdg.cern.ch/pdg/cpep/map_proj.html *The Particle Adventure Roadmap*. This is an excellent site that looks at elementary particles including the standard model of matter.

[23] http://wwwpdg.cern.ch/pdg/cpep/standard_model.html Standard Model of Matter from CERN.
Another excellent site is found at http://www2.slac.stanford.edu/vvc/theory/model.html

quantum property called *colour* (see later)—hence the name.

Note that gravity is not part of the standard model.

Families of Matter

Physicists currently view matter as being grouped into three families—*quarks*, *leptons* and *bosons* (Figure 6.30).

The standard model explains interactions in terms of these families, which it further classifies as:

1 *Matter particles*. These are fundamental particles (that is, they have no *known* smaller parts). They are the *quarks* and *leptons*.

2 *Force-carrier particles*. Each type of fundamental force is caused by the exchange of *force-carrier* particles (also called *messenger or exchange* particles). These are the *fundamental* (or *gauge*) bosons. They include photons and gluons.

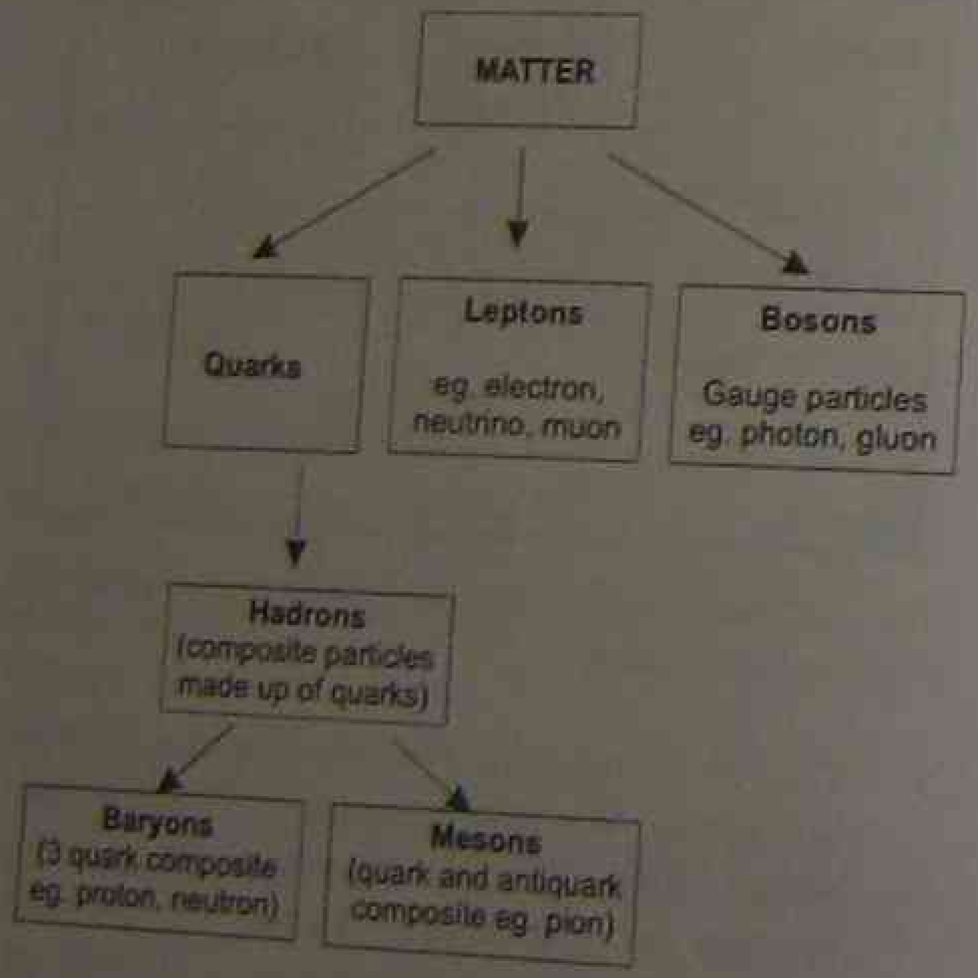

Figure 6.30 Families of matter

MATTER PARTICLES

Twelve fundamental particles make up all known matter. There are six quarks and six leptons. (In addition, for each matter particle there is a corresponding antimatter particle.)

Quarks

In 1964, theoretical considerations led the physicists Murray Gell-Mann and George Zweig to independently propose the existence of particles with charges that were sub-multiples of the electronic charge.

Quarks *are fundamental particles with charges* $-\frac{1}{3}e$ and $+\frac{2}{3}e$

Quarks[24] are considered 'point-like' in that they have no measurable size and are fundamental since they have no known components.

There are six varieties (flavours) of quarks (Table 6.6).

Table 6. 6 Quarks

Quark (q)	Symbol	Mass (GeV/c^2)[25]	Electric charge
up	u	0.004	+2/3
down	d	0.008	-1/3
strange	s	0.15	-1/3
charm	c	1.5	+2/3
bottom	b	4.7	-1/3
top	t	176	+2/3

The theory of *Quantum Chromodynamics* suggests that each quark (and antiquark) has a quantum property called *colour*[26]. (Because it is analogous to electric charge in the *electroweak* theory, physicists often talk about *colour*-charge.) Quarks can be *red*, *blue* or *green* (and antiquarks can be antired, antiblue and antigreen). Quarks of different colour-charge are attracted to each other: red attracts green; red attracts blue... Quarks with similar colour-charge repel each other.

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[24] Gell-Mann took the term *quark* from the book *Finnegan's Wake* by the Irish author James Joyce.

[25] High energy physicists use these units for mass when the mass of the particle is dependent on the velocity according to $m = \dfrac{E}{c^2}$

[26] This has no relationship with colour as we know it. It is just a means used by physicists to identify a quantum mechanical property of matter.

When quarks (and antiquarks) combine to form hadrons (see below), they do so in certain colour combinations. The net colour-charge is zero[27].

The six quarks are generally grouped in three pairs: up/down, charm/strange and top/bottom.

Hadrons

Quarks do not exist in isolation. (Quarks are so strongly bound to each other—physicists say they are confined—that it would take more energy than is currently available in the biggest particle accelerators to separate them.) They are always combined with one or two other quarks forming composite particles called *hadrons*.

Hadrons *are composite particles made of quarks. Hadrons are divided into* **baryons** *(three quark combinations) and* **mesons** *(two quark combinations). Hadrons interact through the strong nuclear force.*

Hadrons always have an integral charge and although individual quarks have *colour-charge*, hadrons are colour-neutral.

As mentioned above, hadrons are classified as either:

1 baryons or

2 mesons.

BARYONS

In the quark model, nucleons—protons and neutrons—are made up of three quarks (denoted *qqq*). A proton is made of two *up* quarks (each with a charge of $+\frac{2}{3}e$ and one *down* quark (with a charge of $-\frac{1}{3}e$). A proton is represented as *uud*. The charge is found from: $\frac{2}{3}e+\frac{2}{3}e-\frac{1}{3}e=+e$. The neutron is made from one up and two down quarks (*udd*). Charge is found from: $\frac{2}{3}e-\frac{1}{3}e-\frac{1}{3}e=0$

MESONS

Mesons are combinations of a quark and an antiquark (denoted as $\overline{q}q$ where $\overline{q}$ is the antiquark).

An example of a meson is a negative *pion* (π^-). It is made from an anti-up-quark and a down quark ($\overline{u}d$).

Mesons are unstable and decay in millionths of seconds.

Leptons

Leptons *are particles with little or no mass. They do not experience the strong force. Rather they interact through the weak force and gravity (and charged leptons also interact through the electromagnetic force).*

As with quarks, there are six varieties (flavours) of leptons (Table 6.7). The electron, muon and the tau are alike in that they are negatively charged but the muon and tau have more mass.

Table 6. 7 Leptons

Lepton (l)	Symbol	Mass (GeV/c^2)	Electric charge
electron	e^-	0.000511	–1
electron-neutrino	ν_e	<7 x 10^{-9}	0
muon	μ^-	0.106	–1
muon-neutrino	ν_μ	<0.0003	0
tau	τ^-	1.7771	–1
tau-neutrino	ν_τ	<0.03	0

The other three leptons are neutrinos. They have no charge and little, if any, mass. Each electrically charged lepton has a corresponding neutrino.

As with quarks, for each lepton there is a corresponding *antilepton*. Unlike quarks, however, that are only found in combination with other quarks, leptons do exist independently.

---

[27] The colours of quarks were chosen as red, blue and green because light of these colours combine to form white light.

Generations

Each of the six quarks and leptons can be paired providing three *generations* of particles (Table 6.8).

Table 6. 8 Generations of particles

Generation	Quark	Charge	Lepton	Charge
First	up	$+\frac{2}{3}$	electron	–1
	down	$-\frac{1}{3}$	electron-neutrino	0
Second	charm	$+\frac{2}{3}$	muon	–1
	strange	$-\frac{1}{3}$	muon-neutrino	0
Third	top	$+\frac{2}{3}$	tau	–1
	bottom	$-\frac{1}{3}$	tau-neutrino	0

Each generation consists of a set comprising each charge type of quark and lepton.

The first generation particles (up and down quarks, the electron and electron-neutrino) constitute everyday matter.

Second and third generation particles are unstable and decay into first generation particles.

As a result, the heavy quarks, *s*, *c*, *b* and *t* do not exist in normal matter. They must be 'created' in particle accelerators.

Each generation is more massive than the previous one.

FORCE-CARRIER PARTICLES

The four forces mentioned earlier are carried by force-carrier particles—bosons (also called *gauge particles*). They are:

1 gravity by the *graviton* (this is still to be discovered);
2 electromagnetic by the *photon*;
3 strong nuclear by the *gluon* (this keeps quarks together); and
4 weak nuclear by the *weakon* (weak boson).

PROBLEMS OF THE STANDARD MODEL

As with all models of matter, the standard model explains some phenomena but not all. It cannot, for example, explain:

1 why quarks have the masses they do
2 why the top quark (discovered in 1995) is so massive (~190 times the proton mass)
3 how to incorporate gravity.

The search continues for the ultimate truth—the so-called *theory of everything*!

SUMMARY

- The Rutherford model of the atom pictured a dense positive nucleus surrounded by electrons. Most of the atom is empty space.
- The line emission spectrum of hydrogen was central to the development of Bohr's model. Each line could be represented by the equation $\frac{1}{\lambda}=R_H\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$
- Planck postulated that energy came in 'lumps' or quanta given by $E = hf$
- Bohr made a number of postulates in his model of the atom, including Planck's postulate.
- Bohr was successful in explaining the existence of line emission spectra.
- Bohr was unsuccessful in explaining a number of observations of spectra.

- Just as light exhibits wave properties (for example, interference) and particle properties (for example, the photoelectric effect), so too de Broglie postulated that all matter has this same wave-particle duality.
- Matter waves have a wavelength given by $\lambda=\frac{h}{p}=\frac{h}{mv}$
- Davisson and Germer successfully demonstrated electron diffraction.
- Matter waves explain the stability of electron stationary states.
- Electron microscopes utilise the wave nature of electrons to provide enormous magnifications.
- Electron microscopes use magnetic lenses to focus electrons.
- Chadwick discovered the neutron in 1932.
- Transmutation, the conversion of one element into another, occurs in natural radioactivity and can be induced.
- Fermi first demonstrated a nuclear chain reaction from nuclear fission in 1942.
- Pauli hypothesised the existence of the neutrino to account for energy discrepancies in beta emission.
- Nucleons (protons and neutrons) are held together by the strong nuclear force.
- The mass defect is the difference between the mass of an atom and the sum of the masses of its parts.
- Mass defect is converted into binding energy according to $E=mc^2$
- Chain reactions can be controlled or uncontrolled depending on how many neutrons are available for the next fission.
- Fission reactors use the heat from nuclear fission to drive generators to produce electricity.
- Radioisotopes find extensive uses in industry and medicine.
- Neutron scattering is an effective way to probe inside bulk matter.
- Physicists use particle accelerators to probe inside atoms.
- Matter is composed of quarks, leptons and bosons.
- Cosmology seeks to explain the universe's structure and existence; it requires quantum mechanics to do this.

Key Terms

accelerator
antiparticle
Balmer series
binding energy
black body radiation
Bohr
Chadwick
chain reaction
control rods
Davisson and Germer
de Broglie
electron diffraction
electron microscope
electroweak theory
emission spectrum
Fermi
fission reactor
gluon
hadron
Heisenberg
hydrogen spectrum
lepton
magnetic lens
mass defect
matter waves
meson
moderator
neutrino
neutron scattering
nucleons
nucleus
orbit
Pauli
photon
quantum
quark
radioactivity
radioisotope
Rutherford
spectra
standard model
tracers
transmutation
wave-particle duality

QUESTIONS AND PROBLEMS ON *QUANTA TO QUARKS*

SECTION 1: MODELS OF THE ATOM

1 Describe the Rutherford scattering experiment.

2 Define the following terms:
   (a) spectra
   (b) line emission spectra
   (c) spectroscope.

3 The Balmer equation for the hydrogen spectrum is $\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$. Explain the meaning of each term.

4 The green line in the spectrum of hydrogen results from the transition of an electron from the 4th energy level to the 2nd energy level. Calculate the wavelength and photon energy of the green light.

5 What was Planck's hypothesis that Bohr used to help explain spectra?

6 State Bohr's three main postulates.

7 What was the major success of Bohr's model of the atom?

8 List five limitations of Bohr's model.

SECTION 2: QUANTUM PHYSICS

1 What is meant by wave-particle duality?

2 Calculate the wavelength of an electron of mass 9.109×10^{-31} kg moving at 1.5×10^6 m.s^{-1}.

3 Describe the Davisson and Germer experiment.

4 How are matter waves used to explain the stability of electron orbits?

SECTION 3: APPLICATIONS OF RADIOACTIVITY

1 Describe Chadwick's experiment that led to the discovery of the neutron.

2 Define the following terms:
   (a) radioactivity
   (b) transmutation
   (c) radioisotope
   (d) nucleon.

3 How can radioisotopes be produced?

4 What were Fermi's contributions to physics?

5 What led Pauli to hypothesise the existence of the neutrino?

6 Define the following terms:
   (a) mass defect
   (b) binding energy.

7 Calculate the total binding energy of the carbon-12 atom. You will require the following data:

mass of carbon-12 = 12.000000 u
mass of proton = 1.007276 u
mass of neutron = 1.00866 u
mass of electron = 0.000546 u

SECTION 4: NUCLEAR APPLICATIONS

1 Explain the basic principles of a fission reactor.

2 Describe *one* medical or industrial use of radioisotopes.

3 What is neutron scattering and what is it used for?

SECTION 5: THE STRUCTURE OF MATTER

1 Briefly describe the operation of *one* type of particle accelerator.

2 Briefly describe the current model of matter.

3 What are quarks?

4 What are the different characteristics attributed to quarks?

TEST QUESTIONS ON QUANTA TO QUARKS

Each QUESTION is composed of a number of parts. Suggested marks for each part are indicated. In keeping with the format of the HSC Examination, each question totals 25 marks.

The following data may be required:

Table 6. 9

Electron volt	1 eV = 1.602×10^{-19} J
Charge on electron	$e = -1.602 \times 10^{-19}$ C
Mass of electron	$m_e = 9.109 \times 10^{-31}$ kg
Planck constant	$h = 6.626 \times 10^{-34}$ J.s
Rydberg constant	$R_H = 1.097 \times 10^7$ m^{-1}
Speed of light	$c = 3.00 \times 10^8$ m.s^{-1}

QUESTION 1

(a) After the results of a famous experiment were analysed, Lord Rutherford commented '*...it was almost as incredible as if you fired a 15 inch shell at a piece of tissue paper and it came back and hit you...*'
   (i) Recall what Rutherford is referring to in this comment. (1 mark)
   (ii) Recall who conducted the experiment about which this comment was made. (1 mark)
   (iii) Recall what Rutherford deduced from this observation. (1 mark)

(b) The equation $\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ is an equation relating to the spectrum of hydrogen.
   (i) Recall the meanings of each of the terms in this equation. (2 marks)
   (ii) For the Balmer series of hydrogen, $n_f = 2$. Predict the value of n_i corresponding to the longest wavelength. (1 mark)
   (iii) Calculate this wavelength in nm. (1 mark)

(c) In 1924 Louis de Broglie proposed the relationship $\lambda = \frac{h}{p}$
   (i) Define the meaning of each symbol. (1 mark)
   (ii) Describe how this equation shows the wave-particle duality of matter. (2 marks)

(d) Briefly describe the experiment conducted by Davisson and Germer in 1923 and discuss its implications. (4 marks)

(e) Pauli postulated the existence of a particle called the neutrino many years before its discovery.
   (i) Recall what led Pauli to postulate the neutrino. (2 marks)
   (ii) Explain why it was so hard to discover. (1 mark)

(f) Radioisotopes have extensive uses in medicine, agriculture and in engineering. Take any one of these areas and recall an example of the use of radioisotopes. (3 marks)

(g) A source of α, β and γ radiation is placed in a strong magnetic field as shown in Figure 6.31. From what you know of the properties of these radiations, draw the likely path of each ray through the field. (2 marks)

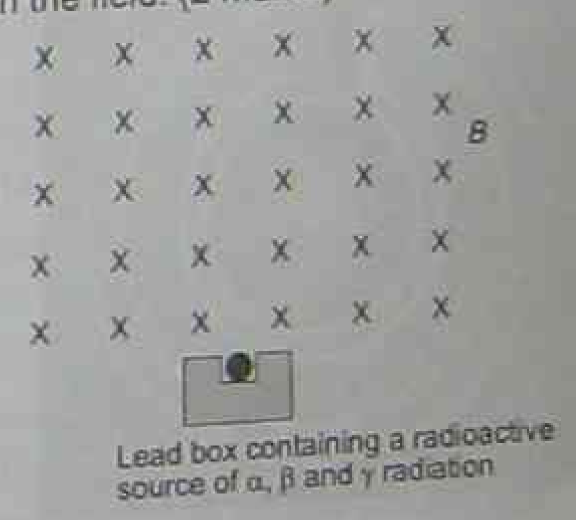

Figure 6. 31

(h) Physicists currently view matter as being divided into three families: *quarks*, *leptons* and *bosons*.
   (i) Define the term quarks. (1 mark)
   (ii) Recall one example of a lepton. (1 mark)
   (iii) Recall one example of a boson. (1 mark)

QUESTION 2

(a) In 1911, at the instigation of Rutherford, Geiger and Marsden investigated the effects of firing alpha particles at a thin sheet of gold foil.
   (i) Recall what results were expected on Thomson's 'plum pudding' model of the atom. (1 mark)

(ii) What results actually occurred and how did Rutherford explain them? (2 marks)

(iii) One problem of the Rutherford model was that it predicted that the electrons in the atom would lose energy continuously and spiral into the nucleus.

(1) List two pieces of evidence to show this was not happening. (2 marks)

(2) Name the scientist who overcame this problem. (1 mark)

(3) What did he postulate to resolve it? (1 mark)

(b) An electron makes the transition between the energy levels –10.4 eV and –6.7 eV of the mercury atom. Calculate the wavelength of the emitted photon. (2 marks)

(c) Explain the significance of 'matter waves' in atomic theory. (2 marks)

(d) Figure 6.32 represents a pattern formed when a beam of electrons is passed through a thin metal foil.

Figure 6. 32

(i) Recall the phenomenon that is being illustrated in this picture. (1 mark)

(ii) What was the significance of this phenomenon? (1 mark)

(iii) State two implications of this discovery. (2 marks)

(e) Chadwick discovered the neutron in 1932. Briefly describe the experiment he performed in this discovery. (2 marks)

(f) Account for why neutrons are more effective 'bullets' than protons or alpha particles to investigate nuclear reactions. (1 mark)

(g) Figure 6.33 represents a graph of the nuclear force between two nucleons.

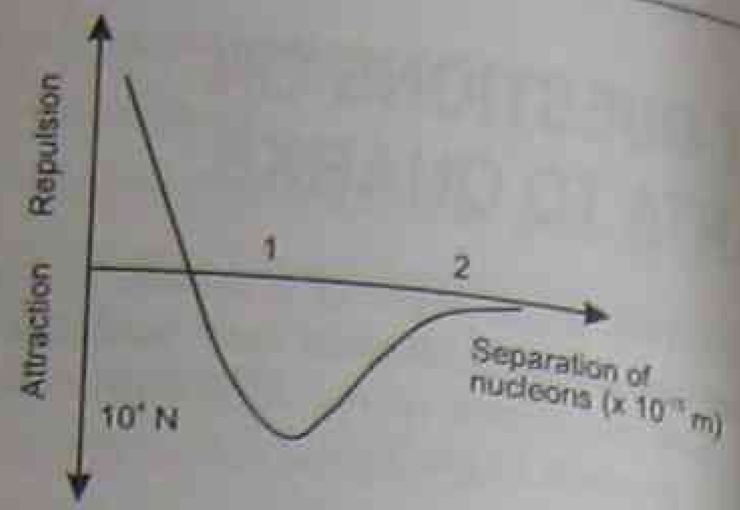

Figure 6.33

(i) Define the term nucleons. (1 mark)

(ii) Explain why the nuclear force is required. (1 mark)

(iii) Recall three properties of this force. (2 marks)

(h) According to the Standard Model of Matter, all matter can be grouped into three families. These families can be further classified as matter particles or force-carrier particles.

(i) Name the three families. (1 mark)

(ii) Give an example of a force-carrier particle and the force that it mediates. (2 marks)

QUESTION 3

(a) What problems concerning the structure of the atom were posed by Rutherford's model? Explain your answer. (2 marks)

(b) One of Bohr's assumptions was that an electron rotates in 'discrete energy levels' without radiating any energy. How do we now account for the non-radiance from such 'stationary states'? (2 marks)

(c) Figure 6.34 is a diagram (not to scale) that shows the energy levels of a hydrogen atom.

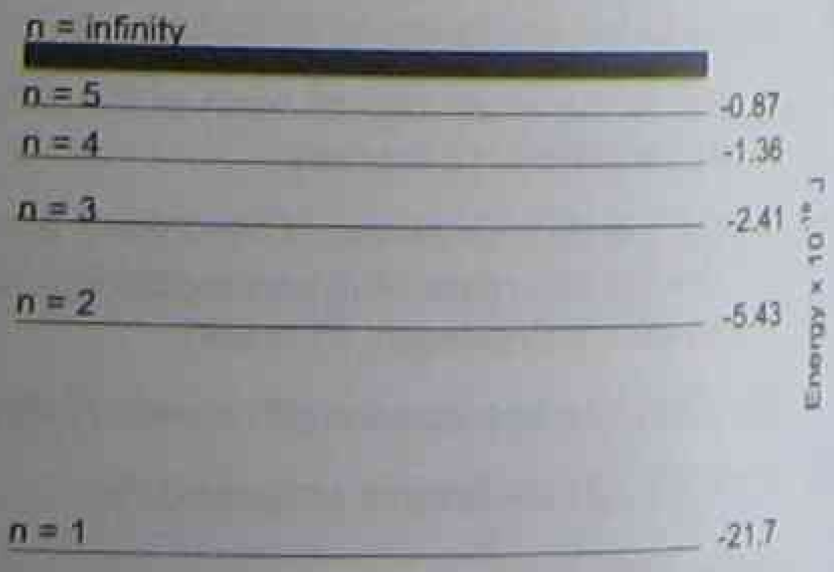

Figure 6. 34

(i) Draw the electron transitions that would represent the Balmer series of lines. (1 mark)

(ii) Label the line corresponding to the red emission line. (1 mark)

(iii) Calculate the frequency corresponding to the longest wavelength in the series? (2 marks)

(d) Enrico Fermi carried out the first controlled nuclear fission reaction in 1942. He used a pile of graphite blocks into which were inserted rods containing uranium-235.

(i) Explain the role of the graphite blocks. (2 marks)

(ii) Explain what happened to the reaction as the rods were pushed into the pile. (1 mark)

(e) Figure 6.35 shows a graph of the binding energy per nucleon versus mass number for the elements.

(i) Define the term 'binding energy'. (1 mark)

(ii) Where does this energy come from? (1 mark)

(iii) Explain why this binding energy is necessary. (1 mark)

(iv) Predict which nucleus is more stable, helium-4 or lithium-6. Explain your reasoning. (2 marks)

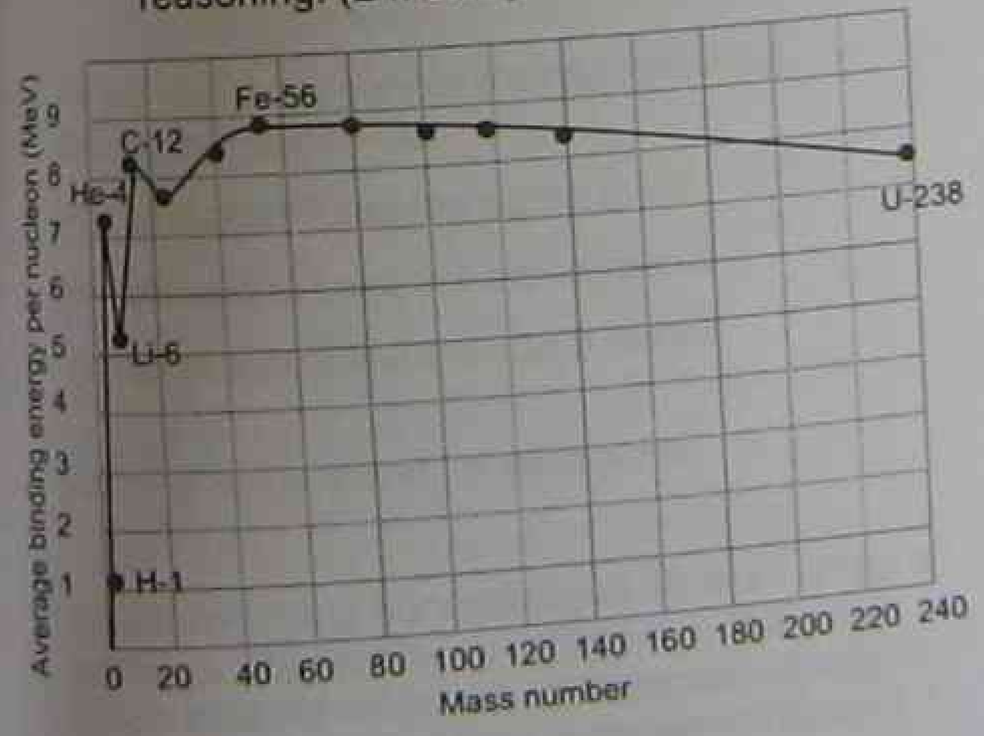

Figure 6. 35

(f) The Manhattan Project represents one of the largest and expensive human endeavours.

(i) What was the Manhattan Project? (1 mark)

(ii) What was the 'short term' result of the Project? (1 mark)

(iii) What were some of the 'longer term' implications? (2 marks)

(g) Particle accelerators have assisted in the discovery of much information about the structure of matter.

(i) Define particle accelerators. (1 mark)

(ii) Explain why physicists 'need' bigger and bigger accelerators. (1 mark)

(h) Quarks come in six varieties or 'flavours': up, down, strange, charm, bottom and top. Explain why individual quarks have never been isolated. (2 marks)

QUESTION 4

(a) The Balmer series of lines in the spectrum of hydrogen are represented by the equation:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n_i^2}\right)$$

The 'series limit' corresponds to the last possible line of the series. Calculate the wavelength of the series limit for the Balmer series. (2 marks)

(b) For all of its successes, Bohr's theory of the atom had its limitations. Recall two of these. (2 marks)

(c) An electron (charge q), accelerated through a potential difference (V) of 50,000 V gains kinetic energy given by $W=qV$

(i) Calculate the speed of the electron at the end of its journey. (1 mark)

(ii) Calculate its de Broglie wavelength. (1 mark)

(iii) Explain how the wave nature of electrons is used to explain the stability of electron orbits in atoms. (2 marks)

(d) A nuclear fission reaction can be either controlled' or uncontrolled'. Compare the differences in these reactions and explain how we control such a reaction. (2 marks)

(e) Define what is meant by 'transmutation'. (1 mark)

(f) The mass of an atom is less than the sum of the masses of the components (protons, neutrons and electrons). Explain why this is the case. (2 marks)

(g) Radioisotopes are used for a variety of purposes in industry and in medicine.

(i) Define radioisotopes. (1 mark)

(ii) Recall the name of one radioisotope and describe its uses in industry or medicine. (3 marks)

(h) Neutron scattering is a powerful investigative technique in physics.

(i) Describe what neutron scattering is used for. (2 marks)

(ii) Recall what property of a neutron allows it to be used for the purposes identified in (i) above. (1 mark)

(i) Briefly describe the main features of the *Standard Model of Matter*. (5 marks)

Chapter Seven

HSC Practice Examinations

The style of these practice examinations is based on the ***2001 Higher School Certificate Specimen Examination*** *made available by the Board of Studies in May 2000. (Note that the number of questions in Section I, Part B, may vary from year to year but will still be worth 60 marks.)*

PRACTICE EXAMINATION ONE

SECTION I

PART A

Total Marks (15)

Attempt Questions 1-15

Allow about 30 minutes for this part

Select the alternative A, B, C or D that best answers the question.

1 Jupiter has a number of moons revolving around it. It is true that:

(A) all moons have the same mass

(B) all moons have the same radius

(C) all moons have the same period

(D) $\frac{r^3}{T^2}$ is the same for all moons.

2 An aircraft flying horizontally at 45 $m.s^{-1}$ drops a package. Neglecting air resistance, the graph which best represents the horizontal velocity of the package against time is shown in Figure 7.1 as:

(A) A

(B) B

(C) C

(D) D

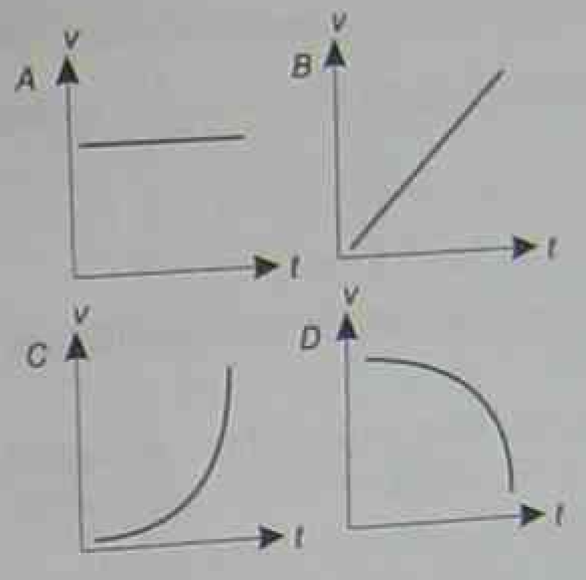

Figure 7. 1

3 Spacecraft to be placed in orbit are generally raised to a suitable height by rockets and then tipped' in an easterly direction. This:

(A) ensures the Earth's rotational velocity is added to the spacecraft's own velocity

(B) avoids flights over rival countries

(C) is done for safety reasons so that the spacecraft travels over water for its initial journey

(D) helps slow the spacecraft down so it can go into orbit.

4 The Theory of Special Relativity is restricted to inertial frames of reference. In such a frame:

(A) there are inertial forces

(B) there are no inertial forces

(C) the frame is accelerating

(D) pseudo or fictitious forces must be used to keep Newton's Laws valid.

5 Special Relativity allows for:

(A) time travel into the future but not into the past

(B) time travel into the past but not into the future

(C) no time travel at all

(D) the speed of light in a vacuum to vary for different observers.

6 The torque on a coil in a magnetic field can be increased by:

(A) increasing the current through the coil

(B) increasing the strength of the magnetic field

(C) using more turns in the coil

(D) all of the above.

7 Faraday's Law of electromagnetic induction can be written mathematically as $\varepsilon = -n\dfrac{\Delta\varphi}{\Delta t}$ where ε is the induced *emf*. In this equation φ is:

(A) the magnetic flux linking the circuit

(B) the average magnetic field strength linking the circuit

(C) the magnetic field resulting from an induced current in the circuit

(D) the electric field strength in the circuit.

8 The correct relationship between the voltage, current and number of turns in the primary (p) and secondary (s) of a transformer is:

(A) $\dfrac{V_p}{V_s} = \dfrac{I_s}{I_p} = \dfrac{n_p}{n_s}$

(B) $\dfrac{V_p}{V_s} = \dfrac{I_p}{I_s} = \dfrac{n_p}{n_s}$

(C) $\dfrac{V_p}{V_s} = \dfrac{I_s}{I_p} = \dfrac{n_s}{n_p}$

(D) $\dfrac{V_s}{V_p} = \dfrac{I_s}{I_p} = \dfrac{n_p}{n_s}$

9 The south pole of a magnet is brought towards a circular metal ring that hangs freely from a vertical string as in Figure 7.2.

Figure 7.2

Looking towards the ring:

(A) a current is induced in a clockwise direction setting up a north pole

(B) a current is induced in a clockwise direction setting up a south pole

(C) a current is induced in an anticlockwise direction setting up a north pole

(D) a current is induced in an anticlockwise direction setting up a south pole.

10 Eddy currents:

(A) can be used to assist in braking of a moving conductor

(B) assist in the generation of an induced emf in a transformer

(C) can be reduced in a transformer by having a single piece of metal as the core

(D) act in a direction to increase the applied *emf*.

11 This question refers to Figure 7.3.

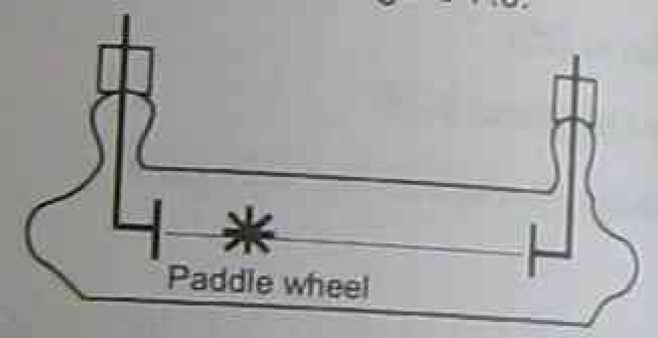

Figure 7. 3

The apparatus shown is used to demonstrate that cathode rays:

(A) are electrons

(B) carry energy and momentum

(C) cause glass to emit X-rays

(D) travel in straight lines.

12 This question refers to Figure 7.4.

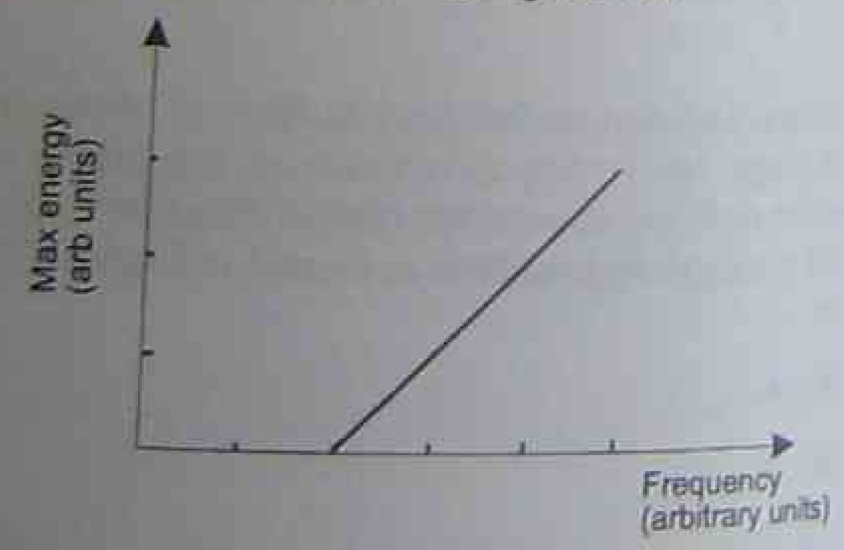

Figure 7. 4

The gradient, *k*, of the graph can be used to estimate:

(A) the charge on the electron

(B) the charge to mass ratio for an electron

(C) Planck's constant

(D) the ionisation energy of zinc.

13 On 1 February 2003 the Space Shuttle *Columbia* with seven astronauts aboard disintegrated over Texas when returning from a mission. The likely cause of the disaster was damage to some of the porous ceramic tiles that cover the shuttle. The role of these tiles is:

(A) to maximise the reflection of the heat generated by re-entry

(B) to maximise the aerodynamic drag to slow the shuttle down

(C) to maximise the conduction of the heat generated by re-entry

(D) to minimise the conduction of the heat generated by re-entry.

14 In semiconductors:

(A) the valence band and conduction band overlap

(B) the valence band is empty and the conduction band is full

(C) the valence band and the conduction band are separated by the forbidden energy gap

(D) the valence band is full and the conduction band is empty.

15 Superconductivity results in:

(A) the photoelectric effect

(B) the Doppler effect

(C) the Meissner effect

(D) the Zeeman effect.

SECTION I

PART B

Total Marks (60)

Attempt Questions 16 – 27

Allow about 1 hour and 45 minutes for this part

Show all relevant working in questions involving calculations.

The following data may be required to answer some of the following questions.

Mass of Earth = 5.983×10^{24} kg

Radius of Earth = 6.38×10^{3} km

$G = 6.67 \times 10^{-11}$ N.m^2.kg^{-2}

Question 16 (3 marks)

The satellite Phobos describes a nearly circular orbit of radius 9.7×10^{6} m round the planet Mars with a period of 2.75×10^{4} s.

(a) Calculate the mass of Mars from this information. (2 marks)

(b) The period of revolution of the other Martian satellite, Demos, is 1.09×10^{5} s. Calculate the radius of its orbit. (1 mark)

Question 17 (4 marks)

In late 1985, the first *AUSSAT* satellite was placed in a geostationary orbit above the equator. This orbit is one in which the period of the satellite is the same as that of the earth, that is, 24 h.

(a) Calculate the height above the Earth's surface that *AUSSAT* is positioned. (2 marks)

(b) Explain the advantage(s) of such an orbit. (2 marks)

Question 18 (5 marks)

When sending space probes to distant planets, scientists make use of so-called 'gravity-assist' (or 'slingshot') trajectories.

(a) Explain the meaning of this term. (3 marks)

(b) Clearly explain how these assist in reducing the fuel required to reach the distant planet. (2 marks)

Question 19 (4 marks)

Newton's Law of Universal Gravitation determines the motion of satellites and other spacecraft in our Solar System. Explain. (4 marks)

Question 20 (4 marks)

(a) Frames of reference can be classified as either inertial on non-inertial. Explain the difference between these two types. (2 marks)

(b) Nineteenth century physicists believed that light travelled through a medium called the ether.

- (i) Explain they proposed the existence of the ether. (1 mark)
- (ii) The ether was supposed to act as an 'absolute frame of reference'. What does this mean? (1 mark)

Question 21 (5 marks)

Figure 7.5 is a schematic diagram of a simple DC motor. Clearly explain how this simple motor works.

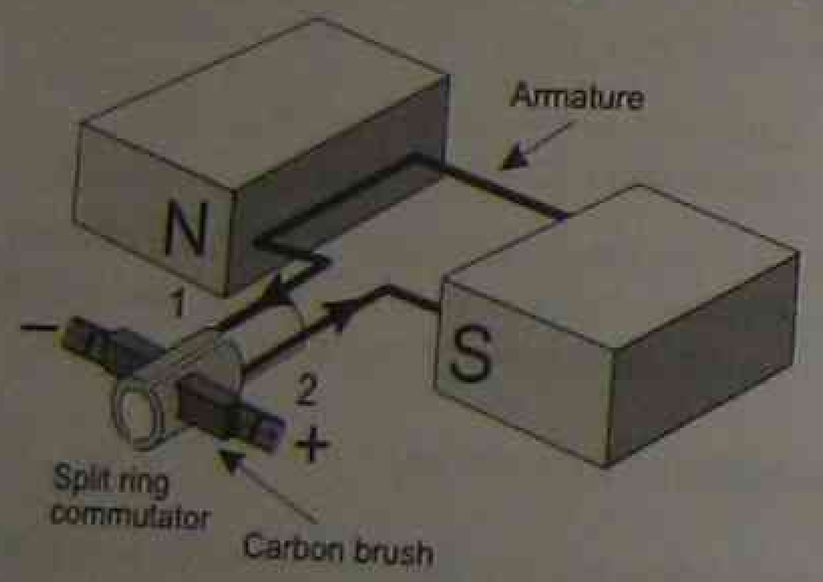

Figure 7. 5

Question 22 (3 marks)

An electric motor rotating at its maximum rate draws 2 A of current from a battery. If the motor is slowed down, however, by applying a force to the spinning shaft, the current increases above 2 A. Explain. (3 marks)

Question 23 (5 marks)

(a) Figure 7.6 is a schematic diagram of a simple AC generator. Clearly explain how it works. (5 marks)

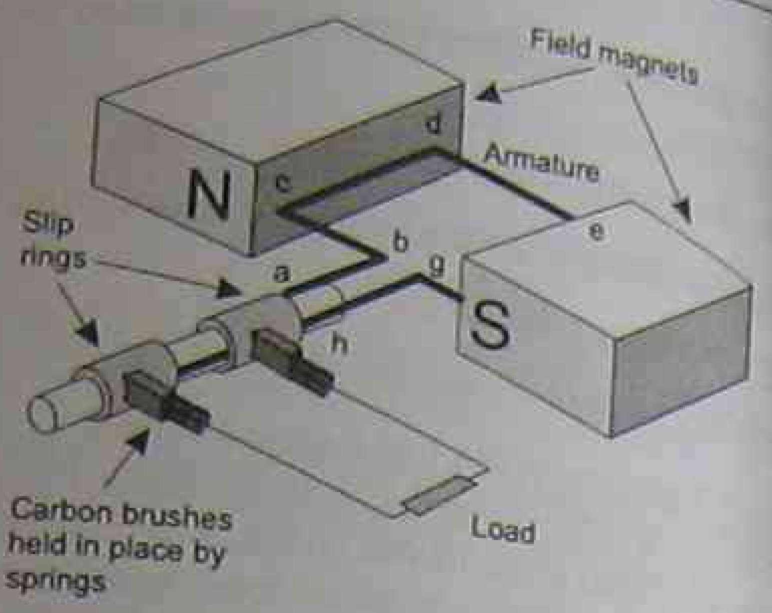

Figure 7. 6

Question 24 (7 marks)

(a) A transformer is used to boost the voltage from the power station from 11 000 V AC to as high as 500 000 V AC for distribution to towns and cities.

- (i) Explain why a transformer can't be used to do the same thing for DC voltages. (1 mark)
- (ii) Explain why the electricity is not transmitted at the lower voltage (say 11 000 V). (2 marks)
- (iii) The wire in the secondary coil of a step-up transformer is generally thinner than the wire in the primary coil. Explain why this is possible. (1 mark)

(b) Eddy currents represent a potential energy loss in a transformer.

- (i) Define eddy currents. (1 mark)
- (ii) Explain how can they be eliminated or minimised in a transformer. Justify your answer. (2 marks)

Question 25 (5 marks)

(a) Figure 7.7 is a schematic diagram of a cathode ray tube (CRT).

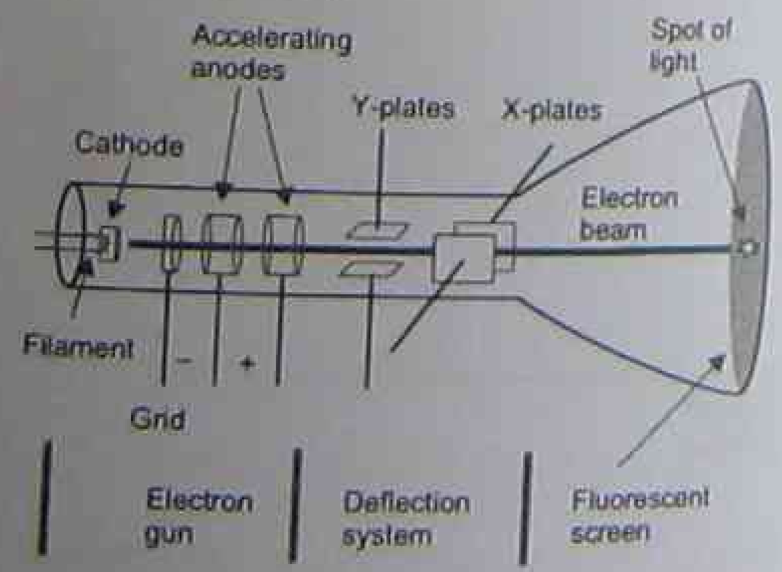

Figure 7. 7

- (i) Explain how an electron beam is produced. (1 mark)
- (ii) Explain what the X and Y plates are used for. (1 mark)

(b) One of the major uses of cathode ray tubes is in cathode ray oscilloscopes (CRO). Describe the purpose of a CRO and give an example of where you have seen it used in your physics class. (3 marks)

Question 26 (8 marks)

Semiconductors are essential to modern life in developed countries such as Australia, having almost entirely replaced thermionic devices in the past two decades.

(a) Define semiconductors. (2 marks)

(b) Explain two reasons why silicon has become the semiconductor of choice rather than germanium. (2 marks)

(c) The process of 'doping' allows scientists to manipulate the semiconductor's electrical properties.

- (i) Define 'doping'. (1 mark)
- (ii) Explain the relationship between one type of semiconductor (*p*-type or *n*-type) and the doping process. (3 marks)

Question 27 (7 marks)

Superconductors hold great potential for improvements in communication, in transportation and in a range of other areas.

(a) Define superconductivity. (1 mark)

(b) List four specific current or potential uses of superconductors. (2 marks)

(c) Briefly describe the current theory of superconductivity (the BCS theory). (4 marks)

SECTION II – OPTIONS

Total marks (25)

Attempt ONE question from Questions 28 - 30

Allow about 45 minutes for this section

Show all relevant working in questions involving calculations.

Question 28	**Medical Physics**
Question 29	**Astrophysics**
Question 30	**Quanta to Quarks**

Question 28 — Medical Physics (25 marks)

(a) Ultrasound is an imaging technique used in medical diagnosis. It relies on the piezoelectric effect.

- (i) Define the piezoelectric effect. (1 mark)
- (ii) Clearly describe how this effect is used to make ultrasound images. (5 marks)

(b) Explain how ultrasound is used to assist in the diagnosis of osteoporosis. (2 marks)

(c) Describe how a radiopharmaceutical may be metabolised by the body to bind or accumulate in the target organ. Give two examples. (4 marks)

(d) Describe the major difference between scans obtained from radioisotopes and other types of scans such as X-rays, CT and MRI. (1 mark)

(e) Compare the advantages of PET scans over CT scans. (2 marks)

(f) PET scans rely on the process of *pair annihilation*. Explain the meaning of this term, clearly stating where each 'half' of the 'pair' comes from. (3 marks)

(g) MRI measures the concentration of hydrogen atoms in biological materials.

- (i) Explain the significance of the 'Larmor frequency' in MRI. (2 marks)
- (ii) Describe how the hydrogen concentration is measured. (3 marks)
- (iii) Explain how this provides us with information about the condition of the tissue/organ being imaged. (2 marks)

Question 29 — Astrophysics (25 marks)

(a) Astronomers are continually looking for ways to improve the sensitivity of their telescopes.

  (i) Define what is meant by a telescope's sensitivity. (1 mark)

  (ii) Recall what factor(s) affect(s) the sensitivity. (1 mark)

  (iii) Briefly describe a method currently used in the new generation of optical telescopes to improve sensitivity. (3 marks)

(b) A particular star α has an apparent magnitude of 1.0. Another star β has an apparent magnitude of 4.0.

  (i) Define the term 'apparent magnitude' in relation to stars. (1 mark)

  (ii) Which star is brighter? Explain. (2 marks)

  (iii) Calculate how much brighter the brighter star is than the duller star. (1 mark)

(c) Explain why it is that some stars show strong hydrogen lines (dark lines, since absorption) while other stars have weak hydrogen lines. (2 marks)

(d) Compare a red giant with a white dwarf in terms of:

  (i) luminosity

  (ii) spectral class

  (iii) diameter

  (iv) surface temperature

  (v) density

  (vi) fuel source. (4 marks)

(e) α-Crucis, the brightest star in the Southern Cross, is a *visual binary*.

  (i) Explain what this means. (1 mark)

  (ii) State the names of *two* other types of binary star systems. (1 mark)

(f) A binary pair has a parallax of 0.125 arc seconds, a separation of 20 AU and a period of 50 years, calculate

  (i) the distance from us (1 mark); and

  (ii) the sum of its masses. (2 marks)

(g) Describe in what major way (in terms of their fuel) a main sequence star differs from a red giant. (1 mark)

(h) Three stars α, β and γ have masses of 4 solar masses, 1 solar mass and 1.6 solar masses respectively.

  (i) Predict the likely end state of each star. (2 marks)

  (ii) Justify why α ends up the way you stated in (i). (2 marks)

Question 30 — Quanta To Quarks (25 marks)

(a) For simple gases such as hydrogen, the frequency of any spectral line is simply the sum or difference of the frequencies of other spectral lines of the same gas. Use Bohr's model to account for this observation. (2 marks)

(b) Bohr's model had many successes. It also had its failures.

  (i) One of its failures was its inability to explain why electrons could revolve around the nucleus without radiating energy. Recall *three* other things about Bohr's model which indicated its inadequacy in successfully explaining all facts about the structure of matter. (2 marks)

  (ii) Explain how the non-radiance of electrons in their orbits was explained at a later date. (2 marks)

(c) The German physicist Heisenberg stated in 1924 that: 'Light and matter are but single entities, the apparent duality of their nature lying in the limitations of language.' Identify two experiments which show that matter (for example, electrons) exhibits:

  (i) a wave nature; (1 mark) and

  (ii) a particle nature. (1 mark)

(d) Describe the contribution made to atomic theory by Fermi and Heisenberg. (4 marks)

(e) The curve of binding energy per nucleon for the elements is shown in Figure 7.8. By reference to the graph, explain why:

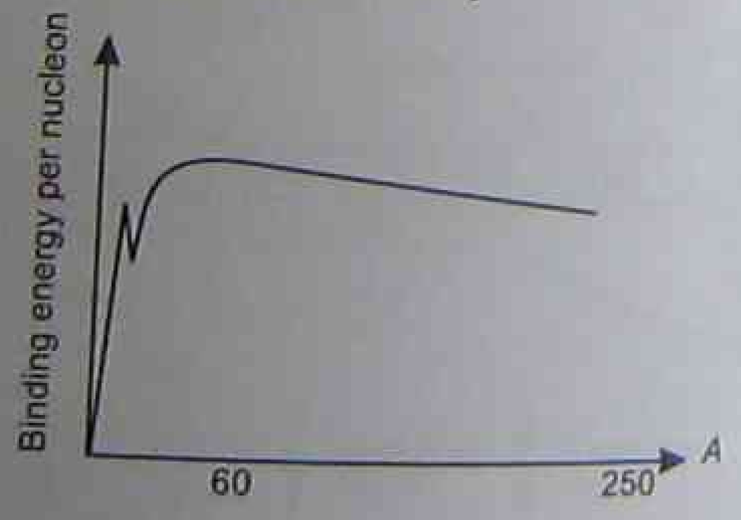

Figure 7. 8

  (i) the nucleus of U-235 is less stable than the nucleus of Kr-92; (1 mark) and

  (ii) the U-235 nucleus will undergo spontaneous fission but the Kr-92 nucleus will not. (2 marks)

(f) It is found that $^{238}_{92}U$ is the beginning of a long sequence of radioactive decays, each of which change the nucleus involved to that of another element. Some of the steps in this *decay series* are shown below. Fill in the spaces denoted by '?'. (2 marks)

$^{238}_{92}U \rightarrow ^{234}_{90}Th + ?$

$^{234}_{90}Th \rightarrow ^{?}_{?}Pa + ^{0}_{-1}e$

$^{?}_{?}Pa \rightarrow ^{234}_{?}U + ^{0}_{-1}e$

$^{234}_{?}U \rightarrow ^{?}_{?}Th + ^{4}_{2}He$

(g) The purpose of a fission reactor is to produce heat energy from nuclear fission in a controlled manner. Important components in such reactors are the fuel, the moderator, the control rods and shielding. Briefly describe the purpose of each of these components. (4 marks)

(h) A student was provided with three radioactive samples that he was assured were an alpha emitter, a beta emitter and a gamma emitter. Unfortunately the labels had fallen off. Explain how the student could deduce which was which using apparatus available in a typical school science department. (2 marks)

(i) The massive top quark (mass ~190 x proton mass), although postulated to exist as far back as the 1970s, was not discovered until 1995. Propose a reason for this based on your knowledge of how subatomic particles are discovered. (2 marks)

PRACTICE EXAMINATION TWO

SECTION I

PART A

Total Marks (15)

Attempt Questions 1-15

Allow about 30 minutes for this part

1 The period of a satellite placed in orbit half-way between the Earth and the Moon is approximately:

(A) 5 days

(B) 10 days

(C) 15 days

(D) 20 days.

2 For satellites orbiting a celestial object, Kepler's Law can be written $\frac{r^3}{T^2} = k$. For satellites orbiting the Earth (mass M), the constant k is equal to:

(A) $\frac{GM}{4\pi^2}$

(B) $4\pi^2 GM$

(C) $2\pi GM$

(D) $\frac{4\pi^2}{GM}$

3 The escape velocity of a rocket is:

(A) a measure of the maximum speed a rocket needs to leave the Earth and go into orbit

(B) determined by the mass of the planet (or moon) and the universal gravitational constant

(C) the more for a rocket than for a gas molecule

(D) is less on the Earth than on the Moon.

4 The mass of a particular fully equipped astronaut on the Earth is 120 kg. What is his mass on the Moon where gravity is 1/6th that on Earth?

(A) 20 kg

(B) 196 N

(C) 120 N

(D) 120 kg

5 The Michelson-Morley experiment was unsuccessful in proving what it set out to prove because:

(A) the apparatus was not sensitive enough

(B) length contraction in the arm perpendicular to the 'ether wind' occurred

(C) the speed of light is constant and is independent of the motion of the source or the observer

(D) the ether was 'carried along' with the Earth.

6 Two parallel wires each carry 2 A of current as shown in Figure 7.9. The wires exert a force per unit length on each other of:

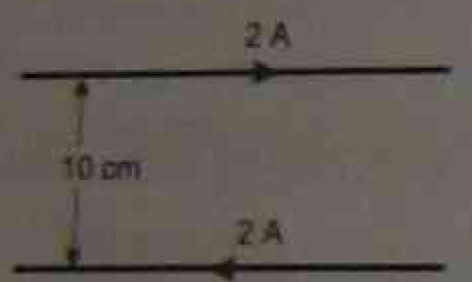

Figure 7. 9

(A) 4×10^{-6} N.m^{-1} outwards

(B) 4×10^{-6} N.m^{-1} inwards

(C) 8×10^{-6} N.m^{-1} outwards

(D) 8×10^{-6} N.m^{-1} inwards.

The following information is for question 7 and 8.

AB is a section of conductor moving with velocity *v* across a uniform magnetic field that is directed vertically into the page as shown in Figure 7.10.

7 As a result of the movement of the conductor electrons in the conductor:

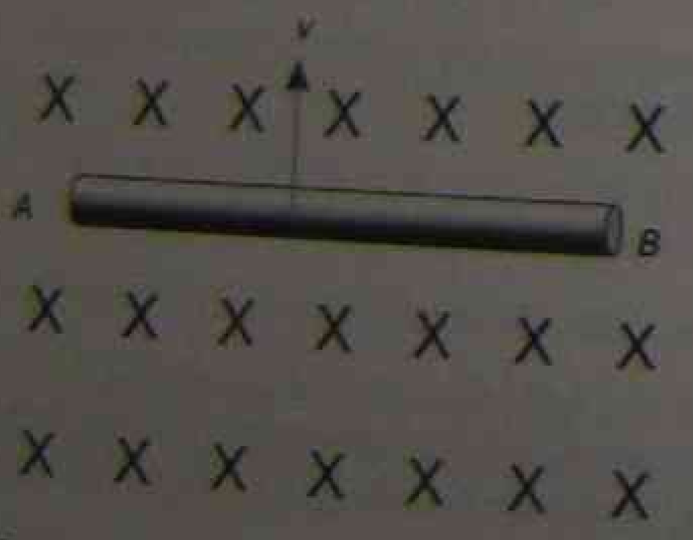

Figure 7. 10

(A) move towards *A*

(B) move towards *B*

(C) move only in the direction of *v*

(D) do not move.

8 The magnitude of the induced *emf* can be changed by all except:

(A) reversing the field direction

(B) increasing the speed of the conductor

(C) changing the angle of movement of the wire in the field

(D) increasing the strength of the field.

9 Slip rings:

(A) are used with commutators

(B) are used with DC motors and generators

(C) are used with AC motors and generators

(D) carry direct current to a motor and from a generator.

10 In a generator, the induced *emf* is a maximum when:

(A) the coil lies are parallel to the magnetic field

(B) the coil lies at right angles to the magnetic field

(C) the coil lies at 45 degrees to the magnetic field

(D) the coil first starts to move.

11 Cathode rays:

(A) travel from the anode to the cathode

(B) have a *q/m* ratio greater than that of the hydrogen ion

(C) easily pass through glass

(D) carry energy and momentum.

12 Charges are trapped in the Earth's magnetic Van Allen radiation belts because:

(A) unlike charges attract

(B) they are attracted to the north pole of the Earth

(C) they spiral around magnetic lines of force

(D) they are too light to escape the Earth's gravitational field.

13 Figure 7.11 shows apparatus similar to that used by Lenard to investigate the photoelectric effect.

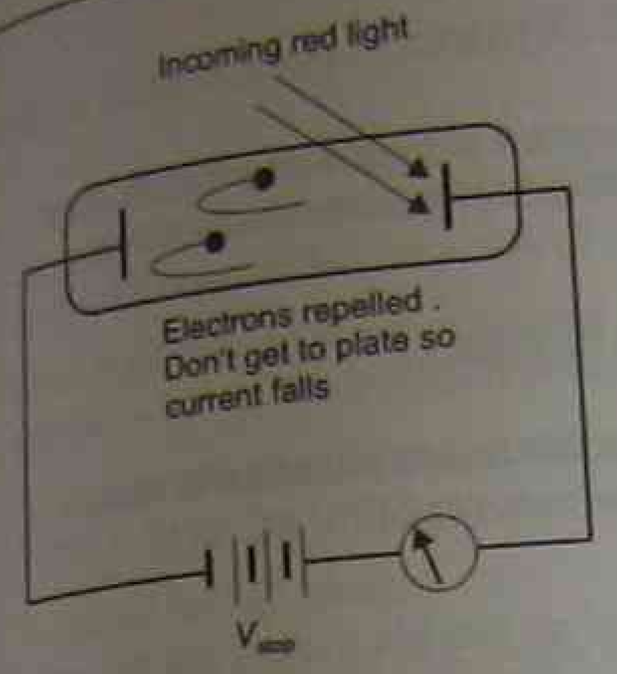

Figure 7. 11

Electrons are emitted when red light of intensity *I* is shone onto the plate. V_{stop} is the voltage needed to reduce the photocurrent to zero. V_{stop} will be greatest when:

(A) the intensity of light is increased and the light remains red

(B) there is no increase in intensity but the colour of the light is changed to blue

(C) the intensity is increased and the colour of the light is changed to blue

(D) both B and C above.

14 As temperature increases:

(A) the resistance of metals decreases

(B) the resistance of semiconductors increases

(C) the resistance of semiconductors decreases

(D) all substances become superconductors.

15 Bragg diffraction is the diffraction by crystals of:

(A) electrons

(B) neutrons

(C) X-rays

(D) radio waves.

SECTION I

PART B

Total Marks (60)

Attempt Questions 16 – 28

Allow about 1 hour and 45 minutes for this part

Show all relevant working in questions involving calculations.

Question 16 (6 marks)

(a) A planet Alpha has a mass 1.5 times that of Earth. The acceleration due to gravity on the planet is three times that of the Earth.

- (i) Calculate the mass of a space explorer setting foot on Alpha if he/she weighs 800 N on Earth. (1 mark)
- (ii) Calculate the weight of the explorer on Alpha. (1 mark)
- (iii) Calculate the radius of Alpha compared to that of Earth (R_E). (2 marks)

(b) A body is discovered orbiting the sun at a distance equal to ¼ of the distance of the Earth from the sun. Calculate (in years) the time it takes the body to complete one orbit of the Sun. (2 marks)

Question 17 (5 marks)

It is a remarkable indication of scientific achievement every time a manned *Space Shuttle* successfully blasts off into orbit. It is an even more remarkable feat to bring the astronauts safely back to Earth. Clearly describe the major issues affecting a safe re-entry of the spacecraft and how they are 'overcome'.

Question 18 (3 marks)

Geostationary satellites orbit at a height of approximately 35,800 km above the Earth's surface. The radius of the Earth is 6380 km. Assume the orbit is circular.

(a) Calculate the orbital velocity of such a satellite. (2 marks)

(b) Explain where the necessary centripetal force comes from. (1 mark)

Question 19 (6 marks)

(a) Describe a thought experiment ('Gedanken') using a 'light clock' to show why time is lengthened in a moving frame of reference relative to a stationary frame of reference. (4 marks)

(b) The *Starship Enterprise* has just returned after a 5 year voyage while travelling at 0.92 *c*.

  (i) If the '5 year voyage' referred to 'Earth time', calculate how much time elapsed for the crew on the ship. (1 mark)

  (ii) If it meant '5 years' of 'ship time', calculate how much time passed on Earth. (1 mark)

Question 20 (3 marks)

Two parallel wires *AB* and *CD* are carrying currents of 3 A and 5 A respectively in opposite directions. They are separated by 1 cm in air.

(a) Calculate the force per unit length acting between the wires. (2 marks)

(b) If the current *AB* is reversed predict what happens to the force. (1 mark)

Question 21 (5 marks)

This question refers to Figure 7.12.

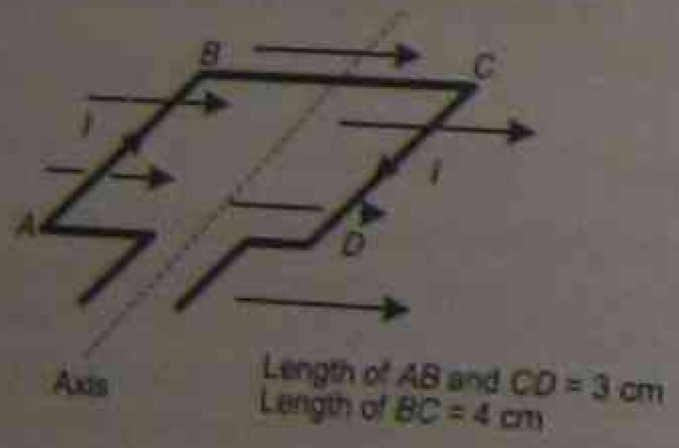

Figure 7. 12

A rectangular coil *ABCD* of 500 turns lies in a plane parallel to the magnetic induction *B* of 10 T. A current of 4 A from a battery flows along the path *ABCD*.

(a) What is the direction of the force on the sides *AB* and *CD*? (1 mark)

(b) Calculate the size of the force acting on sides *AB*, and *BC*. (2 marks)

(c) If the side *BC* is 4 cm long and *AB* is 3 cm, calculate the maximum torque acting on the coil. (2 marks)

Question 22 (3 marks)

Explain the purpose of a split-ring commutator, clearly describing how it performs its function. (3 marks)

Question 23 (5 marks)

(a) Clearly explain how a transformer can be arranged to convert 240 V AC to 12 V AC. (2 marks)

(b) Over 95% of all electric motors are AC induction motors. Give three reasons why this is so. (3 marks)

Question 24 (4 marks)

Discuss the impact of electric generators and transformers on the way people live in an industrialised society such as Australia. (4 marks)

Question 25 (5 marks)

Figure 7.13 illustrates some scientific apparatus commonly used in schools to demonstrate various properties of cathode rays.

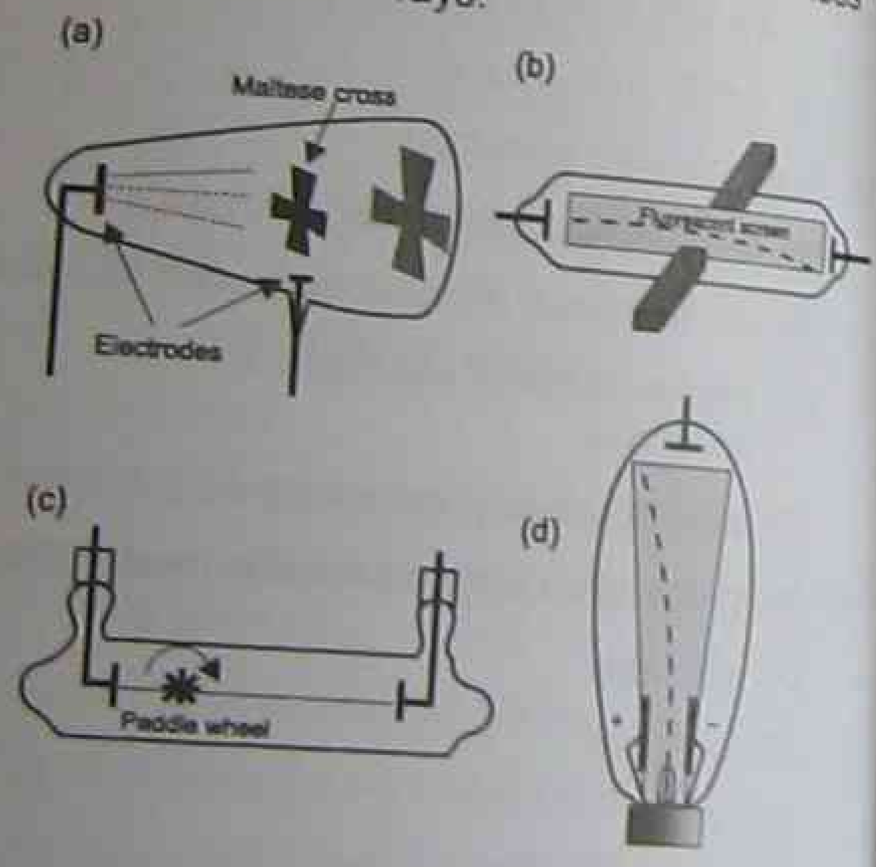

Figure 7. 13

(a) Take any TWO of these and clearly describe what property each one is demonstrating and how this is deduced from the observations. (4 marks)

(b) Give one *practical* application of one of these properties. (1 mark)

Question 26 (6 marks)

(a) In 1900, Max Planck introduced the concept of the 'quantisation of energy''. Explain why Planck introduced this concept. (2 marks)

(b) When light falls on some materials electrons are ejected — this is the *photoelectric effect*.

  (i) The photoelectric equation is given by: $E_{k_{max}} = hf - \phi$. What do these symbols stand for? (2 marks)

  (ii) Describe how the maximum energy of the emitted electrons depends upon the intensity and frequency of the light. (1 mark)

  (iii) By reference to the equation in (i), explain why light above a certain frequency is necessary to release electrons from the material. (1 mark)

Question 27 (3 marks)

Briefly describe how energy bands are formed in metallic conductors. (3 marks)

Question 28 (6 marks)

When a potential difference is applied across the ends of a metal conductor, the electrons 'drift' along from the low potential to the high potential.

(a) Define the term 'drift velocity'. (1 mark)

(b) Explain why potential difference is needed for this drift velocity when the electrons are in continual motion anyway. (2 marks)

(c) If the same potential difference was applied across a semiconductor and insulator respectively (of the same dimensions as the metal), compare the currents in each material and explain any differences. (3 marks)

SECTION II – OPTIONS

Total marks (25)

Attempt ONE question from Questions 29 – 31

Allow about 45 minutes for this section

Show all relevant working in questions involving calculations.

Question 29	**Medical Physics**
Question 30	**Astrophysics**
Question 31	**Quanta to Quarks**

Question 29 — Medical Physics (25 marks)

(a) Acoustic impedance is an important characteristic in ultrasound diagnosis

  (i) Define what is meant by 'acoustic impedance'. (1 mark)

  (ii) What qualities (characteristics) affect the acoustic impedance of a material? (1 mark)

(b) An ultrasound echo is received from an interface 300 µs after emission from a transducer. Calculate how far away the interface is from the transducer. (Take the speed of sound in the medium to be 1540 m.s^{-1}.) (2 marks)

(c) Doppler echocardiography is commonly used to diagnose cardiac problems. It relies on the Doppler Effect.

  (i) Clearly describe the Doppler effect. (2 marks)

  (ii) Describe how it is used in echocardiography. (2 marks)

(d) Recall *three* advantages of CT scans over a simple radiograph. (3 marks)

(e) Medical radioisotopes are used in the diagnosis of certain diseases.

  (i) Explain why such radioisotopes have short half-lives. (2 marks)

  (ii) Describe how they are used to aid in the diagnosis of disease. (3 marks)

(f) Compare MRI with PET imaging, clearly stating how each is done and the advantages and disadvantages of each scan type. (9 marks)

Question 30 — Astrophysics (25 marks)

(a) The theoretical resolution of a telescope is never achieved in practice.

- (i) Define what is meant by a telescope's resolution. (1 mark)
- (ii) Suggest two reasons the theoretical resolution is never achieved for ground-based telescopes. (2 marks)

(b) The star Sirius has an apparent magnitude (m) = –1.45 and an absolute magnitude (M) of +1.41. Calculate how far (in parsecs) Sirius is from the Earth. (1 mark)

(c) Balmer lines are prominent in the hydrogen spectrum of stars with temperatures of ~10 000 K but weaker in both hotter and cooler stars. Explain. (2 marks)

(d) A distant stellar object is observed to produce two spectra, as shown in Figure 7.14(a) and (b).

- (i) Predict what type of stellar object it is. (1 mark)
- (ii) Account for the differences in the spectra. (2 marks)

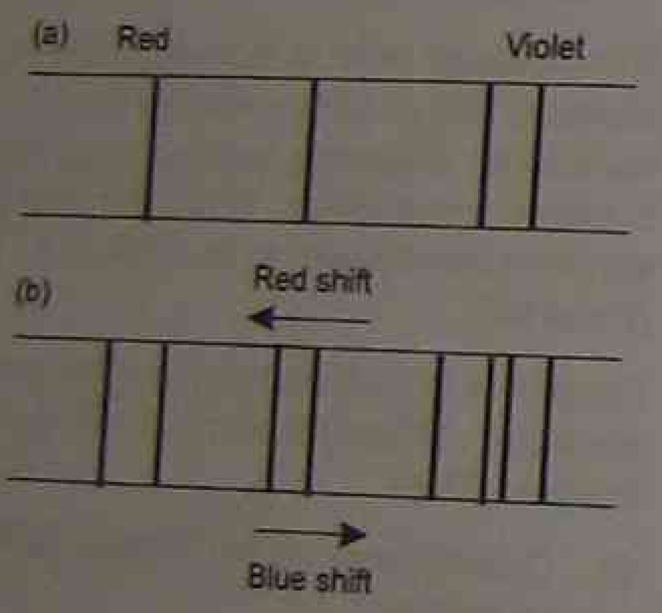

Figure 7. 14

(e) If a star has a temperature twice that of the Sun but a luminosity only $\frac{1}{10000}$ that of the Sun, how does its radius compare to that of the Sun? (2 marks)

(f) Sirius has a colour index ($B - V$) = 0 and Betelgeuse has a colour index = + 0.86.

- (i) Which star is redder? Justify your answer. (1 mark)
- (ii) Predict which star would be found more towards the top left hand side of the main sequence of a Hertzsprung–Russell diagram. Explain your reasoning. (2 marks)

(g) In certain stars the following nuclear reactions take place:

$$^{12}_{6}C + ^{1}_{1}H \rightarrow ^{13}_{7}N + \gamma$$
$$^{13}_{7}N \rightarrow ^{13}_{6}C + ^{0}_{+1}e + \upsilon$$
$$^{13}_{6}C + ^{1}_{1}H \rightarrow ^{14}_{7}N + \gamma$$
$$^{14}_{7}N + ^{1}_{1}H \rightarrow ^{15}_{8}O + \gamma$$
$$^{15}_{8}O \rightarrow ^{15}_{7}N + ^{0}_{+1}e + \upsilon$$
$$^{15}_{7}N + ^{1}_{1}H \rightarrow ^{12}_{6}C + ^{4}_{2}He$$

- (i) What is the end result of all these reactions? (1 mark)
- (ii) What purpose does the carbon serve? (1 mark)

(h) These reactions in (g) above constitute the so-called carbon cycle (more correctly the carbon-nitrogen-oxygen or CNO cycle).

- (i) What other cycle of nuclear reactions commonly take place in stars? (1 mark)
- (ii) Which cycle predominates at temperatures greater than 1.8 x 10^7 K? (1 mark)

(i) What is the probable origin of the gold found in the Earth? Explain. (2 marks)

(j) Figure 7.15 (a) and (b) are H-R diagrams for two clusters, NGC2264 and M3. One is an open (galactic) cluster and the other is a globular cluster.

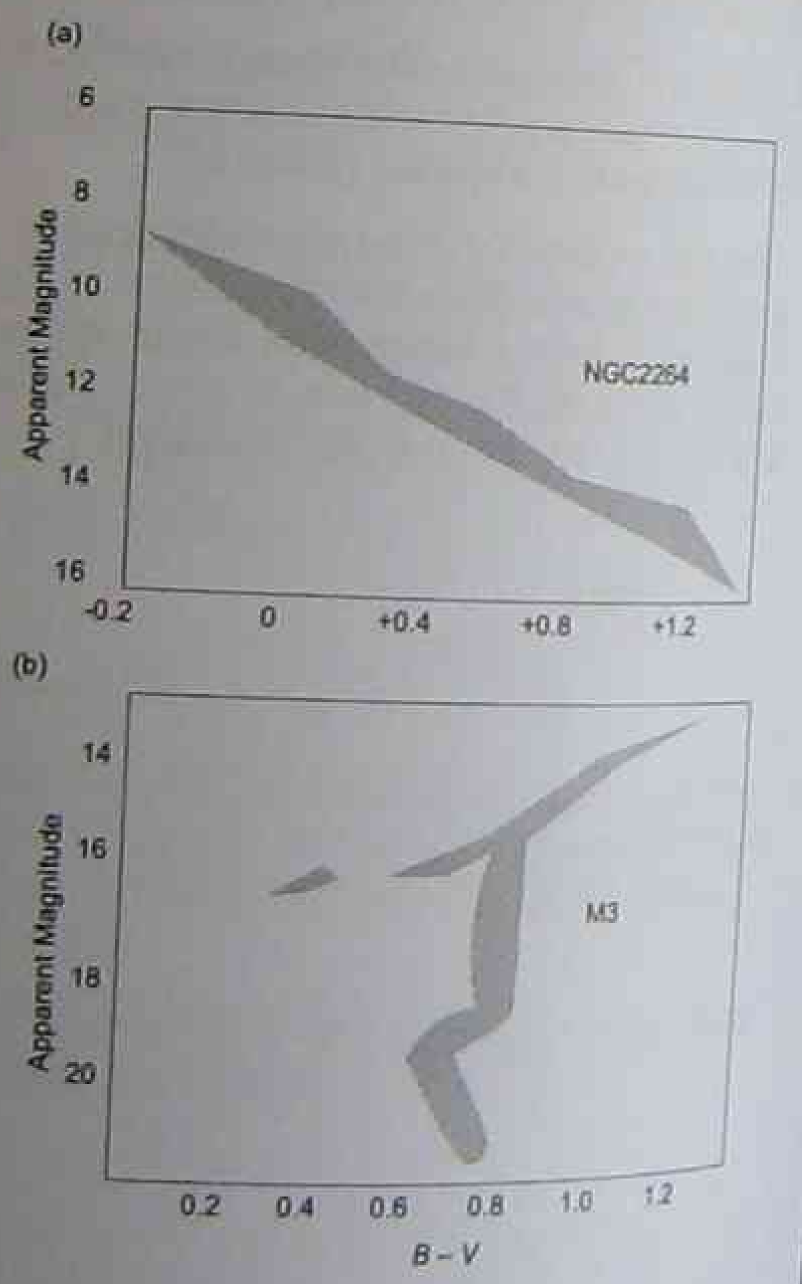

Figure 7. 15

- (i) Which cluster is the globular cluster? Justify your answer. (1 mark)
- (ii) Give two reasons to support your answer. (2 marks)
- (iii) On Figure 7.15(b) indicate the position of a blue (B) star and a yellow (Y) star (like our Sun). (2 marks)

Question 31 — Quanta to Quarks (25 marks)

(a) Account for the formation of the Balmer series of emission lines in the spectrum of hydrogen when excited by passing an electrical discharge through it. (3 marks)

(b) The wavelength of the yellow sodium D_1 line is 589.6 nm. Calculate the difference in energy between the levels involved in the emission or absorption of the line. (1 mark)

(c) An electron is moving at 10 per cent of the speed of light (0.1c). Calculate its wavelength. (1 mark)

(d) Davisson and Germer are credited with providing experimental evidence for de Broglie's 'matter waves'. Briefly describe what they did to show this. (2 marks)

(e) In 1932 James Chadwick discovered the neutron.

- (i) What is a neutron? (1 mark)
- (ii) Briefly describe how Chadwick detected the neutron. (2 marks)

(f) In a controlled fission reactor, U-235 atoms absorb neutrons and splits up into fragments.

- (i) What makes a chain reaction possible? (1 mark)
- (ii) Explain the effect on the chain reaction of:
  - (1) moderators; (1 mark) and
  - (2) control rods. (1 mark)

(g) Rutherford performed the first artificial transmutation in 1919 when he bombarded nitrogen gas with alpha particles.

- (i) Define what is meant by 'transmutation'. (1 mark)
- (ii) Complete the following equation which shows the reaction studied by Rutherford.

$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{?}_{?}X + ^{1}_{1}p$ (1 mark)

(h) Calculate the total binding energy and the average binding energy (that is, the binding energy per nucleon) for $^{56}_{26}Fe$, the most common stable isotope of iron. The following 'rest mass' data may be required:

$^{56}_{26}Fe$ = 55.9349 u,
p = 1.007276 u,
n = 1.008665 u,
e = 0.000549 u (3 marks)

(i) In the fuel rods used in thermal fission reactors, the proportion of the isotope U-235 relative to the isotope U-238 is increased compared to the amounts in natural uranium. Explain why the fuel is enriched. (2 marks)

(j) The Standard Model divides matter into 'matter particles' and 'force carrier particles'. The 'matter particles' can be further divided into two families.

- (i) Recall these two families. (1 mark)
- (ii) Give an example of a particle which belongs in each family in (i) above (2 marks)
- (iii) Give an example of a 'force carrier particle' and the interaction that it mediates. (2 marks)

PRACTICE EXAMINATIONS ANSWERS AND WORKED SOLUTIONS

EXAM 1

MULTIPLE CHOICE ANSWERS

1	D
2	A
3	A
4	B
5	A
6	D
7	A
8	A
9	B
10	A
11	B
12	C
13	D
14	C
15	C

SHORT ANSWER SOLUTIONS

16 (a) (i) Kepler's Law can be written:

$$\frac{r^3}{T^2}=\frac{GM}{4\pi^2}$$

$$M=\frac{4\pi^2 r^3}{GT^2}$$

$$=\frac{4\pi^2\times(9.7\times10^6)^2}{6.67\times10^{-11}\times(2.75\times10^4)^2}$$

$$=7.14\times10^{23}\text{ kg}$$

(ii) $\frac{r^3}{T^2}=k$ therefore:

$$\frac{r_1^3}{T_1^2}=\frac{r_2^3}{T_2^2}$$

$$r_2^3=\left(\frac{T_2^2}{T_1^2}\right)\times r_1^3$$

$$=\frac{(9.7\times10^6)^3}{(2.75\times10^4)^2}\times(1.09\times10^5)^2$$

$$=1.428\times10^{22}$$

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PRACTICE EXAMINATIONS ANSWERS AND WORKED SOLUTIONS

EXAM 1

MULTIPLE CHOICE ANSWERS

1	D
2	A
3	A
4	B
5	A
6	D
7	A
8	A
9	B
10	A
11	B
12	C
13	D
14	C
15	C

SHORT ANSWER SOLUTIONS

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$$M = \frac{4\pi^2 r^3}{GT^2}$$

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27 (a) Superconductivity is the phenomenon where the resistance of certain materials becomes zero below a certain temperature that was initially a few degrees above absolute zero but is now as high as 134 K.

(b) Superconductors are currently, or will be used in the future in: large magnets for MRI (Magnetic Resonance Imaging) machines; in magnetic levitation (the Maglev train); in electricity transmission (lowers the resistance of the transmission cables); in computer technology…

(c) The BCS theory of superconductors explains superconductivity as follows: electrons moving through a crystal lattice cause the lattice to distort which increases the *positive charge density* in the vicinity of the electron. This attracts a second electron to the first to create a *Cooper Pair*. (Quantum physics indicates that this lowers the energy state of the electrons, which is why it can occur even though like charges repel.) The Cooper pairs pass unimpeded through the lattice. The Cooper pairs are continually being formed, broken and reformed but effectively allow the electrons to pass through the lattice with no resistance.

Question 28 – Medical Physics

(a) (i) The piezoelectric effect is where certain crystals distort under the effect of an electric field. Conversely, an electric field is produced between the crystal's faces when a distorting force is applied.

(ii) A piezoelectric transducer emits pulses of ultrasound (sound waves with frequencies above 20 kHz) about 1 ms apart. These pulses reflect off various interfaces within the body. The amount of reflection depends on the acoustic impedance of the material on either side of the interface. The greater the difference in acoustic impedance, the more energy is reflected. These reflections can be used to make a simple scan to effectively measure distances to the interface (*A*-scan) or to make an image of the internal structures (*B*-scan). Two-dimensional *B*-scans can be done in 'real time' to produce an image like the familiar wedge-shaped (sector scan) picture of a foetus within the womb.

(b) Osteoporosis is a disease of the bones which leads to decreased bone density, with an associated increased risk of bone fractures. By measuring the attenuation of ultrasound through the heel bone an indication of bone quality can be achieved. This can lead to an effective diagnosis of osteoporosis.

(c) A radiopharmaceutical is a chemical that can be used by the body in which a radioisotope is used to 'label' the chemical. Many organs take up specific chemicals. For example iodine accumulates in the thyroid. By using I-131, the functioning of the thyroid can be measured. Similarly glucose is extensively used in the brain.

(d) Radioisotopes emit radiation from within the body (X-rays); CT and MRI provide radiation from outside the body.

(e) PET scans show the function of the particular organ. CT scans show the anatomical structure. PET is able to detect certain abnormalities before CT can, including brain tumours.

(f) Pair annihilation results from the collision between a positron and an electron in which two gamma rays are produced that move off in opposite directions. The positron comes from the radiopharmaceutical and the electron comes from tissue within the patient.

(g) (i) The Larmor frequency is the resonant frequency of the hydrogen atoms in the patient's tissues. At this frequency, radio-frequency (RF) waves are strongly absorbed. As the hydrogen atoms 'relax', this energy is re-emitted and is detected.

(ii) The more RF energy that is detected, the greater is the hydrogen concentration. This allows a map of hydrogen atom concentrations (and hence tissue types) to be imaged.

(iii) The hydrogen atom concentration will be affected by the condition of the tissue. Abnormal amounts will indicate possible problems with the tissue or organ.

Question 29 – Astrophysics

(a) (i) The sensitivity of a telescope is a measure of its light gathering power.

(ii) This is determined by the area (and hence the diameter) of the mirror or lens.

(iii) The sensitivity of telescopes can be improved by using interferometry. In this technique, two or more separate telescopes have their information integrated to simulate a single telescope with an effective diameter equal to the distance between the two (or more) telescopes. This has been used extensively for radio telescopes but has recently been extended to optical telescopes such as the two largest in the world, the two 10 m *Keck Telescopes* in Hawaii.

(b) (i) The apparent magnitude of a star is a measure of its brightness when viewed from Earth.

(ii) The smaller the magnitude, the brighter the star. Hence α is the brightest star.

(iii)

$$\begin{aligned}\frac{I_\alpha}{I_\beta} &= 2.5^{(m_\beta - m_\alpha)}\\ &= 2.5^{(4-1)}\\ &= 15.625\end{aligned}$$

That is, α is 15.625 times brighter than β.

(c) For strong hydrogen lines to be visible, the temperature must be in the range of ~4,000 K to ~12,000 K. Too low a temperature and the electrons will be in the ground state. For hydrogen lines to be in the visible portion of the spectrum the electrons must be in the second energy level to absorb a photon. Too high a temperature and the atoms are completely ionised and no absorption is possible.

(d) Refer to Table 7.1 for a comparison

Table 7. 1

Characteristic	Red Giant	White Dwarf
luminosity	very high	very low
spectral class	K and M	A
diameter	very large (> solar system)	2 x Earth's
surface temperature	2,000 – 3,000 K	very high (~30,000 K)
density	very low	very high
fuel source	helium and heavier elements	none — no nuclear reactions are occurring.

(e) (i) A visual binary consists of two stars that revolve around a common centre of mass. The stars can be resolved into two separate objects through an optical telescope.

Comment: Many binary star systems are so far away that they cannot be resolved into separate objects with even the best telescopes. Other indirect methods are used to classify them as binary systems.

(ii) Spectroscopic and eclipsing binaries.

(f) (i) Distance and parallax are related by:

$$\begin{aligned}d &= \frac{1}{p}\\ &= \frac{1}{0.125}\\ &= 8\text{ parsecs}\end{aligned}$$

(ii) The sum of the masses of binary stars is found from:

$$\begin{aligned}m_1 + m_2 &= \frac{a^3}{T^2}\\ &= \frac{20^3}{50^2}\\ &= \frac{8000}{2500}\text{ solar masses}\\ &= 3.2\text{ solar masses}\end{aligned}$$

(g) Main sequence stars fuse hydrogen into helium. Red giants fuse helium into heavier elements (up to iron).

(h) (i) Likely end states are:

α — black hole
β — white dwarf
γ — neutron star or pulsar

(ii) When the cores of stars with masses exceeding 3 solar masses collapse, they continue collapsing in on themselves until the diameter is exceedingly small. The intense gravitational field produced is strong enough to prevent even light escaping — a black hole is the result.

Question 30 – Quanta to Quarks

(a) In the Bohr model of the atom, spectral lines result from the transition of an electron from a higher energy level to a lower level. The frequency is proportional to the energy difference. Since an electron can 'fall back' from a higher level to a lower level in more than one step (unless $n_i = n_f + 1$) then each step (frequency) is the sum (or difference) of the other steps.

(b) (i) Bohr's model could not explain the following: (Any three)

- Why the electrons obeyed some classical laws and not others.
- The spectra of multi-electron atoms.
- The relative intensities of the spectral lines.
- The hyperfine structure of spectral lines.
- The Zeeman effect – the splitting of spectral lines in a magnetic field.

(ii) In 1924 de Broglie postulated that electrons and all matter had a wave characteristic where

$\lambda = \frac{h}{mv}$ where λ is the wavelength and m and v are the mass and velocity respectively. Matter waves were used to explain the stability of electrons in their orbits. Provided an integral number of electron wavelengths fitted into the orbit they would constructively interfere and not radiate energy.

(c) (i) Wave nature: Electron diffraction (as shown by Davisson and Germer and G.P. Thomson).

(ii) Particle nature: The photoelectric effect (and Compton scattering).

(d) Fermi is remembered as the man who initiated the first controlled nuclear fission reaction and as the man who postulated the existence of the neutrino. Heisenberg 'discovered' the uncertainty principle that is essential to an understanding of quantum mechanics.

(e) (i) U-235 is less stable than Kr-92 because the binding energy per nucleon for U-235 is lower than that of Kr-92.

Comment: Binding energy is a measure of how much energy must be put into a nucleus to disrupt it into its parts. The greater the binding energy per nucleon, the more energy is needed to break the nucleus up, that is, the more stable the nucleus.

(e) When the U-235 nucleus splits up, the binding energy per nucleon of its products exceeds that of the U-235; hence energy will be released and so the reaction can occur spontaneously. Kr-92 on the other hand would form products with less binding energy per nucleon than the parent nucleus; energy would be required and so the reaction cannot be spontaneous.

(f) The sum of the atomic numbers and mass numbers must be conserved on both sides of the equation so:

$${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$
$${}^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$$
$${}^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}e$$
$${}^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}He$$

(g) Nuclear fission reactors generate heat from nuclear fission. In this process, neutrons are absorbed by uranium nuclei which split into two or more fragments and release neutrons that can cause further fission. Fission occurs more readily in enriched uranium, that is, uranium which has a higher proportion of uranium-235 (U-235) than is found naturally. The moderator is a material, usually boron, whose role is to slow down the neutrons produced in the reaction to energies that increase the probability of causing fission (so called thermal neutrons). The control rods absorb neutrons without undergoing fission and this controls the rate of the reaction (avoiding an uncontrolled chain reaction). The shielding protects the personnel and prevents the loss of neutrons through the reactor walls.

(h) The student could place a Geiger counter near the samples, one at a time and gradually move the counter away from the source. The source whose count rate falls off the quickest (that is, in the shortest distance) is alpha; the one that falls off the least is gamma and the other is beta.

(i) Subatomic particles are artificially produced in particle accelerators. The more massive the particle, the more energy is needed to 'create' it (according to Einstein's mass-energy relationship $E = mc^2$). Since the top quark is so massive, an enormous amount of energy is required, energy levels that were unattainable until recently. This is why it was not discovered earlier although it had been predicted to exist.

EXAM 2

MULTIPLE CHOICE ANSWERS

1	B
2	A
3	B
4	D
5	C
6	C
7	B
8	A
9	C
10	A
11	D
12	C
13	D
14	C
15	C

SHORT ANSWER SOLUTIONS

16 (a) (i) $m = \frac{W}{g} = \frac{800}{9.8} = 81.6 \text{ kg}$

(ii) $W' = mg' = 81.6 \times 9.8 \times 3 = 2400 \text{ N}$

(ii) The acceleration is found from $g = \frac{GM}{R^2}$.

$$\frac{g_{Alpha}}{g_{Earth}} = \frac{\frac{GM_{Alpha}}{R^2_{Alpha}}}{\frac{GM_{Earth}}{R^2_{Earth}}}$$
$$= \left(\frac{M_{Alpha}}{M_{Earth}}\right) \times \left(\frac{R_{Earth}}{R_{Alpha}}\right)^2$$
$$3 = 1.5 \times \left(\frac{R_{Earth}}{R_{Alpha}}\right)^2$$
$$\left(\frac{R_{Earth}}{R_{Alpha}}\right)^2 = 2$$
$$R_{Alpha} = 0.71 R_{Earth}$$

17 Safe re-entry of manned spacecraft centres around two major potential problems: the heat build up as the spacecraft enters the Earth's atmosphere and the g-forces generated as the craft is decelerated by the atmosphere. Safe re-entry is restricted to a small window of $-6.2 \pm 1°$ relative to the horizontal. Too shallow an approach and the spacecraft will 'bounce' off the atmosphere back into space; too steep and the generated g-forces could prove fatal for the occupants.

18 (a) The geostationary orbit means the satellite has a period of 24 hours, that is, 86400 s. The orbital speed is hence found from:

$$v = \frac{2\pi r}{T}$$
$$= \frac{2\pi \times (35800 + 6380) \times 10^3}{86400}$$
$$= 3067 \text{ m.s}^{-1}$$

(b) The centripetal force is supplied by the gravitational attraction between the Earth and the satellite.

19 (a) Consider a simple light 'clock' as shown in Figure 7.16(a).

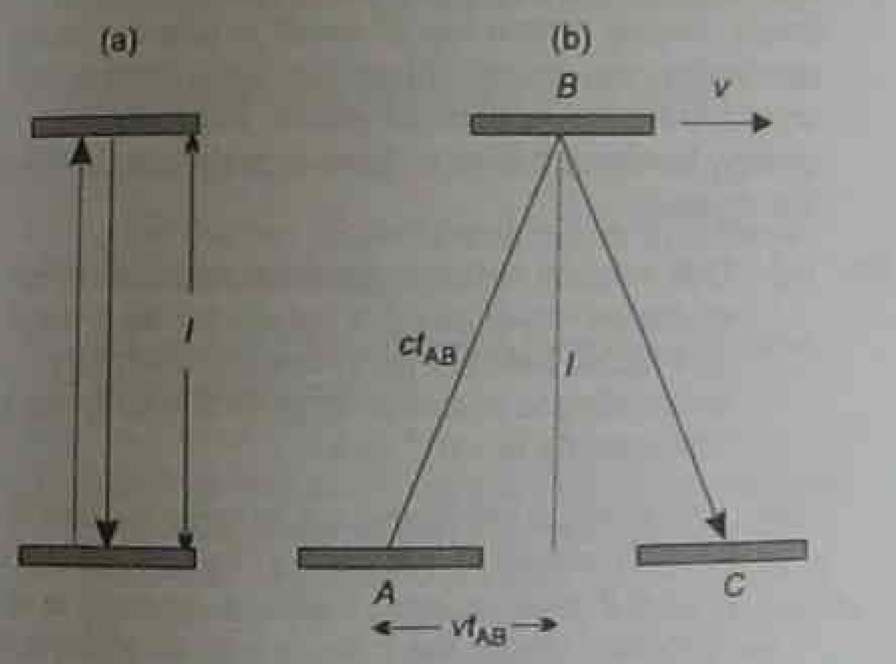

Figure 7. 16

The clock operates by bouncing a light beam from mirrors. The clock registers one click for one complete up and down motion. When viewed by an observer travelling with the clock, the light follows the path as indicated in Figure 7.16(a). From the point of view of an observer who sees the clock moving past at constant speed, the path is as in Figure 7.16(b). This path is longer than that in Figure 7.16(a) and since both observers agree on the speed of light as c, then the outside observer must conclude that time goes slower in the moving frame!

(b) (i) Time dilation is found from:

$$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where t_o is the time as *measured by an observer at rest relative to the frame* (in this case, the crew of the *Enterprise*). Rearranging we have:

$$t_o = t \times \sqrt{1 - \frac{v^2}{c^2}}$$
$$= 5 \times \sqrt{1 - \frac{(0.92c)^2}{c^2}}$$
$$= 1.96 \text{ years}$$

(ii) $t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$

$$= \frac{5}{\sqrt{1 - \frac{(0.92c)^2}{c^2}}}$$
$$= 12.76 \text{ years}$$

20 (a) From the force law we have:

$$\frac{F}{l} = k\frac{i_1 i_2}{d}$$
$$= 2 \times 10^{-7} \times \frac{3 \times 5}{1.0 \times 10^{-2}}$$
$$= 3.0 \times 10^{-4} \text{ N.m}^{-1}$$

(b) Reversing the direction of the current changes the force to attraction.

21 (a) Force on AB is down and on CD is up.

(b) Force on AB is given by:

$$F = Bil \sin\theta$$
$$= 500 \times 10 \times 4 \times 3 \times 10^{-2} \times \sin 90$$
$$= 600 \text{ N}$$

Force on BC is zero since the current is parallel to the field

(c) Torque is found from:

$$\tau = nBiA$$
$$= 500 \times 10 \times 4 \times (4 \times 10^{-2} \times 3 \times 10^{-2})$$
$$= 24 \text{ N.m}$$

22 A split ring commutator consists of a metallic ring (usually copper) split into two halves that are electrically isolated from each other. Each half is connected to one end of the armature windings. As the commutator rotates, each half comes into contact with one terminal of the battery through a carbon brush, held against the ring by springs. Half a turn later the commutator halves now come into contact with the other battery terminal. This effectively reverses the direction of the current in the armature, ensuring a constant direction of rotation of the coil.

23 (a) A step-down transformer can convert 240 V AC to 12 V AC. The primary coil has 20 times more turns than the secondary coil. Then:

$$\frac{V_p}{V_s}=\frac{n_p}{n_s}$$

$$V_s=\frac{n_s}{n_p}\times V_p$$

$$=\frac{n_s}{20n_s}\times 240$$

$$=12\text{ V}$$

(b) Induction motors:

- have a simple design
- are very efficient
- have relatively low cost.

24 Electric generators and transformers allow electricity to be generated on a vast scale and distributed with relatively high efficiency. This energy is used to power industry and commerce. It is used in almost everything we use. Without it, lifestyle as we know it would cease to exist. No more TV, computer games, cold food, train travel…

25 (a) Any two of the following:

(i) Maltese Cross experiment – cathode rays travel in straight lines.

(ii) Fluorescent screen and magnet – cathode rays are affected by magnetic fields showing they are negatively charged.

(iii) Paddle wheel experiment – cathode rays carry energy and momentum (cause the wheel to move).

(iv) Electric field – cathode rays deflected by electric fields (again showing their negative charge).

(b) Consider (ii) above. This effect is put to good use in cathode ray tubes, found in oscilloscopes and televisions. The fluorescent screen has an image formed on it by beams of electrons that are controlled by magnetic fields (in TVs) and electric fields (CROs).

26 (a) Planck was investigating the emission of radiation from a black body – an object that was a perfect radiator. He found that he could only get agreement between theory and reality if he made the assumption that energy came in 'bundles' or 'quanta' rather than being continuous which was the belief up to that time.

(b) (i) $E_{k_{max}}=hf-\varphi$ where: $E_{k_{max}}$ is the maximum kinetic energy of the emitted electrons; h is Planck's constant; f is the frequency of the incident light; and φ is the work function.

(iii) The energy of the emitted electrons is independent of intensity but is dependent on the frequency according to $E=hf$.

(iii) It follows that $E_{k_{max}}>0$ only if $hf>\varphi$. This requires f to be greater than some minimum value (the threshold frequency).

27 In the simple model of atoms, electrons fill up the lowest possible energy states first – the ground state – and each level can hold a certain maximum number of electrons: two in the first level, eight in the second level, eighteen in the third level… A typical atom containing many electrons has its lower energy levels filled. The highest occupied energy level, however, may or may not be filled depending on the element. When atoms come together to form a crystal, electrons in the upper level – the valence electrons – 'feel' the attraction of surrounding nuclei. As a result the energy levels are split. Two atoms brought close enough to each other to interact will result in the two-atom system having two closely spaced energy levels; twenty atoms would result in twenty closely spaced energy levels. Since any finite sample of a crystal contains millions of atoms, the individual energy levels combine to form *energy bands* within the crystal.

28 (a) Drift velocity is the average speed with which electrons move along a conductor as a result of an electric field set up in the conductor by connecting to a source of potential difference. The velocity is ~10^{-4} m.s^{-1}.

(b) Although the electrons are in rapid motion, the random nature of this motion means that there is no net flow of charge (that is, a current) in any direction. Under the influence of an electric field, the electrons slowly drift towards the positive terminal.

(c) The semiconductor would conduct less current than the metal but more than the insulator (which would conduct very little current). The difference lies in the number of free electrons. These are most prevalent in the metal and almost non-existent in the insulator. There are some free electrons in the semiconductor.

Question 29 – Medical Physics

(a) (i) Acoustic impedance is a measure of how easy it is for sound to travel through a material. The greater the acoustic impedance the more difficult it is for sound to travel through.

(ii) Acoustic impedance is the product of the density and the speed of sound in the material: $Z=\rho v$

(b) If the distance to the interface is s then:

$$v=\frac{2s}{t}$$

$$s=\frac{vt}{2}=\frac{1540\times 300\times 10^{-6}}{2}\text{ cm}$$

$$=23\text{ cm}$$

(c) (i) The Doppler Effect is the apparent change in frequency of sound when there is relative movement between the source and the observer. For example, as a sound source approaches an observer, the waves 'bunch up'. This results in increased frequency.

(ii) Moving blood cells will reflect ultrasound. If the blood is moving towards the transducer, there is a frequency increase. As it moves away the frequency drops. (False colour can be added to make the changes more obvious.) The degree of frequency shift depends on the velocity. Abnormal readings may indicate problems with the heart and/or the blood vessels attached to it.

(d) Compared to simple radiographs, CT scans:

- have greater detail;
- allow for two dimensional 'slices' and three dimensional images; and
- are superior for detecting tumours and other space-filling lesions.

(e) (i) Medical radioisotopes used for diagnosis need short half-lives so that they decay away to harmless amounts soon after the diagnosis is completed. This minimises the radiation dose to the patient and so minimises any potential damage to healthy cells.

(ii) By attaching radioisotopes ('labelling') to certain biologically important chemicals, the path and concentration of the chemical can be determined. Too little uptake (a 'cold spot') or too much uptake (a 'hot spot') may indicate a problem with the particular organ.

(f) In a CT scan a series of X-ray beams is directed through the patient from various angles in a plane. Computers take the information and build up a picture of a 'slice' of the particular organ. This can be displayed on a TV screen or on a photographic plate. In a MRI scan the patient is placed in a strong magnetic field which tends to align some of the 'atomic magnets' in the molecules within the patient, particularly the hydrogen atoms. Pulses of radio-frequency (RF) electromagnetic waves bombard the patient and at particular frequencies RF energy is absorbed and emitted. A computer decodes this information and an image (2D or 3D) is produced. The advantages and disadvantages are shown in the following table (Table 7.2)

Table 7. 2

CT Scan

Advantages	Disadvantages
▪ Resolution much better than conventional X-rays (allowing finer detail to be seen). ▪ Creates a cross-sectional image of the viewed organ. ▪ Three-dimensional images can be generated. ▪ Good for diagnosing tumours and other space-filling lesions. ▪ Preferred for evaluating stroke.	▪ Shows structure but not the function of the organ. ▪ Ionising radiation used and so exposure must be accurately controlled. ▪ More expensive than conventional X-ray.

MRI Scan

Advantages	Disadvantages
▪ No ionising radiation (that is, X-rays or radioactive emissions) is used. ▪ Provides the clearest pictures of organs such as the brain. (MRI hardly 'sees' bone.) ▪ Can be used to scan the chest, abdomen and joints. ▪ The technique of choice for imaging the brain and central nervous system. ▪ With *functional magnetic resonance imaging* (fMRI) it can provide both anatomical and functional views of the brain.	▪ Most expensive imaging technique. The machine itself costs ~$1M. ▪ Some people experience claustrophobia from the closeness of lying in the long tube. (2-3% cannot complete the examination.) ▪ MRI requires a long time for a scan (~40 min) compared to ~5 min for a CT scan. This impacts on operating costs. ▪ Aneurism clips may 'toggle' and tear the artery they are supposed to repair. ▪ People with pacemakers or metal protheses (for example artificial hips) cannot be scanned (due to the intense steady magnetic fields used).

Question 30 – Astrophysics

(a) (i) The resolution of a telescope is a measure of its ability to distinguish between two close objects.

(ii) The resolution of ground-based telescopes is limited by the phenomenon of 'seeing' and imperfections in the mirrors (or lenses). Seeing is the distortion of an image from a distant light source by the Earth's atmosphere. Gravitational forces on the mirrors distort them as they are pointed to different areas of the sky.

Comment: Adaptive and active optics assists in reducing these effects.

(b) Applying the magnitude, distance relationship, we have:

$$m - M = 5\log_{10}\frac{d}{10}$$
$$-1.45 - 1.41 = 5\log_{10}\frac{d}{10}$$
$$-2.86 = 5\log_{10}\frac{d}{10}$$
$$\frac{d}{10} = 0.27$$
$$d = 2.7 \text{ parsecs}$$

(c) The Balmer series requires the electrons to be in the second energy level. Too high a temperature and the atoms are ionised, too cool and they are in the ground state. A band of temperatures will allow the spectral lines to form.

(d) (i) These spectra indicate a spectroscopic binary.

(ii) Consider Figure 7.17. In Figure 7.17(a) the stars are moving perpendicular to the line of sight of the observer. Consequently no spectral shift is observed and the spectra from the two stars combine as in Figure 7.17(c). In Figure 7.17(b) the stars are moving parallel to the observer's line of sight and hence the *Doppler shift* is present. Star *A* would show a red shift while *B* would suffer a blue shift. As a result of this motion the spectral lines would be doubled, as shown in Figure 7.17(d).

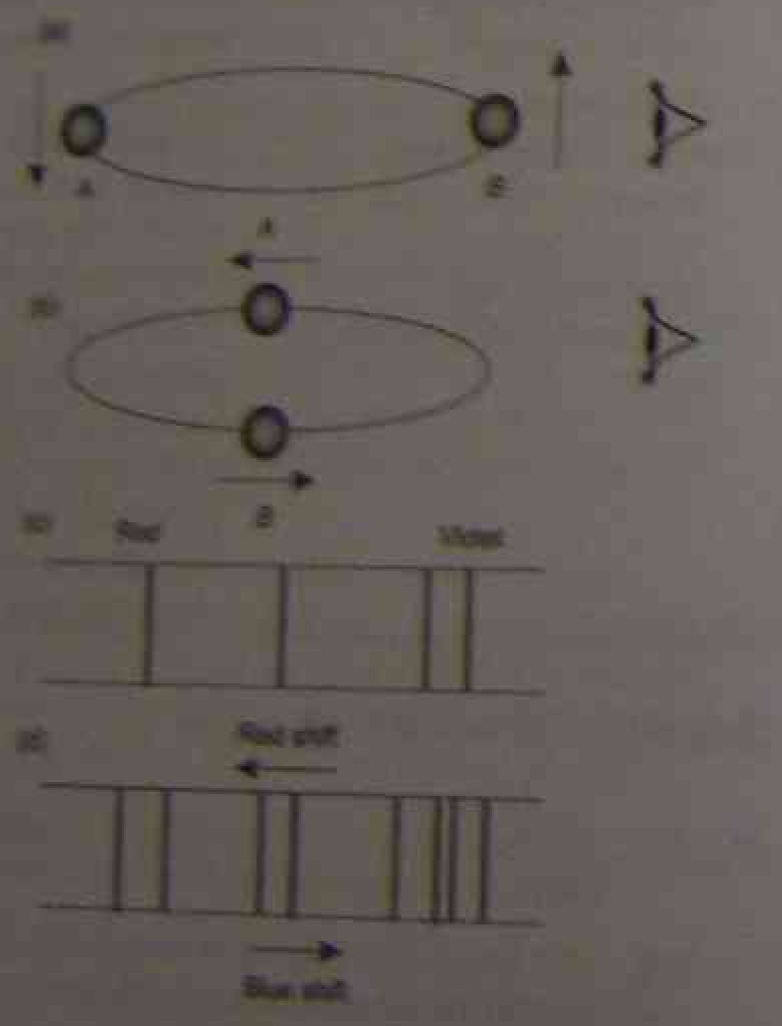

Figure 7. 17

Comment: Periodic doubling of spectral lines as in this example represents a spectroscopic binary.

(e) The luminosity of a star is proportional to the fourth power of its temperature and the square of its radius, that is, $L \propto R^2T^4$. Hence:

$$\frac{L_{star}}{L_{sun}} = \frac{R_{star}^2 T_{star}^4}{R_{sun}^2 T_{sun}^4}$$
$$R_{star}^2 = \left(\frac{L_{star}}{L_{sun}}\right) \times \frac{T_{sun}^4}{T_{star}^4} \times R_{sun}^2$$
$$= \left(\frac{\frac{1}{1000}}{1}\right) \times \frac{T_{sun}^4}{(2T_{sun})^4} \times R_{sun}^2$$
$$= \frac{1}{160\,000} \times R_{sun}^2$$
$$R_{star} = 0.0025\,R_{sun}$$

(f) (i) Betelgeuse.

(ii) Sirius. White stars are found towards the top left hand corner of the main sequence.

(g) (i) The end result is to convert 4 protons into 1 helium nucleus with the release of energy.

(ii) The carbon acts as a catalyst in the reaction (being reconstituted in the final step).

(h) (i) The proton-proton chain.

(ii) The CNO cycle.

(i) Elements up to iron can be synthesised in large mass stars. Up to iron, nuclear fusion releases more energy than it uses. Above iron, energy input is required. As a result, elements above iron have to be made in supernovae explosions (by neutron capture).

(j) (i) M3 is the globular cluster since it contains older evolved stars such as red giants and white dwarfs. It follows that NGC2264 is an open cluster since it is much younger with no 'old' stars.

(ii) See Figure 7.18

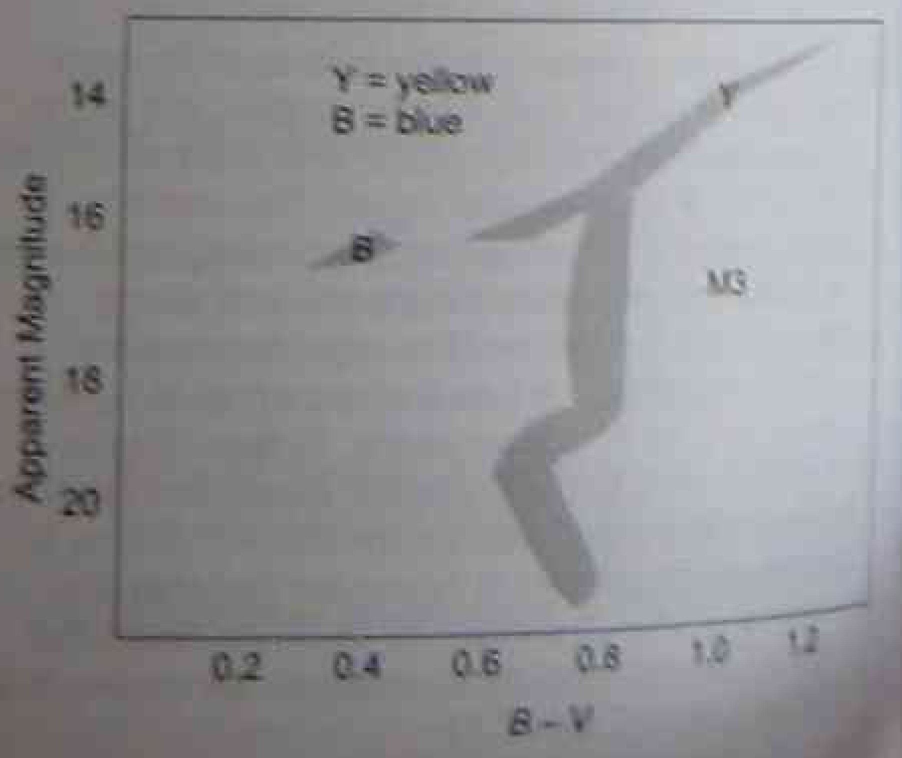

Figure 7. 18

Question 31 – Quanta to Quarks

(a) When an element is excited by passing an electrical discharge through it, electrons absorb energy in discrete amounts and move to a higher energy level. Almost immediately they 'fall back' to a lower energy level, emitting a photon of light as they do so as in the diagram below (Figure 7.19) The frequency of the photon is given by $\Delta E = hf$ where ΔE is the energy difference between the two energy levels, h is Planck's constant and f is the frequency. When the electrons fall back to the second energy level, they form the Balmer series. This can occur in a number of ways accounting for the series of lines.

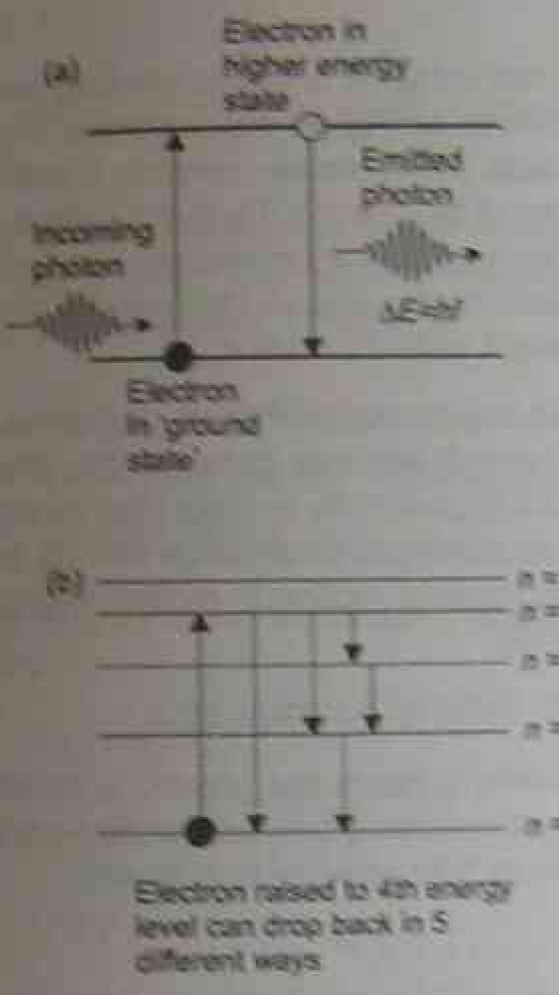

Figure 7. 19

(b) Energy is found by:

$$\Delta E = hf = h\frac{c}{\lambda}$$
$$= 6.6\times10^{-34} \times \frac{3.0\times10^{8}}{589.6\times10^{-9}}$$
$$= 3.36\times10^{-19}\text{ J}$$
$$= 2.1\text{ eV}$$

(c) The wavelength of the electron matter waves is:

$$\lambda = \frac{h}{mv} = \frac{6.6\times10^{-34}}{9.1\times10^{-31}\times3.0\times10^{8}}\text{ m}$$
$$= 2.4\times10^{-12}\text{ m}$$

(d) Davisson and [illegible] ombarded a nickel crystal with a bea[illegible]. They found that the electrons [illegible] ne crystal surface in a manner consiste[illegible] cting as waves. In doing so they pr[illegible] e nature of electrons.

(e) (i) A neutron is as neutral particle found in the nucleus of atoms. It has a mass similar to the mass of a proton.

(ii) Chadwick bombarded beryllium with alpha particles from a radioactive source. Neutrons ejected from the beryllium fell onto a paraffin block, rich in protons, causing protons to be ejected. These were then detected. By applying the conservation laws of energy and momentum, Chadwick was able to prove the existence of the neutron.

(f) (i) A chain reaction is made possible when neutrons from one split nucleus hit other nuclei causing further fission.

(ii) Moderators slow down the neutrons to speeds (energies) that increase their probability of being absorbed and causing fission.

Control rods absorb neutrons without undergoing fission. This allows the rate of the reaction to be controlled.

(g) (i) Transmutation is the conversion of one element into a new element.

Comment: This can be as a result of natural radioactivity or can be induced by bombarding the element with neutrons or protons.

(ii) $^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow ^{17}_{8}\text{O} + ^{1}_{1}p$

(h) $^{56}_{26}\text{Fe}$ has 26 protons, 30 neutrons and 26 electrons. Mass defect is found by subtracting the mass of the atom from the sum of the masses of its components as follows:

$$\text{Mass defect} = \begin{bmatrix} 26\times1.007276 \\ +30\times1.008665 \\ +(26\times0.000549) \end{bmatrix} - 55.9349$$
$$= 0.5285\text{ u}$$

Binding energy = 492.0 MeV

Binding energy per nucleon = $\frac{492}{56}$ = 8.79 MeV per nucleon

(i) U-235 is more easily fissionable than U-238. By enriching the U-235, the probability of a successful collision of a neutron with U-235 is increased.

(j) (i) quarks and leptons

(ii) Quarks – Any one of: proton, neutron, pion.

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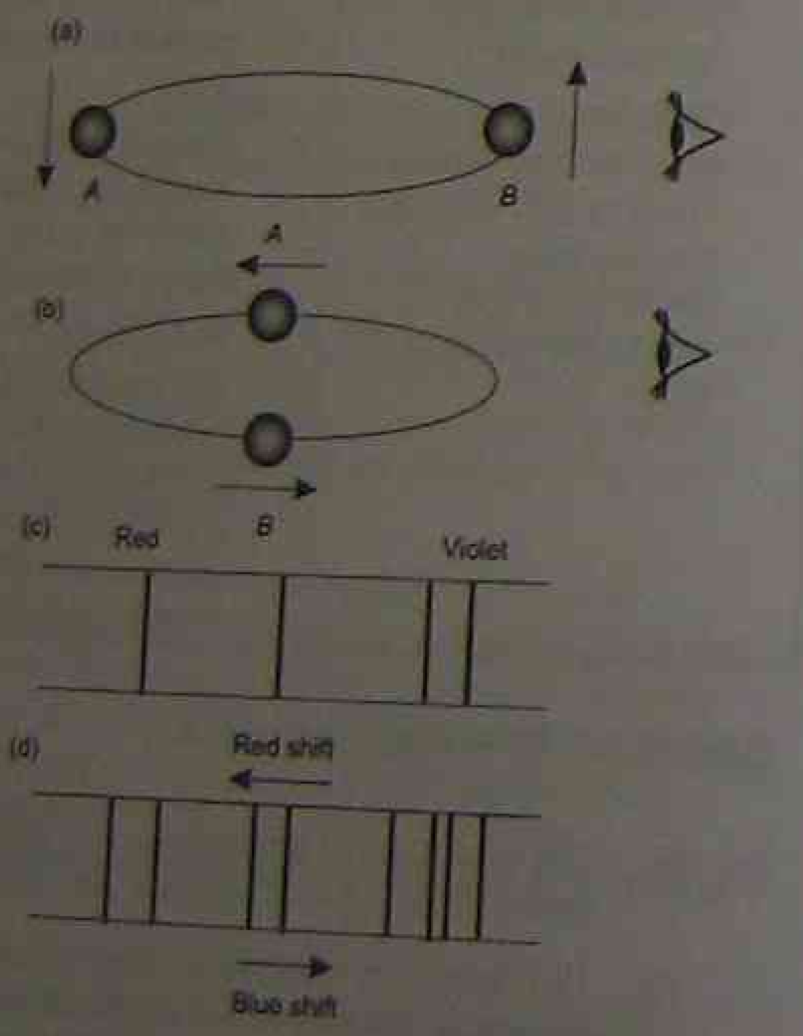

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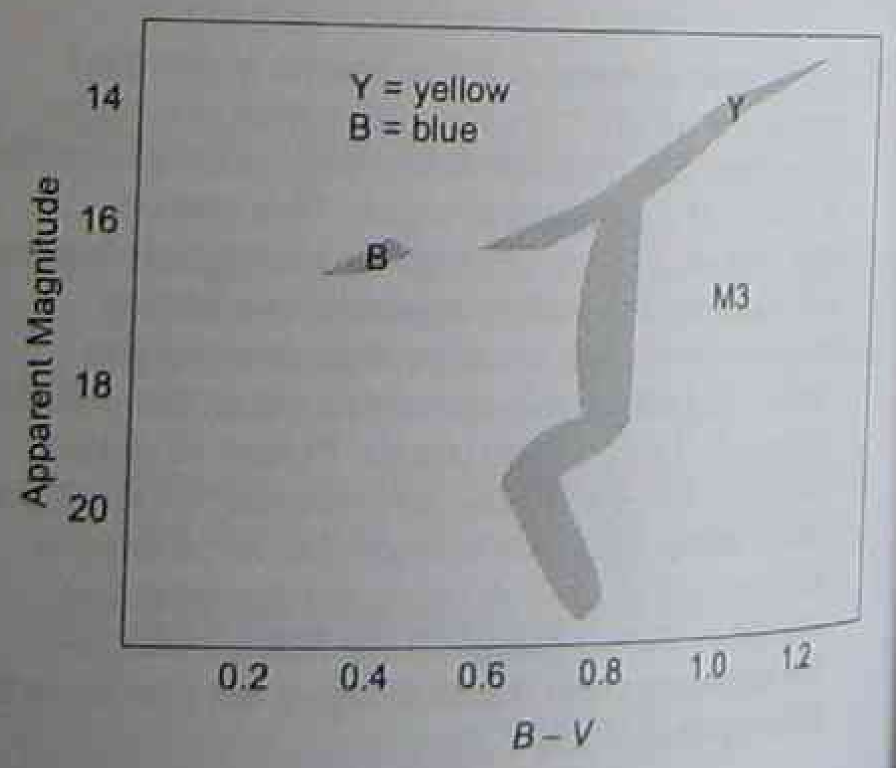

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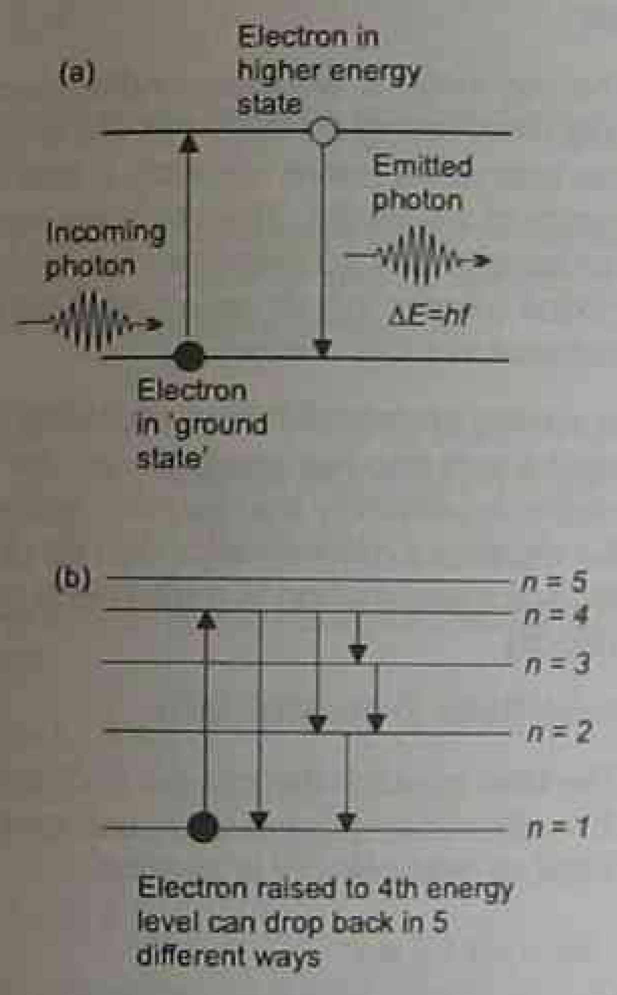

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Chapter Eight

Answers and Worked Solutions

Answers are given for all questions except definitions and where it is simply a restatement of information in the text. For these questions the reader is directed to go to the relevant part of the text.

CHAPTER ONE: *SPACE* ANSWERS TO QUESTIONS AND PROBLEMS

SECTION 1: GRAVITY

1 See text.

2 See text.

3 The acceleration due to gravity at a height *R* from the Earth's centre is given by:

$$g=\frac{GM}{R^2}$$
$$=\frac{6.67\times10^{-11}\times5.983\times10^{24}}{\left[(6380+1600)\times10^3\right]^2}$$
$$=6.3\,\text{m.s}^{-2}$$

4 Mass and weight are related by $W=mg$. The mass can be found from $m=\frac{W}{g}=\frac{80}{9.8}=8.16$ kg. The new weight is hence:

$$W'=mg'$$
$$=8.16\times25=204\,\text{N}$$

Alternatively, since mass is constant we can solve as follows:

$$\frac{W'}{W}=\frac{g'}{g}$$
$$W'=\frac{25}{9.8}\times80=204\,\text{N}$$

5 The change in gravitational potential energy is found from:

$$\Delta E_p=GmM_E\left(\frac{1}{6380\times10^3}-\frac{1}{(6380+35800)\times10^3}\right)$$
$$=6.67\times10^{-11}\times1000\times5.983\times10^{24}\times1.33\times10^{-7}\,\text{J}$$
$$=5.31\times10^{10}\,\text{J}$$

SECTION 2: SPACE LAUNCH AND RETURN

1 See text.

2 (a) The two motions are independent because the only force acting on the projectile is gravity and this acts down (more correctly it acts towards the centre of the Earth). Thus only the vertical component has acceleration; the horizontal motion (neglecting air resistance) remains constant velocity motion.

(b) In solving projectile motion problems, the motion can be split into two components: the vertical motion is uniformly accelerated motion, for which the equations of kinematics can be used, and the horizontal motion is motion with constant velocity.

3 *Comment:* Refer to question 2(b).

(a) The time to reach the ground is determined by the vertical component of motion only. Here the initial vertical velocity is zero so:

$$\Delta y=u_yt+\tfrac{1}{2}a_yt^2$$
$$100=0+\tfrac{1}{2}\times9.8\times t^2$$
$$t=4.5\,\text{s}$$

(b) The horizontal distance is determined by the horizontal component of velocity and the time of flight, that is:

$$x=u_xt$$
$$=10\times4.5$$
$$=45\,\text{m}$$

(c) The horizontal velocity after 4.5 s is still 10 m.s^{-1}. The vertical velocity after 4.5 s is found from:

$$v_y=u_y+a_yt$$
$$=0+9.8\times4.5$$
$$=44.1\,\text{m.s}^{-1}$$

From the vector diagram, Figure 8.1, the resultant velocity is 45.2 m.s^{-1} at 77.2° to the water surface.

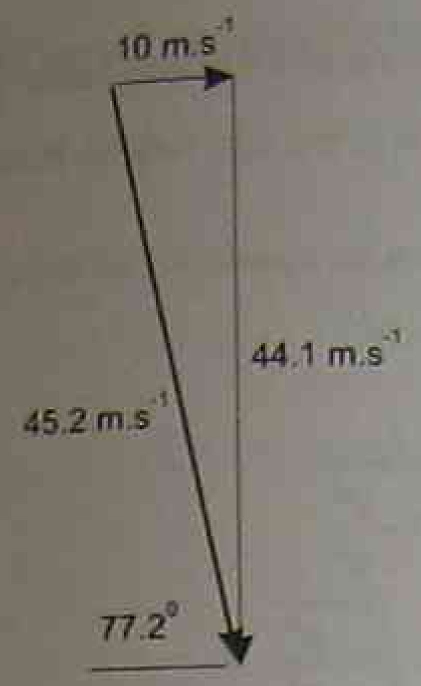


Figure 8. 1

4 Looking at the two motions independently solves this question.

(a) The initial vertical component of velocity is given by $v\sin\theta$. The final vertical velocity at the top of the motion is zero. Therefore:

$$v_y^2=u_y^2+2a_y\Delta y$$
$$0=(1000\sin30)^2+2\times(-9.8)\times s$$

i.e. $\Delta y=12.76\,\text{km}$

(b) The time to reach maximum height is found from:

$$v_y=u_y+a_yt$$
$$t=\frac{v-u}{a_y}=\frac{(0-1000\sin30)}{(-9.8)}$$
$$=51\text{s}$$

(c) The range can be found directly from the range formula, namely:

$$R=\frac{v^2\sin2\theta}{g}$$
$$=\frac{1000^2\times\sin60}{9.8}$$
$$=8.84\times10^4\,\text{m}$$

Alternatively the range can be found from first principles (and this is the best approach):

$$R=\text{horizontal velocity}\times\text{time of flight}$$
$$=v\cos\theta\times T$$
$$=1000\cos30\times102$$
$$=8.84\times10^4\,\text{m}$$

5 (a) 4286 m

(b) 140 m.s^{-1} at 25° to the horizontal

6 See text.

7 The escape velocity depends on the mass and radius of the planet ($v_e\propto\sqrt{\frac{M}{R}}$). The mass and radius of Mars are smaller than the Earth such that the escape velocity is smaller.

Comment: This accounts for the lack of atmosphere on Mars.

8 Newton imagined firing a cannon horizontally from a 'very high' mountain. If the speed of the cannon ball was fast enough, he reasoned that the ball would go into circular orbit around the Earth. Today satellites are put into orbit in a somewhat similar manner except they are raised to a high altitude by rockets and are then given the necessary horizontal velocity.

9 An object travelling with a constant speed but whose direction is changing will have a changing velocity. Uniform circular motion is such a motion — the acceleration causing the direction change and hence the velocity change is directed towards the centre of the circle.

10 See text.

11 The Earth spins (rotates) on its axis from west to east. It also orbits (revolves around) the Sun at a speed ~30 km.s^{-1} (relative to the Sun). By firing a rocket in an easterly direction and in the direction of the Earth around the Sun, additional momentum can be transferred to the spacecraft which assists in reducing fuel demands.

12 (a) A geostationary orbit is one with a period of 24 hours and lies in the plane of the equator

(b) 24 h (c) 3069 m.s^{-1}

(d) 3.07×10^3 m.s^{-2}

13 Satellites in low Earth orbit are affected by the upper layers of the Earth's atmosphere which slows them down by friction. This causes the satellite to spiral closer to the Earth which in turn increases the friction; this slows the satellite down resulting in the satellite burning up in the Earth's atmosphere, because of the high temperatures generated.

14 Safe re-entry for manned spacecraft is a juggling act between keeping the *g*-forces within safe limits and keeping the heat generated by the atmosphere from burning up the spacecraft (see Q15 above). Too steep a descent and the *g*-forces are too great to withstand; too shallow and the spacecraft 'bounces' off the atmosphere back into space. The heating effects of the atmosphere can be reduced by special heat shields. Older spacecraft used *ablative* tiles that burnt off and reduced the heating effects. The *Space Shuttle* now uses special tiles of silica and carbon composites that can withstand the intense heat.

SECTION 3: FUTURE SPACE TRAVEL

1 See text.

2 See test.

3 The gravitational attraction between the Sun and its planets controls the motion of the planets as described by Newton's Law of Universal Gravitation. Similarly, satellites, both natural (moons) and artificial are controlled by gravity.

4 Slingshot' (or 'gravity-assisted') trajectories work by the spacecraft picking up angular momentum from planets. As the spacecraft approaches a planet it speeds up *relative to the planet*. As it leaves the planet it slows down *relative to the planet* but relative to the Sun it has sped up. The spacecraft has picked up angular momentum from the planet.

SECTION 4: SPECIAL RELATIVITY

1 See text.

2 The Michelson-Morley experiment attempted to measure the speed of the Earth through the ether (a 'material' supposed to permeate all of space and matter and whose purpose was to propagate light waves). It tried to do this by measuring the speed of light through the ether as the Earth moved in different directions in its orbit around the Sun. No motion of the Earth relative to the ether could be detected. This indicated that the ether did not exist (and so no absolute frame of reference existed).

3 The fact that the 'speed of light is the same for all observers in relative motion with constant velocity' leads to the link between space and time – the *space-time continuum*. This has implications such as length contraction, time dilation (and mass dilation) and the relativity of simultaneity.

4 See text.

5 Length contraction is found from:

$$l = l_o\sqrt{1-\frac{v^2}{c^2}}$$

$$l = 1.0\times\sqrt{1-\frac{v^2}{c^2}}$$

$$= 1.0\times\sqrt{1-\frac{(0.5c)^2}{c^2}}$$

$$= 0.87\text{ m}$$

The electron moves a shorter distance than an observer on the Earth measures.

6 A light year is the distance travelled by light in one year (at the speed of *c*).

(a) If travelling at 0.6*c*, light takes $\frac{5.0}{0.6} = 8.33$ years to travel to the star *relative to an observer on the Earth*.

(b) The time as measured by the crew is found from:

$$t = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$t_o = t\times\sqrt{1-\frac{v^2}{c^2}}$$

$$= 8.33\times\sqrt{1-\frac{(0.5c)^2}{c^2}}$$

$$= 7.2\text{ years}$$

7 Mass dilation is found from:

$$m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$= \frac{9.1\times10^{-31}}{\sqrt{1-\frac{(0.9c)^2}{c^2}}}$$

$$= 2.08\times10^{-30}\text{ kg}$$

8 See text.

9 The significance of the *twin paradox* is that Special Relativity is restricted to inertial frames of reference. The twin who leaves the Earth and returns is not in an inertial frame of reference all of the time. He in is a non-inertial frame when he leaves, turns around and comes to rest and so there is no paradox.

Comment: General relativity shows that the twin who leaves and returns is in fact younger than the twin who remained on Earth.

CHAPTER ONE: SPACE WORKED SOLUTIONS AND ANSWERS TO TEST

MULTIPLE CHOICE ANSWERS

1 D; $F = \frac{Gm_1m_2}{d^2}$, so $F' = \frac{G(2m_1)(2m_2)}{(d/4)^2} = 64F$

2 D; $g = \frac{GM}{d^2}$

3 C; centripetal force = gravitational force.

4 B; $\frac{T^2}{R^3} = k$, so $R \propto T^{\frac{2}{3}}$

5 B

6 C

7 B

8 D

9 A

10 D

11 C

12 B

13 B

14 A

15 D

SOLUTION TO SHORT ANSWER QUESTIONS

16 The gravitational field strength is found from:

$$g = \frac{GM}{R^2}$$

$$= \frac{6.67\times10^{-11}\times5.98\times10^{24}}{\{(6380+900)\times10^3\}^2}$$

$$= 7.53\text{ m.s}^{-2}$$

17 See Figure 8.2. Dividing the motion into its two components, we have:

Vertically: $\Delta y = \frac{1}{2}a_yt^2$

So $t = \sqrt{\frac{2\Delta y}{g}} = \sqrt{\frac{2.0\times0.70}{9.8}}$

$= 0.38\text{ s}$

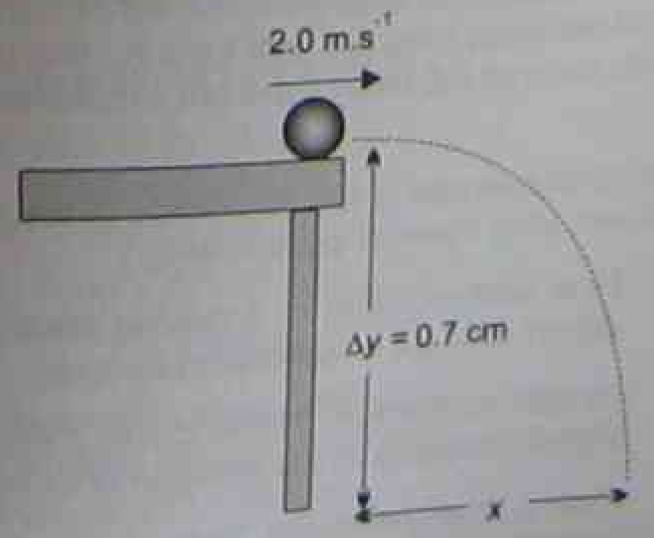


Figure 8. 2

Horizontally: $x = v_xt = 2.0\times0.38 = 0.76\text{ m}$

That is, the ball lands 0.76 m from the table's edge.

18 A rocket works by ejecting high-pressure gases produced by combustion of fuel and oxygen. These gases exert a force on the rocket in the opposite direction (Newton's Third Law) which propels the rocket.

19 (a) g-forces are forces generated by acceleration. For example astronauts are subject to large g-forces when they accelerate from the launch pad.

(b) If the g-forces are too large, they can cause a person to 'black out' (or experience a 'red-out' depending on the direction of the acceleration). In extreme cases they can prove fatal.

20 Multistage rockets are used to allow spacecraft to escape from the Earth's gravitational pull. Once the stage has consumed its fuel it is jettisoned to either fall back to Earth for re-use or burn-up in the atmosphere. This reduces the mass needing to be propelled and so less fuel is required.

21 (a) For a satellite of mass M_s orbiting the Earth (mass M_E), at a distance R from the Earth's centre, the necessary centripetal force is supplied by the gravitational force of attraction between the satellite and the Earth. That is:

$$F_{\text{centripetal}} = F_{\text{gravity}}$$

$$\frac{M_sv^2}{R_E} = G\frac{M_sM_E}{R_E^2}$$

$$v^2 = \frac{GM_E}{R_E}$$

(b) From the above equation it follows that:

$$v = \sqrt{\frac{GM_E}{R_E}}$$

$$= \sqrt{\frac{6.67\times\times10^{-11}\times5.983\times10^{24}}{(6380+35800)\times10^3}}$$

$$= 3076\text{ m.s}^{-1}$$

22 Both satellites obey Kepler's Law of Periods, so.

Hence: $\frac{r^3}{T^2} = k$

$$\frac{r_T^3}{T_T^2} = \frac{r_N^3}{T_N^2}$$

$$\left[\frac{r_T}{r_N}\right]^3 = \left[\frac{T_T}{T_N}\right]^2$$

$$\left[\frac{r_T}{r_N}\right] = \left[\frac{T_T}{T_N}\right]^{2/3}$$

$$= \left[\frac{5.8}{360}\right]^{2/3}$$

$$= 0.064$$

23 The planets obey Kepler's Law which for objects orbiting the Sun is given by $\frac{r^3}{T^2}=1$ when r is in AU and T is in years. For Jupiter:

$$\frac{r^3}{T^2}=\frac{5.203^3}{11.87^2}=0.9997\equiv 1$$ and obeys Kepler's Law.

24 From Kepler's Law and Universal Gravitation we have:

$$\frac{r_p^3}{T_p^2}=\frac{GM_P}{4\pi^2}$$

$$M_P=\frac{4\pi^2\times r_P^3}{GT_P^2}$$

$$=\frac{4\pi^2\times(5.91\times10^9 x10^3)^3}{6.67\times10^{-11}\times(248.4\times365.25\times24\times60\times60)^2}$$

$$=1.99\times10^{30}\text{ kg}$$

25 (a) Tsiolkovsky:

- Published first correct theory of rocket power.
- Suggested multistage rockets and liquid fuels.
- Invented wind tunnels and used them to study aerodynamics.
- Investigated the problems of air friction.

(b) Esnault-Pelterie:

- Gave one of the first scientific discussions of the problems inherent in space travel
- Published the book *Astronautics* and introduced the word to the world
- Deduced that chemical energy would be sufficient to send a man to the moon.

(c) Goddard:

- Proved rockets worked in a vacuum.
- Developed the first liquid fuel rocket.
- Launched the first liquid fuel rocket.
- Launched the first instrument-carrying rocket.

(d) Oberth:

- Mathematically determined the conditions for a rocket to reach escape velocity.
- Simulated weightlessness.
- Predicted the development of electric propulsion and ion engines.

26 (a) The Michelson-Morley experiment attempted to measure the velocity of the Earth relative to the ether.

(b) The half-silvered mirror was used to split the light beam to form two coherent beams so that an interference pattern could be formed to measure motion through the ether.

(c) The expected change in the speed of light was expected to be tiny. A sensitive measuring device was needed—an interferometer was such a device

(d) No motion of the Earth relative to the ether was detected.

27 Two events that occur at the same time relative to an observer are said to be simultaneous. These same two events, however, will not be simultaneous for a second observer moving with constant velocity relative to the first observer. This can be illustrated as follows (Figure 8.3):

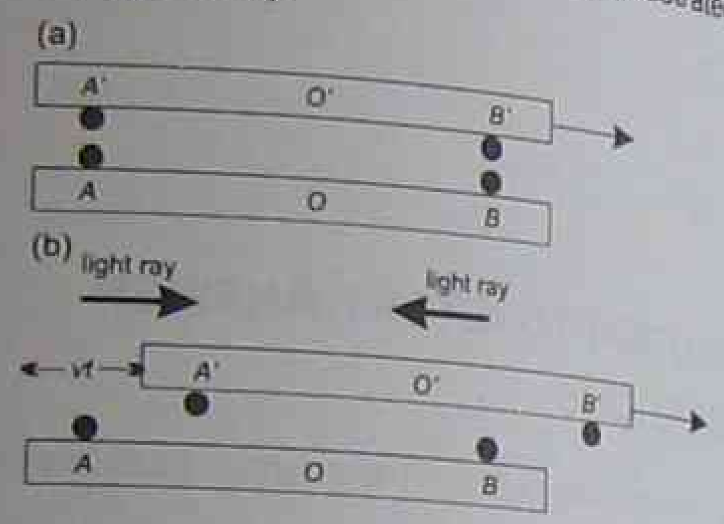


Figure 8. 3

Assume two Einsteinian spaceships are travelling through space with relative velocity v parallel to each other. Further assume that observer O and O' are in the middle of their respective spaceships and that highly charged points A and A' and B and B' are directly opposite each other at some instant (Figure 8.3(a)).

Now assume that sparks jump between A and A' and B and B' so that the flashes are simultaneous for O. Will the events also be simultaneous for O'?

As shown in Figure 8.3(b), in the finite time t the spacecraft would have moved on relative to each other. O sees O' approaching the light from B (still at c) and receding from the light from A', and hence O concludes that the events are not simultaneous for O'.

28 The consequences of the constancy of the speed of light are: (Any three of the following.)

- Time dilation. Time for a moving observer goes slower than for a stationary observer.
- Length contraction. The length of a moving object contracts in the direction of its motion.
- Space-time continuum. Space and time are interdependent. An event requires four dimensions (*x, y, z, t*) to define it.
- Relativity of simultaneity. (See question 27).
- Mass dilation. The mass of a moving object increases with increasing speed.

29 See text.

30 (a) The length of a moving object is given by $l=l_o\sqrt{1-\frac{v^2}{c^2}}$ where l is the length relative to a stationary observer and l_o is the length for an observer moving with the object. Hence:

$$l=l_o\sqrt{1-\frac{v^2}{c^2}}$$

$$l_o=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$=\frac{10}{\sqrt{1-\frac{(0.4c)^2}{c^2}}}$$

$$=10.91\text{ m}$$

(b) The time in a moving frame is given by

$$t=\frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$=\frac{1.0}{\sqrt{1-\frac{(0.4c)^2}{c^2}}}$$

$$=1.09\text{ h}$$

$$=1\text{h}\,5.4\text{ min}$$

LONGER QUESTION SOLUTIONS

31 (a) The time to reach the ground is determined by the displacement through which the stone falls, that is: $\Delta y=u_yt+\frac{1}{2}a_yt^2$ where the initial vertical component of velocity is given by: $u_y = 29.4\sin30 = 14.7\text{ m.s}^{-1}$

Taking up as the positive direction:

$$-49=14.7\times t+\tfrac{1}{2}\times(-9.8)\times t^2$$

$$-49=14.7t-4.9t^2$$

$$t^2-3t-10=0$$

$$(t-5)(t+2)=0$$

$$t=5\text{ s}$$

(b) Horizontal velocity after 5 s
= original horizontal velocity
= 29.4cos30 = 25.5 m.s^{-1}.

Distance travelled horizontally is given by:

$$x=u_xt=25.5\times5$$

$$=127.5\text{ m}$$

(c) Vertical velocity after 5 s is given by:

$$v_y=u_y+a_yt$$

$$=29.4\sin30-9.8\times5$$

$$=-34.3\text{ m.s}^{-1}$$

From Figure 8.4, the magnitude of the final velocity is 42.7 m.s^{-1}

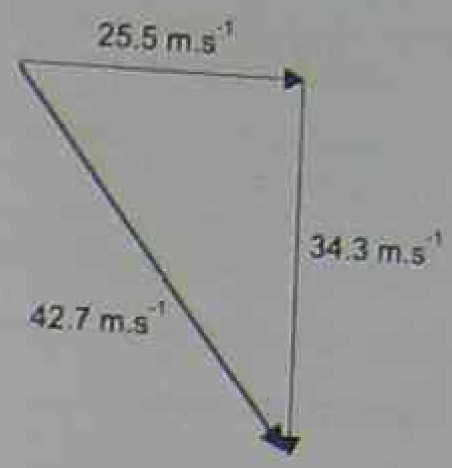


Figure 8. 4

32 (a) The centripetal force required to keep the moon in orbit is provided by the gravitational attraction between the planet and its moon, therefore:

$$F=\frac{GMm}{R^2}=\frac{4\pi^2mR}{T^2}$$

$$M=\frac{4\pi^2R^3}{GT^2}$$

$$=\frac{4\pi^2\times(9.7\times10^6)^3}{6.67\times10^{-11}\times(2.5\times10^4)^2}$$

$$=7.1\times10^{23}\text{ kg}$$

(b) $$\frac{T_1^2}{R_1^3}=\frac{T_2^2}{R_2^3}\quad\therefore R_2=\left(\frac{T_2}{T_1}\right)^{2/3}\times R_1$$

$$R_2=\left(\frac{1.09\times10^5}{2.75\times10^4}\right)^{2/3}\times9.7\times10^6$$

$$=2.43\times10^7\text{ m}$$

33 See text.

34 (a) The safe re-entry window is such that if the spacecraft approached at a shallower angle it would 'bounce' off the atmosphere back into space. If it approached at a steeper angle, the g-forces would be too great for the astronauts to survive.

(b) See text.

35 (a) Two reasons put forward to explain the negative result of the Michelson-Morley experiment are:

- Length contraction had occurred in the arm parallel to the direction of the motion of the apparatus.
- The ether was being 'dragged along' by the Earth.

(b) Einstein explained the negative result by stating that the speed of light is constant and is unaffected by the velocity of the source of the observer.

(c) See answer to Q 28 for implications from this law.

36 (a) The ether was proposed to be the medium through which light waves could propagate.

(b) (i) The muon 'sees' the atmosphere contracted in its direction of motion to an extent such that it can traverse the shorter distance before it disintegrates.

(ii) Earth observers see the muon's lifetime dilated by the factor $\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ allowing it to 'live' long enough to reach the Earth's surface.

Comment: Experiments such as this have provided conclusive evidence supporting the Theory of Special Relativity.

37 (a) $l = l_o\sqrt{1-\frac{v^2}{c^2}}$

$$\begin{aligned}75 &= l_o\sqrt{1-\frac{(0.8c)^2}{c^2}}\\ &= l_o \times 0.6\\ l_o &= 125\,m\end{aligned}$$

(b) Mass dilation is given by:

$$\begin{aligned}m &= \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}\\ &= \frac{1}{\sqrt{1-\frac{(0.8c)^2}{c^2}}}\\ &= \frac{1}{\sqrt{0.36}}\\ &= 1.67\text{ kg}\end{aligned}$$

(c) We need to find t_o in the time dilation formula:

$$t = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$t_o = 100 \times 0.6 = 60$ light years

38 One of the consequences of Special Relativity is that time dilates, that is, time for a moving observer goes slower relative to a stationary observer. Suppose a spacecraft was sent to a star 100 light-years. At the enormous speed of 0.999*c*, this would take slightly over 100 years *relative to a stationary observer on Earth*. As measured by the crew of the spacecraft, however, it would take much less time (~4.47 years). Although they could return to Earth in around 10 years of their time, *over two centuries* would have passed on Earth. No government is going to invest in such an expedition!

CHAPTER TWO: MOTORS AND GENERATORS ANSWERS TO QUESTIONS AND PROBLEMS[1]

1 See text.

2 See text.

3 (a) Up the page. (b) To the left of the page

4 (a) Force on the current-carrying wire is given by: $F = Bil\sin\theta$. Hence:

$$\begin{aligned}F &= Bil\sin\theta\\ &= 10\times5\times1.5\times\sin 0\\ &= 0\,\text{N}\end{aligned}$$

(b) $$\begin{aligned}F &= Bil\sin\theta\\ &= 10\times5\times1.5\times\sin 60\\ &= 65\,\text{N}\end{aligned}$$

(c) $$\begin{aligned}F &= Bil\sin\theta\\ &= 10\times5\times1.5\times\sin 90\\ &= 75\,\text{N}\end{aligned}$$

5 See text.

6 Force Law is: $\frac{F}{l} = k\frac{i_1 i_2}{d}$ so:

$$\begin{aligned}F &= 2\times10^{-7}\times\frac{2\times3}{5\times10^{-2}}\times2\\ &= 4.8\times10^{-5}\,\text{N repulsion}\end{aligned}$$

7 See text.

8 (a) $\theta = 0^0$ for maximum torque

(b) $$\begin{aligned}\tau &= nBiA\cos\theta\\ &= 200\times0.02\times4\times(2\times10^{-2}\times4\times10^{-2})\times\cos 0\\ &= 1.28\times10^{-2}\,\text{N.m}\end{aligned}$$

---

[1] NB: lower case *i* will be used for current in this section to distinguish it from *l* for length.

SECTION 2: ELECTROMAGNETIC INDUCTION

1–5 See text.

6 (a) Up the rod (b) To the right. (c) Up the rod. (d) To the right.

7 (a) Initial flux through circuit

$$\begin{aligned}\varphi &= BA\\ &= 0.02\times(2\times10^{-4}\times4\times10^{-2})\\ &= 1.6\times10^{-5}\text{ Wb}\end{aligned}$$

(b) $$\begin{aligned}\varepsilon &= -n\frac{\Delta\varphi}{\Delta t}\\ &= -1\times\frac{1.6\times10^{-5}}{0.1}\text{ V}\\ &= -1.6\times10^{-4}\text{ V}\end{aligned}$$

8 This experiment demonstrates the phenomenon of self-induction. When the current is DC, the associated magnetic field of the coil is unchanging. On AC, however, the magnetic field of the coil is continually changing; the iron bars are hence in a region of changing magnetic flux and so electromagnetic induction will occur. Tiny circular 'eddy currents' are induced in the bars, causing the bars to heat up. In addition a back *emf* is induced in the coil, opposing the applied *emf* and causing the globe to dim.

SECTION 3: ELECTRIC GENERATORS

1–3 See text.

SECTION 4: TRANSFORMERS

1 See text.

2 (a) A step-up transformer.

(b) $$\begin{aligned}\frac{V_p}{V_s} &= \frac{n_p}{n_s}\\ V_s &= \left(\frac{n_s}{n_p}\right)\times V_p\\ &= \left(\frac{10000}{500}\right)\times 20000\\ &= 400000\text{ V}\\ &= 400\text{ kV}\end{aligned}$$

3 High voltages mean lower currents in the secondary circuit. This reduces the heating losses ($\propto i^2$) in the transmission lines.

4 See text.

SECTION 5: ELECTRIC MOTORS

1–2 See text.

MOTORS AND GENERATORS WORKED SOLUTIONS AND ANSWERS TO TEST

1 C; application of the right-hand grip rule has the fields of both wires going into the page.

2 A; $\frac{F}{l} = \frac{2\times10^{-7}\times2\times3}{0.05} = 2.4\times10^{-5}$ attraction (like currents attract).

3 C; $F = k\frac{i_1 i_2}{d} \therefore F' = k\frac{i_1 i_2}{\frac{d}{2}} = 2F$ where F is the force per unit length.

4 B; the force is one of repulsion.

5 B; right-hand palm rule.

6 D; the direction of the force depends upon the direction of the field and the current.

7 B; $F = Bil$

8 A.

9 C; current induced to oppose entry of N pole.

10 D

11 C

12 A

13 A

14 D

15 B

SHORT QUESTION ANSWERS

16 (a) From the force Law:

$$\begin{aligned}\frac{F}{l} &= k\frac{i_1 i_2}{d}\\ &= \frac{2\times10^{-7}\times2\times4}{0.01}\\ &= 1.6\times10^{-4}\text{ N.m}^{-1}\end{aligned}$$

(b) The force has the same magnitude but the direction changes.

17 See Figure 8.5

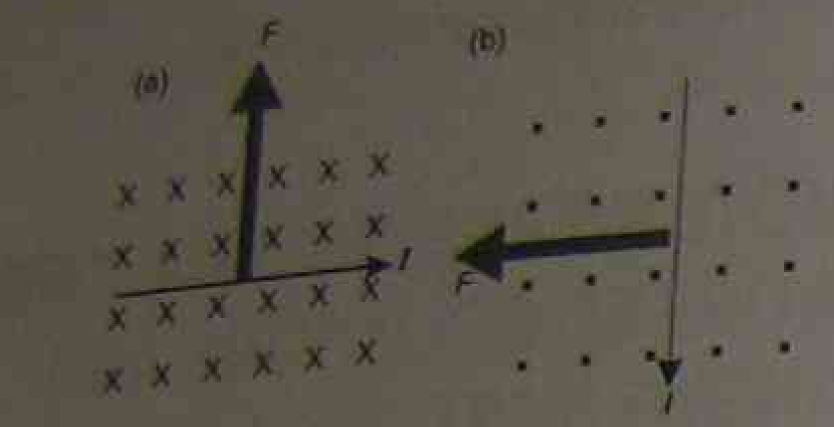


Figure 8. 5

18 (a) With no current, the reading is simply the weight of the rod:

$W = mg = 0.2 \times 9.8 = 1.96\text{ N}$

(b) When a current flows from north to south, application of the right-hand palm rule shows a magnetic force directed vertically up. The reading on the spring balance is now

$R = mg - Bil = 1.96 - 0.5 \times 10 \times 0.2 = 0.96\text{ N}$

(c) When current flows from south to north, the magnetic force is vertically down so

$R = mg + Bil = 2.96\text{ N}$

19 (a) To the left (right-hand palm rule).

(b) $F = Bil$ and $i = \frac{V}{R} = \frac{12}{2} = 6\text{ A}$ so

$F = Bil = 0.5 \times 6 \times 0.10 = 0.3\text{ N}$

20 When current flows through the coils, the 'like' currents in adjacent coils cause them to attract, lifting the bottom out of the mercury and breaking the circuit. The spring falls back, the circuit is re-established and the process repeats.

Comment: The device is called *Rigot's* spiral.

21 (a) Force on *AB* is down and on *CD* is up.

(b) $F = Bil = 10 \times 2 \times 0.04 = 0.8\text{ N}$. This is the force on each turn or loop and since there are 100 turns the total force is 100 x 0.8 = 80 N. This is for sides *AB* and *CD* (but in opposite directions). On *BC*, $F = 0$ since the current is parallel to the field.

(c) $\tau = nBiA = 100 \times 10 \times 2 \times 0.04 \times 0.02$

$= 1.6\text{ N.m}$

Comment: In real motors the magnetic field is radial so that the torque remains constant throughout the motion.

22 A transformer connected to 240 V AC will have a back *emf* induced in the coil opposing the change (Lenz's Law). This reduces the current to acceptable limits. With 240 V DC, the current may be large enough to burn out the wiring.

23 (a) Current required to deliver 10,000 W at 1000 V is:

$P = Vi$

$i = \frac{P}{V} = \frac{10000}{1000} = 10\text{ A}$

Power lost in transmission cable

$P = i^2R = 10^2 \times 0.5 = 50\text{ W}$

(b) Current required to deliver 10,000 W at 200,000 V is:

$P = Vi$

$i = \frac{P}{V} = \frac{10000}{200\,000} = 0.05\text{ A}$

Power lost in transmission cable

$P = i^2R = 0.05^2 \times 0.5 = 1.25 \times 10^{-3}\text{ W}$

24 Electromagnetic braking uses the principle that circular eddy currents will be induced in bulk conducting material in the presence of changing magnetic flux. The direction of the induced currents opposes the cause of these currents (by Lenz's Law). By bringing powerful magnets near to the moving conductor, braking can occur.

25 An AC induction motor uses the principle that alternating current in the field coils of the stator are arranged to produce a rotating magnetic field. This field induces an electric current in the rotor (hence an 'induction' motor) which sets up a second magnetic field. These two fields interact with the rotating stator field 'dragging' the rotor after it.

LONGER QUESTION ANSWERS

26 (a) Anticlockwise. Application of the right-hand palm rule indicates the force on the right-hand side to be up and that on the left-hand side to be down.

(b) The current must be reversed each half-cycle.

Comment: If the current is not reversed, the coil will come to rest in the vertical plane. A commutator is used to keep the coil continually rotating.

(c) (i) Zero.

(ii) $\phi = BA = 0.2 \times 0.02 \times 0.06$

$= 2.4 \times 10^{-4}\text{ Wb}$

(d) (i) $\tau = nBiA$

$= 100 \times 0.2 \times 5 \times 0.02 \times 0.06\text{ N.m}$

$= 0.12\text{ N.m}$

(ii) 0; there is zero torque when the coil and field are perpendicular (see (b) above).

27 (a) One could reverse the direction of the current flow and the direction of the magnetic field. Each change separately would reverse the direction of the force.

(b) At balance, the weight must just equal the magnetic deflecting force, that is:

$mg = Bil$

$B = \frac{mg}{il} = \frac{2 \times 10^{-4}}{2 \times 0.02}$

$= 5.0 \times 10^{-3}\text{ T}$

(c) The long sides can be neglected since they are parallel to the field and so experience no force.

28 (a) See Figure 8.6.

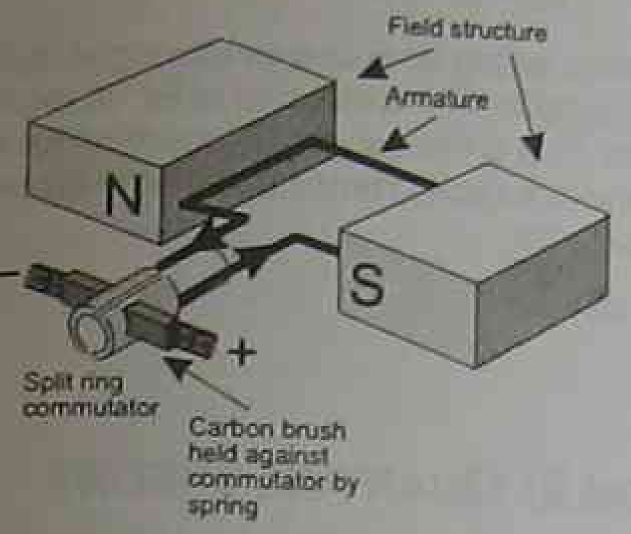


Figure 8. 6

(b) The split-ring commutator is used to reverse the direction of the current each half revolution. This ensures that the armature experiences a torque in the same direction throughout its rotation.

(c) The motor could be improved by:

- Curving the pole pieces to provide a radial field.
- Having more coils at angles to each other.
- Increasing the field strength.
- Increasing the current.

29 (a) A moving coil meter works on the motor principle, that is, that a current-carrying wire experiences a force in a magnetic field. The greater the current, the greater the force. A spiral spring ensures that the coil, to which is attached a pointer, turns only until the forces are balanced. The pointer allows the current to be read off a scale.

(b) The radial magnetic field ensures a constant torque since the coil always lies in the plane of the field and so experiences maximum torque. This also means that the scale is linear.

30 (a) See Figure 8.7.

(b) As the coil rotates, the magnetic flux through the coil changes. This changing flux results in an induced *emf* from the phenomenon of electromagnetic induction.

(c) The induced *emf* is a maximum when the coil is moving perpendicular to the field.

(d) The generator could be supplied with a split-ring commutator to convert the AC to DC.

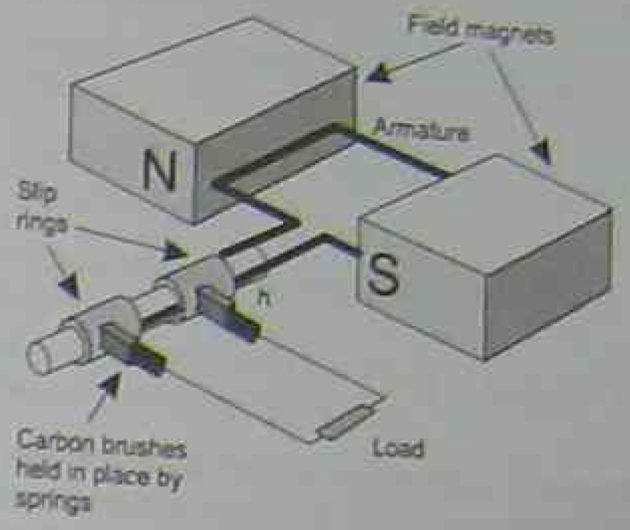


Figure 8. 7

31 (a) The relationship between voltage and number of turns in a transformer is:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

$$V_s = \left(\frac{n_s}{n_p}\right) \times V_p$$

$$= \frac{200}{4000} \times 240\text{ V}$$

$$= 12\text{ V}$$

(b) Energy losses can be minimised in the transformer by:

- using a soft-iron core to increase the flux linkage.
- laminating the core to reduce eddy currents.

32 (a) Nothing happens in loop *B* since there is no changing flux in *A*.

(b) As the resistance is lowered, the current increases. This sets up an increasing magnetic field in loop *A* with a north pole at the top of *A* (looking from above). A current is induced in *B* since *B* is now in the presence of changing flux. The direction of this current is such as to oppose the increasing north pole, that is the current flows clockwise in *B* (when viewed from above).

33 (a) When current flows through both loops they each have an associated magnetic field. These fields interact producing a force between the loops.

(b) From *d* to *c*. ('unlike currents' repel.)

(c) The force can be indirectly measured by placing small masses on the pointer. The further out the mass has to be placed to restore equilibrium, the larger the force of repulsion between the loops.

(d) See Figure 8.8.

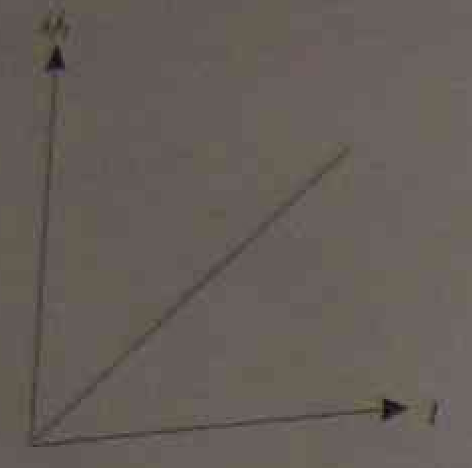


Figure 8. 8

34 Modern industrialised society could not exist without electricity and hence its generators and transformers. The generators produce the vast amounts of electricity consumed each day and the transformers allow for its transmission from its point of production to its points of consumption. Imagine the world with no computers, TVs, refrigerators, video recorders… The impact of electricity on the way we live is enormous.

CHAPTER THREE: *FROM IDEAS TO IMPLEMENTATION* ANSWERS TO QUESTIONS AND PROBLEMS

SECTION 1: CATHODE RAYS

1 See text.

2 See text.

3 See text.

4 (a) See Figure 8.9.

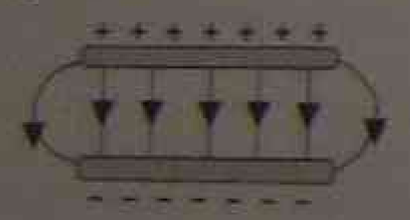


Figure 8. 9

(b) $E = \frac{V}{d}$

$= \frac{10000}{1.0 \times 10^{-3}}$

$= 10^{7}\ \text{V.m}^{-1}$

5 The force on a moving charge can be found as follows:

(a) $F = qvB\sin\theta$

$= 1.6 \times 10^{-19} \times 2.5 \times 10^{6} \times 0.20 \times \sin 0$

$= 0$

(b) $F = qvB\sin\theta$

$= 1.6 \times 10^{-19} \times 2.5 \times 10^{6} \times 0.20 \times \sin 45$

$= 5.66 \times 10^{-14}\ \text{N}$

(c) $F = qvB\sin\theta$

$= 1.6 \times 10^{-19} \times 2.5 \times 10^{6} \times 0.20 \times \sin 90$

$= 8.0 \times 10^{-14}\ \text{N}$

6 The force acting on a charge moving at right-angles to a magnetic field is directed at 90° to the direction of motion. This is the necessary condition for a particle to travel in a circle. Hence the charge follows a circular path.

7–10 See text.

SECTION 2: QUANTUM THEORY

1–6 See text.

7 (a) Planck's relationship is:

$E = hf$

$= 6.6 \times 10^{-34} \times \frac{3.0 \times 10^{8}}{450 \times 10^{-9}}$

$= 4.4 \times 10^{-19}\ \text{J}$

(b) Matter wave relationship:

$\lambda = \frac{h}{mv} = \frac{h}{p}$

$= \frac{6.6 \times 10^{-34}}{450 \times 10^{-9}}$

$= 1.47 \times 10^{-27}\ \text{kg.m.s}^{-1}$

8 See text.

SECTION 3: SOLID STATE DEVICES

1 See text.

2 In *n*-type semiconductors the majority carriers are electrons. In *p*-type semiconductors the majority carriers are holes.

3 See text.

SECTION 4: SUPERCONDUCTORS

1–5 See text.

CHAPTER THREE: *FROM IDEAS TO IMPLEMENTATION* WORKED SOLUTIONS AND ANSWERS TO TEST

MULTIPLE CHOICE ANSWERS

1	B
2	C
3	B
4	A
5	B
6	A
7	C
8	B
9	C
10	D
11	B
12	A
13	C
14	B
15	B

SHORT ANSWER SOLUTIONS

16 Any four of the following:

Cathode rays:

(a) Travel from the cathode in straight lines.

(b) Are deflected by electric and magnetic fields.

(c) Cause glass to fluoresce.

(d) Affect photographic film.

(e) Carry a negative charge.

(f) Possess energy and momentum.

17 (a) Maxwell had proposed that a changing electric field would induce a changing magnetic field which would induce a changing electric field, and so on, to form an electromagnetic wave. Hertz demonstrated that accelerated charges produce these waves. They were shown to exhibit the properties of reflection, refraction, interference, diffraction and polarisation and to travel at the speed of light.

(b) The photoelectric effect can only be explained by assuming the light energy is quantised, that is, it comes in packets or *photons* of energy. This provides evidence for the particle model of light.

18 Classical wave theory predicts that:

- electron emission is independent of the frequency of the incident light; and
- as the intensity increases, the energy of the electrons increases.

Both these predictions are shown experimentally to be incorrect. By relating energy and frequency in $E = hf$ the photon theory of Planck and Einstein explains the photoelectric effect.

Comment: The wave theory of light, so successful in explaining interference and diffraction of light, is completely inadequate when applied to the photoelectric effect. Only the photon theory can explain the experimental results. To explain *all* properties of light, *both* theories must be used — this is the *wave-particle duality* of light.

19 (a) $E_{k_{max}} = hf - hf_o$

(b) f_o is the minimum frequency required to cause electron emission. For frequencies $< f_o$ no emission occurs (regardless of the intensity).

(c) 4 units. $E_{k_{max}} = h(3f_o - f_o) = 2hf_o = 4$ units

20 From the photoelectric equation, we have:

$E_{k_{max}} = hf - \varphi = h\frac{c}{\lambda} - \varphi$

$= 6.6 \times 10^{-34} \times \frac{3 \times 10^{8}}{450 \times 10^{-9}}$

$- 2.4 \times 10^{-19}\ \text{J}$

$= 2.0 \times 10^{-19}\ \text{J}$

21 (a) Wave nature: Interference, diffraction.

(a) Particle nature: Photoelectric effect. (Compton scattering).

22 The wave packet is 'particle-like' in its finite size but wavelike in its varying amplitude.

Comment: The 'wave' is a wave of probability. Where the amplitude is largest, the chance of finding the photon 'there' is greatest.

23 (a) Fluorescent tube, electron gun and deflecting plates.

(b) The electron gun produces the electrons; the fluorescent screen creates a spot of light when struck by the electrons; the deflecting plates move the electron beam up and down and back and forth.

24 (a) Planck investigated the radiation emitted and absorbed from a 'black-body' – a perfect emitter and absorber of radiation.

(b) The only way that he could get the observed emission to agree with theory was to hypothesise that energy is quantised, that is, it comes in discrete amounts given by $E = hf$.

25 (a) Photocell - see text.

(b) Solar cell - see text.

26 (a) As intensity increases, the number of photoelectrons emitted increases proportionally.

(b) The maximum kinetic energy is unaffected.

(c) (i) The number of photoelectrons emitted is unaffected.

(ii) Maximum kinetic energy increases.

27 (a) From the Einstein relationship:

$$\begin{aligned} E_{k_{max}} &= hf - \phi \\ \phi &= hf - E_{k_{max}} \\ &= (6.6 \times 10^{-34} \times 6 \times 10^{14}) - 1.5 \times 10^{-19}\ \text{J} \\ &= 2.46 \times 10^{-19}\ \text{J} \end{aligned}$$

(b) The minimum frequency is when the energy equals the work function, that is:

$$\begin{aligned} \phi &= hf \\ f &= \frac{\phi}{h} = \frac{2.46 \times 10^{-19}}{6.6 \times 10^{-34}}\ \text{Hz} \\ &= 3.73 \times 10^{14}\ \text{Hz} \end{aligned}$$

28 Silicon is preferred over germanium because (any three of the following): Silicon:

- is more abundant than germanium and so is cheaper.
- is easier to purify.
- has a lower 'leakage current'.
- forms an oxide layer with oxygen, vital in the manufacture of integrated circuits.

29 (a) Thermionic valves are evacuated tubes containing two or more electrodes. The cathode (negative electrode) emits electrons after heating from a hot filament.

(b) Semiconductors have replaced valves because (any three of the following):

- smaller size allows for miniaturisation.
- lower power requirements.
- no 'start-up' time.
- faster switching.

30 (a) $E = \frac{V}{d} = \frac{100}{10 \times 10^{-3}} = 10^4\ \text{V.m}^{-1}$

(b) $F = qE = 1.6 \times 10^{-19} \times 10^4$
$= 1.6 \times 10^{-15}$ N up

(c) The magnetic field needs to be directed into the plane of the page (right-hand palm rule).

(d) The electron is undeflected when the upward electric force equals the downwards magnetic force. Therefore:

$$qE = qvB$$

$$v = \frac{E}{B} = \frac{10^4}{0.04} = 2.5 \times 10^5\ \text{m.s}^{-1}$$

31 (a) The electron will deflect upwards (toward the positive plate).

(b) Force due to electric field is $F = qE$ and force due to magnetic field is $F = qvB$ where F is force, q is charge, E is electric field, v is velocity and B is magnetic field.

(c) $F = qvB = qE \Rightarrow v = \frac{E}{B}$

(d) $q/m = 1.76 \times 10^{11}\ \text{C.kg}^{-1}$. This value is 1800 times the value for hydrogen 'atoms' measured by other methods. This meant either the charge was larger or the mass was much smaller than the previously known smallest particle. They were also found to be present in all materials tested and so were deduced to be 'parts' of atoms. We now know them to be electrons.

32 (a) Hertz set up apparatus similar to that in Figure 8.10. Sparks were made to jump across the spark gap and Hertz noticed that sparks were induced in the detector coil. Hertz hypothesised that the sparks set up oscillating electric and magnetic fields that propagated as an electromagnetic wave as postulated by Maxwell. These waves falling on the gap in the detector induced sparks.

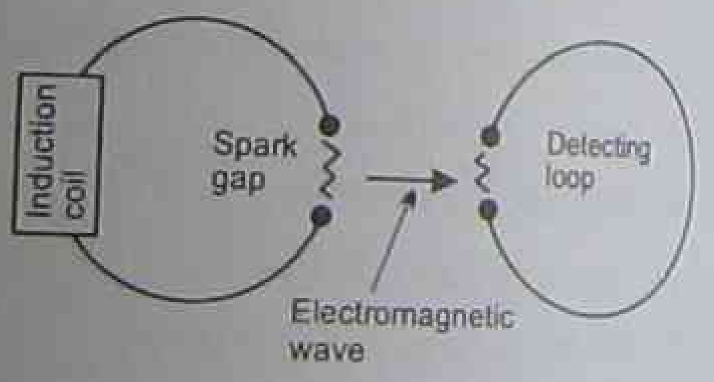


Figure 8. 10

(b) The waves exhibited the properties of: reflection; refraction; interference; diffraction, polarisation and travelled at c (the speed of light).

(c) Hertz noticed that in the presence of ultraviolet light the sparks could be induced in the spark generator at lower voltages than in its absence. (He failed, however, to investigate further.)

33 (a) The work function is the minimum energy required to allow the electrons to escape from the surface.

(b) $E = hf = 6.6 \times 10^{-34} \times \frac{3.0 \times 10^8}{600 \times 10^{-9}} = 3.3 \times 10^{-19}\ \text{J}$

(c) Nothing happens. The energy of the photon is too low to cause electrons to be ejected from the surface.

(d) Still nothing happens. The intensity does not affect the energy of the incident photon.

34 By doping we mean adding a Group III or Group V element from the Periodic Table to the semiconductor (a Group IV element). This creates excess charge carriers that add to the small number of carriers already present. If we dope with Group III elements we get a p-type semiconductor which has 'holes' as the majority carriers. If we dope with Group V we have electrons as the majority carriers. Both holes and electrons are used to conduct electricity in semiconductors.

35 William Bragg and his son did a lot of pioneering work on X-ray diffraction. By diffracting X-rays off crystal surfaces they not only proved the wave nature of X-rays but also the uniform structure of crystal lattices. X-ray crystallography is an important investigative tool for understanding the structure of matter.

36 (a) A hole is a positive charge and represents the 'absence' of an electron from a bond.

(b) Holes appear to move because electrons moving in the other direction 'fill' the hole and create another hole further along as in Figure 8.11.

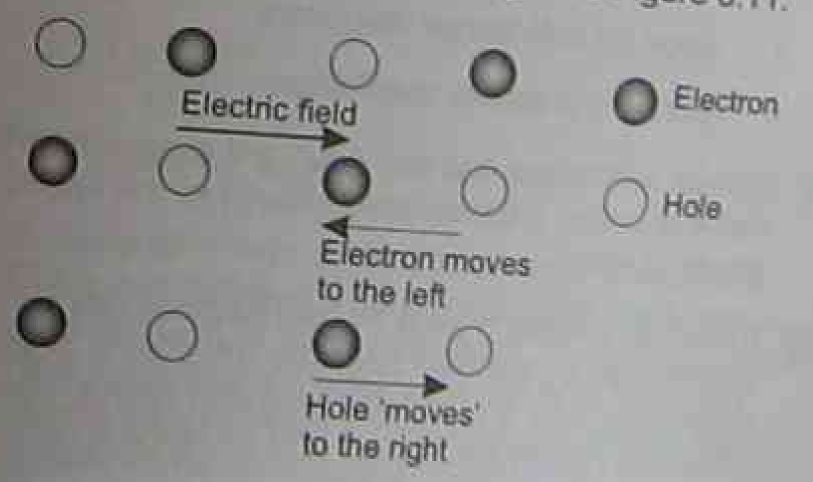


Figure 8. 11

37 (a) The 'electron sea' model of metals has the positive ions of the crystal lattice surrounded by a 'sea' of electrons that are free to move through the lattice. Resistance comes about as these electrons collide with imperfections in the lattice.

(b) Random motion of the electrons means that there is no net movement in any direction. To get the electrons to move in a particular direction an electric field needs to be set up by connecting to a source of potential difference.

(c) Electrons colliding with other electrons and imperfections in the lattice are continually being accelerated and decelerated. The drift velocity is the speed with which the electrons 'drift' along under the influence of the electric field.

38 (a) Superconductivity is a phenomenon whereby certain materials lose all electrical resistance as their temperature falls below a critical value (originally ~4 K but now as high as ~150 K)

(b) Mercury

(c) Superconductors are currently, or will be used in the future in:

- magnetic resonance imaging (MRI) machines.
- *Maglev* trains.
- Electricity transmission cables.
- Computer switching.

(d) In *Maglev* trains, large superconductors are used to levitate the train off the tracks. This reduces friction and allows for great speeds.

(e) The advantages and disadvantages are shown in Table 8.1.

Table 8. 1

Advantages	Disadvantages
Produces intense magnetic fields with little current wastage.	Brittle Difficult to make into wires.
Reduces energy losses in transmission wires.	Chemically unstable.

39 The BCS theory of superconductors explains superconductivity as follows: electrons moving through a crystal lattice cause the lattice to distort which increase the *positive charge density* in the vicinity of the electron. This attracts a second electron to the first to create a *Cooper Pair*. (Quantum physics indicates that this lowers the energy state of the electrons, which is why it can occur even though like charges repel.) The Cooper pairs pass unimpeded through the lattice. The Cooper pairs are continually being formed, broken and reformed but effectively allow the electrons to pass through the lattice with no resistance.

CHAPTER FOUR: *MEDICAL PHYSICS* ANSWERS TO QUESTIONS AND PROBLEMS

SECTION 1: ULTRASOUND

1 See text.

2 $\frac{I_r}{I_0}=\frac{[Z_2-Z_1]^2}{[Z_2+Z_1]^2}$

$$\frac{I_r}{I_0}=\frac{[(1.70-1.38)\times10^6]^2}{[(1.70+1.38)\times10^6]^2}$$
$$=0.011$$

3 See text.

4 See text.

5 See text.

6 $s=vt=1540\times\frac{0.025\times10^{-3}}{2}=0.019\text{ m}$

$$s=vt=1540\times\frac{0.040\times10^{-3}}{2}=0.031\text{ m}$$

7 See text.

8 See text.

SECTION 2: ELECTROMAGNETIC RADIATION

1–6 See text.

SECTION 3: RADIOACTIVITY

1–5 See text.

SECTION 4: MAGNETIC RESONANCE IMAGING

1–3 See text.

CHAPTER FOUR: *MEDICAL PHYSICS* WORKED SOLUTIONS AND ANSWERS TO TEST

Question 1

(a) (i) Ultrasound is sound with frequencies greater than 20 kHz.

(ii) In medical scanning, *piezoelectric transducers* produce the ultrasound. These work on the principle that certain crystals can be made to vibrate by applying a varying potential difference to the crystal. The vibrating crystal sets up ultrasound waves that can be directed into a patient.

(iii) The large difference in acoustic impedance between the air and skin means that most of the energy is reflected and does not pass into the patient. Gel lessens the amount of reflection so that the ultrasound can enter the body and reflect off internal interfaces.

(b) Advantages of ultrasound include (any three of the following):

- non-invasive
- no ionising radiation used
- no known detrimental health effects
- good for soft-tissue diagnosis
- portable units are available.

(c) Human soft tissue and the brain are predominantly made of water. (Hence the similarity to the speed of sound in water.)

(d) Electrons emitted from a heated filament are accelerated by the high potential difference in an evacuated tube and strike a tungsten target. The electrons rapidly decelerate and produce X-rays (and heat).

(e) (i) Half-life is the time it takes for half the mass of an element to decay into a new element.

(ii) The fraction of element remaining decreases by half, for each half life. In 18 day there are 18/6 = 3 half-lives. So fraction remaining = $\frac{1}{2}\times\frac{1}{2}\times\frac{1}{2}=\frac{1}{8}$

(iii) A short half-life means that the radiation is reduced to 'safe' limits soon after the diagnostic technique is completed.

(i) The disadvantage is that a continuous supply of radioisotope is required and this means that the source needs to be close to where it is used.

(f) (i) The cyclotron produces radioisotopes for medical diagnosis.

(ii) F-18, a positron emitter is a radioisotope used in PET scans. (It is used in labelling glucose which is taken up by active sites.)

(iii) It is placed near the hospital because the short half-life means it rapidly decays away.

(g) In a MRI scan, the patient is placed in a strong magnetic field which tends to align some of the 'atomic magnets' in the molecules within the patient. Pulses of radio-frequency (RF) electromagnetic waves bombard the patient and at particular frequencies RF energy is absorbed and emitted. A computer decodes this information and an image (2D or 3D) is produced.

Question 2

(a) (i) High frequency waves are absorbed more readily than low frequency waves. This means they cannot penetrate as far and this limits their use.

(ii) Disadvantages of ultrasound include:

- they cannot pass through bone and so are of no use on the brain.
- not very good at distinguishing between soft tissues.

(b) From the relationship between acoustic impedance, density and speed we have:

$$Z=\rho v$$
$$\rho=\frac{Z}{v}$$
$$=\frac{1.68\times10^6}{1541}\text{ kg.m}^{-3}$$
$$=1.09\times10^3\text{ kg.m}^{-3}$$

(c) A beam of X-rays is directed through the patient. Bone and different tissue types allow the X-rays to pass through to varying degrees. An image is formed on a photographic plate as a series of 'shadows'. Bones absorb more X-rays than soft tissue. They appear white on a darker background.

(d) Tc-99m is attached to a biologically active chemical such as glucose. This is injected (or in some cases inhaled) by a patient and gets 'taken up' in the metabolic processes. Different chemicals are organ specific and so accumulate in particular organs. 'Hot spots' (too much uptake) and 'cold spots' (too little uptake) can indicate abnormalities within the organ. These spots are detected by 'gamma ray' cameras that move over the organ being investigated. The greater the amount of radioactive emissions, the greater the concentration of the radioisotope.

(e) Pure gamma emitters are used because the gamma rays can 'escape' from inside the body to be detected and they cause less 'local' damage than the more heavily ionising alpha and beta emitters/rays.

(f) (i) A positron is a positive electron. (An electron's antiparticle.)

(ii) In PET imaging the positron comes from the radiopharmaceutical used in the patient.

(g) (i) The spin of an atom is a measure of the atom's angular momentum. (It is a quantum property like mass and charge.)

(ii) Spinning atoms placed in a magnetic field tend to align in the field (either 'parallel' or 'antiparallel').

(iii) MRI uses a powerful cylindrical magnet which surrounds the patient. The intense magnetic field forces nuclei (which act as tiny magnets) in some of the atoms in the tissue being scanned (notably hydrogen) to 'line up'. The atoms do not line up exactly with the field: rather they precess around it. Pulses of radio-frequency electro-magnetic waves are then directed at the body and, if their frequency equals that of the nuclei - the *Larmor* frequency – *resonance* occurs and nuclei absorb the radio wave's energy. When the radio wave is 'turned off' the nuclei return to their original orientation in the field. In doing so they release the absorbed energy as weak radio signals of the same frequency as the incident wave. A receiving coil detects this energy. Before the atoms have re-aligned, the field is changed from a constant field to a variable field – a *gradient*. Different atoms realign to different strength fields giving out radio frequencies of slightly different frequency. Each frequency corresponds to a particular field strength and the latter can be localised to a particular location in the patient's body. The strength and duration of the signals is dependent on the properties of the tissue from which they are emerging. The higher the spin density, the greater the concentration of hydrogen nuclei in the site being imaged. A computer decodes the signals into a visual image in a similar manner as for CT and PET scans.

(iv) MRI is preferred for brain imaging because it can 'see through' bone and it can distinguish between white and grey matter.

Question 3

(a) In an *A*-scan (amplitude scan) a single transducer scans along a line in the body and the resulting echoes are plotted as a function of time. In the *B*-scan (brightness mode) a linear array of transducers scan a plane in the body (that is, a 'slice' from front to back). In a *B*-scan mode, a point represents the echo for each scan. The point's position is given by the time delay and the brightness depends on the signal strength. The largest amplitude corresponds to the brightest spot, displayed as almost white. The smallest amplitude is the dullest spot and is almost black. Intermediate brightness is represented by various shades of grey.

(b) (i) The cathode produces the electrons.

(ii) The anode accelerates the electrons to high energies.

(iii) The tungsten 'target' stops the electrons. The energy is released as X-rays (and heat).

(iv) The X-rays could be made 'harder' by increasing the accelerating potential difference.

(v) In its simplest form, a beam of X-rays is directed through the patient. Bone and different tissue types allow the X-rays to pass through to varying degrees. An image is formed on a photographic plate as a series of 'shadows'.

(c) To produce a CAT (or CT) image, the patient lies on a table that is able to pass through a circular-scanning machine called a gantry. (The table lies along the axis of the gantry, hence the use of the term axial in CAT.) X-rays from the gantry are fired at the organ being scanned and pass through the tissue. The degree of absorption – *attenuation* – depends on the tissue type (or bone) that it passes through. Detectors measure the amount of X-rays that pass through. The gantry rotates around the patient and X-rays are fired from different angles. The data is analysed by a computer which uses an *algorithm* to produce a cross-sectional 'slice' on a video screen. A series of 'slices' (think of a sliced loaf of bread) can be made to build a picture of an entire organ or even the whole body.

(d) (i) A radiopharmaceutical is a biologically useful chemical that is labelled with a radioisotope.

(ii) Injected or inhaled.

(iii) In *isotope scanning* (also called *nuclear imaging* and *nuclear scanning*) a radioisotope is introduced into the body. The radioisotope acts identically to its stable isotope and so can take part in physiological processes. The radioactivity means that it can be easily traced (for example, by *gamma cameras* moving back and forth over the organ being scanned), even in minute quantities. This allows the passage and accumulation of the radioisotope to be determined. Abnormalities are identified by either a complete or partial lack of uptake (*cold spot*) or excessive uptake (*hot spot*) of the radioisotope. By taking a series of images over time, any irregularities in the movement and concentration of the radioisotope could indicate a problem organ. Nuclear imaging works well with both bone and soft tissue.

(e) MRI

Advantages	Disadvantages
▪ No ionising radiation (that is, X-rays or radioactive emissions) is used. ▪ Provides the clearest pictures of organs such as the brain. (MRI hardly 'sees' bone.) ▪ Can be used to scan the chest, abdomen and joints. ▪ The technique of choice for imaging the brain and central nervous system. ▪ With *functional magnetic resonance imaging* (fMRI) it can provide both anatomical and functional views of the brain.	▪ Most expensive imaging technique. The machine itself costs ~$1M. ▪ Some people experience claustrophobia from the closeness of lying in the long tube. (2-3% cannot complete the examination.) ▪ MRI requires a long time for a scan (~40 min) compared to ~5 min for a CT scan. This impacts on operating costs. ▪ Aneurism clips may 'toggle' and tear the artery they are supposed to repair. ▪ People with pacemakers or metal prothesis cannot be scanned (due to the intense steady magnetic fields used).

Question 4

(a) (i) Ultrasound has no harmful effects on the foetus.

(ii) A sector scan is the familiar 'wedge' or 'fan' shaped scan. Modern ultrasound scanners have a scan head consisting of more than 100 piezoelectric transducer elements. Each element is a block of *PZT* less than 1 mm wide and ~1 cm tall. This 'phased array' is electronically controlled so that each successive beam makes a small angle with the previous beam producing the two-dimensional scan.

(b) (i) Acoustic impedance is a measure of the ease with which sound travels through the medium.

(ii) $$\frac{I_r}{I_o}=\frac{[Z_2-Z_1]^2}{[Z_2+Z_1]^2}$$

$$\frac{I_r}{I_o}=\frac{[(1.62-1.54)\times10^6]^2}{[(1.62+1.54)\times10^6]^2}$$
$$=0.0006$$

(c) A CAT scan is better than ultrasound and simple radiography because it is much more sensitive. For example, it can distinguish ~256 shades of grey in an image whereas a radiograph can only distinguish ~12 shades.

(d) (i) An endoscope is a tube that is inserted in an opening in the body to see inside the body and even to take tissues samples.

(ii) The coherent bundle is one where the optical fibres are kept in the same relative position to each other. This allows them to transmit an image.

(iii) A cable running the length of the endoscope controls miniature surgical instruments such as toothed (biopsy) forceps. The biopsy forceps can take a tiny sample which can then be removed for analysis.

(e) The first step in making a PET image is to give the patient a radioisotope (also called a *radiopharmaceutical* that closely resembles a natural substance in the body. For example, a commonly used radiopharmaceutical is 2-fluoro-2-deoxy-D-glucose (FDG), which is similar to natural glucose but is labelled with the radioisotope fluorine-18. F-18 has a half-life ~2 hours and is readily produced in a particle accelerator called a cyclotron. The radiopharmaceutical releases positrons, which interact with electrons in the patient's body, and the subsequent gamma rays are detected. Since the gamma rays are emitted with the same energy and in opposite directions, a pair of detectors placed at 180° to each other will detect the two rays. Computers calculate the place from which they emerged by comparing the arrival times of the two photons. This data is analysed by powerful computers (in the same manner in which CAT is analysed) and is displayed as a series of 'slices' or 'sections' on a video screen. By taking several adjacent slices at the one time, a *three-dimensional image* can be produced.

CHAPTER FIVE: *ASTROPHYSICS* ANSWERS TO QUESTIONS AND PROBLEMS

SECTION 1: MAKING OBSERVATIONS

1–5 See text.

SECTION 2: ASTROMETRY

1 See text.

2 See text.

3 From the relationship between parallax and distance we have:

$$d=\frac{1}{p}$$
$$p=\frac{1}{d}=\frac{1}{5}=0.2\text{ arc seconds}$$

SECTION 3: SPECTROSCOPY

1– 6 See text.

7 From Wein's Law:

$$\lambda_{max}=\frac{W}{T}$$
$$T=\frac{W}{\lambda_{max}}$$
$$=\frac{2.89\times10^{-3}}{600\times10^{-9}}$$
$$=4817\text{ K}$$

SECTION 4: PHOTOMETRY

1 See text.

2 The apparent magnitude is its magnitude as viewed from the Earth. The absolute magnitude is the magnitude it would have if it were 10 pc from Earth. Because the Sun is much closer than this, its apparent magnitude is brighter than its absolute magnitude. (The smaller the magnitude, the brighter the star.)

3 The distance-magnitude relationship is:

$$m-M=5\log\frac{d}{10}$$
$$M=m-5\log\frac{d}{10}$$
$$=6-5\log\frac{40}{10}$$
$$=6-5\log 4$$
$$=3.0$$

4 As for question 3 above

$$m-M=5\log\frac{d}{10}$$
$$8-0=5\log\frac{d}{10}$$
$$\log\frac{d}{10}=\frac{8}{5}$$
$$\frac{d}{10}=39.8$$
$$d=398\text{ parsecs (pc)}$$

5 The star would be red with a surface temperature of approximately 4000 K.

SECTION 5: BINARY AND VARIABLE STARS

1 See text.

2 See text.

3 The sum of the masses of a binary star is found from:

$$m_1 + m_2 = \frac{a^3}{T^2}$$
$$= \frac{22^3}{40^2}$$
$$= 6.66 \text{ solar masses}$$

4–6 See text.

SECTION 6: STELLAR EVOLUTION

1 See text.

2 See text.

3 Red giants have their energy spread over an enormous surface area. Consequently the gas cannot be heated to a very high temperature and so the star appears red (surface temperature is ~3000 K). Luminosity is the total power radiated by the star. The enormous surface area of the red giant ensures it liberates large amounts of energy per second even though the temperature is relatively low.

4 See text.

5 See text.

6 See text.

7 See text.

8 Black holes do not emit radiation and so their apparent and absolute magnitude and temperature cannot be measured. Hence they cannot be plotted on the H-R diagram.

9 See text.

CHAPTER FIVE: *ASTROPHYSICS* WORKED SOLUTIONS AND ANSWERS TO TEST

Question 1

(a) Any two of the following:

- Approximately twice as high as the next major observatory.
- Lies above 40% of the Earth's atmosphere.
- Calm, clear nights.
- Remains above the clouds almost all of the time.

(b) (i) Trigonometric parallax.

(ii) The age of the universe was reassessed as ~12 billion years since the distances were greater than previously calculated.

(c) (i) The relationship between distance and parallax is:

$$d = \frac{1}{p}$$
$$p = \frac{1}{d}$$
$$= \frac{1}{\frac{4.3}{3.26}}$$
$$= 0.76 \text{ arcseconds}$$

(ii) From the relationship between absolute and apparent magnitudes, we have:

$$M = m - 5\log_{10}\frac{d}{10}$$
$$= 0.06 - 5\log_{10}\frac{\frac{4.3}{3.3}}{10}$$
$$= 4.5$$

(d) (i) Spectroscopy relies on the fact that elements emit (or may absorb) definite frequencies of electromagnetic radiation (e.g. light, infrared, etc). The frequencies emitted (or absorbed) are unique to that element and serve to fingerprint the element.

(ii) A photomultiplier tube allows much fainter stars to be measured than photographic plates. It also gives instantaneous readout.

(e) (i) Colour index is the difference between the magnitude of a star photographed through a blue filter (*B*) and its magnitude photographed through a yellow filter (*V*) — the latter approximates to the visual response, that is, colour index = *B*–*V*.

(ii) Astronomers use colour index to help classify stars, which aids in the description and understanding of stars.

(f) (i) Approximately 5.4 days, from the graph.

(ii) Stars are spheres of gas and as such are capable of expansion and contraction. The light intensity brightens and fades as the star undergoes expansion and contraction respectively.

(g) (i) A white dwarf represents one of the final stages in stellar evolution. White dwarfs are stars with a radius of ~5000 km but an average density of 10^9 kg.m^{-3} at a surface temperature of 10^4 K.

(ii) White dwarfs are formed when red giants have used their fuel supply. The outer layers of gas of the red giant are released as a planetary nebula and the inner core contracts to a diameter about that of the Earth. In white dwarfs, no nuclear reactions are occurring. They continue to release residual energy until it eventually ceases to radiate.

(h) (i) Absolute or apparent magnitude.

(ii) See text Figure 5.22

X — red giants

Y — main sequence

Z — white dwarfs.

(iii) As you move from bottom right to top left, the stars are: hotter, larger, bluer and give out more light.

(i) The lower the turn off point for a cluster on an H-R diagram the older the cluster. The hotter more massive stars (*O* stars) leave first followed by the next hottest (*B* and *A* stars). A lack of *O* and *B* and *A* indicates they have had sufficient time to evolve away from the main sequence.

Question 2

(a) (i) Any two of the following observations:

- The rough features of the Moon.
- The phases of Venus.
- The moons of Jupiter.
- Millions more stars were visible than with the unaided eye.

(ii) These observations conflicted with the beliefs of the time that: the heavens are perfect; they are unchanging; and that the planets revolved around the Earth and not the Sun.

(b) Factors affecting the brightness of a star viewed from Earth include:

- The intrinsic brightness of the star (which depends on its surface temperature and radius).
- The distance to the star.
- The effects of the atmosphere such as pollution (including light pollution).
- Whether it is measured by photographic means or by photomultiplier tubes.

(c) $d = \frac{1}{p} = \frac{1}{0.76} = 1.31$ parsecs

(d) $\lambda_{max} = \frac{W}{T} = \frac{2.89 \times 10^{-3}}{6000} = 4.8 \times 10^{-7}\text{ m} = 480\text{ nm}$

(e) From the distance-magnitude relationship:

$$m - M = 5\log\frac{d}{10}$$
$$M = m - 5\log\frac{d}{10}$$
$$= 26.7 - 5\log\frac{4.8\times10^{-5}}{10}$$
$$= 6 - 5\times(-6.318)$$
$$= 4.89$$

(f) (i) Spectroscopic parallax is a method used to measure distances to stars. (Contrary to its name, it does not use parallax.) Astronomers estimate the absolute magnitude from its stellar class (and so its temperature) and knowing its apparent magnitude, they can calculate the distance.

(ii) Using the distance formula:

$$m - M = 5\log\frac{d}{10}$$
$$1.0 - (-2.5) = 5\log\frac{d}{10}$$
$$\log\frac{d}{10} = \frac{3.5}{5}$$
$$d = 50 \text{ pc}$$

(g) Colour index (*B* – *V*) is the difference between the magnitudes of a star measured through a blue filter and a yellow filter (approximates to the visual response). For a red star, the intensity in yellow-green would exceed that in blue, so *B* – *V* is positive (remember, as brightness increases, magnitude decreases). Conversely, blue stars have negative values of *B* – *V*.

(h) (i) This light curve is produced by an eclipsing binary.

(ii) At X and Z the brighter star is being eclipsed by the duller of the pair. At Y, the duller star is being eclipsed by the brighter star (i.e. the brighter star is moving in front of the duller star).

(i) *Red giants* — As hydrogen is burnt to helium in the nuclear furnace, the internal temperature of the star increases. The helium is less transparent to energy than the hydrogen and so the rate of conversion of hydrogen to helium increases. These high temperatures cause the outer regions to expand. As they do, the outer layers cool as the energy is spread over a larger surface area. The temperature drops to ~3000 K and the star becomes a red giant.

Binary stars — These consist of two stars orbiting about their common centre of mass and obeying the Law of Universal Gravitation. There are three main types: visual, spectroscopic and eclipsing.

Open (Galactic) clusters — These consist of loose irregular aggregations of a few hundred to a few thousand stars. Individual stars are easily distinguished. They are young clusters containing large amounts of dust and gas from which stars are born.

Globular clusters — These are tightly packed collections of hundreds of thousands and even millions of stars. They are old clusters containing evolved stars such as red giants and white dwarfs.

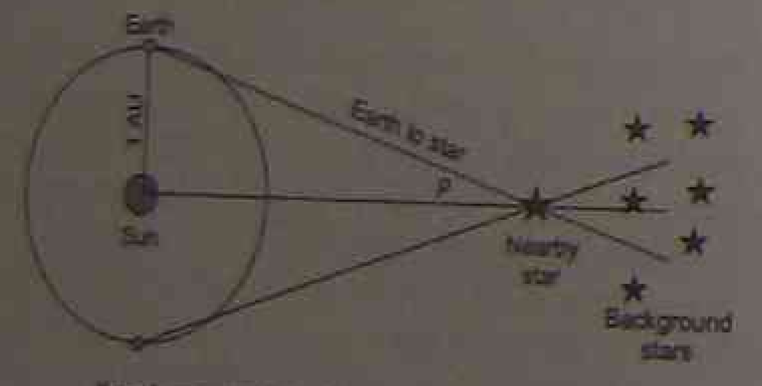
Dust clouds — The interstellar medium consists of dust and gases. The dust may consist of graphite and some silicate materials as well as ice. The total mass of dust and gas is small compared to the stellar mass.

(j) Stars form from local condensations of cool, extremely rarefied gas and dust globules. A chance disturbance may cause a larger mass of gas to form and its stronger gravitational field will attract further gas. As the gas condenses further, the temperature of the cloud rises as gravitational potential energy is converted to heat energy. The temperature continues to rise until the star becomes luminous and reaches the main sequence. Fusion of hydrogen into helium produces the light emitted by the star. The larger the mass, the more to the left of the main sequence the star joins.

Question 3

(a) Adaptive optics involves sampling part of the incident light (for example from a star), and measuring the amount of atmospheric distortion (bending) in a *wavefront sensor*. Any distortions in the wavefront sensor correspond to distortions in the atmosphere above the telescope. By sampling the light up to 1000 times per second and feeding the information back to an adjustable 'flexible mirror', astronomers can effectively 'straighten out' the light that has been bent by the atmosphere. Ideally this allows the part of the light used to create the image to pass through the telescope undistorted, dramatically improving image resolution.

(b) (i) See Figure 8.12.



If p = 1 arc second, the distance to the nearby star is 1 parsec

Figure 8. 12

(ii) As in Figure 8.12.

(iii) Trigonometric parallax is limited by the ability of telescopes to measure the very small parallax angles for all but ~700 of the nearest stars.

(iv) The period-luminosity relationship for Cepheid Variables OR Spectroscopic parallax.

(c) Solving the distance formula we have:

$$
\begin{aligned}
m - M &= 5\log\frac{d}{10} \\
M &= m - 5\log\frac{d}{10} \\
&= 6 - 5\log\frac{20}{10} \\
&= 4.5
\end{aligned}
$$

(d) Spectral line width is affected by the star's density. The greater the density, the more spread out the lines. This allows the density of the stars to be estimated.

(e) The temperature determines the colour index of stars. The higher the temperature, the bluer the star: the cooler the star, the redder the star. Similarly the spectral classes are determined by the presence or absence of certain spectral lines which are in turn determined by the temperature. Thus temperature, spectral class and colour index are all related.

(f) Cepheids are variable stars which vary in magnitude with absolutely regular periods. A relationship exits between the apparent brightness and the period (log scale). By reading off this period-luminosity curve, the apparent brightness can be determined. Since the absolute brightness can be estimated from other data, the distance can be determined by the inverse square law for light. For a star of apparent brightness m at a distance r and absolute brightness M at a distance R (10 parsecs) $\frac{m}{M} = \frac{R^2}{r^2}$ i.e. $r = R \times \sqrt{\frac{M}{m}}$.

(g) (i) The energy radiated by the Sun can be considered to move outwards from the Sun in the shape of a sphere centred on the Sun. At the distance from the Sun to the Earth the surface area of this sphere is given by:

$$
\begin{aligned}
A &= 4\pi R^2 \\
&= 4\pi \times (1.5 \times 10^{11})^2 \\
&= 2.8 \times 10^{23}\ \text{m}^2
\end{aligned}
$$

$$
\begin{bmatrix}\text{energy radiated} \\ \text{per m}^2\text{ per sec} \\ \text{from the sun}\end{bmatrix} = \begin{bmatrix}\text{energy received} \\ \text{per m}^2\text{ per sec} \\ \text{on the earth}\end{bmatrix} \times \begin{bmatrix}\text{surface area} \\ \text{of the 'sphere'} \\ \text{of radiation}\end{bmatrix}
$$

$$
\begin{aligned}
&= 1400 \times 2.8 \times 10^{23} \\
&= 3.9 \times 10^{26}\ \text{J.m}^{-2}.\text{s}^{-1}
\end{aligned}
$$

(ii) The energy comes from nuclear fusion reactions whereby hydrogen is fused to form helium + energy.

(iii) See text Figure 5.29

(h) The switch on of helium burning (when the supply of hydrogen in the core is depleted) occurs very quickly so once the stars leave the main sequence they evolve quickly into red giants. This creates the H-R gap.

(i) (i) The oldest cluster is M67

(ii) This is because it has the lowest turn-off point. This indicates that the larger, hotter stars (O, B and A) have already evolved off the main sequence. Since this takes millions of years to occur, the cluster must be old.

Question 4

(a) (i) An interferometer is formed when two or more telescopes have their data integrated with each other so that they act as a 'single' telescope.

(ii) Its advantages include: increased resolution; reduces the need for single large diameter mirrors and lenses (with their inherent engineering problems).

(b) A star approximates to a black body and as such there is a relationship between the energy radiated and the surface temperature of the star. By use of the Stefan-Boltzmann Law (which states that $E \alpha T^4$, where E is the energy radiated per unit surface area per unit time and T is absolute temperature) or Wien's Law ($\lambda_{max} \propto \frac{1}{T}$), which states the maximum wavelength from a hot body is inversely proportional to the absolute temperature), the surface temperature can be estimated.

(c) (i) Sirius. The brighter a star the smaller is its magnitude.

Comment: This situation arises from historical reasons where a first-magnitude star was defined to be one-hundred times brighter than a sixth-magnitude star.

(ii) The hotter a star, the bluer it will appear. This corresponds to a smaller value of its colour index. Hence Sirius will be the hottest star of those given.

(iii)

$$
\begin{aligned}
m - M &= 5\log_{10}\frac{d}{10} \\
-0.73 - (-4.70) &= 5\log_{10}\frac{d}{10} \\
\log_{10}\frac{d}{10} &= \frac{3.97}{5} = 0.794 \\
\frac{d}{10} &= 6.22 \\
d &= 62.2\ \text{parsecs}
\end{aligned}
$$

(iv) $p = \frac{1}{d} = 1.6 \times 10^{-2}$ arc seconds

Comment: This is far too small to be measured on Earth.

(v) ~M2

(d) (i) It was proposed that gravitational potential energy was converted into heat energy as the dust cloud collapsed to form the star.

(ii) The energy available from this conversion could not account for the total energy output of the star.

(iii) Bethe proposed that hydrogen nuclei fused to form helium with the release of energy, that is:

hydrogen + hydrogen → helium + energy

(e) From the graph: $M \sim -3$, so:

$$
\begin{aligned}
m - M &= 5\log_{10}\frac{d}{10} \\
4 - (-3) &= 5\log_{10}\frac{d}{10} \\
\frac{d}{10} &= 25.1 \\
d &= 251\ \text{parsecs}
\end{aligned}
$$

(f) (i) See Figure 8.13 The following are the likely states:

Sun — main sequence

Antares — red giant

Sirius — main sequence

Betelgeuse — red giant

Barnard's star — main sequence

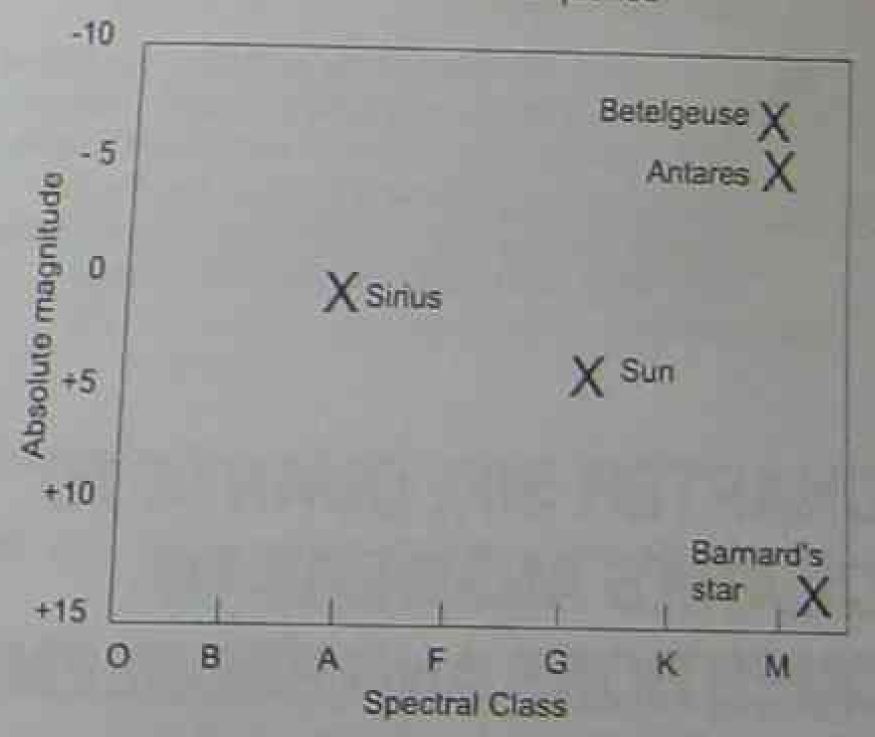


Figure 8. 13

(ii) Sirius (spectral class A). The hottest stars are O, followed by B, A, F ...

(iii) Helium. (Betelgeuse is a red giant.)

(iv) Red. (Spectral class M.)

(g)

Open Cluster	Globular cluster
H-R diagrams look different for different clusters.	H-R diagrams all look similar.
Both giants and supergiants are present.	There are no supergiants.
The giant branch occurs at zero absolute magnitude.	The giant branch commences at absolute magnitude of ~ -3.5 and proceeds downwards to fainter stars.
Giant branch is separate from main sequence.	A narrow band connects the giant branch with the main sequence.
Some are young, some are old	All have low 'turn-off' points indicating they are old clusters.

(h) (i) A *protostar* is the beginnings of a star. It results when local condensations of interstellar gas and dust occur. These heat up from the conversion of gravitational potential energy into heat — fusion reactions don't occur as yet and so they do not emit light.

(ii) The greater the mass of the protostar, the further to the left of the main sequence it joins. Stars with a mass similar to that of the Sun will evolve into red giants and then into white dwarfs. The more massive stars will evolve into neutron stars (and even black holes for the most massive stars).

CHAPTER SIX: *QUANTA TO QUARKS* ANSWERS TO QUESTIONS AND PROBLEMS

SECTION 1: MODELS OF THE ATOM

1 See text.

2 See text.

3 λ is the wavelength of the light emitted when an electron falls from an initial energy level n_i to a final energy level n_f and R_H is Rydberg's constant.

4 From the Balmer equation:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$= 1.097 \times 10^7 \times \left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

$$\lambda = 486 \text{ nm}$$

$$E = hf$$

$$= h \times \frac{c}{\lambda}$$

$$= 6.6 \times 10^{-34} \times \frac{3.0 \times 10^8}{486 \times 10^{-9}}$$

$$= 4.0 \times 10^{-19} \text{ J}$$

5–8 See text.

SECTION 2: QUANTUM PHYSICS

1 See text.

2 $\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.5 \times 10^6} = 4.8 \times 10^{-10}$ m

3-4 See text.

SECTION 3: APPLICATIONS OF NUCLEAR PHYSICS

1–6 See text.

7 Binding energy and mass defect are related.

$$\text{Mass defect} = \begin{bmatrix} 6 \times 1.007276 + \\ 6 \times 1.008665 + \\ 6 \times 0.000549 \end{bmatrix} - 12.000000$$

$$= 0.09894 \text{ u}$$

Binding energy = 0.09894 x 931 = 92.1 MeV

SECTION 4: NUCLEAR APPLICATIONS

1–3 See text.

SECTION 5: STRUCTURE OF MATTER

1–4 See text.

CHAPTER SIX: *QUANTA TO QUARKS* WORKED SOLUTIONS AND ANSWERS TO TESTS

Question 1

(a) (i) The experiment showed that thin gold foil was capable of bouncing back bombarding alpha particles.

(ii) Geiger and Marsden.

(iii) That the positive charge is concentrated in a dense core of nucleus and most of the atom is empty space.

(b) (i) λ is the wavelength of the emitted light;

n is the principal quantum number;

n_f is the final energy level; and n_i is the initial energy level;

R_H is the Rydberg constant.

(ii) The longest wavelength corresponds to the smallest frequency. This occurs for $n_i = 3$.

Comment: The closer the energy levels, the lower the frequency.

(iii) From the equation we have:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$= 1.097 \times 10^7 \times \left(\frac{1}{4} - \frac{1}{9}\right)$$

$$\lambda = 656 \text{ nm}$$

(c) (i) $\lambda = \frac{h}{p}$ where λ is the wavelength of the matter wave, h is Planck's constant and p is the momentum.

(ii) The equation links wavelength (a wave characteristic) to momentum (a particle characteristic).

(d) Davisson and Germer fired a beam of electrons at the surface of a nickel crystal. They varied the angle of the beam and measured the intensity of the reflections. They found that the electron beam exhibited the phenomenon of diffraction. This indicated that the electrons were acting as waves— the matter waves postulated earlier by de Broglie.

(e) (i) Pauli noticed a discrepancy between the mass and energy of electrons in beta decay. He believed that the 'lost' energy and momentum was being carried away by a neutral, mass-less particle.

(ii) The neutrino hardly interacts with matter due to its neutrality and zero rest mass. Without interaction, it is difficult to detect.

(f) Medicine — Radioisotopes can be used in both diagnostic and therapeutic roles. In diagnosis, a radioisotope is attached to a chemical used by the body to form a radiopharmaceutical. This chemical moves throughout the body and accumulates in specific organs. By scanning with a gamma ray camera, the path and concentration of the radiopharmaceutical can be assessed. A 'hot spot' (too much uptake) or a 'cold spot' (too little uptake) can indicate abnormalities.

(g) See Figure 8.14.

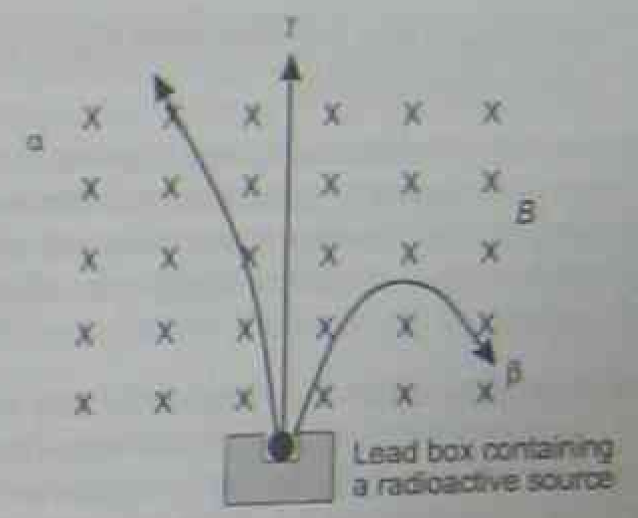


Figure 8. 14

(h) (i) Quarks are the elementary building blocks of matter.

(ii) Leptons: Any one of: electron; electron-neutrino; muon; muon-neutrino; tau; tau-neutrino.

(iii) Bosons: Any one of: photon; graviton; gluon, weakon.

Question 2

(a) (i) All of the alpha particles should pass through with only minor deflections.

(ii) Most alphas passed straight through, but about 1 in 8000 bounced back. Rutherford proposed that there was a dense nucleus containing all the positive charge and most of the mass — the rest of the atom was empty space except for a few electrons. Those alphas that bounced back were involved in 'head-on' collisions with the nucleus. Most alphas, however, missed the tiny nucleus and passed through the 'empty' region surrounding the nucleus.

(iii) (1) Atoms are stable. Elements give off line emission spectra and not continuous spectra.

(2) Bohr.

(3) Bohr postulated that electrons can orbit in 'discrete energy levels' without radiating energy.

(b) For an electron transition, we have:

$$\Delta E = E_2 - E_1 = 10.4 - 6.7 = 3.7\,\text{eV}$$
$$= 5.92 \times 10^{-19}\,\text{J}$$

$$\Delta E = hf = \frac{hc}{\lambda} \therefore \lambda = \frac{hc}{\Delta E}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{5.92 \times 10^{-19}}$$
$$= 3.3 \times 10^{-7}\,\text{m (330 nm)}$$

(c) Matter waves are useful in explaining the stability of atoms. As long as an integral number of electron matter waves fit into the 'orbit', they can constructively interfere and hence no energy is lost.

(d) (i) Electron diffraction.

(ii) This showed that electrons were acting as waves—matter waves.

(iii) Any two of the following: electron microscopes; the wave nature of matter; the indeterminacy of the position of electrons and other sub-atomic entities; the probability interpretation of quantum physics...

(e) Chadwick following-on from experiments by Joliot and Curie, bombarded beryllium with alpha particles, as shown in Figure 8.15. A very energetic uncharged emission came from the beryllium (and analysis showed it not to be gamma radiation) and this was then allowed to bombard paraffin (rich in hydrogen, that is, protons). Protons were detected emerging from the paraffin. By application of the laws of energy and momentum conservation to a collision between particles, Chadwick deduced the existence of the neutron.

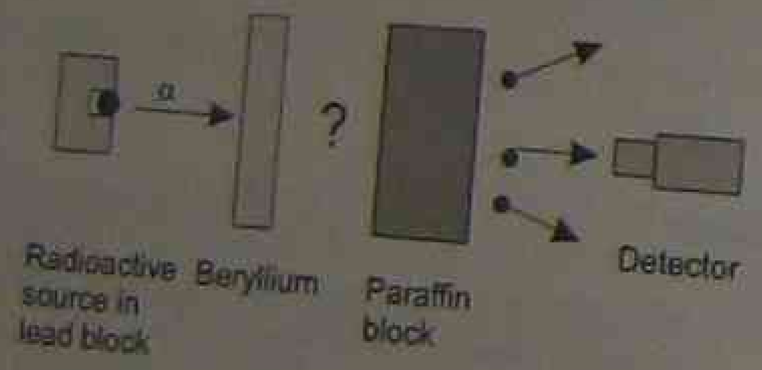


Figure 8. 15

(f) Neutrons, with a neutral charge are not repelled by the positive nucleus whereas alphas and protons are (because of their positive charge).

(g) (i) Nucleons are protons and neutrons.

(ii) A nuclear force of attraction is needed to keep the positively charged protons together in the nucleus.

(iii) The nuclear force:

- is extremely strong
- is very short range
- can be attractive or repulsive depending on the separation of the nucleons.

(h) (i) Leptons, quarks and bosons.

(ii) Any one of the following: graviton mediates gravity; photon mediates the electromagnetic force; gluon mediates the strong nuclear force; weakon mediates the weak nuclear force.

Question 3

(a) Rutherford's model with the electrons 'orbiting' the nucleus created problems regarding the stability and spectra of atoms. The atoms should radiate a continuous spectrum and eventually 'run down'.

Comment: According to Maxwell's electromagnetic theory, any accelerated charge (and one going in a curve must be accelerating) would give out energy continuously and hence the electron should spiral into the nucleus. The existence of line spectra and the stability of atoms showed that this did not happen.

(b) The non-radiance of electrons in stationary states is explained in terms of 'matter waves'. Particles like electrons have a wave nature including a wavelength. As long as an integral number of electron wavelengths fit into the 'electron orbit', constructive interference occurs and no energy is lost (that is, radiated away).

(c) (i) See Figure 8.16.

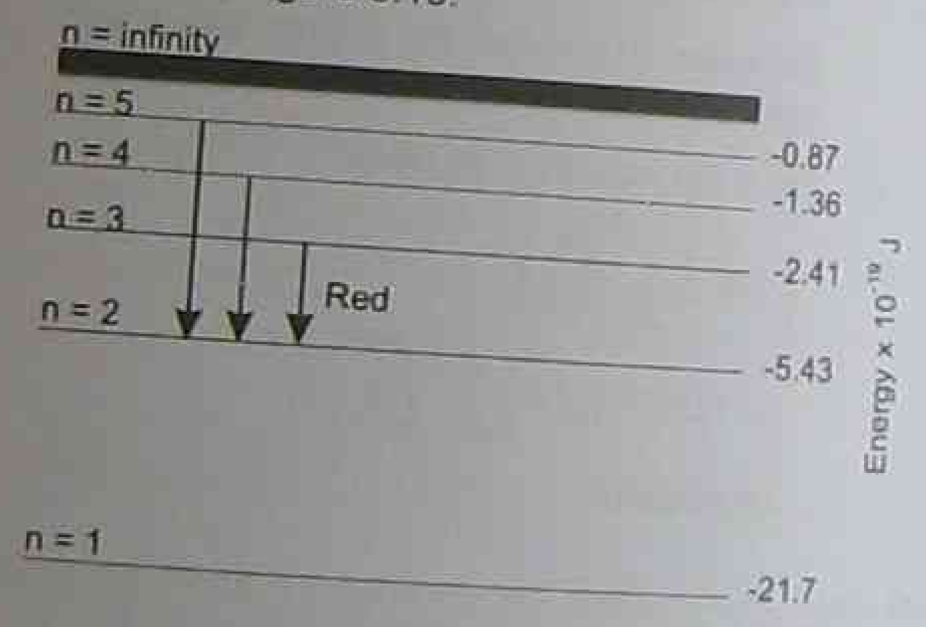


Figure 8. 16

(ii) Red has the longest wavelength and thus the lowest frequency. This corresponds to the electron making a transition from the third energy level to the second energy level.

(iii) $\Delta E = hf$

$$f = \frac{\Delta E}{h} = \frac{3.02 \times 10^{-19}}{6.6 \times 10^{-34}} = 4.6 \times 10^{14}\,\text{Hz}$$

(d) (i) The graphite blocks acted as a moderator, that is they slowed the fast neutrons down sufficiently for them to be captured by the U-235 nuclei to initiate fission.

(ii) As the rods were pushed into the pile the reaction increased as more neutrons could interact with the nuclei.

(e) (i) The binding energy is the energy needed to split a nucleus into its constituent parts.

(ii) The energy comes from the mass defect, that is, the mass of an atom is less than the sum of the masses of its components. The loss of mass is converted into binding energy (by Einstein's $E = mc^2$).

(iii) Protons are positively charged and so repel each other. To keep them together in the nucleus requires energy – the binding energy.

(iv) He-4 is more stable than Li-6 since it has a higher binding energy per nucleon. This means that each nucleon is held more tightly in He-4 than in Li-6.

(f) (i) The Manhattan Project was designed to put together the first atom bomb during WWII.

(ii) The bomb was built and used, helping to end WWII.

(iii) The threat of Mutually Assured Destruction (MAD) hangs over the world. Money has been spent on weapons that could have been spent on wiping out world poverty and improving the health of billions of people…

(g) (i) Particle accelerators are machines for increasing the energy of atoms and subatomic particles by accelerating them in electric and/or magnetic fields.

(ii) The greater the energy, the greater the mass. Massive particles therefore, need large energies to be synthesised in accelerators for research.

(h) Quarks are bound tightly to each other, so much so that to isolate one would require more energy than is currently available in accelerators.

Question 4

(a) For the series limit, $\frac{1}{n^2} \to 0$, that is:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2}\right) = \frac{1.097 \times 10^7}{4}$$
$$\therefore \lambda = 3.6 \times 10^{-7}\,\text{m} = 360\,\text{nm}$$

(b) Any two of the following:

- It was a mixture of classical and modern physics.
- It could not explain the relative intensities of the spectral lines.
- It could not explain the splitting of spectral lines in a magnetic field — the Zeeman effect.
- It could not explain why spectral lines were often found to consist of two or more very fine and close lines — hyperfine spectral lines.
- It only worked for hydrogen (and some atoms with one electron in their outer shell).

(c) (i) Energy and work are related by: $\frac{1}{2}mv^2 = qV$

$$v = \sqrt{\frac{2qV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 50000}{9.1 \times 10^{-31}}}$$
$$= 1.33 \times 10^{8}\,\text{m.s}^{-1}$$

(ii) $$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.33 \times 10^{8}} = 5.4 \times 10^{-12}\,\text{m}$$

(iii) If an integral number of electron waves fit in the electron orbit, the waves can constructively interfere and no energy is lost. Hence the orbit is stable.

(d) In an uncontrolled nuclear fission reaction the number of neutrons increases exponentially causing an exponential increase in the number of nuclei undergoing fission. This results in an enormous amount of energy being released in a very short time. In a controlled reaction the number of free neutrons is limited with control rods that absorb excess neutrons. This ensures that the energy is released more slowly.

(e) Transmutation is the conversion of one element into another element. This can occur in natural radioactivity or by bombarding with subatomic particles.

(f) To separate the nucleus into its parts, energy must be added to overcome the nuclear force of attraction between the constituent nucleons. This energy is converted into mass. Hence the mass of the separate parts is greater than when they are combined in an atom.

(g) (i) Radioisotopes are radioactive isotopes, that is, isotopes that emit alpha and/or beta and/or gamma radiation.

(ii) Iodine-131 (I-131) is commonly used in treatment of thyroid malfunction…

(h) (i) Neutron scattering is used to investigate the internal structure of matter.

(ii) Neutral.

(i) The Standard Model of Matter is a theory that attempts to describe all interactions of subatomic particles (except those due to gravity). Its success lies in its ability to use a small number of particles and interactions to explain the existence of hundreds of particles and their interactions. The standard model has two main components to explain these forces: *the electroweak theory* which describes interactions through the electromagnetic and weak forces; and *quantum chromodynamics* which is the theory of the strong force.

Physicists currently view matter as being grouped into three families – *quarks*, *leptons* and *bosons*. The standard model explains interactions in terms of these families, which it further classifies as: *matter* icles – these are fundamental particles (that is, have no *known* smaller parts) and are the rks and *leptons*; and the *force-carrier particles*. n type of fundamental force is caused by the ange of *force-carrier* particles (also called *senger or exchange* particles). These are the *amental* (or *gauge*) bosons. They include ons and gluons.

APPENDIX A

Practical Skills

SYLLABUS AIMS

The syllabus sets out its aims in three broad areas:

1 *knowledge and understanding*;
2 *skills*; and
3 *values and attitudes*.

The knowledge and understanding outcomes form the basis of this book. Skills, however, are integral to the syllabus and to the successful completion of the course. They are best mastered in the laboratory (or classroom) and library and should be woven into your work at school.

Practical experiences are mandatory. Students must complete a minimum of 80 hours during the Preliminary and HSC courses, with a minimum of 35 hours in the HSC course. In addition, at least one open-ended investigation incorporating the skills, knowledge and understanding outcomes is required in both the Preliminary and the HSC courses.

This section illustrates some of the skills that you will be expected to master by the end of this course. *These skills are assessable.*

PRACTICAL SKILLS[1]

The practical experiences in the syllabus are designed to develop student proficiency in the *key competencies* of:

1 planning investigations
2 conducting investigations
3 communicating understanding and information
4 developing scientific thinking and problem solving techniques
5 working individually and in teams.

These competencies are put to good use in the *scientific method*.

THE SCIENTIFIC METHOD

Physics, like all the other sciences, can be viewed as:

1 a search for knowledge; or
2 a set of *processes*[2] that can be used to systematically gain and refine information (Figure A.1).

The processes are the *skills* of physics. These are the *'doing'* parts of physics—the methods and procedures physicists use in the *scientific method*.

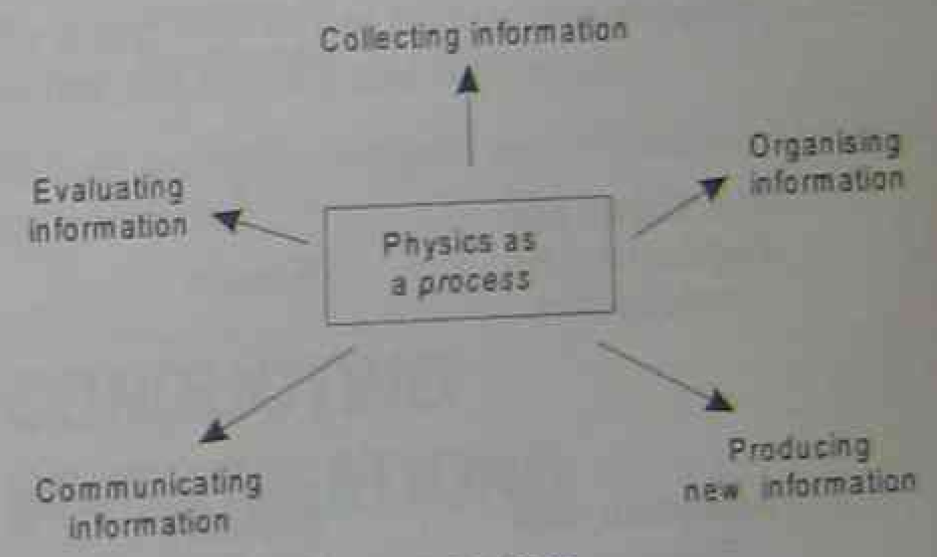


Figure A. 1 Physics as a process

These processes basically involve the series of steps shown in Figure A.2:

1 *Observation*. Information is collected from the results of experiments relating to a particular problem. Observing means more than 'seeing'—it involves the five senses of *sight, touch, taste, smell* and *hearing*.
2 *Classification*. The observations are organised to see if any regularities or patterns exist. As a result, a problem is posed.

'l is the ability to do something well as a result of aining and practice.

[2] A process is a systematic series of actions directed towards some purpose.

3 *Hypothesis.* A possible solution—an '*educated guess*'—to the problem is proposed. This will suggest new outcomes of new experiments.

4 *Experiment.* The predictions of the hypothesis are then tested to see if they occur. If not, the hypothesis is discarded and a new one proposed; new predictions are tested until experiments show the hypothesis to be valid.

Laws and Theories

If the hypothesis is found to apply generally (without exceptions), it is regarded as a *law*. A number of related hypotheses relevant to the original problem may then be joined to form a *theory*. The theory is put through rigorous tests and although no number of experiments can ever prove a theory absolutely correct, it only takes one experiment (that is properly *controlled* and can be repeated) to prove it wrong!

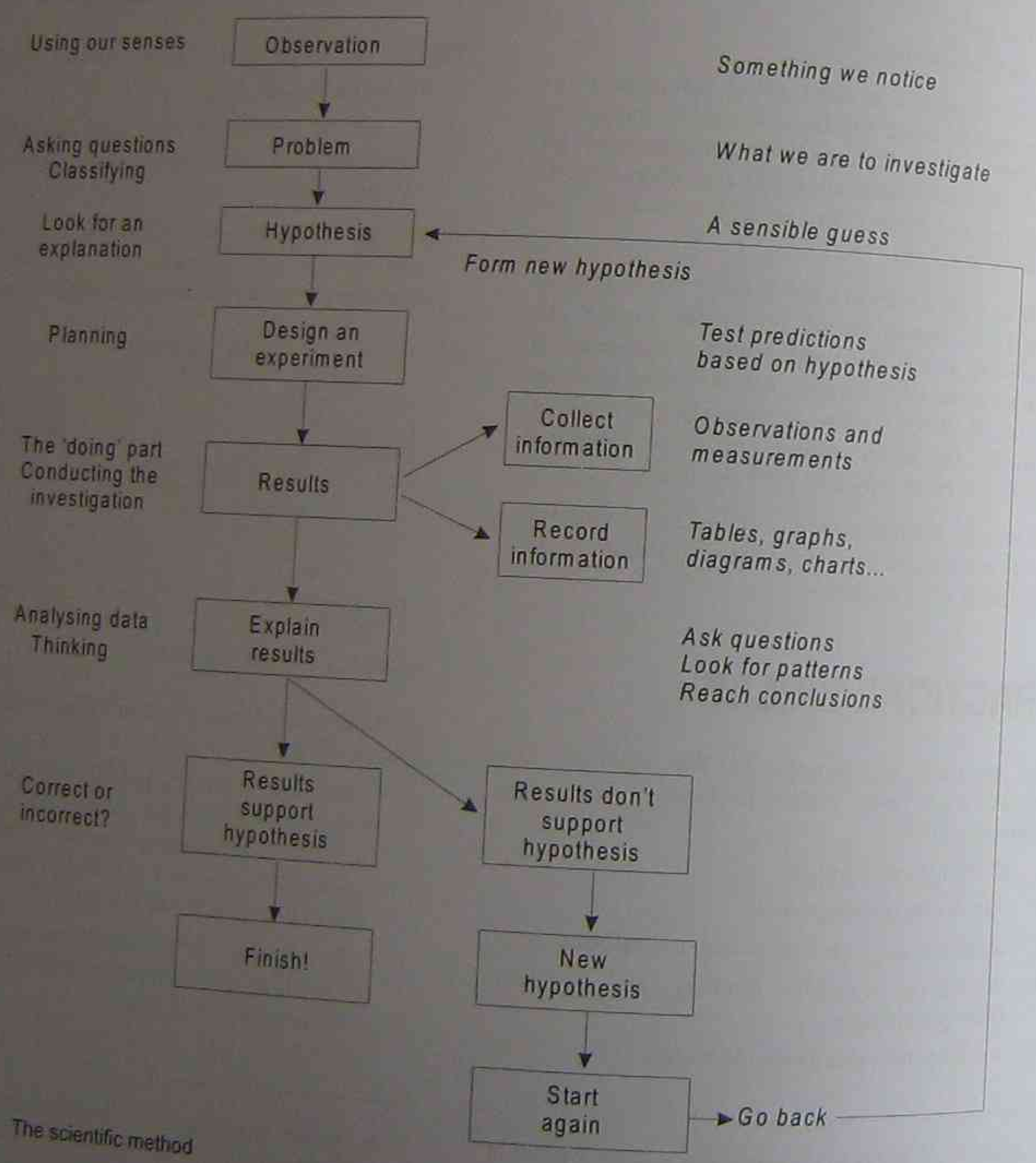


Figure A.2 The scientific method

PLANNING INVESTIGATIONS

Planning (designing) an experiment—a practical investigation—is obviously a vital process in the scientific method. It involves a number of steps including:

1 effectively managing time and resources
2 selecting appropriate techniques and equipment
3 prioritising between tasks
4 minimising risks in using laboratory equipment.

When planning an investigation, you need to ask yourself questions like:

1 When is the investigation due?
2 What equipment (if any) can I use to do it?
3 What do I want to find out?
4 What is the best way of going about the task?
5 What do I need to do first?
6 How can I avoid potential dangers from the equipment?

You may be able to think of other questions.

Good experimental design includes the use of *controlled experiments.*

Variables

All experiments have *variables.*

A **variable** *is an environmental factor or condition, for example, temperature, the length of string supporting a weight, the mass of the object…*

These variables can be *independent* or *dependent.*

The **independent variable** *is the factor or condition being tested. It is the one you have control over. The* **dependent variable** *is the factor that responds to the change in the independent variable. You have no control over this variable.*

EXAMPLE 1

While investigating motion, a group of students measured how long it took other students to run 100 metres. What is the dependent variable and what is the independent variable in this investigation?

ANSWER

You determined the distance as 100 m so this is the independent variable. The time for each runner depends on the distance so time is the dependent variable.

Controls

How do we design an experiment to fairly test a hypothesis? In science, we use a *control.*

In a **controlled experiment** *all the variables are kept constant except the one we are investigating.*

By doing this we can be sure that any affects are due to that one variable and nothing else.

Having carefully designed our investigation we now have to do it.

CONDUCTING INVESTIGATIONS

In conducting investigations you need to be familiar with:

1 locating and gathering information
2 first-hand investigations including gathering first-hand data
3 accessing and collecting information from secondary sources.

Locating and Gathering Information

Information for a planned investigation can be obtained from a range of sources including:

1 your teacher
2 text books
3 science magazines
4 the library

5 the Internet
6 your own observations!

You can probably think of other sources.

First-Hand Investigations

These are ones where you (and/or your group members) gather actual data. They require controlled experiments (see earlier).

Accessing and Collecting Information from Secondary Sources

We are currently living in *The Information Age* where 'knowledge is power'. To be empowered, therefore, requires that the skills of accessing and collecting information from secondary sources be learned.

What are these skills and how can you become familiar with them?

Information Skills

Information skills can be classified as:

1. finding information; and
2. using and making sense of this information.

Finding Information

Information can be found in a variety of *forms* and from a variety of *sources* including:

1. *print material*—books, magazines, newspaper articles…
2. *electronic*—CD-ROM, computer programs, Internet …
3. *visual*—photographs, video, film …
4. *audio*—tapes, records, CDs, radio …

Using and Making Sense of Information

These skills include:

1. asking questions
2. selecting evaluating, and if necessary, discarding information
3. combining information from different sources
4. presenting the most relevant information
5. presenting information according to the audience
6. gauging the success of the presentation.

The Information Process

A systematic approach to use information skills in a meaningful way is the following:

1. *Defining* the task for which the information is required
2. *Locating* the required information
3. *Selecting* information relevant to the task
4. *Organising* the selected information
5. *Presenting* the organised information in the most appropriate manner
6. *Assessing* the performance of the task.

Table A.1 illustrates this process and expands on the headings with a series of questions that you can ask yourself when using these skills.

Table A. 1 The Information Process

Steps in process	**What it means**
Defining	What do I really want to find out? What is my purpose? Why do I need to find this out? What are the key words and ideas of the task? What do I need to do?
Locating	Where can I find the information I need? What do I already know? What do I still need to find out? What sources and equipment can I use?
Selecting	What information do I really need to use? What information can I leave out? How relevant is the information I have found? How credible is the information I have found? How will I record the information I need?
Organising	How can I best use this information? Do I need to use all this information? How can I best combine information from different sources?
Presenting	How can I present this information? What will I do with this information? With whom will I share this information?
Assessing	What did I learn from this? Did I fulfil my purpose? How did I go with each step in the information process? How did I go presenting the information? Where do I go from here?

COMMUNICATING INFORMATION AND UNDERSTANDING

Processing and Presenting Information

Conducting investigations is of little use unless accurate records of kept of what you did, observed and found out.

> **Data**[3] *are the results we get when we conduct experiments.*

Physicists (and physics students) present their data in a variety of forms, which can include:

- prose (full sentences)
- point form (like this list)
- tables
- graphs
- diagrams
- photographs
- flowcharts
- video
- multi-media presentations.

This is primarily done:

1. so that we can refer back at a later date
2. to gain new knowledge
3. to communicate with others about what we did and found out.

The method we use is the one that is the 'best' way of presenting it to the particular 'audience'.

Prose

Prose is often used when we want to describe a series of sequential events or changes in some characteristic. For example, *'When the copper wire was placed in the bunsen flame it started to glow red hot and a green flame was observed coming from the vicinity of the wire'.*

Lists

A more concise way of describing the events/changes is to use point form. For example:

- copper wire glows red hot
- green 'flame' comes from vicinity of the wire.

Flowcharts

A flowchart is a simple but useful method of presenting data pictorially of sequential events. They range from the very simple to the very complex. The scientific method, for example, can be shown in a diagram (Figure A.2 p.314).

Tables

Tables are used to compare data so that relationships can be clearly discerned. Tables are best used with quantitative data. Tables (see Figure A.3) are constructed by:

1. making an appropriate grid (consisting of rows and columns)
2. adding headings to the grid (with units if appropriate)
3. carefully recording the data
4. giving the table a title (or caption).

Figure A. 3 Speed of sound in different media

Medium	**Speed (m.s^{-1})**
air (at 0°C)	331
air (at 15°C)	340
Helium (at 20°C)	1005
Hydrogen (at 20°C)	1303
water (distilled)	1496
glass	4540
aluminium	5000
steel	5200

Data tables can be used for a range of purposes including:

1. directly locating and extracting information
2. showing trends and relationships
3. recognising patterns
4. drawing conclusions
5. making generalisations
6. making predictions.

---

[3] Data is plural. Datum is singular

EXAMPLE 2

From Table A.3 answer the following questions:

(a) What is the speed of sound in hydrogen?

(b) What trends can be seen?

(c) What generalisations can be made?

(d) What do you predict about the speed of sound in carbon dioxide relative to the speed of sound in air?

SOLUTION

(a) From the table, the speed of sound in hydrogen is 1303 $m.s^{-1}$.

(b) Sound travels faster in solids than in liquids and gases.

(c) As the density of a gas decreases, the speed of sound increases.

(d) Since carbon dioxide is more dense than air we predict that sound will travel slower in carbon dioxide.

Use of Diagrams, Symbols and Graphs to Convey Information and Understanding

Although prose and point form are very common ways of communicating information, physics makes extensive use of diagrams, symbols and graphs to convey data in a meaningful way.

Diagrams

Diagrams are used extensively in physics. A book such as this has a large number of diagrams. Why is this?

Presenting data in a diagram can show information much more clearly and precisely than writing a description. For example, consider Figure A.4, which shows image formation by a concave mirror. It would be difficult to explain this with words only.

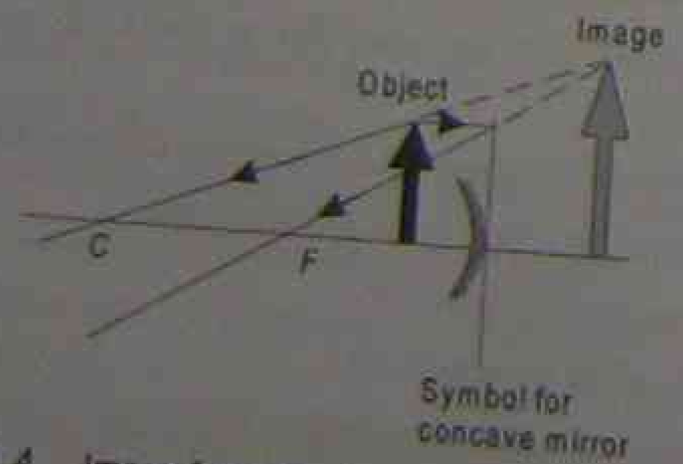


Figure A. 4 Image formation in a concave mirror

Symbols

Physics is largely explained by using models, in particular *mathematical (symbolic) models*. For example, the following mathematical model is used to help describe the relationship between the quantities speed, distance and time: $v = \frac{s}{t}$. Similarly the relationship between the force of attraction (F), between two objects of masses m_1 and m_2 separated by a distance d is given by: $F = G\frac{m_1 m_2}{d^2}$. This is easier to convey information than by saying '*The force of attraction between two masses is equal to a constant multiplied by the product of the masses divided by the square of their separation...!*'.

Graphs

Graphs *are a visual way of communicating. They show a 'picture' of the relationship between quantities.*

Graphs are a good way of both recording data and displaying them in such a way that trends or changes can be easily seen.

The two main reasons for plotting experimental data on graphs are:

1 to communicate in a compact easily understood form the results of the experiment, and

2 to aid in the *analysis*[4] of the results.

The data we plot are called **variables**, *that is, quantities that can take on different values—they can vary.*

Variables can change continuously or abruptly. The temperature during the day, for example, varies in a continuous manner. The names of students in a class vary in a non-continuous manner. (Names are examples of non-numerical variables.)

Graphs come in a variety of forms including:

1 column and bar graphs (charts)

2 histograms

3 pie graphs

4 line graphs.

The type of graph you choose depends on the type of data you have.

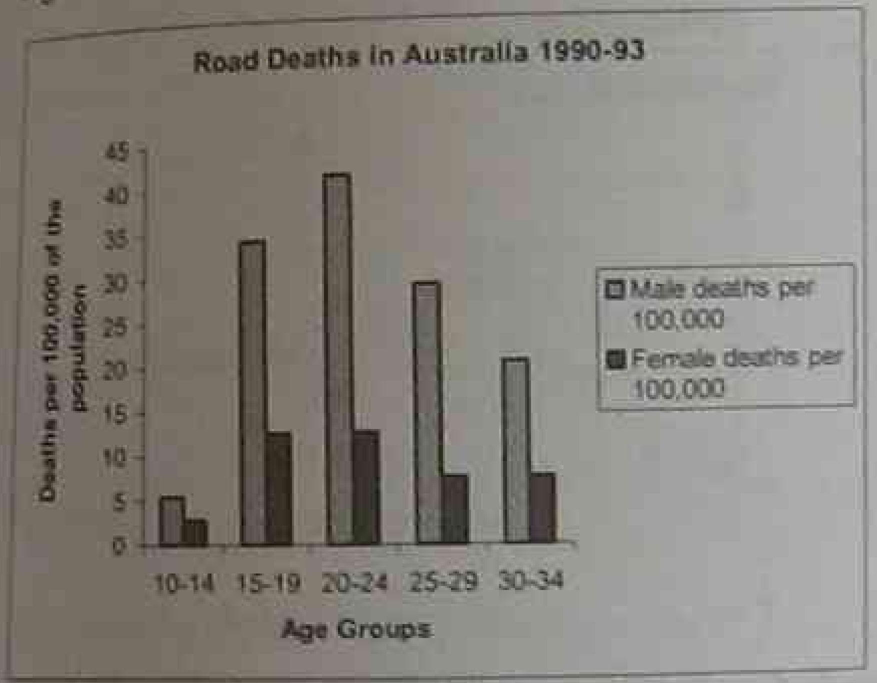
---

[4] When we analyse something we determine its essential features and relationships.

Column and Bar Graphs

These are used when we plot a variable that does not change in a continuous manner. For example we could use such a graph to plot the number of road deaths for various age groups (Figure A.5).

Figure A. 5 A column graph



Histogram

Histograms are like column graphs but the rectangles touch. They are used to represent *frequency distributions*, that is, how often (frequently) a particular value (or range of values) occurs.

Pie Chart

This is another way of drawing a graph for a non-continuous variable. It generally takes up less space than the equivalent column or bar graph.

Pie charts (graphs) are especially good at showing proportions or percentages. Figure A.6 is a pie chart for the composition of the Earth's crust.

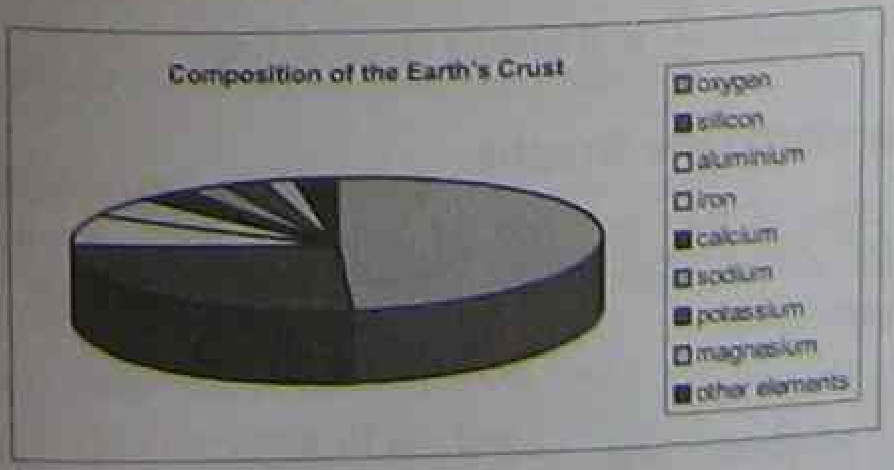


Figure A. 6 A pie chart

Line Graphs

Line graphs *are used when both variables can change in a continuous manner. They are the most commonly used graph in physics.*

Choice of Axes

All line graphs (Figure A.7) have two axes—a vertical axis (y-axis) and a horizontal axis (x-axis).

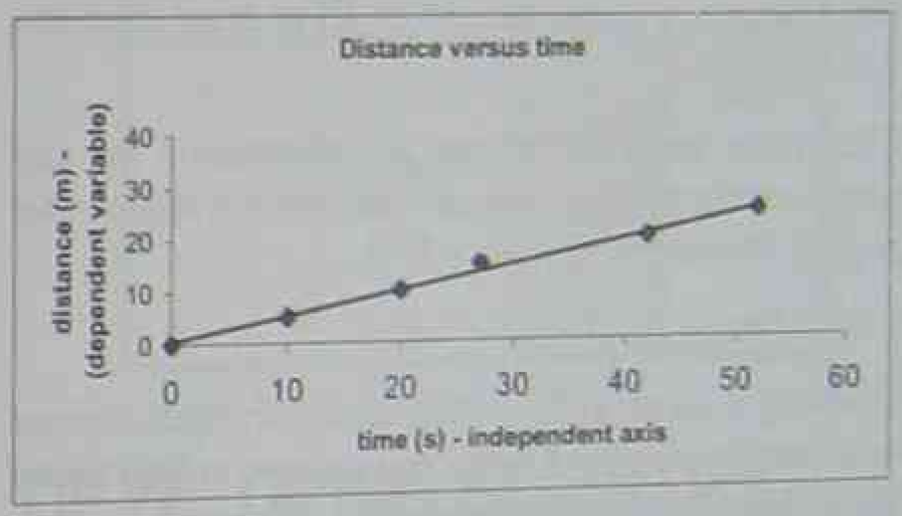


Figure A. 7 A simple line graph

It is generally accepted that the *independent variable* (that is, the one that you generally have control over) is plotted on the x-axis and the *dependent variable* (the one whose value depends upon the other variable) along the y-axis.

It is not always clear which variable is dependent and which is independent—often it is up to you to decide. For example, when we plot distance moved by an object against time, displacement is the dependent variable and time is the independent one (see Figure A.7)—how far you go depends upon how long you have been travelling. When plotting the voltage across a conductor against the current through it, however, either one could be considered to be the independent variable depending on whether you are varying the current and measuring the resulting voltage or varying the voltage and measuring the resulting current!

Scales

The size of the graph should be large enough to convey the desired information. Usually this means making the graph fill as much as is practicable of the available graph paper. On the other hand, choose a scale that is easily subdivided, such as 5 $volts.cm^{-1}$. A scale such as 3 $volts.cm^{-1}$ is difficult to subdivide and is hence likely to cause mistakes.

Labels

Each axis must be clearly labelled with the name and/or symbol of the quantity plotted and the name of the unit. Values should be marked at regular intervals on each axis. The graph should be given a descriptive title or caption so that it is quite clear what it is meant to show.

Plotting the Values

The recommended procedure is to mark each point with a fine pencil dot and to make some other mark (for example, a circle, box or an **X**) to draw attention to its location.

The really important pieces of information on any graph are the original points—not any curve that you may fit to them.

Curve Fitting

Drawing a curve to fit a plotted set of points always involves some prior knowledge or assumption about the expected result. The curve you draw is, therefore, an interpretation.

If there is no evidence to the contrary, a scientist always draws the simplest satisfactory explanation—so draw a smooth curve.

The curve does not have to pass through all the points. Any curve that passes within the error range of each point is a possibility. Remember that the more complex the curve you fit, the more data you must have to be reasonably confident of your interpretation.

As a general rule, draw a curve, which comes as close as practicable to each point without being kinky. The points should lie with roughly equal numbers on the two sides of the curve—this is the *line of best fit*.

Analysis of Results

No experiment is complete until its results have been analysed and interpreted[5]. The whole point in analysing experimental data is to try to fit it into the structure of scientific knowledge—to try to understand how the results might have come to be so.

Graphical Analysis

There is only one shape of curve which is easily recognised unambiguously—the straight line. Hence, if we wish to find out by looking at a graph whether a certain set of data fits a particular kind of mathematical relationship we need to transform the data so that the expected relationship is the equation of a straight line.

Linear Equations

The general equation of a straight line is: $y = mx + b$. When this is plotted it looks like Figure A.8. Note that this graph intersects the y-axis ($x = 0$) at the point where $y = b$. The slope of the graph is given by:

$$m = \frac{\text{vertical rise}}{\text{horizontal run}}$$

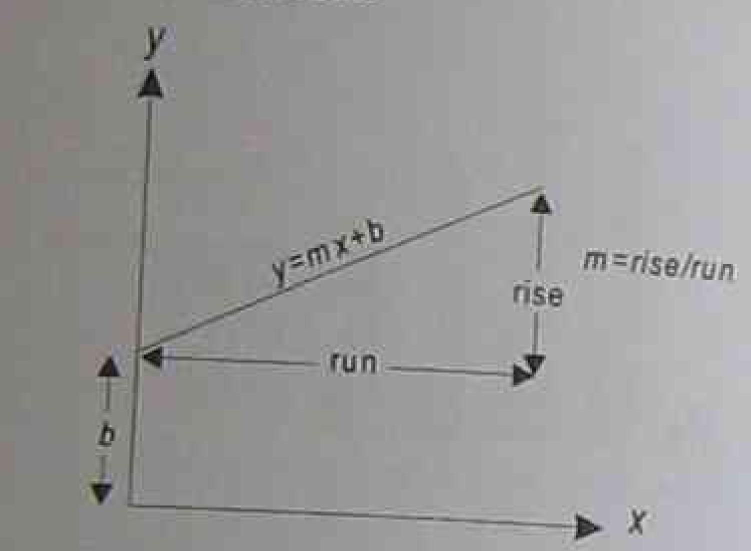


Figure A. 8 The linear graph

Non-linear Equations

If we suspect that a relationship between two quantities is governed by a non-linear equation the most obvious approach is to calculate new quantities from the data, which when plotted should obey a linear equation.

EXAMPLES

1 If $T = 2\pi\sqrt{\frac{l}{g}}$ then T plotted against $\sqrt{l}$ (or T^2 plotted against l) would yield a straight line.

2 If $P = \frac{k}{V}$ where k is a constant, then P plotted against $\frac{1}{V}$ will yield a straight line.

Standard Line Graphs

In most of the work we do at school level, we will come across three basic graph types (as shown in Figure A.9.):

1 linear;
2 parabolic; and
3 hyperbolic.

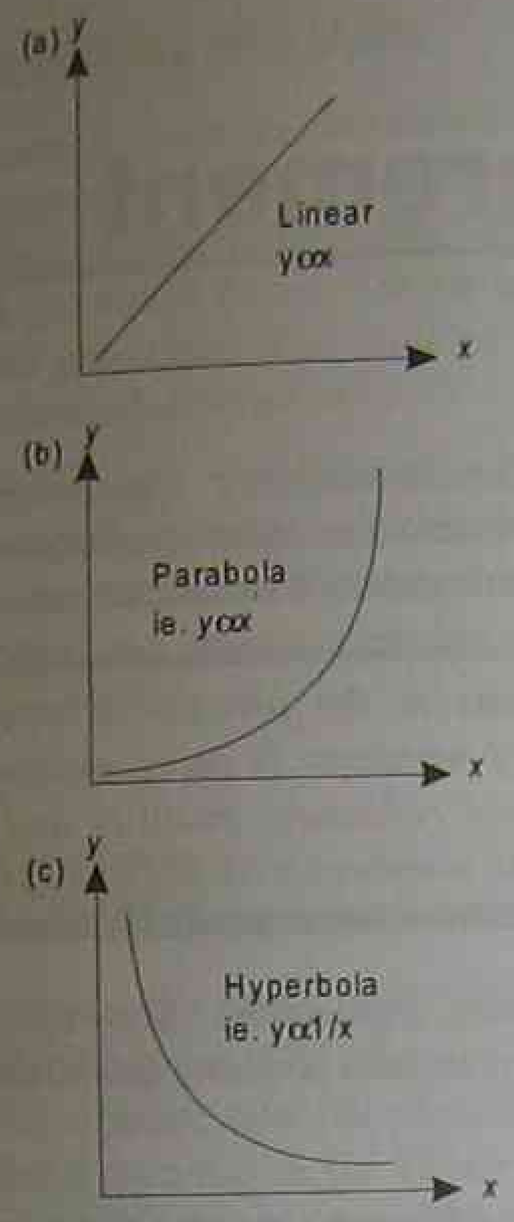


Figure A.9 Standard graphs

The linear graph shows:

$$\boxed{y \,\alpha\, x \text{ or } y = kx}$$

The parabolic curve suggests:

$$\boxed{y \,\alpha\, x^2 \text{ or } y = kx^2}$$

(which we verify by plotting y against x^2).

The hyperbolic curve suggests:

$$\boxed{y \,\alpha\, \frac{1}{x} \text{ or } xy = k}$$

(which we verify by plotting y against $\frac{1}{x}$).

Summary of Graphs

There are essentially three things that we can do with graphs:

1 read values directly from them.
2 find the slope of the line
3 find the area under the graph.

Table A.2 summarises these three things for the graphs we will meet in the course.

Table A. 2 Using graphs

Graph	Direct reading	Slope	Area under
$x - t$	$x \rightarrow t$ $t \rightarrow x$	v	
$v - t$	$v \rightarrow t$ $t \rightarrow v$	a	s
$F - t$	$F \rightarrow t$ $t \rightarrow F$		Δmv
$F - s$	$F \rightarrow s$ $s \rightarrow F$		W

DEVELOPING SCIENTIFIC THINKING AND PROBLEM SOLVING TECHNIQUES

Clarifying Issues and Problems Relevant to Physics

Physics is dynamic. New ideas are constantly being generated and new theories are put to the test. As you progress through the Physics Syllabus, look at these areas and reflect on how you might go about them.

WORKING INDIVIDUALLY AND IN TEAMS

This is one of the *key competencies* and is important in all areas of endeavour, be it at school, at home or in the workforce. When working as a team it is important that the team members:

1 identify collective goals
2 define and allocate roles fairly
3 communicate within the team.

---

[5] Interpreting a graph means extracting and using the information contained in them.

APPENDIX B

Physics and Measurement

WHAT IS PHYSICS?

A simple answer would be that Physics is what physicists do. This definition however doesn't help us much unless we know what physicists do! Some are interested in the fundamental building blocks of matter. Others are interested in the electrical, mechanical, thermal, magnetic and other properties of matter. Still others are interested in the properties of matter at low temperatures.

Astrophysicists study the structure of the stars, galaxies and our universe. There are geophysicists, biophysicists, solid state physicists; the list goes on and on. In general, the physicist, whatever his or her full title, is studying some aspect of how the universe is put together and how it works.

In all cases the physicist is studying the properties of matter and its energy relationships. Broadly speaking,

> **Physics** *is the study of matter and its energy relationships in an attempt to discover the laws that rule our universe.*

These laws are statements, usually mathematical which summarise our knowledge about a particular area of physics or type of experiment. The laws are acquired by the study of how the universe behaves, until some generalisation is possible; this involves application of the scientific method (see Appendix A).

MEASUREMENT

> *'I often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you can scarcely in your thoughts, advance to the stage of Science, whatever the matter may be.'*
>
> Lord Kelvin (1824 - 1907)

Physics is the most basic (fundamental) of the sciences; it is also the most quantitative; that is, it involves the processes of measurement.

> **Measurement** *is the process of comparing the properties of whatever is being measured against some selected reference quantity and expressing the answer in numbers with a unit.*

These reference quantities are referred to as *fundamental quantities* (or *base quantities*).

FUNDAMENTAL QUANTITIES

When a quantity is defined in physics, the definition must provide rules for calculating it in terms of other quantities that can be measured.

The measurement of velocity, defined as distance/time, requires the measurement of length and time. Length and time, however, cannot be measured in simpler or more fundamental quantities. Length and time are thus regarded as fundamental quantities. In mechanics, a third fundamental quantity is mass.

See Appendix C for a complete list of the fundamental quantities of physics.

Fundamental Units

For measurements to be meaningful they must have a unit associated with them. In the SI (Système International d'unités) system of units, in which this book is written, the fundamental units are the *metre* (m) for length, the *kilogram* (kg) for mass and the *second* (s) for time.

Derived Quantities and Units

Quantities such as velocity, acceleration and force, whose measurement involves either directly or indirectly the measurement of two or more of the fundamental quantities (mass, length and time), are called *derived quantities*. The units of these derived quantities are called *derived units*.

For example velocity = distance/time; the units of velocity are therefore distance units divided by time units; metres/second or m/s or m.s^{-1} with the latter symbolism being the most acceptable; this is what is used throughout this book.

STANDARDS

For units to mean the same thing everywhere, they need to be standardised. The rules for measuring the fundamental quantities take the place of a definition. An international committee, the *General Conference of Weights and Measures*, to which all the major countries send delegates, decides these rules.

A good standard should be:

1 unchangeable;
2 easily accessible;
3 indestructible;
4 if possible, part of an actual measuring instrument.

SI Units

The SI standards and their units are shown in Table B.1. Refer to Appendix C for rules governing the use of SI units.

Table B. 1 Definitions of the fundamental quantities

Quantity	Standard	Unit
length	since 1982, based on the speed of light, which is accurately known	1 m = the distance travelled by light in a vacuum in the fraction 1/299 792 458 of a second
mass	mass of a certain platinum-iridium cylinder that is kept in Paris	1 kg
time	time interval between the vibrations in the caesium atom	1 s = time for 9 192 631 770 vibrations

DIMENSIONS

The way in which a derived quantity depends upon the fundamental quantities of mass, length and time (symbolised as M, L and T respectively) determines the dimensions of that quantity. For example, area is length x length, so its dimensions are:

$L \times L$, or L^2

Numbers such as 2, ½ and pi are dimensionless. Table B.2 shows the dimensions of some common quantities in physics.

Table B. 2 Dimensions of Some Common Quantities

Quantity	Dimension
volume	L^3
velocity	LT^{-1}
acceleration $\left(\frac{velocity}{time}\right)$	LT^{-2}
force (mass x acceleration)	MLT^{-2}
momentum (mass x velocity)	MLT^{-1}

Dimension Checking

The dimensions of the left-hand side of an equation must be identical to those on the right-hand side. This can sometimes be used as a quick check on the correctness of an equation. Remember this will not check numbers but only physical quantities.

APPENDIX B

Physics and Measurement

WHAT IS PHYSICS?

A simple answer would be that Physics is what physicists do. This definition however doesn't help us much unless we know what physicists do! Some are interested in the fundamental building blocks of matter. Others are interested in the electrical, mechanical, thermal, magnetic and other properties of matter. Still others are interested in the properties of matter at low temperatures.

Astrophysicists study the structure of the stars, galaxies and our universe. There are geophysicists, biophysicists, solid state physicists; the list goes on and on. In general, the physicist, whatever his or her full title, is studying some aspect of how the universe is put together and how it works.

In all cases the physicist is studying the properties of matter and its energy relationships. Broadly speaking,

> **Physics** *is the study of matter and its energy relationships in an attempt to discover the laws that rule our universe.*

These laws are statements, usually mathematical which summarise our knowledge about a particular area of physics or type of experiment. The laws are acquired by the study of how the universe behaves, until some generalisation is possible; this involves application of the scientific method (see Appendix A).

MEASUREMENT

'I often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you can scarcely in your thoughts, advance to the stage of Science, whatever the matter may be.'

Lord Kelvin (1824 - 1907)

Physics is the most basic (fundamental) of the sciences; it is also the most quantitative; that is, it involves the processes of measurement.

> **Measurement** *is the process of comparing the properties of whatever is being measured against some selected reference quantity and expressing the answer in numbers with a unit.*

These reference quantities are referred to as *fundamental quantities* (or *base quantities*).

FUNDAMENTAL QUANTITIES

When a quantity is defined in physics, the definition must provide rules for calculating it in terms of other quantities that can be measured.

The measurement of velocity, defined as distance/time, requires the measurement of length and time. Length and time, however, cannot be measured in simpler or more fundamental quantities. Length and time are thus regarded as fundamental quantities. In mechanics, a third fundamental quantity is mass.

See Appendix C for a complete list of the fundamental quantities of physics.

Fundamental Units

For measurements to be meaningful they must have a unit associated with them. In the SI (Système International d'unités) system of units, in which this book is written, the fundamental units are the *metre* (m) for length, the *kilogram* (kg) for mass and the *second* (s) for time.

Derived Quantities and Units

Quantities such as velocity, acceleration and force, whose measurement involves either directly or indirectly the measurement of two or more of the fundamental quantities (mass, length and time), are called *derived quantities*. The units of these derived quantities are called *derived units*.

For example velocity = distance/time; the units of velocity are therefore distance units divided by time units; metres/second or m/s or m.s^{-1} with the latter symbolism being the most acceptable; this is what is used throughout this book.

STANDARDS

For units to mean the same thing everywhere, they need to be standardised. The rules for measuring the fundamental quantities take the place of a definition. An international committee, the *General Conference of Weights and Measures*, to which all the major countries send delegates, decides these rules.

A good standard should be:

1 unchangeable;
2 easily accessible;
3 indestructible;
4 if possible, part of an actual measuring instrument.

SI Units

The SI standards and their units are shown in Table B.1. Refer to Appendix C for rules governing the use of SI units.

DIMENSIONS

The way in which a derived quantity depends upon the fundamental quantities of mass, length and time (symbolised as M, L and T respectively) determines the dimensions of that quantity. For example, area is length x length, so its dimensions are:

$L \times L$, or L^2

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Quantity	Standard	Unit
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ORDERS OF MAGNITUDE

Often when dealing with very large or very small numbers in physics we are concerned more with the 'order' of their size rather than their actual value.

> *The* **order of magnitude** *of a number is the power of ten closest to that number.*

EXAMPLES

1 The number 7 is closer to 10^1 (10) than to 10^0 (1), so we say its order of magnitude is 10^1.

2 Similarly, 85 is closer to 10^2 (100) than to 10^1 (10), so its order of magnitude is 10^2. Table B.3 shows the order of magnitude of some very large and small quantities.

Table B.3 gives the order of magnitude of various quantities

SCIENTIFIC NOTATION

To find the order of magnitude of very large or very small numbers, it is best to write them in scientific notation, also known as *exponential notation*.

Table B.3 Orders of magnitude

Quantity	Order of Magnitude
distance of the furthest observable galaxy	10^{26} m
distance to the sun	10^{11} m
your height	10^{0} m
diameter of an atom	10^{-10} m
age of the universe	10^{17} s
one year	10^{7} s
shortest lived subatomic particles	10^{-23} s

> *A number is written in* **scientific notation** *by writing it as a number between 1 and 10 multiplied by the appropriate power of ten.*

EXAMPLES

1 400000 in scientific notation is written as 4.0×10^5. The order of magnitude of 4.0 is 10^0 and so the order of magnitude of 400000 is simply 10^5

2 Similarly, $0.00000012 = 1.2 \times 10^{-7}$. So its order of magnitude is 10^{-7}.

SIGNIFICANT FIGURES

> **Significant figures** *are those figures in a measurement that are accurately known, plus the first uncertain figure.*

EXAMPLES

1 Using a ruler calibrated in cm and mm, a student may measure the length of an object as 8.5 cm. This measurement has two significant figures.

2 A calculation is only as accurate as its least accurate component and should contain no more significant figures than that part in the calculation.

A student uses a vernier (a measuring device) to measure the length of the side of a metal cube as 1.03 cm and wishes to calculate the volume the cube. Now, $(1.03)^3 = 1.092727$.

To what accuracy should the answer be expressed? The initial measurement was to three significant figures and so the answer can also only be to three significant figures:

ie. Volume = 1.09 cm^3.

Some Rules on Significant Figures

1 All non-zero figures in an actual measurement are significant.

2 For numbers less than one, zeros directly after the decimal point are not significant. For example, 0.00125 has only three significant figures.

3 For numbers greater than one, zeros between integers are significant. For example 1.007 has four significant figures.

4 Zeros at the end of a number may or may not be significant, depending upon the circumstances:

(a) If the zeros are just 'rounding off' a number they are not significant. For example: 25 kg = 25000 g, and there are only two significant figures in both notations.

(b) If zeros follow numbers after a decimal point they are significant. For example, a mass of 0.60 g has two significant figures.

LIMITATIONS OF MEASUREMENT

When any quantity in physics is measured, there is always a certain amount of inaccuracy in the reading. There are at least three sources of error:

1 Systematic or regular errors.

2 Random or accidental errors.

3 Errors due to the limit on reading of the instrument.

Systematic or Regular Errors

The instrument may show a regular error.

EXAMPLE

A beam balance reads 0.5 g when there is no mass on the pan, thus every mass reading is 0.5 g greater than the correct value. That is, if the reading is 1.5 g, the true mass of the object is only 1.0 g. This error can be *allowed for* or eliminated by readjusting the instrument.

Another source of regular or systematic error is experimenter bias such as parallax error, where the eye is not placed in the correct position (Figure B.1) Systematic errors can be eliminated (or at least minimised by the use of correct technique).

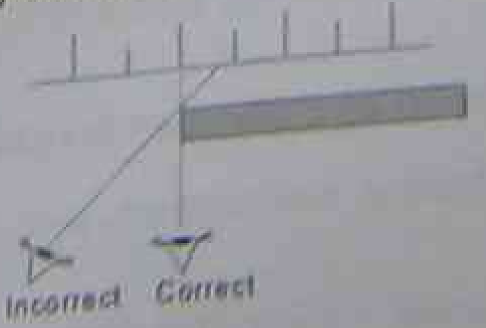

Figure B.1 Parallax error

Random or Accidental Errors

When an experimenter makes a series of repeated measurements with the greatest possible precision (and with systematic errors allowed for) the numbers will often differ. These differences arise from various unknown and therefore *uncontrollable* sources of error.

EXAMPLE

The experimenter used a micrometer to measure the thickness of a metal slab and obtained the following results: 4.821, 4.824, 4.820, 4.827, 4.827, 4.822, 4.823 and 4.825 cm. These differences may be due to the following:

1 The quantity being measured is not uniform.

2 The jaws on the micrometer are closed differently each time.

3 Such factors as temperature variations.

Assuming that a series of measurements is subject only to random error, the *arithmetic mean* is the most probable value.

What is the value for the thickness of the slab in this example? That is, what is its 'true' value? This cannot be worked out, but assuming random error only, the arithmetic mean $\bar{x}$ can be taken as the most probable value for the thickness.

Table A.4 The results of a series of measurements

Reading, x (cm)	Residual $x - \bar{x}$ (cm)
4.821	-0.003
4.824	0.000
4.820	-0.004
4.827	+0.003
4.827	+0.003
4.822	-0.002
4.823	-0.001
4.825	+0.001
Sum 38.589	
Mean 4.824	

The mean is almost certainly not the 'true' value. An estimate of the *maximum error* is needed and this is given by the *greatest residual*. The value is then expressed as the *arithmetic mean ± the maximum error*.

Again, for the metal slab the maximum error, or the greatest residual, is 0.004 cm. Thus the value is 4.824 ± 0.004 cm. Note that this value covers the range from 4.820 to 4.828 cm.

Errors Due to Limit of Reading of Instrument

Even if repeated readings give the same result, this is still not the 'true' value, because of the limit of reading of the instrument.

The error due to the limit of reading of the instrument is half the limit of reading. Sometimes the scale is too coarse, in which case you may have to subdivide and estimate the limit of reading of the instrument. Always overestimate the error.

EXAMPLE

A student takes a reading on a scale (marked in tenths of mm) of 83.8 mm. By giving this value, and not 83.7 or 83.9 mm, the student is saying that the value is closer to 83.8 mm than to either of the other two.

A reading that is less than half of a tenth of a mm either side of 83.8 mm (that is, half the limit of reading = ± 0.05 mm) is called 83.8 mm. So when the student measures 83.8 mm this actually means a range of ± 0.05 mm about 83.8 mm.

Order of Accuracy: Percentage Error

The importance of an error does not depend upon its *absolute* magnitude but upon its magnitude relative to that of the quantity measured. For example, an error of 1 m in a distance of 100 m is an error of 1/100 or 1%, but the same error (1 m) in a distance of 2 m is of much greater significance, 1/2 or 50%. A percentage error can normally be rounded off to an integer; for example, 2½% rounds to 3%.

Accuracy and Precision

In everyday language these two terms are used interchangeably; in physics they have different meanings:

***Accuracy** is an indication of how close a measurement is to the accepted value. This is indicated by the relative or percentage error.*
***Precision** is an indication of how reproducible a series of measurements is. This is indicated by the absolute error.*

EXAMPLE

Consider two measured quantities as follows:

$$a = 1.00 \pm 0.05 \text{ cm}$$

$$b = 10.0 \pm 0.2 \text{ cm}$$

a is more precise than b (its absolute error is smaller, indicating that successive readings were closely grouped); b, however, is more accurate (its % error is 2% while that of a is 5%).

Calculating with Errors

Addition and Subtraction Involving Errors

For addition and subtraction, add the maximum errors.

EXAMPLE

Consider the distance between two points determined by subtracting one measured length from another, taking no account of errors.

length a – length b

$a = 9.46 \pm 0.05$ cm

$b = 2.29 \pm 0.04$ cm

ie. $a - b = 7.17$ cm

Now a lies somewhere between 9.41 and 9.51 cm, and b lies somewhere between 2.33 and 2.25 cm. Then $a - b$ is either 7.08 or 7.26 cm, taking the extreme values for error. It can be seen that these values differ from 7.17 cm by 0.09 cm, which is the sum of the maximum errors. So the distance is written as 7.17 ± 0 09 cm. Similarly $a + b = 11.75 \pm 0.09$ cm.

Multiplication and Division Involving Errors

For multiplication and division, add the percentage error.

Consider length $= l \pm x$ (x = maximum error in l) and breadth $= b \pm y$ (y = maximum error in b).

The most inaccurate product is:

$(l + x)(b + y) = lb + ly + bx + xy.$

Since x and y are small, the product xy is very small and can be neglected. Thus we have:

$lb + ly + bx.$

The true value is lb. The difference is then $ly + bx$. Therefore, percentage error in lb

$$= \frac{lx + ly}{lb} \times 100$$

$$= \frac{y}{b} \times 100 + \frac{x}{l} \times 100$$

= percentage error in b + percentage error in l.

EXAMPLE

$l = 7.26 \pm 0.03$ cm, percentage error = 0.4%

$b = 6.31 \pm 0.02$ cm, percentage error = 0.3%

$lb = 45.8106 \text{ cm}^2$, percentage error = 0.7 %

Thus maximum error in $lb = 45.8106 \times \frac{0.7}{100} = 0.3 \text{ cm}^2$

to one significant figure. That is,

$lb = 45.8 \pm 0.3 \text{ cm}^2.$

Note that the last figure in a quantity is of the same order as the first significant number in the error term.

APPENDIX C

SI Units and Abbreviations

THE SI INTERNATIONAL SYSTEM OF UNITS

The International System (SI) of metric units is used in science in all countries as well as for general measurements in the vast majority of countries (the USA being the major exception). The following tables give the names of the fundamental or base quantities of physics, the base units and symbols as well as the common prefixes, and many of the derived quantities and units met throughout the physics course. In addition rules governing the correct use of metric units are given.

FUNDAMENTAL AND DERIVED QUANTITIES OF PHYSICS

In physics a number of quantities have been defined as *fundamental* in that they cannot be expressed in simpler terms. These are identified in Table C.1. Other quantities that can be defined in terms of combinations of these fundamental quantities are called *derived* quantities. Velocity, which is defined as distance/time, is a derived quantity. Distance (length) and time are fundamental quantities. For more examples, see Table C.3.

ABBREVIATIONS OF SI PREFIXES

All quantities have a standard metric unit; for example, length is measured in metres. Smaller and larger units of the quantity are derived from the standard on a decimal basis, using prefixes to show the size of the derived unit. Thus: centimetre (1/100 metre), kilometre (1000 metres), and so on. The prefixes each have their own abbreviation. The commonest ones are shown in Table C.2.

RULES FOR WRITING METRIC UNITS

As mentioned earlier, each unit has a standard abbreviation (symbol), as shown in Table C.1, and prefixes are used to make the unit more convenient to use. Hence the abbreviation for any unit of a quantity is obtained by combining two abbreviations:

First	Second
abbreviation of proper prefix	abbreviation of standard unit of quantity

The two abbreviations are written together without a space and without a full stop. So, for example:

millimetre	mm
centigram	cg
megagram	Mg
microsecond	µs

Some quantities like area, volume, speed and acceleration are derived from fundamental ones so their units are made from the combined units of the simpler quantities. Thus, for example:

Quantity	SI unit
area	square metres
volume	cubic metres
speed	metre per second
acceleration	metre per second per second

The abbreviations of these units make use of algebraic notation to give a very compact abbreviation. Dots indicate multiplication, negative indices show division, and the power shows the number of times, just as in algebra. For example, area is measured in square metres, that is m^2. Other examples include the following:

Quantity	Example of unit	
	Full name	*Abbreviation*
area	square metre	m^2
volume	cubic metre	m^3
speed	metre per second	$m.s^{-1}$
acceleration	metre per second per second	$m.s^{-2}$

Table C. 1 Fundamental quantities and units of physics

Quantity	SI unit	SI symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	Kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd
Supplementary quantities		
plane angle	radian	rad
solid angle	steradian	sr

Table C. 2 The common prefixes and units

Prefix and symbol	Meaning	Value	Factor
micro (µ)	one millionth	0.000 001	10^{-6}
milli (m)	one thousandth	0.001	10^{-3}
centi (c)	one hundredth	0.01	10^{-2}
deci (d)	one tenth	0.1	10^{-1}
kilo (k)	a thousand	1 000	10^{3}
mega (M)	a million	1 000 000	10^{6}
giga (G)	a thousand million	1 000 000 000	10^{9}

Table C. 3 Some derived quantities and units

Table C. 3 Some derived quantities and units

Quantity	SI unit	SI symbol
velocity (*v*)	metre per second	$m.s^{-1}$
acceleration (*a*)	metre per second per second	$m.s^{-2}$
force (*F*)	newton	N
momentum (*p*)	kilogram metre per second	$kg.m.s^{-1}$
energy, work (*E, W*)	joule	J
power (*P*)	watt	W
electric charge (*q*)	coulomb	C
electric field intensity (*E*)	newton per coulomb	$N.C^{-1}$
potential difference (*V*)	volt	V
resistance (*R*)	ohm	Ω
frequency (*f* or *n*)	hertz	Hz
volume (*V*)	litre (non SI unit)	L

Table C. 4 Physics data

Characteristic	Value
Elementary charge	-1.6×10^{-19} C
Velocity of sound in air	$340\ m.s^{-1}$
Earth's gravitational acceleration g	$9.8\ m.s^{-2}$
Speed of light *c*	$3 \times 10^{8}\ m.s^{-1}$
Universal gravitational constant *G*	$6.7 \times 10^{-11}\ N.m^{2}.kg^{-2}$
Mass of Earth	5.98×10^{24} kg

Table C. 5 Greek Alphabet

Greek letter			Greek letter		
Capital	Lower case	Greek name	Capital	Lower case	Greek name
Α	α	alpha	Ν	ν	nu
Β	β	beta	Ξ	ξ	xi
Γ	γ	gamma	Ο	ο	omicron
Δ	δ	delta	Π	π	pi
Ε	ε	epsilon	Ρ	ρ	rho
Ζ	ζ	zeta	Σ	σ	sigma
Η	η	eta	Τ	τ	tau
Θ	θ	theta	Υ	υ	upsilon
Ι	ι	iota	Φ	ϕ	phi
Κ	κ	kappa	Χ	χ	chi
Λ	λ	lambda	Ψ	ψ	psi
Μ	μ	mu	Ω	ω	omega

Glossary

A

A scan. In this type of ultrasound scan a single transducer scans along a line in the body and the resulting echoes are plotted as a function of time.

Absolute error. The difference between a measured value and its accepted value.

Absolute magnitude. The magnitude a star would have if it were 10 parsecs from Earth. It is a measure of the actual brightness rather than the apparent brightness. *See* magnitude.

Absolute zero. The temperature of a body at which its kinetic energy is a minimum; equal to 0 K or -273°C.

Absorption spectra. Spectra that are produced when light (or more generally electromagnetic radiation) has been absorbed by matter. Consist of a continuous spectrum crossed by dark lines or bands. They result from the absorption caused when light from the source such as a star passes through its relatively cooler outer layers. These lines or bands are characteristic of the medium through which the light passes and can be used to identify the elements present.

AC. *See* alternating current.

Acceleration. The time rate of change of velocity; can be a speeding up, slowing down and/or changing of direction.

Accretion. The process of dust grains colliding and coalescing. Used to help explain the formation of the sun and planets.

Accuracy. The closeness of a measurement to the accepted value of a certain physical quantity; it is a function of the relative or percentage error.

Acoustic impedance. A measure of how easy it is to transmit sound waves through a medium.

Air resistance. Friction caused by movement of bodies through the air.

Alpha (α) particle. A nucleus of helium-4 emitted from a nucleus of an atom undergoing radioactive decay.

Alpha particle scattering. The deflection of alpha particles when fired at thin gold foil. The analysis of this scattering by Rutherford led to the discovery of the nucleus.

Alternating current (AC). An electric current that reverses direction periodically.

Ammeter. A meter used to measure electric current.

Ampere. The unit of the fundamental quantity of electric current.

Ampere's Law. The force between two parallel current-carrying wires is proportional to the product of the currents and inversely proportional to the separation of the wires.

Amplitude. The maximum displacement of a vibrating particle from its equilibrium position.

Amplitude modulation. A type of modulation where the amplitude of the carrier wave is varied by an imposed signal.

Angle of incidence. The angle between the incident ray and the normal at the point of incidence; the angle between the incident wavefront and the boundary.

Angle of reflection. The angle between the reflected ray and the normal at the point of incidence; the angle between the reflected wavefront and the boundary.

Angle of refraction. The angle between the refracted ray and the normal at the point of refraction (or between the wavefront and the boundary).

Angular momentum. The moment of linear momentum. It is equal to the product of a body's moment of inertia and its angular velocity.

Angular velocity. The time rate of change of angular displacement.

Antimatter. 'Matter' composed entirely of antiparticles. For example, an antihydrogen atom consists of an antiproton surrounded by a positron. When matter and antimatter collide, they are converted into energy in the form of gamma rays.

Antinodal lines. Lines joining points of constructive interference.

Apparent magnitude. This is the magnitude as measured by an observer on Earth. See magnitude.

Armature. The rotating part in an electric motor or generator. Generally consists of conductors wrapped around a soft iron core.

Astrometry. The science of the measurement of the positions of stars and other celestial objects.

Astrometric binary. A binary star in which one component is too faint to be observed directly. The presence of the unseen component is inferred from the perturbation of the motion of the visible component.

Atmosphere. The layers of gas surrounding a planet.

Atom. The smallest part of an element that has all the properties of the element.

Atomic number. (*Z*) The number of protons in the nucleus of an atom; defines the element.

Average velocity. Total displacement divided by total time for that displacement.

B

***B* scan.** In ultrasound, a linear array of transducers scans a plane in the body (that is, a 'slice' from front to back). A point represents the echo for each scan. The point's position is given by the time delay and the brightness depends on the signal strength.

Back *emf*. An *emf* that opposes the applied *emf* in an electric circuit such as a motor.

Balmer series. The visible lines in the emission spectrum of hydrogen. Occur when an electron falls from a higher energy level to the *second* energy level.

Baryons. One class of matter. Made up of three quarks. Includes protons and neutrons.

Bearings. Angles measured clockwise from north. Used in vector analysis.

Beats. The interference effect of two almost identical waves passing through the same medium together. The resultant is a series of alternate maxima and minima in the amplitude of vibration.

Beta (β) particle. An electron emitted from a radioactive nucleus.

Big Bang. An explosion which is postulated to have begun the expansion of the universe approximately 15 billion years ago.

Binary star. A double star system in which two stars orbit around their common centre of mass under the influence of their mutual gravitational attraction. *See also* astrometric binary, eclipsing binary and spectroscopic binary.

Binding energy. The energy that must be supplied to disrupt a nucleus into its constituent parts.

Black body. An idealised body which absorbs all radiation that falls on it according to Planck's Law.

Black body radiation. Radiation emitted by a black body that obeys Planck's Law.

Black hole. A star which has collapsed under its own gravitation to such an extent that its gravitational field is so intense that even light cannot escape from its surface.

Bosons. A class of matter. Involved in the weak nuclear force.

Brightness. The intensity of light or other radiation emitted or received from a celestial body.

Brushes. Conductors used to provide electrical contact to the moving parts of an electric motor or generator. Usually made of graphite.

C

Carbon cycle. A chain of nuclear fusion reactions by which energy may be generated in stars. The overall result is to transform hydrogen into helium. Carbon acts as a catalyst and nitrogen and oxygen are produced as intermediates. Sometimes called the carbon-nitrogen cycle or CNO cycle.

Cathode. The electron-emitting electrode in an electron tube (discharge tube).

Centre of mass. That point in a body at which all of the mass can be considered to lie.

Centripetal acceleration. The acceleration directed towards the centre of a circle about which an object is moving.

Centripetal force. The force directed towards the centre of a circle necessary for an object to follow a circular path.

Cepheid variables. A class of pulsating stars which vary periodically in brightness. Their brightness can be determined directly from their periods and they are used as an important aid in the measurement of the distances to star clusters and galaxies. The first such star to be investigated was Delta Cephei.

Charge. *See* electric charge.

Chain reaction. When the product of a reaction is itself used to initiate further reactions.

Circuit. *See* electric circuit.

Circular motion. Motion of a body along a circular path.

Cluster. A group of stars or galaxies whose members are sufficiently close to each other to be physically associated.

Coherence. The property of two wave trains with identical wavelengths and a constant phase relationship. Light waves must be coherent to show observable interference phenomena.

Coherent bundle. A bundle of optical fibres in which the individual fibres are kept in the same relative positions in the bundle at both ends.

Colour index. The colour of a star expressed as the difference in magnitudes when measured through blue and yellow filters. Colour index equals blue magnitude minus yellow magnitude ($CI = B–V$).

Communication. The transfer of information from a sender to a receiver via a medium.

Commutator. A device used in motors or generators to reverse the direction of the current each half-revolution of the armature.

Compact disk. A plastic disk that has digital data encoded on it as a series of pits.

Component. One of the numerous vectors that can be added vectorially to yield a resultant vector.

Compression. The region in a longitudinal wave where the particles are closer than in their normal equilibrium position.

Compton scattering. The deflection of X-rays by electrons in matter. Proves the particle nature of X-rays.

Computerised axial tomography (CAT). A non-invasive technique that uses X-rays to produce images of various internal parts of the body such as the head, heart and abdomen.

Concave. Surface with centre of curvature on the same side as the observer.

Concave lens. A lens that diverges parallel light rays. It is thinner in the centre than on the edges.

Concave mirror. A mirror that converges parallel light rays incident on its surface.

Concurrent forces. Forces whose line of action pass through the same point.

Conductor. A material that allows heat and electric charge to move easily through it.

Continuous spectrum. A spectrum that shows a complete spread of colours from red to violet.

Control rods. Rods used to control the rate of a nuclear fission reaction. Generally made of neutron absorbing material such as boron.

Conventional current. The flow of charge carriers from positive potential to negative potential.

Converging lens. *See* convex lens.

Convex. Having a surface with the centre of curvature on the opposite side to the observer.

Convex lens. A lens that causes parallel light beams to come together at a common point. It is thicker in the centre than at the edges.

Convex mirror. A mirror that causes parallel light beams to diverge.

Cosmology. The study of the organisation, structure and evolution of the universe.

Coulomb. The unit of electric charge; equal to one ampere second.

Crest. A region of upward displacement in a transverse wave.

Critical angle. The angle of incidence for which the angle of refraction is 90 degrees. Only occurs for waves going from a dense medium to a less dense medium.

Critical mass. The minimum mass of radioactiv material able to sustain a fission chain reaction.

Current. *See* electric current.

D

DC. *See* direct current.

Degenerate matter. Matter in a highly dense form that can exert a pressure as a result of certain quantum-mechanical effects. This pressure stabilises a white dwarf against the gravitational force.

Derived quantity. A quantity which is the combination of two or more fundamental quantities of science.

Diffraction. The spreading of a wave into the geometrical shadow of an object.

Diffraction grating. A device for producing a spectrum of white light. It consists of a series of straight parallel lines scratched on an optically flat surface.

Dipole. Two small equal but opposite charges separated by a distance.

Direct current (DC). Current that flows in one direction only.

Dispersion. The spreading of white light into its components as a result of refraction through a triangular prism.

Displacement. Change in position in a given direction.

Domain. A small region containing ~10^{17} atoms with their magnetic moments aligned.

Doppler effect. (1) The apparent change in frequency (or wavelength) when there is relative motion between the source of waves and an observer. (2) In astronomy, a star receding from us would experience a 'red shift' in its spectrum. The Doppler effect can be used to determine distances to galaxies and the presence of spectroscopic binaries.

Drift velocity. The average speed of movement in one direction of charge carriers in a conductor.

DVD. Digital video (virtual) disk.

Dwarf. Any star lying on the main sequence of the Hertzsprung-Russell diagram.

Dynamics. The study of the causes of motion.

E

Earth connection. The connection to the earth of an appliance to protect a user from electrocution.

Echocardiography. The use of ultrasound to diagnose heart (cardiac) problems.

Eclipsing binary star. A binary star system in which the orbital planes are seen almost edge-on so that eclipses occur. This causes the total brightness of the pair to vary periodically as each star passes in front of the other, the deeper minimum corresponding to the eclipse of the brighter star.

Elastic collision. A collision in which kinetic energy is conserved.

Elasticity. The ability of a material to return to its original size and shape when any deforming forces are removed.

Electric charge. That property of matter which allows it to attract opposite charges and repel similar charges. Can be positive or negative.

Electric circuit. Consists of a source of electric energy, a conducting pathway and a device that uses electric energy.

Electric current. The rate of flow of electric charge past any point in a circuit.

Electric field. The region in which a charge experiences an electric force.

Electric field intensity. The force per unit positive charge acting on a charge in an electric field.

Electric potential difference. The difference in electric potential energy per unit charge.

Electric potential energy. The energy stored in a charge placed in an electric field.

Electrodynamics. The study of electric charges in motion.

Electromagnetic radiation (waves). Transverse waves composed of alternating electric and magnetic fields, the components of which are perpendicular to each other and to the direction of the energy flow.

Electromagnetic spectrum. The range of electromagnetic waves from high frequency gamma waves to low frequency radio waves.

Electromotive force. *See* emf.

Electron. A negatively charged subatomic particle found in all neutral atoms; has a charge of -1.6×10^{-19} C and a mass of 9.1×10^{-31} kg.

Electron diffraction. As a consequence of the wave nature of electrons, electrons exhibit diffraction when they pass through a crystal lattice.

Electron microscope. An instrument, analogous to a light microscope, that uses the wave nature of electrons to view and magnify objects.

Electron volt. A unit of energy equal to the energy acquired by one electron accelerating through a potential difference of one volt.

Electroscope. A device used to detect the presence of electric charges.

Electrostatics. The study of electric charges at rest.

emf. The energy per unit charge supplied by a source of electric current. It is equal to the open circuit potential difference across a cell or battery.

Emission spectrum. A spectrum produced by an incandescent solid, liquid or gas after dispersion by a prism or grating.

Endoscopy. The medical examination of the interior of the body by inserting an optical tube – an *endoscope* – through an opening in the body (either natural of as a result of an incision).

Energy. The capacity for doing work.

Energy level. One of a number of energy values allowed for an electron revolving around a nucleus.

Equilibrium. The state in which a body does not undergo any changes in its motion; the resultant force is zero.

Escape velocity. The minimum velocity required by an object to escape the gravitational pull of the Earth (or other planet or moon).

Ether. A hypothetical non-material fluid formerly hypothesised to permeate all space and having the property of propagating electromagnetic waves.

F

Field. A region in which a physical force is operating; a region of influence.

Fission. The splitting of a heavy nucleus into smaller nuclei.

Flux. Refers to the flow of physical entities such as charge, energy, radiation and atomic particles across a given area in a given direction; similarly refers to the flow of imaginary 'lines of force'.

Focal length. The distance between the principal focus of a lens or mirror and its optical centre.

Focus. A point at which light rays meet or appear to diverge from.

Force. That which changes the motion or shape of a body.

Fraunhofer lines. The dark conspicuous lines appearing in the solar spectrum. *See* absorption spectra.

Frequency. Number of waves to pass a point per second; the number of oscillations of a particle per second.

Frequency modulation. A type of modulation where the frequency of the carrier wave is altered by an imposed signal.

Friction. A force that always opposes motion. Arises as a result of contact between different materials.

Fundamental quantities. Those quantities in science that cannot be formed from combinations of other quantities; they include mass, length, time, the mole, electric current and thermodynamic temperature.

Fuse. A device consisting of a wire that melts when a predetermined current flows through it.

Fusion. The process by which light nuclei join together to produce a heavier nucleus.

G

Galactic (open) cluster. An open, irregular cluster of stars usually numbering about 100. Such clusters are found in the spiral arms of our galaxy and they contain substantial amounts of dust and gas. They are comparatively young systems containing few or no evolved stars.

Galaxy. A group of stars, dust and gas bound together gravitationally. Galaxies typically numbers billions of stars.

Gamma (γ) ray. A high-energy photon emitted from a radioactive nucleus.

Gedanken. A thought experiment, that is, one 'conducted' entirely in a person's brain. Used by Einstein in his Special Theory of Relativity.

Geocentric. Any system which has the centre of the Earth as its reference point. The model of the Solar System which has the Earth at the centre.

Geostationary orbit. A circular orbit around the Earth with a period of 24 hours lying in the plane of the equator.

Giant stars. Large, highly luminous stars which are brighter than main sequence stars of the same colour. Giants represent a late phase in stellar evolution.

Global Positioning System (GPS). A system that uses satellites to determine position on the Earth.

Globular cluster. A spherical system of old stars usually found in the halo of a galaxy. Typically containing about 100 000 stars with very little dust or gas. They contain lots of evolved stars like red giants and white dwarfs.

Gluon. The elementary particle that binds quarks together.

Gravitational field. That region of space in which a mass experiences a force of attraction from other masses.

Gravity. The force of gravitation on an object.

H

Hadron. An elementary particle that takes part in the strong interaction. Divisible into baryons (3 quark composite) and mesons (quark/antiquark pair).

Half-life. The time it takes for half the given mass of a radioactive element to decay into a new element.

Heliocentric. A description which refers to the Sun as the centre for measurements. The model of the Solar System which has the Sun at the centre.

Helium flash. The explosive onset of helium burning in the degenerate core of an evolved star.

Hertzsprung gap. A region on the H-R diagram to the right of the main sequence in which few stars are found. This is due to the stars rapid evolution away from the main sequence through this region.

Hertzsprung-Russell diagram. A diagram which displays the brightness of stars versus either their colour, spectral class or surface temperature. The H-R diagram is important in the determination of the age, distance and evolutionary history of a star system.

Hubble constant. The constant that relates the speed of recession of the galaxies to the age of the universe.

Hypothesis. A plausible solution to a problem. It forms the basis for further investigations by which it may be proved or disproved.

I

Impulse. The product of force and time; equals the change in momentum.

Induction. The process of charging one object by bringing it near another charged object.

Induction motor. An AC motor in which the current in the stator or rotor (usually the rotor) is induced when current is supplied to the other member (usually the stator).

Inelastic collision. A collision in which kinetic energy is not conserved; it is converted into other forms such as heat and sound.

Inertia. The property of matter that causes it to resist change in its motion.

Infrared. Long-wavelength radiation emitted by hot objects with wavelengths greater than ~700 nm and less than ~1 mm.

Instantaneous velocity. The velocity at an instant of time. Found by taking the average velocity over an extremely small time interval. It is equal to the slope of the tangent at the point on a displacement-time graph.

Insulator. A material that electric charge finds very difficult to move through.

Interface. The boundary between two different materials, for example, glass and water.

Interference. The effect of the superposition of two or more waves on each other when moving through the same region; can be constructive or destructive.

Interstellar matter. Gas and dust found between the stars. It constitutes about 10 per cent of the galactic mass.

Inverse square law. A relationship in which one quantity is directly proportional to the inverse of another quantity squared.

Ionosphere. A spherical shell of ionised gas surrounding the Earth. Can be used to reflect long wavelength radio waves.

Isotopes. Atoms with the same atomic number but different mass number; that is, atoms with different numbers of neutrons but the same number of protons.

J

Joule. The unit of energy (or work); the product of a force of one newton acting through a distance of one metre.

K

Kepler's Laws. Three laws relating the motion of the planets.

Kilogram. The SI unit of mass.

Kinematics. The study of motion without examining the causes; the description of motion.

Kinetic energy. Energy of motion.

Kirchoff's First (Current) Law. The sum of the currents into any point in a circuit is equal to the sum of the currents out of that point.

Kirchoff's Second (Voltage) Law. The sum of the potential drops around a circuit is equal to the sum of the *emf's*.

L

Laser. An acronym for *L*ight *A*mplification by the *S*timulated *E*mission of *R*adiation. A source of intense coherent light.

Law. A statement that describes a natural phenomenon; a principle.

Law of Conservation of Energy. Energy can neither be created nor destroyed but only changed in form.

Law of Conservation of Momentum. In the absence of external forces, the sum of the momenta before the collision is equal to the sum of the momenta after the collision.

Lepton. A class of matter. Includes the electron.

Light curve. A graph on which the magnitude of a variable star is plotted as a function of time.

Light-year. The distance that light travels in one year; equal to 9.5 x 10^{15} m.

Line spectrum. The spectrum of an element consisting of lines of certain frequencies (colours) only (each line being an image of the slit of the spectroscope).

Line of force. A line drawn tangential to the direction of the force on a charge (or mass or magnet) at each point.

Longitudinal wave. A wave in which the particles vibrate parallel to the direction of energy transfer.

Luminosity. A measure of the actual brightness o an astronomical object. It is a measure of the powe emitted by the object and is measured in watts.

M

Magnetic field. A region around a magnet where magnetic force would be felt.

Magnetic flux. Lines of flux through a region magnetic field.

Magnetic flux density. The number of flux lin through unit area perpendicular to the magnetic fie also known as magnetic induction.

Magnetic lens. A magnetic field that is used to fo electrons in an electron microscope.

Magnetic moment. A measure of the turning ef of a spinning charge in a magnetic field. determines how difficult it is for the charge to al its axis of rotation in the direction of an exte magnetic field.

Magnetic pole. Where the magnetism concentrated in a magnet. Always come in pairs.

Magnetic resonance imaging (MRI). A invasive technique used to produce images of tis inside the body using radio-frequency energy strong magnetic fields.

Magnetism. The property of certain materials allows them to attract iron objects.

Magnitude. This is a way of expressing the brightness of an astronomical object. Each magnitude is 2.5 times different from the magnitudes on either side of it. The smaller the magnitude, the brighter the object.

Main sequence. A region on the H-R diagram containing the majority of stars. It is in this region that stars spend the main part of their lives converting hydrogen into helium via the process of fusion.

Mass. A fundamental physical quantity; a measure of the amount of matter or inertia.

Mass number *(A)*. The sum of the protons and neutrons in a nucleus.

Matter. Everything that exists that has mass and takes up space.

Meson. A class of matter. Composed of a quark and an antiquark bound together.

Measurement. The process of comparing a given quantity to a standard and expressing the comparison numerically with a unit.

Mechanics. The study of motion, its description and causes.

Medium. A region through which a wave propagates.

Meson. A family of fundamental particles composed of a quark and antiquark bound together by the exchange of gluons.

Metal. An element with properties such as lustre and good electrical conductivity. Most elements are metals.

Metre. A fundamental unit of length. It is equal to the distance travelled by light in a vacuum in the fraction 1/299 792 458 of a second.

Metric system. A system of measurement based on powers of ten.

Michelson-Morley experiment. An experiment conducted to measure the speed of the Earth through the ether. The inability of the experiment to find this speed led directly to Einstein's Theory of Special Relativity.

Microwaves. Electromagnetic waves with wavelengths ranging from ~1mm to ~0.1 m.

Model. A representation of some phenomenon, generally in terms of things already known and familiar to us.

Moderator. A material used to slow down neutrons in a nuclear fission reactor.

Modulation. The alteration of some electronic or acoustic parameter by another. (*See* amplitude and frequency modulation).

Moment. The product of force and the perpendicular distance from the axis to the line of action of the force.

Momentum. The product of mass and velocity of a moving body.

Monochromatic. Light of one colour (wavelength).

Motion. Change in position relative to an observer.

N

Nebula. A cloud of dust and gas that can be observed as either a luminous patch of light — a bright nebula, or a dark hole or band against a bright background — a dark nebula.

Negative charge. Charge that will repel an electron.

Neutral. In physics, the state of no overall electric charge.

Neutrino. A neutral elementary particle with zero rest mass but carries energy and momentum.

Neutron. A subatomic particle with no electric charge and a mass almost equal to that of the proton.

Neutron scattering. The use of a beam of neutrons to investigate the structure of matter.

Neutron star. A star at the end of its evolution; made up of neutrons. Its mass is similar to that of the sun but its diameter is only about 20 km.

Newton. The SI unit of force; it is that force which will accelerate a mass of 1 kg at 1 $m.s^{-2}$.

Newton's First Law. A body will remain at rest or travel with constant velocity unless acted upon by an unbalanced force.

Newton's Law of Universal Gravitation. The force of attraction between two masses is proportional to the product of the masses and inversely proportional to the square of the distance between their centres.

Newton's Second Law. The acceleration of an object is directly proportional to the resultant force acting on it and inversely proportional to its mass.

Newton's Third Law. If one body exerts a force on a second body, the second body exerts the same force back on the first body; to every action there is an equal and opposite reaction.

Nodal lines. Lines joining points of destructive interference.

Normal. A line drawn at right-angles to another line or surface.

Nuclear fusion. *See* fusion.

Nuclear magnetic resonance (NMR). This is the emission or absorption of electromagnetic radiation by atomic nuclei when subjected to certain magnetic fields.

Nuclear reactor. A device in which controlled nuclear fission is used to obtain energy (and radioisotopes).

Nucleon. The collective name for protons and neutrons.

Nucleosynthesis. The production of the elements by nuclear reactions.

Nucleus. In physics, the dense positive core of the atom containing almost all the mass of the atom; made up of protons and neutrons.

Nuclide. An atom of a particular element with a definite mass.

0

Oersted's experiment. An experiment that showed that a current-carrying wire produces a magnetic field around it.

Ohm. The SI unit of electrical resistance; equal to that resistance which will allow a current of one ampere to flow when there is a potential difference of one volt.

Ohm's Law. The ratio of the applied voltage across a conductor to the current through it is a constant.

Optic fibre. A glass fibre consisting of two layers, the outer layer has a lower refractive index than the inner layer. Used to transmit light over long distances.

Orbit. *In astronomy*, the curved path followed by a planet or comet around the Sun and by moons around planets. In *atomic structure* the path of the electrons in Rutherford's atomic model.

Order of magnitude. The power of ten nearest to a particular number.

P

Parallax. The apparent movement of an object against a background when viewed from different positions.

Parallel circuit. A circuit containing more than one pathway for the current.

Parsec. The distance at which the radius of the Earth's orbit around the Sun subtends an angle of one second of arc.

Period. The time for one wave to pass a point; the time for a particle executing simple harmonic motion to complete one oscillation.

Periodic motion. Motion which repeats itself at regular intervals of time.

Period-luminosity relationship. For Cepheid variables there is a direct relationship between their period of brightness variation and their luminosity. Can be used to determine the distance to the star cluster containing the variable.

Phase. A quantity which tell us what a particle undergoing periodic motion is doing.

Photoelectric effect. The emission of electrons by materials when subjected to electromagnetic radiation of appropriate frequency.

Photometry. The measurement of light intensity, especially that from distant stars.

Photon. A quantum (bundle) of energy.

Physics. The study of matter and its energy relationships.

Piezoelectric effect. Phenomenon where an oscillating potential difference applied to a crystal is converted into a mechanical vibration (and a mechanical vibration into an oscillating potential difference).

Pitch. A subjective quantity. Related to the frequency of sound. The higher the pitch, the higher the frequency.

Plane mirror. A flat mirror.

Planetary nebula. A shell of gas expanding outwards from a star in the later stages of its evolution between the red giant and white dwarf stages.

Planetesimal. Objects a few kilometres in diameter formed by accretion in the early stages of the evolution of the Solar System.

Polarised light. Light in which the electric field vector is restricted to a single plane of vibration.

Population I and II stars. The classes of the stars of different ages. Population II stars were formed early in the history of the galaxy. They are generally older and have a smaller content of heavy elements. Population I stars are younger and are associated with interstellar gas and dust.

Positron. A positive electron. An antiparticle.

Positron emission tomography (PET). A non-invasive technique used to produce images of internally active parts of the human body by the use of short-lived radioisotopes produced in accelerators.

Potential difference. A measure of the work done per unit charge as a charge is moved between two points in an electric field.

Potential energy. Energy due to position or configuration; stored energy.

Power. The time rate of doing work.

Precession. The rotation of the axis of spin due to the application of a torque.

Precision. A statement of how reproducible a measurement is; it is a function of the absolute error.

Pressure. Force per unit area.

Propagate. To travel through a medium or space.

Property. A measurable aspect of matter, for example, weight.

Proton. The positive subatomic particle found in the nucleus of an atom.

Proton-proton cycle. A series of nuclear fusion reactions by which stars generate energy. The overall effect is to convert 4 hydrogen nuclei into 1 helium nucleus. Since the temperature required is about 10 million Kelvin, it is believed to be the major source of energy in the Sun and all main sequence stars cooler than the Sun. The carbon cycle predominates in hot stars.

Protostar. A newly formed star in which nuclear reactions have not yet started.

Pulsar. Another name for a neutron star.

Pulse. A single disturbance.

Q

Quantum. An elemental unit of energy; a photon of energy.

Quark. The fundamental building blocks of matter.

R

Radioactivity. The spontaneous breakdown of an atom by the emission of alpha and/or beta and gamma rays.

Radioisotope. A radioactive isotope of an element.

Radio-waves. Long-wavelength members of the electromagnetic spectrum.

Rarefaction. The region in a longitudinal wave where the particles are spread out further than their equilibrium positions.

Ray. A line drawn at right angles to a wavefront.

Rectilinear motion. Motion in a straight line.

Red giant. A star in its later stages of evolution after it has moved from the main sequence and expanded to a size hundreds of times larger.

Red shift. The shift of the spectral lines from a receding light source towards the red end of the spectrum.

Reflection. The bouncing back of a wave or particle from a boundary.

Refraction. The bending of a wave as it passes from one medium into another; it results from a change in the speed of the wave in the two media.

Refractive index. For a wave travelling from one medium into another, the refractive index is the ratio of the sine of the angle of incidence to the sine of the angle of refraction.

Resistance. The property of a material that makes it difficult for electric charge to flow.

Resolution of optical instruments. The ability of optical instruments to distinguish between two very close objects.

Resolution of vectors. The breaking down of a vector into its components.

Resultant. That single vector which has the same effect as a number of other vectors; the vector sum of a number of vectors.

Resultant force. That single force which would have the same effect as two or more forces applied to the same point.

S

Scalar. A quantity that can be represented completely, purely by a number.

Scientific notation. A number between one and ten multiplied by the appropriate power of ten.

Second. The SI unit of time; equivalent to 9 192 631 770 vibrations of caesium-133.

Series circuit. An electric circuit which has only one pathway.

Simultaneity. The simultaneous occurrence of events. In special relativity, two events that are simultaneous for one observer are not simultaneous for another observer in a different inertial frame of reference.

Significant figures. Those figures in a measurement that are accurately known plus the first uncertain figure.

Snell's Law. A law relating the angle of incidence to the angle of refraction. $n = \dfrac{\sin i}{\sin r}$

Space-time. The four dimensions (x, y, z, t) required to uniquely define an event.

Special Relativity. The Theory of Relativity restricted to inertial frames of reference.

Spectral class. A classification scheme for stars based on the spectrum of the stars. Goes from the hot blue O stars through B, A, F, G, K to the cool red M stars. Each group is divided into 9 others designated by a number. Our sun is a G2 star.

Spectroscope. An optical device used to disperse light from a source into its spectrum.

Spectroscopic binary. A binary star which can be recognised by the periodic doubling of its spectral lines.

Spectroscopic parallax. A method using spectra to determine distances to stellar objects. (It does not actually use parallax)

Speed. Time rate of change of distance.

Spin. A measure of the intrinsic angular momentum of an elementary particle. Spin, like mass and charge, is a fundamental property of all elementary particles. It comes in multiples of ½ and can be + or –.

Standing wave. A wave formed by the superposition of two identical waves travelling in opposite directions in which the energy does not progress forward.

Star. A vast mass of gas hot enough to initiate fusion reactions.

State. The physical form of a substance. It may be solid, liquid or gas.

Static electricity. Electric charges at rest.

Statics. The study of the conditions needed for a body to be at rest.

Steady state. A theory of the universe which suggests that new matter 'pops' into existence to keep the density of the universe constant.

Stellar equilibrium. The balance between the forces of gravity causing a star to collapse and the outward forces due to the energy released in nuclear reactions.

Stellar evolution. The different stages in a star's life from its 'birth' to its 'death'.

Sun spots. Cooler areas on the sun's surface. Also areas of weaker magnetic fields.

Supernova. The end result of a massive star which explodes and increases in brightness by 1 billion times or more. In the explosion, the heavy elements (those heavier than iron) are believed to be formed.

Superposition. The combination of two or more waves by adding their displacements vectorially to produce a resultant wave.

T

Temperature. A measure of the average kinetic energy of translation; a measure of 'hotness' or 'coldness'.

Tension. Forces in ropes, strings, wires, cables…

Theory. An explanation of observed facts and laws. It is supported by experiments upon which it is based, and is confirmed by experiments designed to test predictions based on the explanation.

Thermal equilibrium. The state when the energy gained is equal to the energy lost.

Time dilation. The 'slowing down' of time in a moving frame of reference.

Torque. The product of force and perpendicular distance from the axis to the line of action of the force. It is the rotational analogue of force.

Total internal reflection. The reflection of all the light falling on a boundary when the angle of incidence exceeds the critical angle.

Tracer. A radioactive material used to trace the path of a substance.

Trajectory. The path of a projectile.

Transmutation. The conversion of one element into another.

Transverse wave. A wave in which the particles vibrate at right angles to the direction of energy transfer.

Trough. In a transverse wave, a region of downwards displacement.

U

Ultrasound. Sound with frequencies greater than 20 000 Hz.

Ultrasonography. The use of ultrasound in medical and industrial situations.

Ultraviolet. Electromagnetic waves with wavelengths shorter than violet light.

Universe. Everything that exists.

V

Van Allen radiation belts. Two belts of energetic charged particles (mainly protons and electrons) surrounding the Earth.

Variable star. A star whose brightness varies with time. Includes eclipsing binaries and Cepheid variables.

Vector. A quantity that needs both a size and a direction to describe it fully and which obeys special laws of addition.

Velocity. The time rate of change of displacement.

Visual binary. A binary star whose individual components can be distinguished through a telescope.

Volt. The SI unit of potential difference. The potential difference between two points is one volt if one joule of work is done to move one coulomb of charge between the two points.

Voltmeter. A meter used to measure the potential difference between two points.

Volume (loudness). The degree of loudness of a sound. Depends on the amplitude of the sound.

W

Watt. The SI unit of power; one joule per second.

Wavefront. A line joining points in phase on a wave.

Wavelength. The distance between two corresponding successive points on a wave.

Wave-particle duality. The realisation that matter has both wave and particle characteristics.

Weight. The force of gravity on an object.

White dwarf. A star at the end of its evolution. It has a mass about equal to that of the Sun and a diameter about that of the Earth. No nuclear processes are continuing and it eventually ends up as a cold black dwarf.

Work. The product of force and displacement parallel to the force.

Work function. The minimum energy required to remove an electron from a surface by photoemission.

X

X-ray. High frequency electromagnetic waves of high penetration.

Z

Zeeman effect. The splitting of spectral lines in a strong magnetic field.

Index

PHYSICS DATA SHEET

Numerical values of several constants

Charge on the electron, q_e	-1.602×10^{-19} C
Mass of the electron, m_e	9.109×10^{-31} kg
Mass of neutron, m_n	1.675×10^{-27} kg
Mass of proton, m_p	1.673×10^{-27} kg
Speed of sound in air	340 $\mathrm{m.s^{-1}}$
Earth's gravitational acceleration, g	9.8 $\mathrm{m.s^{-2}}$
Speed of light (in vacuo), c	3.00×10^{8} $\mathrm{m.s^{-1}}$
Magnetic force constant ($k = \frac{\mu_0}{2\pi}$)	2×10^{-7} $\mathrm{N.A^{-2}}$
Universal gravitational constant, G	6.67×10^{-11} $\mathrm{N.m^2.kg^{-2}}$
Mass of Earth	6.0×10^{24} kg
Planck's constant	6.626×10^{-34} J.s
Rydberg's constant, R_H	1.097×10^{7} $\mathrm{m^{-1}}$
Atomic mass unit, u	1.661×10^{-27} kg 931.5 MeV/c^2
1 eV	1.602×10^{-19} J
Density of water, ρ	1.00×10^{3} $\mathrm{kg.m^{-3}}$
Specific heat capacity of water	4.18×10^{3} $\mathrm{J.kg^{-1}K^{-1}}$

Physics Formulae Sheet

$$v = f\lambda$$

$$I \propto \frac{1}{d^2}$$

$$\frac{v_1}{v_2} = \frac{\sin i}{\sin r}$$

$$E = \frac{F}{q}$$

$$R = \frac{V}{I}$$

$$P = VI$$

$$\text{Energy} = VIt$$

$$v_{av} = \frac{\Delta s}{\Delta t}$$

$$a_{av} = \frac{\Delta v}{\Delta t} = \frac{v-u}{t}$$

$$\sum F = ma$$

$$F = \frac{mv^2}{r}$$

$$E_k = \tfrac{1}{2}mv^2$$

$$W = Fs$$

$$p = mv$$

$$\text{Impulse} = Ft$$

$$E_p = -G\frac{m_1 m_2}{r}$$

$$F = mg$$

$$v_x^2 = u_x^2$$

$$v = u + at$$

$$v_y^2 = u_y^2 + 2a_y\Delta y$$

$$\Delta x = u_x t$$

$$\Delta y = u_y t + \tfrac{1}{2}a_y t^2$$

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

$$F = \frac{Gm_1 m_2}{r^2}$$

$$E = mc^2$$

$$l = l_0\sqrt{\left(1 - \frac{v^2}{c^2}\right)}$$

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Physics Formulae Sheet (cont)

$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

$$F = BIl\sin\theta$$

$$\tau = Fd$$

$$\tau = nBIA\cos\theta$$

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

$$F = qvB\sin\theta$$

$$E = \frac{V}{d}$$

$$E = hf$$

$$c = f\lambda$$

$$Z = \rho v$$

$$\frac{I_r}{I_o} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$$

$$d = \frac{1}{p}$$

$$M = m - 5\log\left(\frac{d}{10}\right)$$

$$\frac{I_A}{I_B} = 100^{\left(\frac{m_B - m_A}{5}\right)}$$

$$m_1 + m_2 = \frac{4\pi^2 r^3}{GT^2}$$

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\lambda = \frac{h}{mv}$$

Key

Atomic Number 79

Au — Symbol of element

Atomic mass 197.0

Gold — Name of element

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.06 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.90 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.71 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.59 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc 98.91 Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Cesium	56 Ba 137.3 Barium	57 La 138.9 Lanthanum	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.9 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po - Polonium	85 At - Astatine	86 Rn - Radon
87 Fr - Francium	88 Ra 226.0 Radium	89 Ac - Actinium	104 Unq -	105 Unp -	106 Unh -	107 Uns -	108 Uno -	109 Une -									

58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm - Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dyprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.0 Ytterbium	71 Lu 175.0 Lutetium
90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np 237.0 Neptunium	94 Pu - Plutonium	95 Am - Americium	96 Cm - Curium	97 Bk - Berkelium	98 Cf - Californium	99 Es - Einsteinium	100 Fm - Fermium	101 Md - Mendelevium	102 No - Nobelium	103 Lr - Lawrencium

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At home — at your desk. Read each card thoroughly and make sure you understand all the points. You should also know more detailed information on each topic — if you are not completely sure of a topic, look for the page reference at the bottom of the card and turn to this page in your Excel study guide.

Good luck!

Contents 2 EXCEL HSC Physics Pass Cards

SPACE
The Gravitational Field and Weight

1

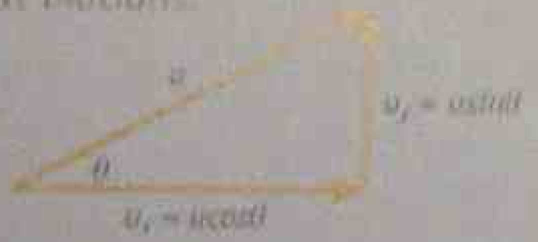
- A **gravitational field** surrounds the Earth.
- This field exerts an **attractive force** on objects on it and around it.
- On Earth the **gravitational field strength g** is equal to ~9.8 $N.kg^{-1}$ This is numerically equal to the **acceleration due to gravity** ~9.8 $m.s^{-2}$
- **Weight** is the force on an object due to the presence of a gravitational field.
- The **weight** W of a mass m on a planet where the acceleration due to gravity is g is given by $W = mg$
- The **mass** of an object is independent of its location. Its weight, however, depends on where it is placed. For example a 10 kg mass weighs 98 N on the Earth but only 38 N on Mars ($g_{Mars} = 3.8\ m.s^{-2}$). Its mass, however, is 10 kg on both planets.

See EXCEL HSC Physics pp. 2–4

SPACE
Projectile Motion

3

- A **projectile** is any object moving under the influence of gravity only.
- **Examples** include golf balls after being hit, artillery shells fired from guns, hit or thrown cricket balls...
- **Projectile motion** has two independent motions.
- The horizontal (x) component is **constant velocity** where $u_x = u\cos\theta$, $v_x = u_x$ and $\Delta x = u_x t$
- The vertical (y) component is **constant acceleration** where $u_y = u\sin\theta$, $v_y^2 = u_y^2 + 2a_y\Delta y$ and $\Delta y = u_y t + \frac{1}{2}a_g t^2$



- Galileo showed the curved path of a projectile — its **trajectory** — is a **parabola**.

See EXCEL HSC Physics pp. 7–13

SPACE
Rocket Launch

5

- For lift-off, the **thrust** on a rocket must exceed the weight of the rocket.
- Rocket engines generate thrust by **burning fuel** and expelling the resulting gases.
- **Conservation of momentum** means that as the exhaust gases move one way the rocket moves in the opposite direction.
- As fuel is consumed the mass of the system decreases so the **acceleration increases** ($a = \frac{F}{m}$)
- During lift-off astronauts experience an apparent weight increase, ***g*-forces.**
- g-forces are equal to $\frac{\text{apparent weight}}{\text{normal weight}}$. They increase as the rocket's acceleration increases.

See EXCEL HSC Physics pp. 17–19

SPACE
Low Earth Orbits and Geostationary Orbits

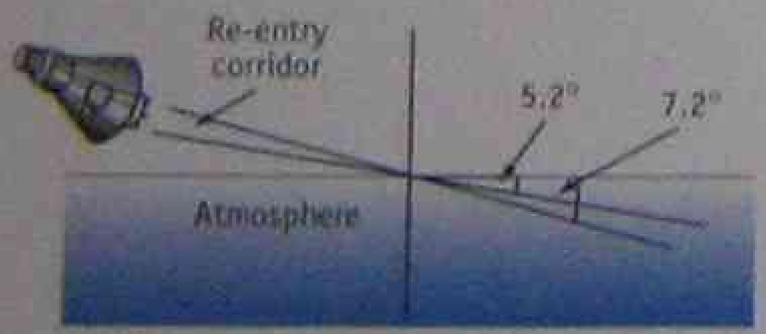
7

- A satellite in **low Earth orbit** (LEO) has an altitude ranging from ~300 km to ~800 km and a period less than 24 hours.
- They are used as **spy satellites** and for **surveying** weather conditions.
- A satellite in a **geostationary orbit** lies in the equatorial plane of the Earth at an altitude of ~35,800 km with a period of 24 hours.
- Geostationary satellites appear to stay above the same point on the Earth and allow **communication signals** to be 'bounced' around the world.
- **Newton's laws** describe the motion of these satellites according to $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$. As radius decreases period decreases and speed increases.
- Satellites in LEO travel faster than satellites further out in space.

See EXCEL HSC Physics p. 21

SPACE
Re-entry

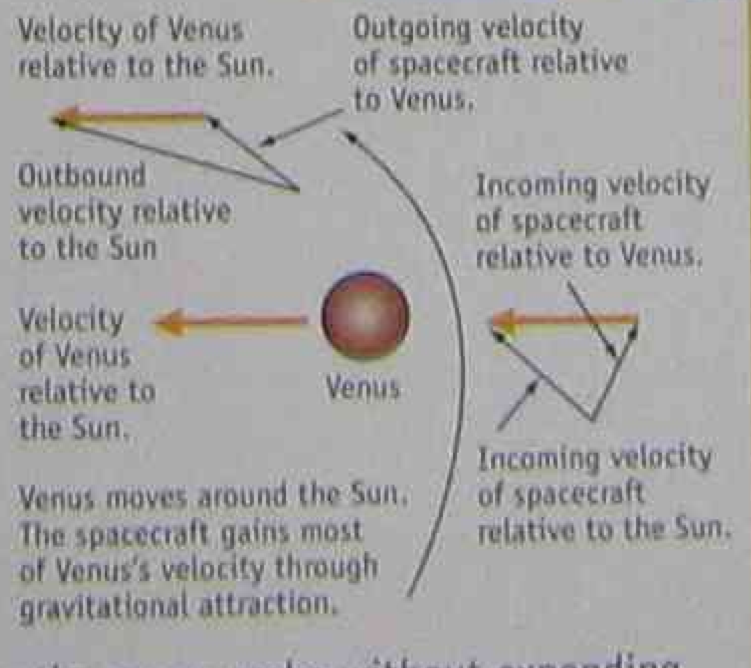
9



- **Re-entry** is the return of a spacecraft into the Earth's atmosphere and its subsequent descent to Earth.
- **Safe re-entry** is limited to a small **'window'** to ensure: the spacecraft does not **'bounce' off** into space if it comes in too shallow; ***g*-forces** are not too high if it comes in too steep; and the **heat** from re-entry is not too high.
- The 'allowed' angle of re-entry is **−6.2° ± 1°** relative to the Earth's horizon.
- **Ionisation blackout** occurs when the high temperatures of re-entry results in ionisation of the air preventing communication with

SPACE
The Slingshot Effect

11



- The **'slingshot effect'** is used to send space probes to distant planets.
- A space probe approaching a planet picks up some of the planets **angular momentum** resulting in a **speeding up** of the spacecraft relative to the Sun.
- The slingshot effect is used to **conserve fuel** for interplanetary travel. It provides additional velocity to the space probe without expending fuel so space probes can **travel further** for the same fuel load.

SPACE
Frames of Reference

13

- A **frame of reference** is a coordinate system with respect to which we take measurements. In a laboratory, the walls and ceiling form a frame of reference for your experiments.
- An **inertial frame** of reference is one moving with constant velocity (or is at rest).
- A **non-inertial frame** of reference is one that is accelerating.
- As a result of his work on how the laws of electromagnetism should look in different frames of reference, Einstein proposed that the **speed of light is constant** (in a vacuum) and is independent of the speed of the source or observer. This is Einstein's law of light.
- It formed the basis of the theory of **special relativity**.

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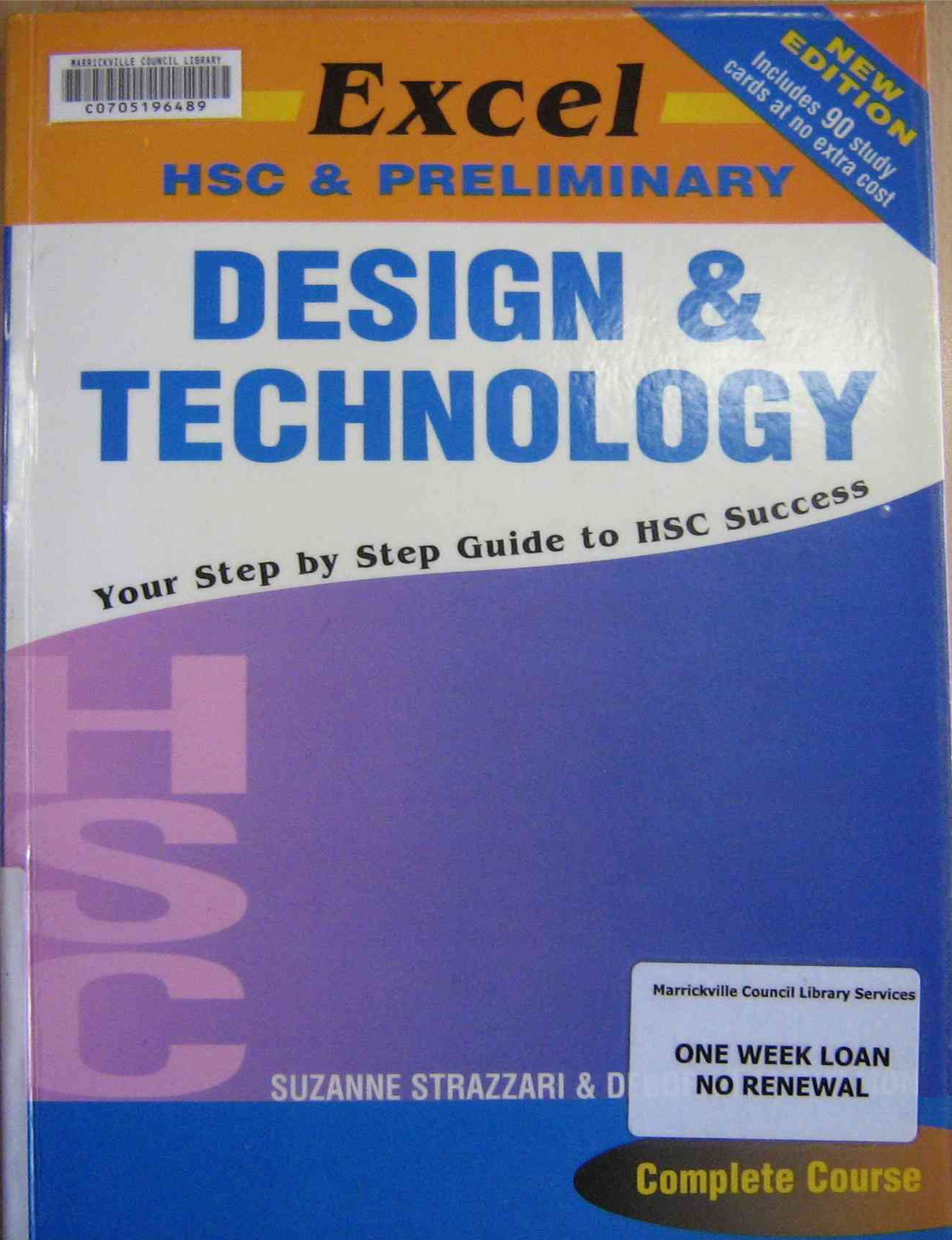

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Suzanne Strazzari

Contents

1 – Introduction

Course Overview

Design and Technology is a complex but exciting course, combining a variety of theoretical subjects with various practical skills. It demands high order thinking and problem-solving skills. Students learn about ingenuity, satisfying needs, deriving solutions and using technology.

For the HSC, students are required to sit for a 1½ hour exam, worth 40 per cent, and to complete a Major Design Project worth 60 per cent of the final external assessment mark. For more details of assessment and syllabus requirements, see the Board of Studies website:

http://www.boardofstudies.nsw.edu.au

1.1 Organisation of this Study Guide

This guide is structured to cover the Preliminary and HSC Design and Technology syllabus. Students should be aware that only HSC Outcomes are assessed in the examination, however, the knowledge and skills developed in the Preliminary year are synthesised and applied to the HSC course. You can obtain the course structure outline from the Board of Studies website at www.boardofstudies.nsw.edu.au.

This study guide is to be used throughout the Preliminary and HSC years and contains:

- Aids to improving your thinking skills and helpful cognitive organisers.
- Mind maps, diagrams and graphs.
- End-of-chapter revision questions and exercises with answers plus extension activities.
- Lists of key terms and concepts.
- A glossary of Design and Technology terms that will be used in the exam and that you **must** use in your Major Design Project.

1.2 General Study Skills

Each person needs to develop a study routine that works for them, but many successful students have the following common study skills:

- Use a study timetable and allocate the same amount of study (not homework) time to each subject.
- Study for one hour and then have a 10-minute break.
- Try to do a small amount of physical exercise in your 10-minute break.
- Study subjects of a dissimilar nature concurrently, for example, Design and Technology followed by English followed by Science.
- Summarise all of your notes and develop your own mind maps around each topic.
- Learn all of the information that you have summarised. Repetition improves retention but this is only the starting point.
- Get people to test you orally.
- Once you can recall facts, you will need to have an understanding of all associated issues in order to improve your marks.
- Study groups and Socratic thinking will raise thinking skills and also grades. (See page 11 for more details.)
- When you have completed your revision, form a study group to write as many HSC questions as possible. (The person who writes the question must also write an answer that would get good marks and also mark the other students' answers.)
- Go back over your past exam papers and re-answer in order to try and obtain full marks or as close to this as possible.
- If possible, collect trial papers from other schools and answer all questions, using examination timing.
- Mark your papers carefully and then ask your teacher to re-mark them for you.

1.3 Achieving Full Potential

In order to try and obtain the best marks that you are able to achieve, you will need to have all of the following:

- **Self-confidence**. It is important that you feel positive about yourself and this subject.
- **Clear and achievable goals**. Planning how to achieve these goals will help you with this.
- **Internal and external motivation**. Motivation is the desire to do something and in order to raise your motivation you may need to reward yourself for a job well done.
- **Organisation and time management**. Being organised helps you make the best use of your time and can increase what you know about a subject.
- **Study skills**. Studying is hard work. There are no easy ways of studying but there are a number of things that will help you to recall what you have learnt.
- **Know your academic holes**. For a variety of reasons, there may be a section of your course work that you do not completely understand. Knowing where your academic holes are means that, with planning and hard work, you can overcome these weaknesses.

The above points are looked at in more detail on the following pages.

1.4 Self-confidence

It is important that you feel positive about yourself and this subject.

Being Positive About the Subject

You know that if your teacher has set you an assessment task that you put a lot of effort into and did well, then you feel positive about the subject and look forward to going to class. On the other hand, if during the last lesson your teacher handed back a class essay or test and your grade was lower than you had hoped, you will be walking into that class the next day saying to yourself 'I hate this subject'. The way we feel about a subject very much influences what we learn.

Think about what you do in your spare time — do you visit and chat with friends, participate in sporting ventures, attend concerts and plays, watch television, or do you prefer to do extra chores around the house? Circle the option that best fits what you prefer to do.

Leisure activities that you enjoy **OR**
chores that you hate.

Chances are, you circled leisure activities because we usually choose to spend our time doing the things that we enjoy!

Now consider your study routine. Do you usually complete assignments that interest you in subjects that you are doing well in or do you first attack the subject that you currently dislike. Once again, circle the option that is closest to how you approach your study.

Subjects you enjoy **OR**
difficult assignments you do not.

As with leisure versus chores, once again chances are that the more difficult tasks get left until last and thus become more of a hassle because you are under pressure, do not do your best work, hand it in at the last minute and get a low grade. This then becomes a **Circle of Underachievement**.

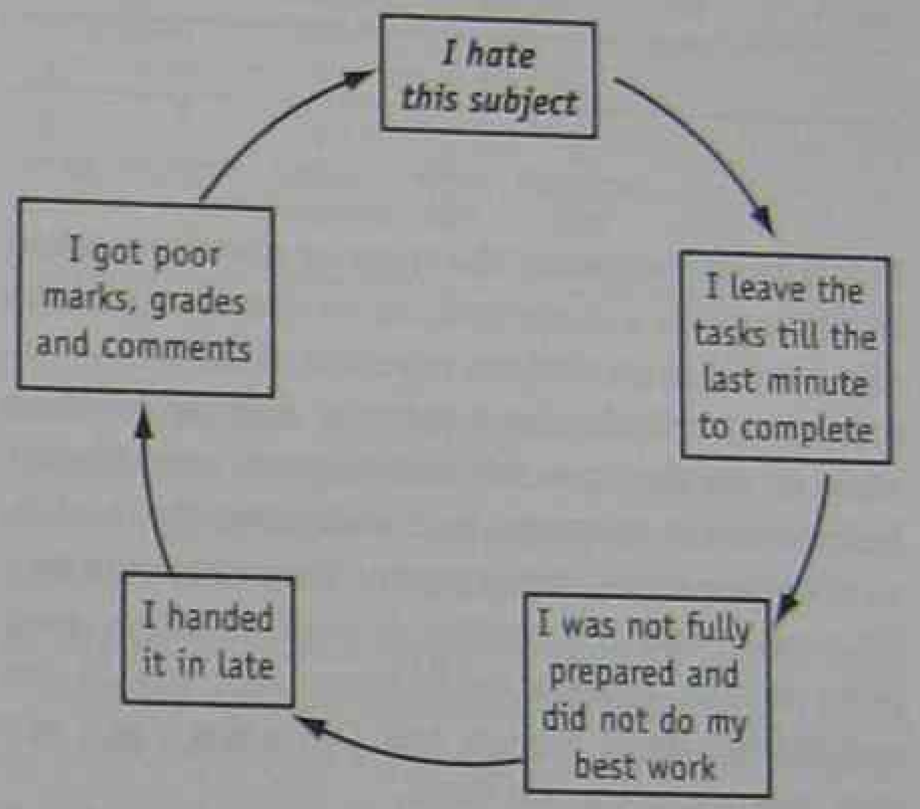

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Figure 1.1 Circle of Underachievement

People Who Affect our Self-confidence

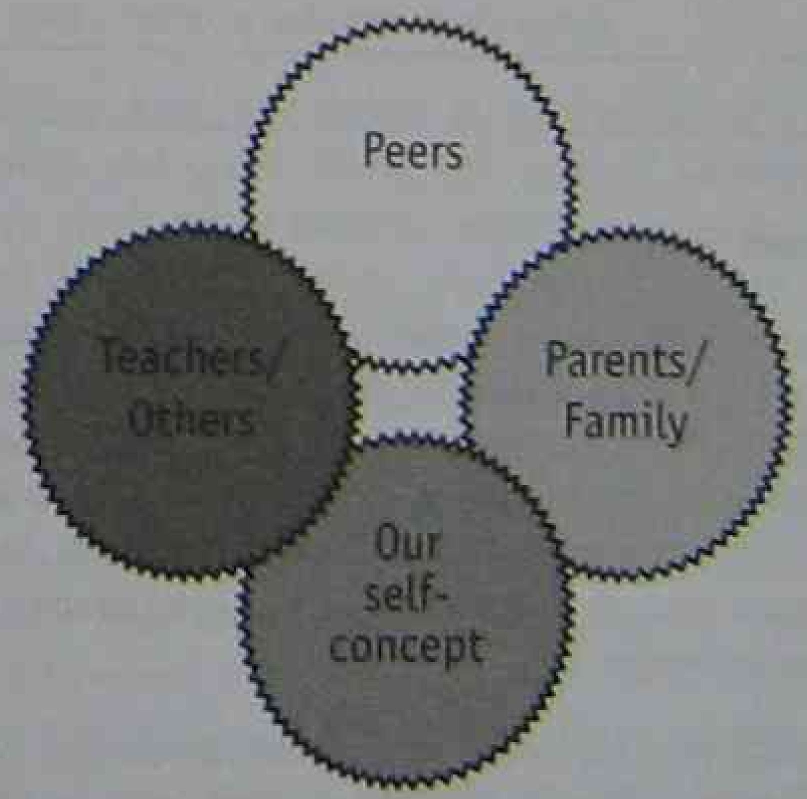

Figure 1.2 Those who affect us

Peer Groups and Teachers

Your friends, your teacher and your feelings towards any given subject will all influence your confidence which, in turn, influences the effort that you make towards that subject and the confidence that you feel in the classroom. All these factors will ultimately affect your performance.

What was the last question that you asked your teacher in Design and Technology?

Peer groups determine the types of questions asked by students in a classroom, as no one likes looking silly by asking an obvious question. If there is something that you do not know the answer to, then chances are that you are not the only one. Do not hesitate to ask questions, and always ask the teacher, as your peers may not give you the correct answer. Remember that the teacher is paid to know, your peers are not. Make a list of things that you do not understand about Design and Technology and ask your teacher to explain them.

Parents

Some students have parents and siblings who think they are young Einsteins, whilst others are overly critical. There are parents who work hard and long hours and are too busy and tired to take much interest, while others try and 'help' too much. Most parents are, at different times, a combination of these attitudes.

Parents who are overly critical risk destroying your self-esteem. If this happens to you, you need to calmly and with respect tell your parents how this makes you feel. You need to ask them to help you to feel positive about yourself.

A student with parents who always praise them may fear disappointing or failing their parents. Students need to learn to communicate with their parents so that realistic expectations can be set. Your parents will continue to love and support you, even if your grades are lower than they had hoped. The HSC can impose stress on the entire household, not just on you.

The following is a true story about a young woman on the first morning of her HSC exams.

After months of stress and anxiety, a mother decided to let her daughter sleep-in while she prepared her a breakfast in bed. When her mother uncovered the breakfast tray, the girl became quite agitated and upset, saying, 'Today of all days, you had to upset me, Mum. You know I don't like the crusts on my toast. Why did you cut the crusts like that? If you cut them diagonally there is less crust to eat!'

What do your parents do that makes you feel good about yourself?

Now make a list of things that you can ask your family to do that will help build your self-esteem.

Our Self-concept

How you feel about yourself will very much influence your level of achievement. If you have attempted a task and given it your all, then you have won a victory, even if it did not turn out quite the way that you had hoped. The worst failure in life is to have not tried at all.

Some students make excuses for themselves and this is called negative self-talk. Have you heard anyone say things like this:

- I would have done better if I had studied.

- I am not going to study because I will fail anyway.
- The teacher hates me. She won't pass me.

People who use negative self-talk often use failure as an excuse for not attempting something in the first place. These people may pretend that all is well, but they often suffer from low self-esteem. As you work on becoming an achiever, make sure you do not talk yourself into being a failure.

You will probably pass and fail many times on your way to success. Celebrate your successes, reward yourself and, if you did badly at something, ask yourself where you went wrong and use this information to avoid making the same mistakes again. This will act as a signpost to send you in the right direction. Learn from the experience and move on to the next task.

Some students have a fear of success and worry that if they get a high grade, their parents will expect the same every time. Others think that their peers may not like them anymore, a fear that is based on what is commonly called the tall poppy syndrome. Remember that 'It is easy to be average and good to be good' (S. Parkes, Principal, Rutherford Technology High School).

Attempting to be successful is a risk, but it is also an exciting adventure. Don't be afraid of success, and take the associated risks, as it is usually worthwhile to commit yourself to a challenge. Reach out a little further than you think you can and you can be proud of what you have tried to do.

1.5 Setting Clear and Achievable Goals

The goals that you set need to be clear and achievable and careful planning will help you reach them.

A goal is something that you want to do or achieve. A goal must be clear. You need to know exactly what it is you want to achieve and remember that a major goal is usually made up of smaller ones. What you want to do when you finish school is one of your goals. However, there will be a number of other smaller goals that you will need to set for yourself before you can attain your dream goal. These goals will be determined by your needs. Each goal should have a clear time frame and you need to be able to see if you have achieved it. For example:

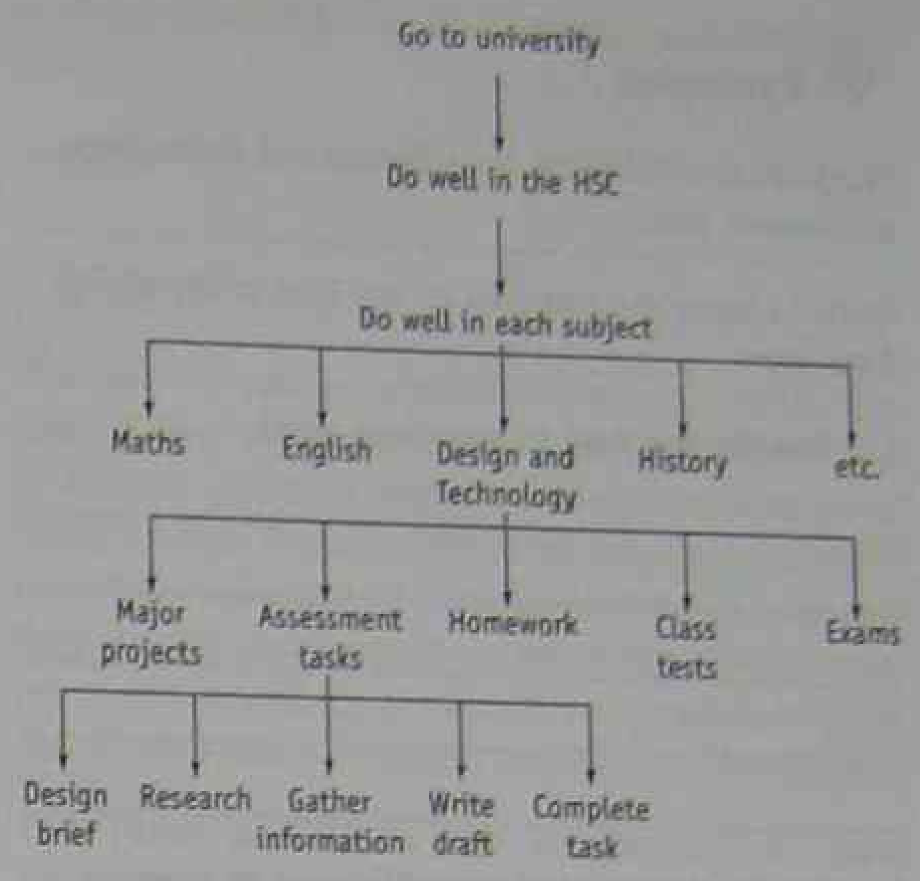

Figure 1.3 Goals

- My first goal is to go to university to train to become a Design and Technology teacher. In order to achieve this, I will need to gain a certain mark in order to gain acceptance to a university.
- My second goal is to gain a mark in the HSC that will get me into university. In order to gain this mark I will need to do well in each of my subjects.
- My third goal is to gain a good mark in each of my subjects in the HSC. In order to do this I will have to do well in all assessment tasks, tests, activities, know my work, come prepared for all lessons and complete all homework. These needs form smaller goals. In order to achieve my first goal I have to achieve at all levels.

Working hard will result in you achieving your dreams and goals. What will a small amount of work result in? In order to achieve your goals you need to plan backwards. Start with your final or ultimate goal and then use backward planning in order to see how you might get there. Luck is a very minor factor in achieving goals. What is the mark that you realistically hope to get in Design and Technology for the HSC? (If you are not sure, ask your teacher what they think you are capable of achieving.) How are you going to get this mark? You will need to plan and set goals for each of your assessment tasks, major projects, homework, class tests and exams. If you achieve your short-term goals, then your major goal will be achieved!

Extension

Complete the following for a Design and Technology assessment task.

Goal: To complete this task to the best of my ability.
Date due: ________

1. **Rewrite the task** in your own words.

____
____
____
____
____

2. **List the things that you will need to know.**

____
____

3. **Complete an information search** from the library, Internet, professionals, teachers and other resources. List the places and books that you will search.

____
____
____
____
____

4. **Collate research, include a clear bibliography and do not forget to reference.** List all the useful references that you found.

____
____
____
____
____

5. **Write a draft copy.**
6. **Take your draft copy** to your teacher to check that you are on the right track. Ask informed questions and write down any ideas that the teacher gives you.
7. **Analyse the marking scale** to be sure that you have thoroughly covered every area. If you do not have a copy of the marking scale, ask your teacher for one.
8. **Complete a PMI** (refer to Chapter 7), then work to overcome any weaknesses in the task.
9. **Complete your task**, using a professional presentation.
10. **Hand it in to your teacher.** You may hand it in ahead of time, but never late.

1.6 Internal and External Motivation

Motivation is the desire to do something and, in order to raise your motivation, you may need to reward yourself for a job well done.

Internal Motivators

Many people believe that achievement and success has less to do with IQ and more to do with 'I will do'. Working hard to achieve goals is what will get you there. You can be the smartest student in the class but you will not get a good HSC result unless you put in the effort. Success is very much influenced by attitude and effort. Hard work will help you achieve your goals. This, along with an 'I will do' attitude, needs to be a part of your work ethic throughout Years 11 and 12.

External Motivators

It is easy to feel motivated when you are doing something that you enjoy and want to do. Often though we are forced to do things that we are not interested in and sometimes study and assignments can fall into this category. When this happens, rather than procrastinating (putting it off till later), we need to find a way of getting motivated.

A teacher may motivate a class by giving them an early mark when they complete all of their work. A parent may motivate a child to keep their room tidy by giving them a reward at the end of the week. As an achiever you need to motivate yourself rather than waiting for others to do it. You may decide that you can only go to the movies on Saturday evening if you complete a certain amount of work. You may reward yourself by studying for 40 minutes then allowing yourself a 10-minute coffee break or a 10-minute walk, a jog along the beach, a play with the dog and so on. You may decide that if you study for three hours tonight, then you can watch your favourite television program tomorrow. Simple rewards like these will encourage regular and effective study patterns.

It is a good idea to do some physical activity in your study breaks, as this will help reduce your stress levels. Hopes and dreams are the building blocks of motivation and you need to keep your goals in sight in order to stay focused and motivated. List five ways below that you can motivate yourself.

____
____
____
____
____

Staying Motivated

People around you will either be:

- A **source of distraction** (inviting you to go out places, playing the class clown or chatting with you while the teacher is explaining something), or,
- A **support network**. They may be emotionally supportive, mentors, peer tutors, study groups or role models.

Family and friends will provide you with emotional support whilst you are under stress. They may offer to word process an assessment task for you, hold the tissues while you cry out any frustrations or go to yoga with you. However, make sure that these outings are deserved and not just a way of procrastinating. How may your family and friends support you?

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____
____

A **role model** is someone that you aspire to be like. They may have the right work ethic, have achieved excellent grades in the HSC, or be an expert in the field that you wish to work in. You may or may not know your role model personally, but they may inspire you to greatness. Name any people that may be your role models and explain what you admire in them.

____
____
____

Mentors are people who are experts in a field. You may or may not know them. It is an excellent idea to find an approved mentor to help you with your Major Design Project. The most important thing is that they will need to take an interest in you and help you for an extended period of time. With Internet access, international mentors are available to assist you if you share a common passion for your project.

Peer tutors are friends who are studying the same subject as you but are more advanced in their understanding of it. Sometimes they are able to answer your questions in terms that you will understand. There are other students in your class who may be able to help you if you do not understand things. Name any mentors or peer tutors that you may have contacted or know.

____
____
____

A **study group** is, as the name suggests, a group of people who get together to discuss a topic at an advanced level. Ahead of the meeting, each person needs to study the topic in detail and write out or obtain from the teacher a question to be discussed. When the group gets together they are already informed and able to discuss the question at an advanced level. Higher order thinking skills are discussed later in this chapter. Name some people that you can work with in a study group.

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1.7 Organisation and Time Management

Being organised helps you to make the best use of your time, which, in turn, can increase your knowledge about a subject. Complete the following questionnaire to determine if organisation is a problem for you. Place a tick beside each question if it is mostly true for you.

____ 1. My folder is such a mess I cannot find where I am up to in each subject.

____ 2. I am always borrowing paper (or pens or pencils) from my friends during class.

____ 3. My school bag has stuff in the bottom but I am not sure exactly what it is.

____ 4. I don't write down what the teacher says about our assessment tasks because at the time I think I can remember it all.

____ 5. If I dropped my folder and everything spilled out, I would never be able to put it all back in the right spot.

____ 6. I have lost my timetable and follow my peers to class.

____ 7. I spend all my time doing my homework and don't have time to study.

____ 8. I forget to bring the things that I need to class on the correct days such as resources and homework, and I also forget to study for class tests.

____ 9. I don't keep a diary or a study timetable as I can remember what is important.

____ 10. My parents keep track of my timetable and after-school activities. I just do what they say.

____ **Total**

Scoring

8–10 ticks	Your organisation skills are atrocious. You **must** fix this problem.
6-7 ticks	Your organisation skills need improvement.
3-5 ticks	Your organisation skills are OK, but there is always room for improvement.
0-2 ticks	Your organisation is excellent but were you **totally honest** with your answers?

Organisation is an essential part of the HSC. The first thing you will need is a student diary and the second thing is that you need to use it. Always take it to class and record all homework and assignments in it on both the day you get them and on their due date.

You also need to have a school supply list to take to school and to keep at home.

Circle which of the following you need for school and/or home. When you have got them, place a tick beside them.

____ A-4 paper
____ Black and red pens
____ Eraser
____ Ruler
____ Stapler
____ Sticky tape
____ Blank CD
____ Hole punch
____ Calculator
____ Foolscap folder
____ Lead pencil
____ Coloured pencils
____ Highlighting pens
____ Glue stick
____ Floppy disks
____ Paper clips
____ Pencil case

List the necessary textbooks and equipment for subjects like Hospitality and Physical Education and note the days that you will need to take them to school with you

Once you have written all of this information in your diary, you need to be able to use it. Once a week or daily, depending on the number of tasks that you need to complete, you should make a 'To Do' list.

This is a list of all tasks and important things that need to be done that week and you get this information from your diary. Once you have the list, you will need to **prioritise** the activities, that is, work out which is the most important and rank them in order.

To Do List

Activity	Date I will do it	Priority ranking	Tick when finished

After you check your diary and make your 'To Do' list, you should work out what you will need for your assignment. Remember that you need to be prepared. You may require resources from the library or the Internet and you may have to purchase special equipment and tools. A quick list of what is needed for the task will help your organisation immensely. This is shown below.

Before beginning your assignment it is necessary to draw up a plan of exactly what has to be done. Very few top-quality assignments are written at the last minute.

Assignment Organisation

Subject: ________________ Due Date: / /

Assessment Task: ________________

____

Materials to be purchased: ________________

____

Research topic information on: ________________

____

Items to be brought home from school: ________________

____

Long-term Planning Assignment Guide

Assignment: Due Date: / /

____

____

____

Marking Criteria: ________________

____

Steps to completion Due Date: / /

1. ________________
2. ________________
3. ________________
4. ________________
5. ________________
6. ________________
7. ________________
8. ________________
9. ________________
10. ________________

Resources and equipment needed: ________________

____

1.8 Study Skills

Studying is hard work and there are no easy ways of doing it. However, there are a number of ways to help you recall what you have learnt.

Study Environment

Your study environment must be a place where you can concentrate without distractions. You will need to remove, if possible, people, music and television. You will need good lighting and ventilation and your seating must be appropriate for study. The room must not be too warm or you will be tempted to snooze.

Do not leave your studying until the last minute, as you will be too tired to recall anything. When reading, always highlight and underline important points. If you have any mental distractions, such as remembering to do something, write it down so there is less to clutter your mind and remember, **studying is not reading through your notes**!

How to Study

When you are learning a subject it is important to summarise important points and then read these summarised facts aloud three times for six consecutive nights in order to remember them. In addition, read those notes again once a week to refresh your memory.

When you reach the end of each topic, you should make a detailed summary of your work. This summary should then be summarised again, to help you learn more facts. You may choose to construct a mind map or illustrate a concept map in order to help you to recall facts. A mind map or spider-gram is a list of topics linked together to make them easier to remember.

For example:

Social trends
•
•
•

Global
•
•
•

Trends in designing and producing

Political
•
•
•

Economic
•
•
•

Environmental
•
•
•

If you know all of your work, you will probably average 12 marks out of 20 for recalling facts and showing some comprehension. In order to raise these marks you will need to show a deeper understanding through analysis, evaluation and synthesis. Answering a series of revision questions and completing some past HSC papers should follow up your general study.

You should read through and summarise facts from as many books and articles related to the topic that you are studying as you can, and also join a study group to extend your knowledge. Some of these groups are accessible as chat forums on the Internet.

Memorisation Techniques

There are a large number of these available for you to use and you may have to experiment to find the one that works for you.

You may try to:

- Relate the new facts to be learned to the ones that you already know.
- Use acronyms by making a word from the first letter of each word you need to learn. For example, the colours of the rainbow are Red, Orange, Yellow, Green, Blue, Indigo and Violet, pronounced Roy-Gee-Biv.
- Make up a rhyme or a song. For example, 'The kneebone's connected to the ...' and so on.
- Visualise the objects on a page or in a room. Close your eyes and, in your mind's eye, walk around the room to see the objects.
- Use examples and stories to reinforce information learned.
- Organise information into categories. Smaller pieces of information are easier to recall.
- Use mind mapping and flow charts to understand the organisation of the information.
- Use a study guide like this one and don't be afraid to write in it, as long as it belongs to you.
- Put your main ideas onto index cards. Write the major point on one side and supporting information or examples on the other.

Because of the large volume of work that you need to understand for the HSC it is not possible to study the night before the exam and still pass with a high grade. Your revision must be constant and ongoing if you are to do well. Nothing will replace hard work. Build your knowledge base over an extended period of time.

Summarising Articles

Many teachers will give you articles to summarise and learn. Firstly, read the article right through in order to get a general idea of what it is about. Then read the article slowly and each time you come to a word that you do not recognise, investigate what it means and write the definition down in your own words. Do not forget to note the main ideas and important concepts as well as up-to-date facts that you can recount in an essay to support your point of view. You may like to use the following scaffold as a guide.

Name of article: ______________________

Author: ______________________

Found in journal/magazine: ______________________

Issue/volume/page number: ______________________

Topic: ______________________

Vocabulary words and definitions:

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________
6. ______________________
7. ______________________
8. ______________________
9. ______________________
10. ______________________

Main ideas:

____

____

____

____

____

____

____

Facts to be recalled:

- ______________________
- ______________________
- ______________________
- ______________________
- ______________________
- ______________________

1.9 Know Your Academic Holes

For a variety of reasons there may be a section of work that you do not understand. Knowing where your academic holes are means that, with planning and hard work, you can overcome this weakness. So, what causes academic holes in learning?

Academic holes may occur because you were absent when a piece of work was taught, you were distracted and not listening, tired and restless, bored, or you did not thoroughly grasp the basics of a concept. Whatever the reason, once you recognise that there are academic holes in your learning, you can set about filling them in.

Identifying Academic Holes

In order to work out where your academic holes occur, you should re-read your tests and assignments to see if there are any questions that you consistently got wrong. You may be able to identify a topic area or concept that you do not understand and has thus become an academic hole.

You may ask your teacher for a copy of the syllabus. This gives you a list of every topic that you need to understand for the HSC. As you revise your work you can tick off each topic on the syllabus leaving, at the end, your un-ticked weaknesses. You can complete past HSC papers (these are available free at the Board of Studies website and on a CD-Rom in your school library), and then ask your teacher to mark your answers. The questions with low marks may show an academic hole.

What To Do About Them

1. Check through the notes that you were given in class. Make a list of questions about anything that you do not fully understand.
2. Borrow a friend's set of notes to see if there is anything that you are missing. Add missing material to your list of questions.
3. Use peer tutoring to ensure that you have an understanding of the basics. Get your peer to write you a list of revision questions to answer. Add any queries to your list.
4. Book a time to see your teacher to ask the questions that you have. Ask them if they can lend you a text to read and organise to see them the following week to see if you have 'filled the academic hole'.
5. Revise what you now know on the topic.
6. Read and make notes on relevant chapters in a number of textbooks. Begin another list of questions.
7. Revisit your teacher and cover additional topic information. Ensure that all your questions are answered.
8. Answer all past HSC questions. Write and answer some of your own questions and get your teacher to check your work.

Metacognition

The students who do well in the HSC have practised and developed their thinking literacy skills by using cognitive enhancers to push them to a higher level. **Metacognition is thinking about how we think**. In studying the way we think we are also studying the way we learn. In thinking about how we learn we should be able to recognise our strengths and build on them, and know our weaknesses and overcome them. For more details on cognitive enhancers, refer to Chapter 7.

Socratic Thinking

Once you have learned your work you should join or organise a study group to discuss more advanced questions relating to your topic. The efficiency of your study group can be greatly enhanced by using Socratic thinking. The great Greek philosopher, Socrates, would always encourage people to question what lay around them and would then claim: 'The answer lies within ourselves'.

This doesn't mean that if we question then answers will automatically come to us. What it does mean is we need to question and talk through issues to come to a deeper understanding of them. In asking what others think about an idea, it is possible to form our own opinions and, if we ask the right questions of the right people, these opinions will be balanced and informed.

As children we often asked questions that were never answered satisfactorily because of the complex issues involved, such as why is the sky blue, how does a television work and so on. As we have matured we have often learnt not to ask difficult questions, but in order to do well in the HSC you need to ask and hopefully answer a variety of 'hard' questions. Discussing these questions and possible answers in a study group will help you arrive at more informed answers.

For a study group to work you will need at least three people working at a similar level of understanding. Each person should write a number of questions related to the topic being discussed and then the group should work through these, noting any new and interesting points raised. The questions should all try to develop a deeper level of understanding. As an example, think about the following Design and Technology requirement: Students must have a thorough knowledge of the topic 'new and emerging technologies'. Possible questions related to this topic could include:

- Much of our food is already genetically engineered to enhance keeping qualities, flavours and textures. Some companies are now using genetic engineering to add human genes to their food products. What do you think are the ethical implications of this and how should the law deal with this issue?
- You can now purchase sperm from a database of information describing the personality and intellectual traits of the donor. After artificial conception, the donor is to remain anonymous. With the need that many adopted children have to trace their parents, do you think that ethical problems could arise? What laws could be put in place to protect the child and both the biological and adoptive parents?

2 — Understanding Design

Chapter Overview

Design is an important part of people's lives. A range of design-related occupations exist but they all relate to similar theories, practices and processes.

Expected Outcomes

On completing this chapter, students should be able to:

- examine design theory and practice, and consider the factors affecting designing and producing in design projects
- relate the practices and processes of designers and producers to the Major Design Project.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

- aesthetics
- animation
- architect
- computer-generated imagery (CGI)
- craftsperson
- decorative design
- design
- design brief
- design process
- digital visual effects
- elements of design
- environment
- fashion designer
- fine artist
- function
- furniture designer
- graphic designer
- industrial designer
- interior designer
- multimedia
- photographer
- principles of design
- product
- production designer
- structural design
- system
- web design

2.1 Design

Whatever the interests or occupation of an individual, design is in some way connected with it. Everything that humans use is designed, but not everything is designed well. Good design only comes about when things are made with attention to both their functional and aesthetic properties. Designers are necessarily concerned with the ordinary, everyday things that we use and a good designer can raise the quality of life if the design is both attractive and effective.

Design may be defined as:

- The plan on which an object is constructed and/or decorated.
- The art of relating or unifying contrasting elements.

Aesthetic design refers to how a design looks. If it is aesthetically pleasing, it is pleasant to look at. If it is aesthetically displeasing, it is 'ugly'. Of course it should be remembered that 'beauty is in the eye of the beholder' and what one person finds attractive, another may perceive to be hideous and vice versa. Aesthetic characteristics include decorative characteristics such as colour, pattern, richness, image and so on.

A **good design** is functionally sound and aesthetically satisfying. It will efficiently fulfill its purpose and present a unified and harmonious appearance. A **poor design** is one that does not function and/or is visually displeasing. As stated above, beauty, like ugliness, is very subjective, but generally speaking a bad design is one that does not sell.

The requirements of a good design include that it:

- Works well (functional requirement).
- Is made of suitable materials (functional requirement).
- Is well made (functional requirement).
- Has a good appearance (aesthetic requirement).

2.2 Criteria to Evaluate the Success of a Design

When students work on practical projects it is important to evaluate the success of their designs. A component of the proposal for the Major Design Project (MDP) is to formulate 'criteria to evaluate success' and students must be able to establish and analyse appropriate criteria to meet this component. One way of achieving this is through an evaluation of the functional and aesthetic characteristics of their design. For example, if a student designs a computer game for a five-year-old child, based on the need to teach young children about cultural awareness and social tolerance, the **criteria to evaluate functional success** may be based on the following:

- Is it easy for a five-year-old child to use in respect of:
  - instructions (clear and appropriate language)
  - buttons/controls (user-friendly)
  - simple pathways
  - clear entry pathways
  - options such as exit and home included throughout
  - clear and appropriate rewards and feedback?
- Does it cover cultural concepts clearly and at an appropriate level for a five-year-old?
- Does it cover social tolerance concepts clearly and at an appropriate level?
- Is it free from negative cultural bias?
- Is it fun for a five-year-old to use?
- Would a child of that age use it more than once?
- Does it contain enough detail to thoroughly engage the child?

The **criteria to judge aesthetic success** could include:

- Are the colours, styles, shapes and so on likely to appeal to the taste of a five-year-old?
- Are the characters interesting, visually pleasing and appropriate for the intended use?
- Do the images complement each other?
- Is there consistency in the presentation of the graphics?
- Are the graphics appropriate for a five-year-old or are they too sophisticated or detailed?

Note: Students often find knowledge of the elements and principles of design useful when analysing, justifying and evaluating designs, which are examined in the following section.

2.3 Elements and Principles of Design

To become a good designer it is important to be aware of the relationship between the basic elements and principles of design. When these factors are taken into consideration good design can be achieved. The elements and principles of design are used to achieve the goal of harmony, unity with variety and appropriateness to person, occasion and use.

All visual design can be reduced to **seven elements**:

- line
- direction
- shape
- size
- texture
- value
- colour.

These are described in greater detail below.

Line

Line can be described as straight or curved, broken or unbroken, weak or strong, wavering or firm, thin or thick, delicate or bold, blurred or sharp. A straight line suggests rigidity and precision. It can be positive, direct, tense, harsh and unyielding.

The slightly curved or undulating line is loose and flexible. It creates the feeling of gentleness and softness but the excessive use of this line can create an aimless, vague effect. The more vigorously curved line changes direction rapidly and the effect is active and forceful. The arc or segment of a circle has an equal and constant change of direction. It is the most unified of curves but it is monotonous and uninteresting. It is sometimes used when another section of the design is to be emphasised.

The spiraling curves seen in living, growing things are interesting and forceful whilst zig-zagged, jagged or crooked lines, with their sudden, abrupt changes of direction, are 'nervous' and jerky. One feature line should dominate if the design is to be interesting.

Smooth, unbroken lines give a longer, slimmer look to the shape of an object whereas short, broken lines shorten and widen the image.

Direction

A line has direction and the three primary directions are vertical, horizontal and oblique (diagonal). These are mainly used to stress good points or modify poor features of figure type. Vertical lines add height and shorter stout figures benefit from using these to add visual length.

Vertical lines appear balanced and strong. They give length and make people look taller and thinner whilst horizontal lines shorten the figure. Diagonal lines attract attention to a specific feature, for example, a neckline is made diagonal to attract the eyes to this area and away from the hips. A diagonal waist feature emphasises a small waist while taking the eyes away from the bust and so on. Diagonal lines suggest movement.

Shape

A series of lines of different directions defines a shape or pattern. Both the shape of the design and the shape of any pattern on the material are important. Large checks and florals draw attention to the design and make it look larger. While smooth, unbroken lines give a longer, slimming effect, short, broken lines shorten and widen the image. Shape is the basic outline or silhouette of the object and must be considered from the front, back and sides. Shape may be created or modified by the cut or design of the article and added to in the form of decorations.

Size

In design work, size may refer to the actual dimensions of the product, system or environment or to the size of the pattern that decorates the design. When a decorative feature or pattern is big, the eye will be drawn to it. The feature can be cleverly placed to give the false impression that this section of the design is larger than it actually is. For example, in the 'flower power' phase of the 1960s and 1970s, it was common for large, brightly coloured daisy motifs to be placed over the breast area of women's clothing to draw attention and make bosoms look larger.

Size may also be used in design to hide figure or design faults such as in the use of a large motif to draw the eye away from areas the designer does not want emphasised.

Texture

Texture refers to the handle, appearance, feel and shine of an object or piece of fabric. Texture can be seen with the eye as well as felt by touch. Glossy surfaces reflect more light than dull surfaces and rough surfaces absorb light more unevenly than dull surfaces. Whatever the surface, all are variations of the four basic textures:

- rough-matt
- rough-glossy
- smooth-matt
- smooth-glossy.

The texture of the material used affects the appearance of the product. Shiny materials reflect more light and tend to make the shape appear larger. Similarly, heavy textures of stiff, crisp, furry and shaggy materials tend to increase size. Dull matt finishes make the product appear smaller.

Value and Colour

Value refers to the tint, shade or degree of colour. If you start with white and continue to add a single hue until you reach black, all the shades in between are referred to as the 'value of the colour'. When describing this colour value, terms such as 'pale', 'listless', 'rich', 'strong' and 'tactile' may be used. Research the meanings of these words and use them in your folio when appropriate.

White and colours with lighter values 'advance' and make small shapes apppear larger. Designers may use this fact to create effects, in much the same way as they use size. Warm colours such as reds, oranges and yellows make a design seem larger whilst black and darker shades recede and result in shapes that look smaller than they actually are. Cool colours such as blues, greens and violets have a minimising effect.

Colours are usually combined to create the desired effects. If you are looking for a colour scheme, you should examine a colour wheel and research the psychological effects of different colour schemes. Design and art textbooks usually contain a lot of information on the use of colour.

Exercise 1

1. Which of the following lines appears to be the shorter?

(A) 

(B) 

2. Consider a small bedroom and explain how the elements of design could emphasise the positive features, hide the less desirable features and enlarge the perception of the room.

☞ *Answers to Exercise 1, p. 30.*

Extension

1. (a) State the desired functional (structural) and aesthetic (decorative) features of a design that you have chosen.
   (b) Explain how each of the elements of design has been used in your design project. You can refer to the answer to Question 2 above and Section 2.3 if you need more clues.

After the elements have been used to produce a design, the principles are then applied. There are **seven basic principles**:

- balance
- symmetry/focal point
- proportion/scale
- contrast
- spacing
- unity/conflict/dominance
- rhythm.

Balance

Balance refers to the distribution of visual weight. It is innate and the lack of it usually disturbs us. Horizontal balance is generally considered more by designers than vertical but in either case equilibrium is desired. Types of balance include:

- **Symmetrical balance** involves repetition of a shape or a design on both axes of symmetry. One side is a mirror image of the other. Conscious symmetrical repetition is static and is hence termed **formal balance**.
- **Asymmetrical balance** is achieved with dissimilar objects that have equal weight or equal eye attraction. In contrast to symmetrical balance, it is more casual and termed **informal balance**.

Types of symmetrical balance include:

- **Balance by colour** — studies show that our eyes are attracted to colour rather than black or white, and therefore to create a balance, more black and white is needed than colour.
- **Balance by value** — black against white is a stronger contrast than grey against white. Therefore a small amount of black is needed to visually balance a large amount of grey.
- **Balance by shape** — here the two elements are exactly the same colour, texture and value and the only difference is shape.
- **Balance by texture** — the eye is attracted to objects with texture so heavily textured areas should be kept to a minimum to achieve a balance.
- **Balance by eye direction** — this balance occurs when features in a design guide our eyes to a small object, thus making it a focal point.
- **Radial balance** involves all the elements radiating out from a common centre point.
- **Crystallographic** (or overall) **balance** occurs over the entire design. There is equal visual attraction or weighting over the design.

Symmetry/Emphasis or Focal Point

Emphasis is a principle that denotes importance. The **focal point** is the spot of interest in a design where the observer's eye comes to rest. Emphasis can be achieved by contrast, isolation and placement.

- **Emphasis by contrast** is achieved when the element that contrasts becomes the focal point.
- **Emphasis by isolation** is when one item that sits apart from the other elements becomes the focal point.
- The **placement of elements** in a design may also be used to create emphasis.

The **degree of emphasis** must be created with subtlety and a sense of restraint. The focal point must remain a part of the overall design, rather than becoming an alien element that looks out of place.

Symmetry allows a design a sense of formal or informal balance and it involves 'cutting' the design in half, either vertically or horizontally, and ensuring that the two halves retain a balanced look. If a design is not vertically symmetrical, it should be symmetrical on the horizontal plane. This will ensure that the design is aesthetically pleasing. Symmetrical balance can be achieved by the use of colour, value, shape, texture and eye direction.

Proportion/Scale

Scale refers essentially to size and it is a consistent relationship of sizes to each other. Proportion refers to relative size measured against other elements. The key to proportion is that it is '**in relation to**' some other element or feature. The most interesting proportion is when one unit approaches 2/3 or 3/5 of the other. Traditionally this proportion is called the **golden mean** or the **golden section**.

Contrast

Each of the elements may be contrasted with each other in order to find a point of emphasis or focal point.

Spacing

Space is an element which, when arranged according to the design principles, creates unity.

Devices used to create an illusion of space include:

- Repeated forms gradually diminishing in size. This is very effective with abstract shapes. Similar shapes of different sizes give an effective illusion of space.
- Hierarchical scaling, where the most important part of the design is drawn larger, scaling down to the least important.
- Overlapping, which is a simple device that creates a feeling of depth.
- Transparency involves the overlapping of forms that are seen completely.
- Vertical location, where elevation can indicate a recession in depth.
- Aerial perspective, where a use of colour or value contrasts will show depth.

Unity/Conflict/Dominance

Unity is a feeling of completeness, a sense of cohesion or oneness making up an integrated totality. It is something complete and harmonious within itself and will make a design coherent.

Ways to achieve unity:

- If the elements are separate they can be ma to look as if they belong together by placing them in close proximity to each other.
- Repetition in different parts of the design ca relate disparate elements.
- Continuation can smoothly carry the viewer's eye from one form to another.

Rhythm

Rhythm is a principle associated with creating visual beat. It is a feeling of organised moveme Rhythm is based on the repetition of colours, te tures, shapes and lines.

2.4 The Design Process

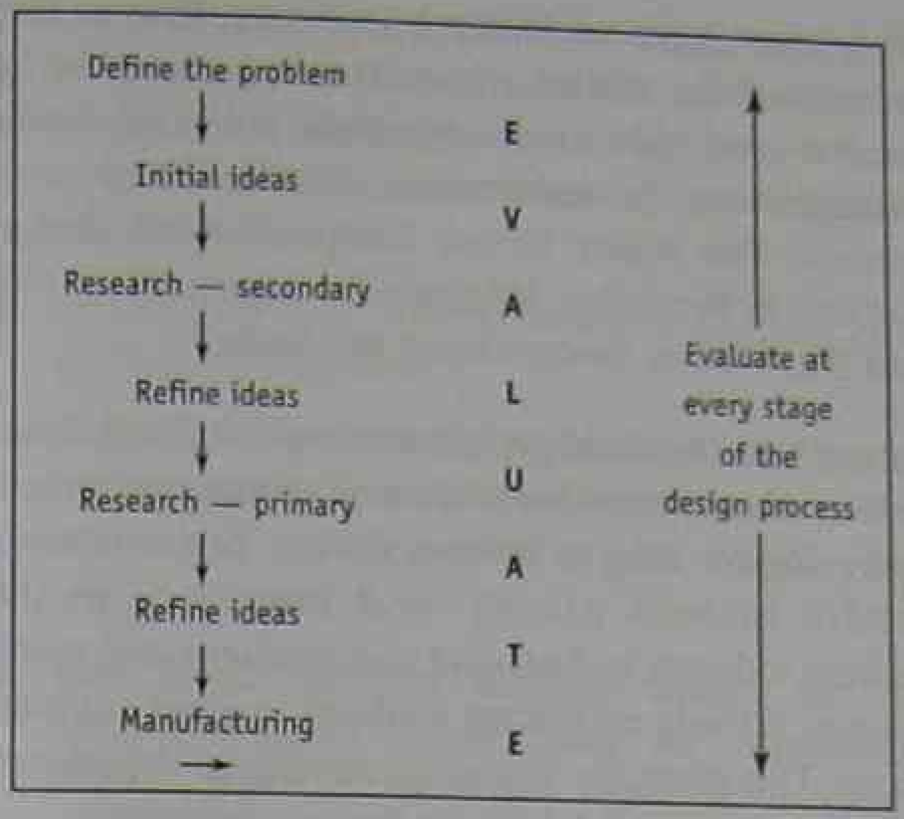
Design is the result of an identified need or perceived opportunity. Senior Design and Technolo students are required to design products, systems environments (refer to Chapter 21). Once a need opportunity is identified, a design brief is form lated. A **design brief** is a clear statement describ a need that can be fulfilled by the development of design.

When designing a product, system or environme it is necessary to use the design process to come with the best solution to the design brief. When y studied Design and Technology in junior school y would have probably used a simplified des process similar to this:

- investigate
- design
- produce
- evaluate.

In Stage 5, you would have followed a proce similar to the one in the next column. You must no the importance of this process of design develo ment. Your first idea may need to be discarded refined and documented.

The design process to be used and recorded in yo folio for the HSC is more detailed and requires mu more depth. For a copy of the marking scale, cons the Board of Studies website or ask your teacher librarian.



2.5 Designers and Their Work

Although there are different types of designers, they all work in much the same way and follow similar processes, as summarised below.

The **briefing** is a meeting between the design team leader and the client. Here the client tells the designer about:

- the product
- significant market features
- the company's marketing strategy
- design objectives
- legal requirements
- technical restraints
- budget
- deadlines.

Market research — most design teams will analyse any existing market research material and then complete primary research of their own. This research may take the form of observations, surveys, questionnaires and interviews, phone polls, random sample distributions and taste tests. Design teams may also visit retail outlets to check the product positioning, lighting and so on that similar existing products receive.

Design development and realisation — initial thumbnail sketches and ideas are the starting point. Each design and its possible development must be thoroughly researched to assess its viability. Designs in development are constantly researched, tested and evaluated until the team is satisfied with the design and decides to move ahead with the concept.

Research and testing occurs concurrently with the development and realisation of the design.

Prototypes — after much research has been carried out and much consulting has occurred with the clients, the team will create a prototype of a product that meets the requirement of the brief.

Ongoing evaluation — the new design needs to be tested on the market to ensure its success before mass manufacturing can begin. Two types of tests may be carried out — one will provide the team with qualitative data and the other with quantitative data. **Qualitative data** deals with preferences and subjective feelings whilst **quantitative data** provides information on objectively measured statistical data. Each stage of the process is frequently evaluated and constant adjustments are made until the client is happy with the final product.

The **final product** should be functional, aesthetically pleasing, consider environmental and social factors and respond to current marketing research.

Successful designers usually possess at least some knowledge of technology, science and mathematics as well as psychology and diplomacy, given that they are often dealing with clients. In addition, they usually possess a strong creative leaning. An average day will involve problem-solving, presenting ideas and executing the final designs, usually all done to tight deadlines. There are a wide range of design-based vocational paths to follow and some of these are examined below.

Architect

The job of an architect is to design buildings and structures which may include houses, apartments, hospitals, schools, prisons, shopping centres, hotels and resorts, offices, bridges, sporting, theatrical or other entertainment structures or entire areas within a community. Architects usually work as part of a team, often in collaboration with other designers such as engineers and interior and landscape designers as well as financial and operational management.

Craftsperson

A craftsperson is someone who has specialised in a particular craft such as jewellery, ceramics, glasswork, metalwork, textiles, woodwork and leatherwork. Professional craftspeople endeavour to earn a living from their craft and thus require additional skills such as business planning and management, marketing, record keeping and presentation. They usually undertake specialist training to upgrade their skills.

Often craftspeople will share studio space or join in a co-operative in order to pool and share resources and meet the costs associated with expensive equipment. This co-operative approach can also help with marketing their products. Many craftspeople exhibit regularly in order to gain a profile and reputation whilst others are happy to work in a cottage industry environment. In recent years there has been a renewed interest in craft products, especially for the home, and thus an increase in career opportunities for creative and self-motivated people.

Fine Artist

A fine artist is a highly skilled or accomplished artist such as a painter, sculptor or musician. A Fine Arts degree is the first step towards employment in galleries, arts administration and the emerging visual media. Some graduates become successful exhibitors and there is also a wide range of teaching opportunities available.

Fine Arts students develop their creativity as well as problem-solving and self-starting skills. A number of musicians, filmmakers, web designers and business people have emerged from art school. In addition, the range of skills taught in a Fine Arts degree can increase graduates' employment prospects, due to the current emphasis on multiskilling in the workplace.

Fashion Designer

Career opportunities for fashion designers are broad and can encompass designing a wide range of products, including men's, women's and/or children's apparel in the styles of day wear, casual, formal, resort wear, working clothes, lingerie, sportswear and footwear. There are also openings in the areas of technical support in pattern design, production planning and quality assurance. Some small fashion design companies work within specialised niche markets whilst other designers work for large companies who design and manufacture for a broader target market.

Fashion designers must focus on the needs of the consumer group who will purchase the product. They must have an in-depth understanding of the group and the market niche. They also need to be creative and able to communicate effectively with management, manufacturers, retailers and consumers. The ability to use computer-aided design systems is becoming increasingly important in this and many other design-based industries.

To work in this field requires formal study in order to learn about the technical as well as the creative and technological side to fashion design. Some courses involve students gaining work experience in the fashion industry in Australia and overseas and many courses actively encourage students to enter competitions. This gives the students commercial experience and provides fresh talent for design companies.

There are a number of types of fashion design, some of which are listed below:

- ***Haute couture*** is a French term for fine tailoring and it was predominant until the 1950s. A couture garment is made for an individual customer. Aesthetics and appearance take priority over the cost of the materials and the time taken to manufacture it.
- The **mass market** caters for a wide range of customers, producing ready-to-wear clothes in large quantities and standard sizes. Cheap materials, creatively used, produce affordable fashions.
- **Designer-label garments** are a cross between couture and mass market. They are not made for individual customers, but care is taken in the cut and choice of fabrics. They are made in small quantities to ensure exclusivity and are expensive.

There are also a number of types of work within the fashion industry, as listed below:

- Freelance workers are self-employed and sell their work to fashion houses, to shops or at markets. If sold to a fashion house, the garment carries the buyer's label.
- Fashion houses employ in-house workers, often on a full-time basis. Their designs are the property of the company and cannot be sold to anyone else. The designer's intellectual property belongs to their employer.

Some designers set up their own companies and gain great satisfaction from this. Their designs are sold under their own label.

The way a fashion studio works depends on the number of staff employed and the market that it caters for. Most designers work as a part of a team in a studio or workroom. Some of the designer's tasks include:

- Fashion design, which involves shaping and styling each garment.
- Knitwear design, which involves sketching shapes for the garment, then working colour combinations and patterns onto a grid. Samples are usually produced.
- The fabric designer designs fabrics for the fashion designer to use. They will experiment with a variety of techniques and styles including sequinning, embroidery and printing.
- Pattern makers and graders, as the name suggests, make and grade the patterns so that the garments can be made to the appropriate sizes.

Designers work about twelve months in advance and design collections for certain seasons in the following year. Every time a collection is completed a new one is started. Every collection is carefully researched and planned so items complement each other and promote a certain look.

The hardest skill that a fashion designer has to master is that of predicting trends. To do this they examine the previous season's clothing, closely observe their competitors' work, use new technologies where appropriate, read fashion magazines and note the popular items of the previous season. Many designers use a theme to inspire their designs.

The design team has three months to design, produce and publicise the collection before the fashion show will launch their work to the buyers. The steps in garment design include:

- **The design** — designers work in different ways; some sketch, others drape fabrics on a dress stand, pinning, folding and tucking whilst some patterns are adapted from previous successes.
- **Making the paper pattern** — the next step is to make a rough paper pattern. This is made from a block. A block is a basic pattern shape, which is a master pattern from which others can be adapted.
- **Making a toile** — a skilled sewing machine operator makes a sample of the garment. It is usually made in calico and is called a toile.
- **Fitting** — the toile is then placed onto a dressmaker's dummy to see how the garment drapes. Small adjustments are often made at this stage.
- **Making a card pattern** — when the designer is happy with the fitted toile, it is given to a pattern cutter who makes the finished working pattern from the toile. The pattern cutter's job is very precise and the success of the garment depends on their accuracy.
- **The finished garment** — finally a sample garment is made in the appropriate fabric. The final garment will be produced in a range of fabrics and colour combinations.

The venue for the show, the lighting, the props, accessories and make-up are carefully selected to promote the collection's theme and to make the clothes look as attractive as possible in order to promote sales. Fashion houses invite buyers and journalists to the launch of the collection. The catwalk display is usually supplemented by ensuring that there is an exhibition area where customers can find out any information they want to know about the collection such as prices, available colours and sizes and delivery dates.

Furniture Designer

Furniture functions in a social way by defining the nature of our living spaces. Together, architecture and furniture can create ambience and make personal statements about style. Designing furniture is about using materials to express your viewpoint in a visual way that satisfies the end user and the commissioning client.

The skills needed are a strong personal sense of design, an understanding of materials and structure, the ability to solve problems, draw technical solutions 3-dimensionally, build prototypes, and have a wide knowledge of production processes and marketing systems. In addition, the ability to present ideas, communicate and co-operate with others is very important.

Furniture designers may work to a design brief for a client or may design and manufacture products to market for themselves. Furniture designers deal with choices — the choice of products that can satisfy, be affordable and reflect the values of the day and the aspirations of tomorrow.

Interior Designer

Interior designers are firstly good listeners, who understand their clients' needs, and are then able to creatively analyse the environment, space and interaction of people within the environment. An interior designer should be both an effective communicator and a good salesperson.

With the vast array of new technology now available, the interior designer must be flexible enough to learn new skills and explore how to utilise the emerging technologies. They must push the boundaries of design. The interior designer is a facilitator and a co-ordinator of tradespeople, suppliers, builders and consultants. Part of their role is to ensure that the work runs smoothly, on budget and on time. The reward for the interior designer is the knowledge that they have created an environment that has improved the lives of those who use it.

Industrial Designer

This profession involves the design of mass-produced products. Essential skills for a career in this area include the ability to think laterally and generate practical designs, and knowledge of ergonomics and the production process. They also need to be able to sketch, build models and document the manufacturing process. Much of this work requires familiarity with software in the area of illustration and 3D modelling.

The creative reward comes when they see their design being used by others or appearing on the supermarket shelf or in a magazine article.

Graphic Designer

Graphic design crosses a range of design disciplines and a range of communication services including marketing, public relations, advertising and multimedia. Graphic designers need to have the attributes of creativity, analytical power, business acumen, interpersonal skills, and technical and organisational ability.

Graphic design is a vehicle for visual communication. The process of design is seen as a way of integrating the cultural fibre of clients in order to make positive change within that culture.

Production Designer

A production designer is responsible for designing every aspect of the visual environment in which a play, opera, dance, film or video takes place. They are responsible for designing the clothes, properties and accessories that together create the mood and ambience of the performance. The production designer must work collaboratively with a lighting designer and a director to create the atmosphere for the performance. Production designers must be able to participate in creative discussion and group activities and work interactively with performers.

Multimedia and Web Designer

Today most multimedia is delivered over the Internet via the World Wide Web. It offers opportunities to utilise full animations, to create interactive graphic experiences, and to deliver CD-quality sound, streamlined video, or 3D animation.

Multimedia and web design embraces a multitude of skills including visual design, interface design, navigation and structure, scriptwriting, and audio and visual production. Multimedia delivered on CD offers more flexibility than on the web and game design is an ever-expanding area. There are game producers in every State of Australia.

Photographer

Photographers can be found working with high fashion models on the catwalk or filming big cats in the game parks of Africa. They photograph sporting and news events, celebrities and trouble spots. There are many different careers in photography and photographers can specialise in whatever they are passionate about. A photographer's skills and interests can be matched to their equipment and techniques and many photographers are moving toward the increased use of digital equipment.

Movie photographers work in teams of up to forty people whilst a still photographer may work in a small group or alone. Commercial photography usually requires consultation with people who brief the photographer about the needs of the client. The photographer then solves the problem with the photograph. Photography is all about communicating visually with people.

Digital Visual Effects and Animation

Digital visual effects and 3D animation are growth areas in television, multimedia and film production. Increasingly, much of the work in television commercials, station promotions and title graphics are being produced through the use of desktop computer software.

The skills needed are the same as graphic design as well as high-level computer graphic skills and close attention to detail. Design, editing and animation skills are an advantage and work tasks are exacting and can be time consuming. Specialisation occurs in compositing or 3D animation, which involves the creation of computer-generated imagery (CGI).

This is an exciting area to work in, with increased opportunities in film, television and multimedia production. The area is being swept by technological change and there is a need for creative and computer literate people to enter the field.

Exercise 2

1. Complete the following table:

Design occupation	Job description	Personal qualities
Architect		
Craftsperson		
Fine Artist		
Fashion Designer		
Furniture Designer		
Graphic Designer		
Industrial Designer		
Interior Designer		
Production Designer		
Multimedia and Web Designer		
Photographer		
Digital Visual Effects and Animation		

2. Explain why there is an overlapping of skills and qualities in design professions.
3. Rank the five most important qualities for a designer to have and explain why these qualities are important.
4. Describe how you have demonstrated or intend to demonstrate each of these qualities in your Major Design Project.

☞ ***Answers to Exercise 2, p. 30.***

2.6 Australian Designers and Their Work

Jimmy Pike and Desert Designs

Jimmy Pike is a celebrated Australian Aboriginal designer. He was born in The Great Sandy Desert, near Japingka, and his early life was spent as part of a nomadic group. His family lived by hunting and gathering, moving from one waterhole to another. During this time Pike learned about the natural environment and its lore and his family was one of the last to come out of the desert. When Pike was 13 years of age he met a white man for the first time. He was taken to Fitzroy Crossing where he worked as a stockman.

Jimmy began designing and painting in 1980 in Fremantle Prison when he started attending design lessons and met Steve Cully, who was the art teacher in the prison.

Cully believed Jimmy Pike was a genius and one of the most talented men he had ever met. Though he had few technical skills at first, he had a great deal of raw energy and he produced works of strength and imagination. He coped with imprisonment, partly because of his deep interest in design. Jimmy Pike is a born teacher and educator. He has a large number of Dreamtime stories at his disposal and in prison he was a natural leader. A cross-cultural exchange was established that invigorated everyone.

Jimmy and Steve worked together closely for three years. Jimmy painted for eighteen months in prison before enrolling in a print-making class. Within a week of starting, he had completed a group of stunning works. His promoters are not surprised at the evidence of Pike's many and varied skills. Among other things, he makes sculptures — large stone heads carved from white desert rock. He is a link to the modern world for his community as he brings subjects such as cars, city buildings and bridges into his design work.

These days, tourists queue in the Sydney Craft Centre to buy the colourful and brilliantly marketed Jimmy Pike-designed shirts, shorts, rugs and fabrics, while the more serious art lovers enjoy his paintings and prints. His work now hangs in all the major State galleries of Australia as well as the Australian National Gallery. He has seen his company, Desert Designs, develop skillfully and with sensitivity to the point where Jimmy is a very successful designer and a wealthy man. Jimmy promoted and developed his company slowly.

Pike has returned to the desert and now lives at Kurlku, 200 km from Fitzroy Crossing. His wife, Patricia Lowe, is a slight, articulate English woman who lives with him in a desert camp almost bare of material possessions. Apart from a 4WD vehicle, he and Patricia have a tree, a canvas fly, a windbreak, a table and some chairs. They used to sleep on the ground but too many centipedes climbed into their sleeping bags so Jimmy built a platform from old packing cases on which to lay their swag. Jimmy wants to set up a community in The Great Sandy Desert where Aboriginal people can maintain their cultural integrity whilst developing the skills needed for the commercial world. Jimmy hopes to one day retrace the waterholes that his nomadic family used to visit as a child but, until then, he intends to paint and design as many Dreamtime stories as he can recall. For additional information on Jimmy Pike and Desert Designs use an Alta Vista search engine and type in: Jimmy Pike Desert Designs Australia or look up the following URLs:

http://waapa.cowan.edu.au/disc/sova/objpike.htm
http://www.cil.com.au/desert/desert.htm

Exercise 3

1. How did Jimmy develop his talents?
2. What are the cultural factors that contribute to Jimmy Pike's designs?
3. Why did Jimmy return to the desert to live?

☞ *Answers to Exercise 3, p. 30.*

Collette Dinnigan

Collette Dinnigan is a Sydney-based clothing designer whose label is sought after by retailers around the world. She was born in New Zealand and trained at Wellington Polytech. On graduation she moved to Australia and started working for the costume department of the Australian Broadcasting Commission in Sydney. In 1990, Collette Dinnigan supplied boutiques and department stores around Australia and New Zealand with designs bearing her own name.

In 1995, she was the first Australian to exhibit a ready-to-wear range in Paris. The Collette Dinnigan label is the only Australian fashion house recognised by the *Chambre Syndicate Du Pret-a-Porter et des Creaturs de Mode*, the official organisation that orchestrates the biannual Paris collections. Collette's designs use quality fabrics, astute cut and fine attention to the female form. She exhibits a variety of styles that often include embroidery, sequins, beads, lurex, velvet and mohair. Collette also designs lingerie and pearl jewellery. The Collette Dinnigan label now sells to over 100 stores worldwide including Saks, Barney's, Harvey Nichols and Maxfields.

2.7 International Designers and Their Work

Victor Papanek

Victor Papanek is an industrial designer who is credited with being the first designer to advocate 'design for human need'. Victor's book, *Design for the Real World*, was originally ridiculed and dismissed as being naive as it dealt with ecological and social change and the ethical responsibility of designers. As human thinking has become more global, Papanek's ideas have become more widely supported to the point where this book is now required reading in many university design courses.

Papanek's more recent book, *The Green Imperative*, continues the argument that design should be more ethical.

He means this in two senses. Firstly, that the design professions should construct codes of ethics that are genuinely regulative, protective, specific and transparent to outside inspection. Secondly, he insists that designers and end users should consider whether a design further marginalises the poor sections of society. Does it ease pain, aid environmental sustainability and so on? These themes have run through Papanek's writing for the past thirty years. To find additional information, try the URL: www.co-design.co.uk/victor.htm

Exercise 4

1. Do designers have an ethical responsibility to future generations? Explain your response.
2. What are the essential features of Papanek's code of ethics, formulated to guide designers in their work?
3. Dr Fred Hollows, the famed Australian humanitarian and eye surgeon, expressed his sadness at the state of the human race. He said, 'It is mankind's shame, my shame, that poor, sick and injured people still exist in our world today.' How could designers contribute to this ethical dilemma and what is your opinion on this issue?

☞ *Answers to Exercise 4, p. 30.*

Henry Dreyfuss (1903–1972)

Dreyfuss began his career as a stage set designer. Later he established his own industrial design office where his primary interest was to design for function. He is credited as the pioneer of applying ergonomic principles to industrial design. Dreyfuss' first commission in industrial design was reworking a traditional storage jar so that it was more space-saving and functional.

In 1933 Dreyfuss developed a telephone design for the Bell Telephone Company that remained basically unchanged until the 1980s. He also designed major equipment for the military, the agricultural industry, Goodyear Tyres and Ansco Cameras, as well as vacuum cleaners for Hoover, televisions for RCA and the PAL razor with disposable blades.

Rene Lalique (1860–1945)

Rene Lalique started working and studying as an apprentice to a well-known goldsmith in Paris. In 1886, he started his own business making glass and jewellery. His style is identified with Art Nouveau, using classic Nouveau motifs such as wilting vegetables and naked women. Lalique's designs were unique because he combined precious metals, gems, semi-precious stones, ivory, rock, crystal, glass and enamel.

Lalique gained his inspirations from the Orient, classical literature, nature and his own vivid imagination. He produced a huge variety of products as one-off designs, and later began to mass-produce items as well. His products included bracelets, brooches, table lamps, paperweights, clock cases, car mascots and tablewear, mostly marketed to France's elite. One of Lalique's innovations was to collaboratively design and manufacture elaborate perfume bottles with Francois Coty. Prior to this, perfumes were sold in plain bottles. Lalique's designs enjoyed worldwide success.

Extension

Select a designer who has inspired you, research their achievements thoroughly and answer the following questions. Possible Australian designers include Ken Done (painting, clothing), Jenny Kee (clothing), Dr David Warren (black box flight recorder), Mervyn Victor Richardson (Victa lawn mower), James Harrison (mechanical ice-making machine).

1. Provide a brief biography of the designer.
2. What are the designer's main innovations and achievements?
3. What historical, cultural and familial factors have influenced the designer's work?
4. What new processes did the designer use that contributed to their success?
5. What were the technological advances of the time that contributed to the designer's success?
6. If this person was/is designing today, predict how they would ensure success in the modern market.
7. What are the main innovations carried out by this designer?
8. Identify the design processes they used to ensure the success of their designs.
9. Explain what you understand to be the emerging technologies that your designer utilised.

The best way to gather first-hand information on design-based occupations is to visit design studios and spend time observing the kinds of work designers do. This may also help students gain a more thorough understanding of the design process, which would be especially useful if it related to their MDP. Alternatively, contact a university that specialises in design and talk with the Head of Department (via the telephone or the Internet) about the future of design. The information gained will complement other aspects of the syllabus such as emerging technologies and trends in design and production.

Useful Websites on International Designers

The Australian Design Awards

http://www.designawards.com.au/home

This is an excellent site showcasing the Australian Design Awards. You can view the entries from the past five years and see their product photographs, design briefs, target market and functions. Categories include Industrial Design, Furniture Design, Textile Design and more.

Bauhaus-Archiv Museum of Design

http://www.bauhaus.de/english/index.htm

This museum in Berlin researches, documents and presents the history of the Bauhaus school. The site includes information about the museum's building, collections, history and relevant news items.

Buckminster Fuller

http://www.bfi.org/introduction_to_bmf.htm

Buckminster Fuller was a designer and philosopher who invented the geodesic dome — the lightest, strongest and most cost-effective structure ever devised.

Consumer Psychology, Information & Wayfinding Displays

http://www.ergogero.com/pages/visualmerchandisinghome.html

This site gives information about the need for designers to be aware of consumers' needs and wants, and the changes needed for design to be more customer-friendly.

DaimlerChrysler Internet

http://www.daimlerchrysler.com/index_e.htm

Daimler Chrysler is one of the world's largest automotive companies. Its passenger car brands include Maybach, Mercedes-Benz, Chrysler, Jeep and Dodge. Have a look at the 'Products' and 'Research & Technology' pages for information on new developments and designs.

Design Institute of Australia

http://www.dia.org.au

The Design Institute of Australia is a representative body for designers from all different industries and disciplines, including industrial, interior, furniture, graphic and textile design. It aims to promote the value of design and designers to industry, business, government and the community.

Famous Designers

http://graphicdesign.about.com/cs/famousdesigners/

This website has information on a selection of famous graphic designers around the world and aims to inspire people looking at the site to go on and create great things.

Famous Designers Archives (The IDE Virtual Design Museum)

http://www.io.tudelft.nl/public/vdm/fda/fda1.htm

This is a fantastic site which features images of products created by a range of famous designers.

Freeman Thomas: Top Designer Aims for Definitive Car

http://detnews.com/specialreports/2000/goldenage/style/style.htm

Freeman Thomas spent nearly 20 years designing cars for Porsche, Volkswagen and Audi, but in the late 1990s became head of the design studios for Chrysler Corp in the USA. This article discusses his 'mission' for creating new designs with a 'uniquely American feel'.

FRYCO: Yacht Designer, Marine Consultant, Naval Architect and Boat Designer

http://members.aol.com/frycomar/pages/prequal.html

This page is on Edward D. Fry, who is a boat designer from Southern Illinois University. Fry has written numerous articles about naval architecture, yacht design, boat design and constructions.

The Innovation Journal

http://www.innovation.cc/

The Innovation Journal is an independent, Internet-based journal for public sector (government) design and innovation which provides articles, case studies, book reviews and news about government design issues.

Josephine Cochran — Inventor of the Dishwasher

http://inventors.about.com/library/inventors/bldishwasher.htm

In 1886, Josephine Cochran decided that 'If nobody else is going to invent a dishwashing machine, I'll do it myself'. And she did, inventing the first practical, hand-operated dishwasher.

Leonardo Home Page

http://www.mos.org/sln/Leonardo/

Leonardo da Vinci was the greatest free thinker of the last 500 years. His ability to analyse the surrounding world and think 'outside the square' is an example for all designers. See the 'Inventor's Workshop' page for information on his inventions and ideas.

William Phillips (Lemelson Center)

http://www.si.edu/lemelson/centerpieces/ilives/phillips/phillips.html

This page is on the scientist William Phillips. Phillips and his colleagues opened up a new field of subatomic research and technology that enabled more accurate atomic clocks and other measuring/navigational devices to be developed.

Women Designers Group

http://www.womendesignersgroup.com/

The Women Designers Group consists of female web designers, graphic artists, web developers and programmers from around the world. Their site offers articles, online forums, a designer directory, useful links and web design resources.

2.8 Achieving Your Goals

At the age of sixteen Jesse Martin decided to do something he had been thinking about for the past two years – he was going to try and be the youngest person to have ever sailed to his antipodal point and back. Your antipodal point is the spot on the globe exactly opposite you, that is, if you drilled a hole through the Earth it is the place where you would come out. Jesse also wanted to try to break the time record for someone of his age for sailing around the world. Inspired by Paul Kelly's song, 'From Little Things Big Things Grow', Jesse took up a part-time job delivering pamphlets to raise money and at 15, with his father and younger brother, sailed a catamaran from Bass Strait to Cape York.

In 1996 he began making plans for his boat, supplies and equipment and gained inspiration from reading the stories of others who had sailed around the world. Having decided to do a solo trip he enrolled in sailing lessons, aware that he would need more experience if he was to embark on such a long and potentially dangerous journey on his own. He also created a logo and letterhead and sent out over 50 sponsorship requests but received no expressions of interest. He did another long trip, from Melbourne to Brisbane, to gain more experience and though he suffered from seasickness he still continued to pursue his dream. After gaining further experience as a crewman on a vessel in the Caribbean, he was ready to plan in earnest. He interviewed the (still current) holder of the youth round-the-world sailing record, David Dicks, and representatives of sailing clubs, as well as reading other's accounts of round the world journeys and gathering articles from books, magazines and the Internet. On the condition that he would complete his VCE on the journey, his mother agreed to borrow the money to buy his yacht, named *Lionheart*.

He wrote to over 60 companies but received a poor response, though entrepreneur and fellow adventurer Dick Smith contributed $2000. Eventually, however, sponsorship began to arrive. *The Melbourne Sun* newspaper commissioned him to write a weekly diary and arranged for the production of an education kit for Victorian school children. The Mistral company agreed to provide sponsorship for work on the boat, communications costs, a dietician to plan meals, and public relations, after Jesse had provided them with a detailed budget. Among other things, he needed to design a customised hammock, as he was a sleepwalker and needed to ensure that he would not walk overboard in the middle of the night! His old school, The Wesley College, raised $3000 for Jesse's trip. After a chance meeting with world-renowned environmentalist, David Suzuki, he decided to attempt to complete his journey without the use of fossil fuels. On the day he sailed out of Port Philip Bay, with a year's worth of food packaged into weekly bundles, Jesse had a total of three hours sailing time on-board *Lionheart*.

Jesse took a computer to work on his VCE and for e-mail access and spent his days reading, navigating, working on the boat, shooting video footage and avoiding whales and tankers. His website recorded 400,000 hits during his absence and he later received messages from children, his musical idol Ben Harper and from the then President of the United States of America, Bill Clinton. He returned home 324 days after he departed, missing the age record set by David Dicks by three weeks. You can discover further information on Jesse and his journey by accessing his website at www.venturebeyond.com.au or by reading his account of his trip in the book, *Lionheart: a journey of the human spirit*.

Exercise 5

Identify how Jesse Martin fulfilled the following elements of the design process in the realisation of his goals.

Project proposal and management

1. Proposal: What did Jesse set out to do and why?
2. Areas of investigation: List all of the areas that would need to be investigated before commencing on a journey such as Jesse's.
3. Criteria to evaluate success: Did Jesse achieve his goal?
4. Time plan: Why did Jesse need a time plan in the lead-up to his trip?
5. Action plan: Why is identifying the order in which to take steps important?

Project development and realisation

6. Evidence of creativity: Identify some of the problems Jesse had to solve and how he achieved this.
7. Research and testing: What evidence is there of both primary and secondary research?
8. Use of communication and presentation: In what ways did Jesse use communication to raise sponsorship for the trip?

Project evaluation

9. Record evaluation procedures throughout: List three ways that Jesse recorded his journey.
10. Impact on society and the environment: What impact might Jesse's trip have had on school children, his old school, his friends and his home town? What may be the use of trying to reduce the use of fossil fuels? Did Jesse achieve his personal goals? Explain your answer.

☞ ***Answers to Exercise 5, p. 31.***

Review Questions

1. Evaluation should be carried out throughout the design process. The role of evaluation is to:
   (A) Ensure the requirements of the brief have been met in the best possible way.
   (B) Limit the time wasted carrying out unnecessary design tests.
   (C) Test all solutions so that the final product meets the design team's functional criteria.
   (D) Assist with the completion of the design process.
2. The design process is the:
   (A) Background information that tells the designer what to do.
   (B) The result of an identified need or a perceived opportunity.
   (C) A plan of finances and time allocation.
   (D) A process that enables the designers to calculate the efficiency of the design produced.
3. When managing a design project, the designer is concerned with:
   (A) The time it will take to complete the task.
   (B) The concept development from the client's brief to project realisation.
   (C) Staying within the client's limitations and parameters.
   (D) Ensuring the project uses sustainable resources.
4. An ethical designer would:
   (A) Not infringe intellectual property rights.
   (B) Be concerned with some environmental aspects of the design.
   (C) Establish an appropriate advertising campaign.
   (D) Be concerned about all legal aspects of the campaign.
5. The steps in the design process include:
   (A) Selecting a solution and testing to evaluate its success.
   (B) Using resources effectively to solve problems.
   (C) Identifying the problem, developing, testing and evaluating solutions.
   (D) Using skills and knowledge to design, make and market the solution.

☞ ***Answers to Review Questions, p. 31.***

Answers to Exercises

Exercise 1 page 17

1. Although they are both the same length, the pupil in the eye follows the diagonal lines and changes shape slightly, giving the false impression that (A) is shorter than (B). In design, a good use of line can make sections appear longer or shorter.
2. The use of light, plain colours will make the room look larger. A feature such as a window could be emphasised by colouring the frame with a dark and contrasting colour. The lines and shape of the frame will draw attention to the window and create the illusion of space. Long curtains or vertical blinds will encourage the eye to look up and down the window thus making the ceiling look higher. Less desirable features should be coloured and textured so they blend in and are not contrasting. Visual contrasting features should be kept to a minimum unless they are part of a feature.

Exercise 2 page 23

1. See table below.
2. The design process is similar in all creative occupations, so similar skills and qualities are required.
3. Creative, good technical skills, good communication skills, team skills, familiar with and able to use technology.
4. Student response.

Design occupation	Job description	Personal qualities
Architect	Designs buildings.	Team worker. Good imagination.
Craftsperson	Makes crafts.	Business skills. Specialist craft skills.
Fine Artist	Specialised and skilled artist.	Highly skilled.
Fashion Designer	Designs clothing and associated fashions.	Creative. Communicates well. Uses technology.
Furniture Designer	Designs furniture.	Communicates well. Creative.
Graphic Designer	Designs using drawings and pictures.	Creativity. Business knowledge. Analytical skills.
Industrial Designer	Design of mass-produced articles.	Thinks laterally. Knowledge of production.
Interior Designer	Designs interiors of buildings.	Good listener. Creative.
Production Designer	Designs every aspect of the visual environment of performing arts.	Collaborative worker. Creative.
Multimedia and Web Designer	Designs multimedia software packages.	High technical expertise.
Photographer	Creates design through taking photographs.	Communicates well. Creative.
Digital Visual Effects and Animation	Designs using digital visual effects and animation.	Skilled in use of technology. Creative.

Exercise 3 page 24

1. Art classes in prison.
2. Aboriginal shapes, designs and motifs, including Dreamtime images. The desire to bridge traditional Aboriginal culture with the modern world.
3. He wanted to live in his own way, on a land he was familiar with and amongst people he wished to be with.

Exercise 4 page 25

1. Yes, as designers not only have an impact on the user, they have an impact on the environment as well. This impact may last for many generations. Designers also have an ethical responsibility to improve the quality of life, which also has an impact on future generations.
2. Essential ethical features are strict regulations and protection of workers, with specific details given and available for outside inspection.
3. Designers can choose to design solely to please the client and increase profits, irrespective of any other implications. They can also choose to create designs that improve the quality of life for members of disadvantaged groups and/or not contribute to social inequalities. It is a matter of individual and societal priorities whether a design is made for short-term benefit or to improve the quality of life for all groups of people.

Exercise 5 page 28

1. He set out to sail solo to his antipodal point and back and to break the age record for the time taken for a youth to sail solo around the world. He wanted to do it to achieve a personal ambition.
2. Areas of investigation would include time, money, energy, medical needs, food and water supplies and equipment and tools.
3. Yes and no. Although he didn't break the record for time, he did sail solo to his antipodal point and back.
4. Because Jesse had gathered sponsorship for his trip, he needed to ensure that he would depart on the date he had set so his sponsors could organise the surrounding publicity. This involved making sure that all supplies were on board and that the boat was ready to sail.
5. To ensure that every part of a project that affects another element is completed or in place in order to avoid delays.
6. Problems and solutions include:
   - Timing – Wrote clear action and time plans and adhered to them.
   - Finances – Convinced Mistral, his old school and a major newspaper to sponsor him.
   - Food – Used the dietician provided by his major sponsor to plan a year's worth of meals, which he divided into weekly lots.
   - Communication – Took a laptop computer for Internet and e-mail access.
   - Completing his VCE – Took assignments and tests plus study resources with him.
7. Primary research:
   - Sailed with his father to get more experience.
   - Got a job crewing on a boat.
   - Consulted a dietician.
   - Interviewed other sailors, including David Dicks.
   - Took weekly sailing lessons.

   Secondary research:
   - Read biographies of sailors and accounts of other round the world trips.
   - Read and gathered articles on books and sailing and did additional research via the Internet and videos.
8. He wrote to companies and individuals who he thought might be interested in sponsoring his journey. Despite initial setbacks, he perseverance paid off. In return for the sponsorship he placed the company logos of his sponsors on *Lionheart*, wore clothing with their logos on it and mentioned his sponsors in interviews and articles.
9. He kept a journal, shot video footage, sent e-mails, wrote articles for a newspaper and helped prepare a school education kit.
10. Jesse's schoolmates and friends shared his enthusiasm and they may have raised their own hopes and goals for their futures when they saw what he achieved. Schools across Victoria followed Jesse's progress via the Internet and shared in his successes and failures. He promoted a sense of pride within his community and helped raise community spirit. When Jesse became aware of the potentially devastating effect of global warming, which is accelerated by the use of non-renewable fossil fuels, he realised he had an opportunity to both do his part for the environment and to educate and encourage others to try and do likewise. Though Jesse did not beat the world record time, he was satisfied that he achieved his goal of sailing solo around the world and that his story might inspire others to try and achieve their goals and realise their wildest ambitions.

Answers to Review Questions page 29

1. (A) Ensure the requirements of the brief have been met in the best possible way.
2. (B) The result of an identified need or a perceived opportunity.
3. (B) The concept development from the client's brief to project realisation.
4. (A) Not infringe intellectual property rights.
5. (C) Identifying the problem, developing, testing and evaluating solutions.

3 – Factors Affecting Design

Chapter Overview

A multitude of factors affects how a product, system or environment is designed and, in a similar manner, a single design is also influenced by many factors. It is worth noting, however, that some of the factors listed in this chapter have a greater influence on specific designs.

Expected Outcomes

On completing this chapter, students should be able to:

- examine design theory and practice, and consider the factors affecting designing and producing in design projects
- critically analyse the factors affecting design and the development and success of design projects.

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Key Terms and Concepts

aesthetics
anthropometric data
durability
energy
ergonomics
function
health
life cycle analysis
needs
obsolescence
quality
recyclability
safety
sustainability
values
wants

3.1 Introduction

Designing is a dynamic process that reflects the needs and wants of society. Designs are influenced by many factors which, in turn, are influenced over time by current social, political, economic and environmental concerns. The factors stated are not an exhaustive list and many of these will change as society changes. Remember that a single design will be influenced by many factors.

3.2 Factors Affecting Design

Some of the factors that affect design include:

- appropriateness of the design solution
- needs
- personal values
- function
- aesthetics
- cost
- ergonomics
- use of design
- sustainability
- energy
- recyclability
- safety and health
- quality
- durability
- obsolescence
- life cycle analysis.

These are examined in more detail below.

Appropriateness of the Design Solution

A designer must consider the appropriateness of the design solution. It must be suitable for the environment in which it will be used.

Design examples

During the 'space race' between the United States of America and the Soviet Union, American designers spent large amounts of time and money designing a pen that would work in zero gravity, while Soviet cosmonauts were simply equipped with lead pencils.

Self-heating cans were developed for the outdoor leisure market. These cans contained chemicals which, when mixed together, produced a reaction that heated the food inside. This product is ideally suited for bushwalkers who want hot food quickly and conveniently. It also enables bushwalkers to consume hot food when there is a total fire ban and the lighting of fires is prohibited.

Needs

Strictly speaking, **needs** are those things a person must have in order to survive and grow. A **want** is something a person would like to have but could live without. Designs are usually based on perceived needs or wants. **Perceived needs** are things that a person **feels they must have**. Perceived needs and wants may be the same thing if the perceived need is not essential to sustain life. Hence the terms 'needs' and 'wants' are often used to mean the same thing. Most designs appeal to perceived needs of the individual, which go beyond basic needs, although not all do.

Basic **individual needs** include:

- **Physical needs** — food, clothing, shelter, health care, rest, exercise.
- **Psychological needs** — love and affection, a sense of security, spiritual guidance, approval and recognition.
- **Social needs** — relating to others, co-operating, making adjustments and showing tolerance.

If a person did not have these needs satisfied they would not survive and grow.

Community needs are those perceived by the whole community to be important and they vary from community to community. They are influenced by a number of factors including the state of the economy, current environmental issues, lobby groups and the media.

Marketed needs and wants are those that have been created through marketing strategies such as advertising. Individuals may feel they must have these marketed products in order to:

- **Belong to a group**. For example, by consuming sports products an individual may feel they belong to the fit and healthy sector of the community.
- **Identify with a role model**. For example, when a well-known person endorses a product, the individual may feel they can relate to that person's particular achievements.
- **Be healthy** by, for example, eating certain breakfast cereals.
- **Maintain their status** by, for example, buying a certain type of car.
- **Keep up with their peers** by, for example, owning and using the latest gadgets.

Design examples

An example of designers designing for a perceived need is illustrated by the massive recent growth in the sale of home bread-makers. Bread is a staple foodstuff for almost every Australian. Using a breadmaker has appealed to many Australians as it satisfies the marketed 'need' to have fresh and homemade bread at a reasonable cost and with minimal effort.

> In response to the need for socks to stay up, Holeproof developed a sock that was shaped and manufactured so it would not slide down the average leg.

Exercise 1

1. Explain the difference between a need and a want.
2. Considering basic individual needs, explain how the design of the following products has been influenced by these needs:
   (a) Shoes
   (b) Telephones
   (c) Cutlery
   (d) Exercise machines.
3. Are all of the above products needs or are they wants? When does a need become a want?
4. Write down some examples of how community needs have influenced designs.

☞ ***Answers to Exercise 1, p. 40.***

Personal Values

Values are those things we regard highly and that are important to us. For example, most people value friendship, belonging to a group, a sustainable economy, having ample financial resources, attaining a certain status and so on. A designer's choice of design is a reflection of what they deem important and of what they value. Victor Papanek, an authority on industrial design and the author of many books, was one of the first to publicly criticise the values of some designers. He believed that too many designers are influenced by commercialism and perpetuate the waste of natural resources. Refer to Chapter 13 for more information on values.

Design examples

Keen to make a profit, Francis McEnroe developed Chiko rolls as a new take-away item to be sold from his caravan. They went on to become very successful and something of an Australian food icon.

In-vitro fertilisation (IVF) gives hope to some couples who value having a family of their own and who have failed to conceive through normal means. The scientists from Monash University Medical Centre, who first developed the process, obviously appreciated the value of this discovery to these couples.

> Two Australian doctors developed the drug penicillin that has since saved millions of lives. These doctors obviously valued human life.

Function

A designer must make sure the design works for its intended use. Function may be assessed in respect of the following factors — safety, strength, ease of use, efficiency, simplicity, durability and so on.

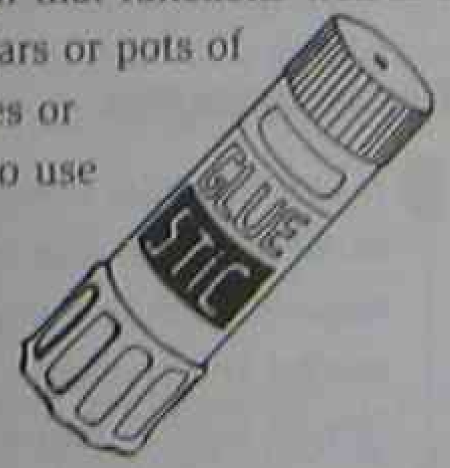
In the past, some designers believed that function determined form and that this led to natural beauty. This meant that function was considered before anything else. The theory was that the shape of a design was created by the functioning design and the resulting product was beautiful because it functioned. Most modern designers do not agree with this argument. Function does not necessarily lead to beauty as, for example, many people may consider road drains functional but not beautiful.

Extension

The Japanese word *chindogu* literally means an odd or distorted tool. It has come to be known in the design world as 'the art of useless design'. Use the Internet to research some examples of these designs.

Design example

An example of a design that functions well is a glue stick. It replaces jars or pots of glue and messy brushes or applicators. It is easy to use and works well for its intended use.



Aesthetics

Aesthetics refers to the beauty of the design. If a design is aesthetically pleasing, this means it looks good or is beautiful. Once again, this is relative to its intended use and subjectively assessed by all of the people who are exposed to the design.

Design example

A chair in a classroom has different aesthetic requirements to a dining chair for use in a home.

Cost

The cost of the design encompasses many facets. The designer must consider:

- Financial costs involved in designing, manufacturing and marketing a product.
- Environmental costs including the impact of production on the environment, the impact of obsolescent products on the environment and so on.
- Social costs such as any effect on accepted values, changes to established cultural norms and so on.
- Cost may also be short-term (financial) or long-term (environmental and social).

Design example

Texas Instruments redesigned an infrared gun-sighting mechanism. The new design not only reduced production time and costs, it also worked better than the previous version.

Ergonomics

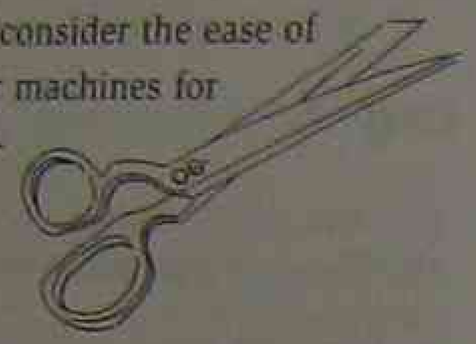
Ergonomics is the study of the relationship between people and their physical environment. Designers need to consider the application of their design for various personal shapes and sizes and in relation to the efficient use of skills. Anthropometric data is used to assist designers to design for the specific requirements of the average-sized human form. **Anthropometry** is the study and technique of taking human measurements for use on a comparative or classification basis. **Anthropometric data** is based on scientifically collected measurements from a wide variety of people of various age groups to provide average sizes for various body parts and the distances between them. It includes measurements such as eye height, finger length, arm length and so on.

Extension

The quantity of available anthropometric data is immense. Use the Internet to research some examples of anthropometric data for your specific age group.

Design example

A designer should consider the ease of use of new tools or machines for both right- and left-handed operators.



Use of the Design

This refers to how the design will be used, who will use it, and any special needs or requirements of the user. Some products are user-friendly while others require a degree of technical expertise to operate successfully. Some designs have many uses while others have a single function, and some objects are designed to last a lifetime while others are intended for single use and disposal. How a designer perceives their creation being used has a direct impact on the final design.

Design example

Clothes lines come in many forms depending on the intended use. Examples include plastic camping clothes lines, retractable clothes lines for limited space areas, and multifunctional rotary clothes lines with collapsible arms and pull-out covers which can be removed when necessary.

Sustainability

If a design uses resources that can be replaced by natural processes in a relatively short space of time, (within the lifetime of the average person), such as plantation timber, it is considered to be using renewable resources and therefore the design is using sustainable resources. Non-sustainable energy sources (resources) are those which have finite reserves, for example, coal, oil and natural gas. These fuels cannot be replaced once they are used up. A designer may choose to use an alternative energy source such as solar, wind, tidal, biomass, geothermal, wave or hydro. The use of solar energy in the Olympic Village in the 2000 Sydney Olympics was a significant factor in the design of the Village. Sustainability of the resources used has become a design factor in recent years, as more people have become concerned about the environment.

Sustainable development can be defined as development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends. The concept of sustainable development has become increasingly important in the development of environmental strategies at both national and international levels.

Design example

Designers may use more sustainable resources because consumers prefer them. For example, consumers may choose to buy furniture made from plantation or recycled wood rather than rainforest timber or they may choose to dye fabric using natural rather than coal tar dyes. In the big picture, consumer influence is minor, but it is becoming increasingly significant.

Energy

Energy is used to create, produce, market and consume designs. The amount of energy used is directly dependent on the value of the end product.

Design examples

A wooden ruler designed for a primary student to measure the size of simple objects would require much less energy to design, produce, market and consume than a depth sounder (sonar) used to measure the depth of the oceans.

Energy consumption of an electrical good has become a major marketing tool. The energy rating, which shows at a glance the running cost of an appliance, can be used to discriminate between products.

Energy may be described as a capacity to do work or a source of power. The energy used may be:

- Human, such as drive and motivation.
- Non-human, such as electricity, gas, petrol, diesel, alcohol and so on.

Recyclability

Recyclability refers to the ability of an item to be broken down after use to serve as a raw material for new manufactured products. Sometimes people confuse the terms reusable and recyclable. Reusable means a good may be used again for the same purpose or to perform a different function.

Design example

Cottee's designed jam jars that can be reused as tumblers. The glass in the jar may also be recycled to make other glass products.

A designer should consider whether consumer demand requires the design to be recycled, in both practical and consumer perception terms.

Design example

The Body Shop use recycled materials in some of their packaging and most of their packaging is recyclable. Consumers also have the option of taking containers back to the shop to refill them. In reality, few people refill containers and most packaging is thrown away and not recycled, but many consumers are happy with The Body Shop's packaging philosophy.

Recycling may be financially expensive in some circumstances, but many consumers demand it. Most municipal councils only recycle a limited range and quantity of goods. Hence, even if a product is recyclable, it still often ends up with other garbage in landfill.

Safety and Health

The safety of a design in terms of its production, use and disposal will influence its success. The design should not pose any health hazards throughout its life cycle to the designer, producer or user.

Design example

The use of nuclear power is energy efficient, but the manufacture of the components and production of the power is potentially very dangerous if not carefully monitored. In addition, the disposal of radioactive waste products causes an environmental dilemma, as they are unsafe for many hundreds of years.

Exercise 2

Explain why safety is a major factor in the design of the following products:

(a) A baby's cot
(b) A pocket knife
(c) A child's toy
(d) A car.

☞ Answers to Exercise 2, p. 40.

Quality

The quality of the design is a major marketing tool. Quality has two dimensions: level and consistency. The **level of quality** refers to the ability of a product to perform its function for an acceptable period of time. It includes the product's overall durability, reliability, precision, ease of operation and repair, and other valued attributes. **Consistency of quality** refers to consistently delivering the targeted level of quality to consumers.

Design example

Certain products are marketed as 'high quality' products such as Mercedes Benz cars. Consumers have specific expectations as to how these cars perform.

Durability

The ability of a design to last for its designated life in the situation or environment for which it has been targeted is a reflection on its durability. A product may not be durable due to poor quality, bad design, poor raw materials or prolonged use.

Some products are classified as non-durable, such as grocery items and single use goods such as disposable gloves. Durable items are products that are used over an extended period of time such as refrigerators, cars, houses and so on. The durability of the product is usually reflected in the cost of the end product in that goods designed to last are generally more expensive.

Design example

An alkaline battery is more expensive than a carbon battery, but lasts longer. Both batteries are popular because they suit different markets and users.

Obsolescence

Obsolescence refers to when the design is no longer of any use and must be discarded or recycled. Obsolescence may result from a design being no longer fashionable, such as when it is superseded by a better design, or the design being environmentally unfriendly, due to changed conditions or laws. For example, a toaster may not match the new decor of a kitchen, or it may work well but there is now a better design on the market.

Built-in obsolescence or **planned obsolescence** is when a product only lasts for a certain time period in order to promote a high turnover. It may result in a lower quality product as well as increased waste products.

Design example

An iron is currently designed to last for two years, whilst in the past it was designed to last five to ten years. The justification for this obsolescence may be attributed to features such as making the iron lightweight and adding more complex electronics which enables the iron to turn itself off when not in use.

Life Cycle Analysis

Life cycle analysis refers to the analysis of a design at all stages, from conception to disposal (cradle to grave), to determine the total cost in terms of resource usage. The resources include human (people, energy, skills) and non-human (finance, time, tools). The designer may use a life cycle analysis to predict the short- and long-term consequences of the planned design. Every design has an environmental impact, but in the framework of responsible design, less is better.

Below is a typical life cycle analysis diagram of the wood required to make a pine coffee table.

Note: Other resources used would also need to be considered, for example, finishes and construction materials.

Design example

BHP uses life cycle analysis to determine the effect of steel production on the environment. As a result it has investigated alternative uses for slag (a waste product of the production process), as an aggregate for building products and a high quality cement substitute.

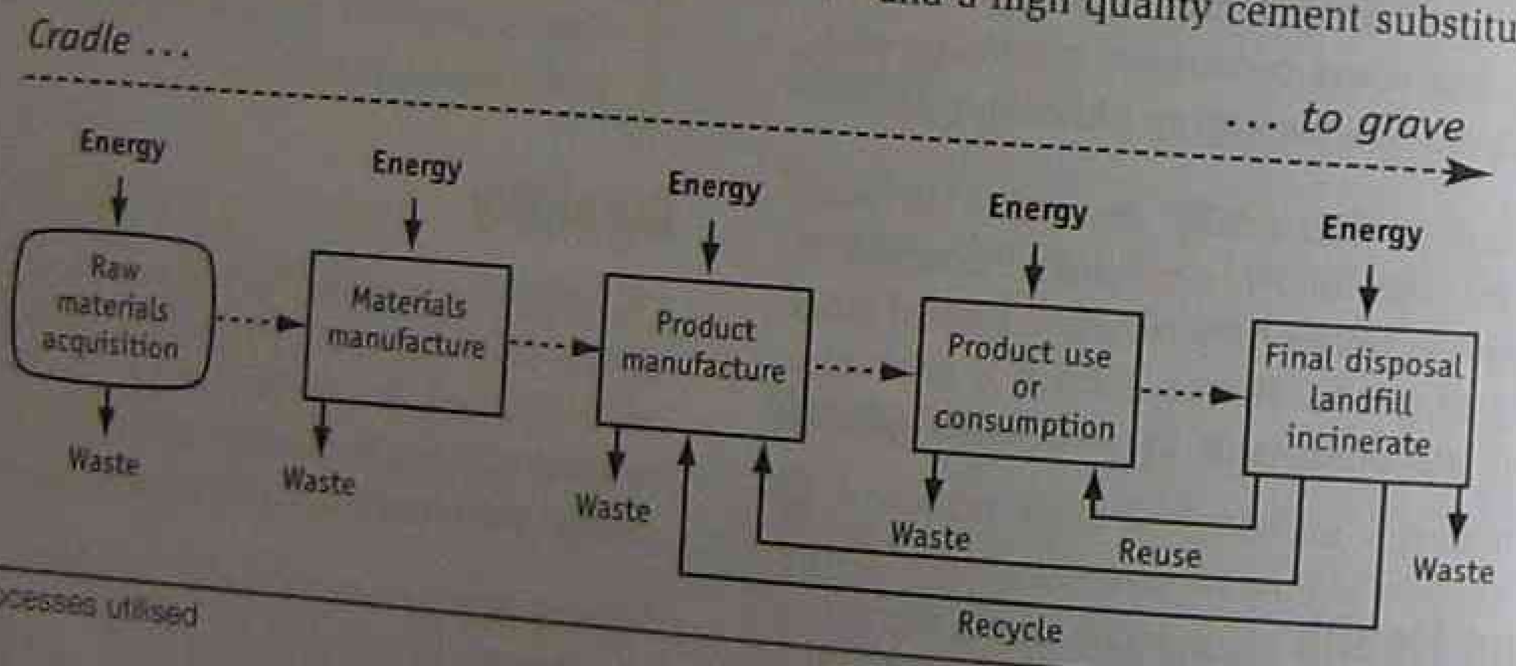


Figure 3.1 Processes utilised

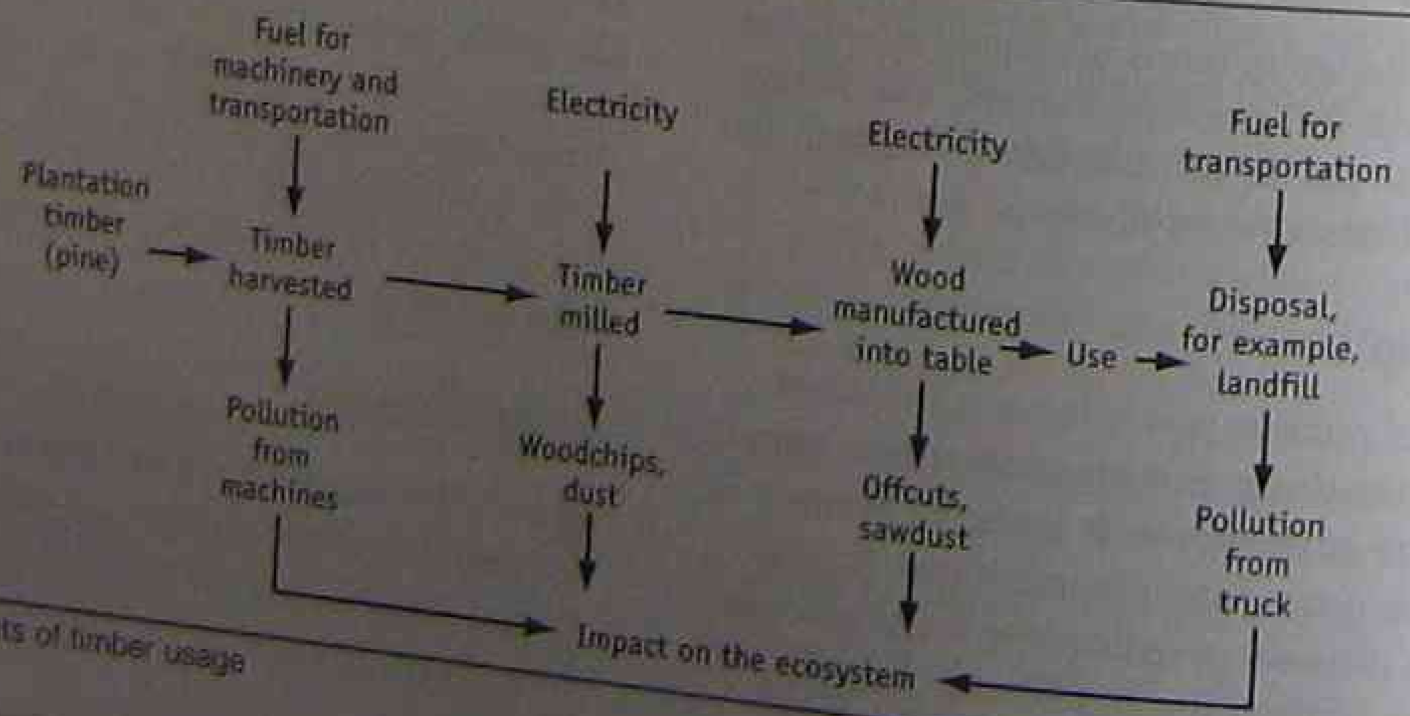


Figure 3.2 Elements of timber usage

Exercise 3

Critically analyse the following designs to determine the key factors that may influence the design:

(a) Banknote
(b) Refrigerator
(c) Staple gun
(d) Wine cask
(e) Collapsible stroller
(f) Pre-stamped envelopes.

☞ *Answers to Exercise 3, p. 40.*

Review Questions

1. What is meant by the term 'ergonomics'?
   (A) The study and technique of taking human measurements.
   (B) Using specified data to build office equipment.
   (C) The study of the relationship between people and their physical environment.
   (D) Designing and making products which are more comfortable for the human form.

2. A life cycle analysis of a plastic plate could consider the following:
   (A) The pollution generated in the production, raw materials and energy used.
   (B) People, manufacturing costs and transport.
   (C) Time, energy, manufacture and the use and disposal of the plate.
   (D) All of the above.

3. A designer has been commissioned to design a secure carrying device for computer disks to be used by students at school.
   (a) Describe in detail **three** functional criteria that would need to be considered in the development of the design.
   (b) Discuss how the quality of the design will influence the final product.

☞ *Answers to Review Questions, p. 40.*

Answers to Exercises

Exercise 1 page 34

1. Needs are those things a person must have in order to survive and grow. A want is something a person would like to have but they could live without.
2. (a) Shoes — needed for protection of feet.
   (b) Telephones — social and business communication needs.
   (c) Cutlery — need to successfully consume food in an appropriate social context.
   (d) Exercise machines — exercise needs for busy lifestyles.
3. They could all be considered wants, as none of these items is essential for life. For example, shoes are essential to protect the feet but designer shoes are clearly a want rather than a need.
4. The need to reduce the quantity of garbage in landfill has led to the redesigning of garbage bins to enable the sorting of refuse into recyclable and non-recyclable items. Folic acid is added to a number of food products, as it is believed it will reduce the number of birth defects if consumed by pregnant women.

Exercise 2 page 37

(a) Many babies have died as a result of poor cot design. Some of the problems include strangulation when the baby has had its head caught between the bars and broken bones when a baby has climbed out due to the mattress sitting too high.

(b) A pocket knife should not open or close too easily to prevent children and adults from accidentally cutting themselves.

(c) A child's toy should not have any small parts that could create a choking hazard or allow fingers to get caught. It should also not have sharp pieces that could cut or pierce the body and so on.

(d) As a carrier of people at relatively high speeds, on increasingly busy roads, a car must be safe.

Exercise 3 page 39

(a) A banknote has to be of high quality, durable, cost effective, aesthetically pleasing, distinctive and difficult to counterfeit.

(b) A refrigerator has to function well, use power economically, not create too much noise, require minimal maintenance and be aesthetically pleasing as it is a large and noticeable household item.

(c) Staple guns need to function well and have safety provisions as they may cause harm if used incorrectly

(d) Wine casks must store wine in a relatively airtight manner to prevent the wine from spoiling. They should also be easily transportable and economical to produce.

(e) A collapsible stroller should transport the baby safely, be convenient for the user to push in a variety of conditions, be easy to collapse and store, and aesthetically pleasing.

(f) Pre-stamped envelopes were designed to save people wasting time attaching stamps to individual letters. They are cost effective compared to traditional envelopes and stamps and are designed to be aesthetically pleasing.

Answers to Review Questions page 39

1. (C) The study of the relationship between people and their physical environment.
2. (D) All of the above.
3. (a) Three functional criteria could include any of the following:
   - Strength — withstand pressure from materials in school bag.
   - Security — locking device, perhaps security coded.
   - Portability — lightweight, easy to hold.
   - Durability — withstand abrasion, drops, impact.
   - Lightweight — for ease of transport.
   - Rigid — stop disks from bending.
   - Ease of use — easy to open and close, easy to remove disks.

   (b) The quality must suit the life of the product. If it is of poor quality, the reputation of the product will be affected. The quality will influence the cost. The designer will need to determine the expected life of the product and in turn relate this to an acceptable quality.

4 — Trends in Design and Production

Chapter Overview

Social, global, political, economic and environmental issues influence people's perceptions of how they see the world and what they consider important. These issues in turn influence design and production. Design trends change as society changes.

Expected Outcome

On completing this chapter, students should be able to:

- explain the influence of trends in society on design and production.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

appropriate technology
economic issues
global issues
millennium products
political issues
social issues
trends

4.1 The Influence of Trends in Society on Design and Production

The direction of design and production has been influenced by many factors. Materials and methods of production, along with changes in consumer behaviour and tastes, have changed what is available and what people consume. There is also a new movement in design and production which takes into account the impact of the design on society as a whole. The results of this are referred to as '**millennium products**'. **Appropriate technology** is a similar concept that influences designers and may be defined as 'technology which in its creation and use meets human needs whilst considering the short and long term consequences for society and the environment'. Products described as 'appropriate technology' are different from mainstream products.

Design examples

The wind-up radio is an example of a millennium product. Important messages can be delivered to people without the expense of batteries in developing countries where resources are scarce.

A pencil made from recycled materials is also another example of a millennium product. The impact it has on the environment is minimal.

Exercise

What factors have contributed to the development and production of millennium products and appropriate technology?

☞ *Answers to Exercise, p. 44.*

The following issues influence trends in designing and producing:

- social
- global
- political
- economic
- environmental.

Many of these issues are interrelated, thus making it difficult to always state precisely which issue fits into which category. They are examined in more detail below.

4.2 Social Issues

How people view society will influence design and production. Some social issues include:

Patriotism

People's attitudes towards their society vary, from patriots who defend it, to reformers who want to change it, to those who want to leave it. In Australia, the trend in the 1960s and 1970s was towards declining patriotism and increased criticism of the country's direction. The 1980s saw a resurgence in patriotism, albeit with a great deal of uncertainty as to our national identity — a British-based motherland, a US satellite or an independent nation with closer ties to Asia? In addition, our emerging multicultural society in an Anglo-based culture, issues of Aboriginal heritage and aspirations, and the debate over changing our flag occupied many Australians. In the 1990s, the issue of republicanism became one of great importance.

People's view of society influences consumer patterns. Many designers have responded to the patriotism surge by producing Australian products and advertising them as such — 'Australian Made', 'Buy Australian' and 'Australian Owned and Manufactured' and so on. There is also a greater emphasis on the Australian 'heritage' of products even though some, such as Vegemite, are produced by foreign-owned companies. Production of Olympics-related goods in 2000 is an illustration of this, as some of the mascot toys, though promoting Australia, were made in China.

Hedonism

How people view themselves and what their priorities are will influence trends. Hedonism is a devotion to pleasure. Most people seek personal pleasure, want fun, change and escape and so on. Many products and marketing strategies are developed around these needs, for example, a low-alcohol beer advertised 'for an extreme thirst' and featuring skiing and diving with sharks.

Design example

The Cherokee Jeep is designed for the active leisure seeker who wants luxury and the image of a person who enjoys the rugged outdoors. It does not necessarily appeal to people who wish to seriously use a 4WD vehicle to access remote areas.

The leisure industry (camping, boating, arts, crafts, fitness and sport) faces good growth prospects in a society that seeks self-fulfilment.

Multiculturalism

Multiculturalism is the theory that it is beneficial to a society to maintain more than one culture within its structure. Australia is a multicultural nation and the various ethnic groups within it have influenced what is designed and produced. The impact of multiculturalism on all Australians may be demonstrated by the availability of a wide variety of foods from various cultures. Many new convenience foods are designed around traditional flavours from other countries.

Social Class

Social class is a relatively permanent and ordered division within a society whose members share similar values, standards, interests and behaviours. Social class is often defined by occupation. In Australia, more people consider themselves middle class than is clearly defined by occupation. Middle-class values have encouraged the design and production of goods and services that go beyond satisfying basic needs.

Egalitarianism

Egalitarianism asserts the equality of all people. Some products have been designed to help reduce inequalities in our society including products for Aboriginal groups, the disabled, ethnic groups and other socially disadvantaged groups.

Social Conscience

A social conscience refers to a person's determination of what is right and wrong with respect to issues that influence society and the long-term quality of life of its members. A person's social conscience may drive them to taking action on issues such as the environment or disadvantaged groups. If enough people share the same opinion this will influence the design of goods and services.

4.3 Global Issues

Global issues are those that have worldwide significance. The world economy has undergone radical changes during the last quarter of a century and geographical and cultural distances have shrunk with faster communication, more efficient transportation and major advances in technology. This has resulted in a more complex marketing environment that has changed consumers' needs and the types of products produced. Global issues have a major impact on designing and producing.

Design examples

A product may be designed in Australia, the raw materials sourced in New Zealand and processed in Hong Kong. The final product may be manufactured in China and the goods then freighted to stores around the world.

Dynamic Lifter Fertilisers (an Australian product) is also manufactured and sold overseas for world markets. The products are designed to suit specific markets and to reduce transport costs of raw materials and products.

Companies such as IBM, Microsoft, General Motors, Shell, Nestlé, Toshiba, Sony, Nissan and many others operate globally, which means they have access to world markets, technology and skills. Global competition is intense and has an impact on domestic markets. Foreign-owned companies now make products that are considered by many to be Australian. Some of the better known examples include Vegemite (USA), Aspro (USA), Cottees (UK), Bushells Tea (UK), Billy Tea (Denmark), Rosella (UK), Bundaberg Rum (UK), and Tooheys and XXXX Beer (NZ).

Design example

The entrepreneur, Dick Smith, set up his own food company, 'Dick Smith Foods', in response to massive foreign ownership of food companies. His company aims to use only Australian food supplies and carry out the processing in Australia, thus creating jobs for Australians and profits which remain in Australia. The first product was Dick Smith's Peanut Butter, launched in 2000.

Extension

1. Look up the Dick Smith Foods website (http://www.dicksmithfoods.com.au) to investigate the rationale and philosophy guiding the economic decisions made by the company.
2. Look up the Vegemite website (http://www.vegemite.com.au) and investigate the historical development of the company.

4.4 Political Issues

Laws, government agencies and pressure groups influence trends in designing and producing. **Legislation** affecting businesses has increased steadily over the years and has been developed to protect businesses from each other and to protect consumers. Laws to define and prevent unfair competition in Australia are enforced by the Australian Competition and Consumer Commission (ACCC) and the Foreign Investment Review Board, if a foreign organisation is involved. In Australia, every marketing organisation must follow the *Trade Practices Act* 1974 (Cth) and its amendments. The Act deals with anti-competitive prices, unfair consumer practices, product safety and information, conditions, warranties, and actions against manufacturers amongst other things. The law ultimately affects designs and their production.

Design example

Every year products are recalled due to faulty design. In 1999, Hyundai recalled the EF Sonata 1999 model as the airbags were faulty.

Trade systems also affect designing and producing. When selling to another country, companies usually face trade restrictions. The most common of these is the **tariff**, which is a tax levied by a government on certain imported goods. The tariff may raise revenue or protect domestic producers. The exporter may also face a quota that sets limits on the amount of goods that the importing country will accept in certain product categories. The purpose of the quota is to conserve foreign exchange and to protect local agriculture, industry and employment.

An **embargo** is the strongest form of quota, which totally bans some kinds of imports. Australian firms may also face currency controls that limit the amount of foreign exchange and adjust the dollar's exchange rate against other currencies. A company may also face non-tariff trade barriers such as a bias against overseas company bids or product standards, and quarantine laws.

Extension

Look through *CHOICE* magazine and list some products that were recalled or exhibited misleading advertising.

4.5 Economic Issues

The economic environment consists of factors that affect consumer purchasing power and spending. Designers need to consider buying power as well as the people they are designing for. **Total buying power** depends on current income, prices, savings and credit. Buying power is also affected by the state of the economy and the public's confidence in it. When the economy is more buoyant, people will accept a design that is less of a need and more of a want.

There was a surge in the 1990s for the demand of 'cut price' items and hence a massive growth in stores such as Go-Lo, the Reject Shop, Crazy Prices and so on. At these stores, people with low incomes can obtain lifestyle products such as decorator items, clothing and household goods at a very low cost, though these products tend to be of a lower quality.

Another economic issue is the cost of manufacture. In Australia, manufacturing costs are often increased by the cost of wages. Many Australian companies produce their products **offshore**, usually in South-east Asia, to take advantage of low wages (and often poor working conditions) that make products much cheaper. Many of Australia's clothing manufacturers have stopped local production for this reason, though many of the clothes are still designed here.

4.6 Environmental Issues

The natural environment has become a major issue since the 1960s. Air and water pollution, massive waste disposal problems, concern about the depletion of the ozone layer, extinction of species and the greenhouse effect are issues that are constantly being discussed by politicians, environmental groups and individuals.

There are four environmental trends that have long-term implications on designing and producing:

- Shortage of raw materials — both renewable and non-renewable resources.
- Increasing energy costs.
- Increasing levels of pollution in the environment caused by the build-up of substances that do not decompose or only decompose slowly.
- Increasing government intervention in natural resource management.

Design examples

Fluorescent light bulbs were redesigned to fit into regular light fittings, as they are very energy efficient if used correctly.

Most toilets are fitted with dual flush systems to reduce water usage.

Products such as chairs, tables, engines and electrical goods have been 'designed for disassembly', which means that the products can be pulled apart, reused and/or recycled.

Figure 4.1 Recycling bins were used at the 2000 Sydney Olympics in response to growing world concerns about the environment.

Review Questions

1. The leisure industry in Australia is a growing market segment. This trend is a reflection of:
   (A) Social attitudes that encourage the seeking of self-fulfilment.
   (B) Advances in technology which make clothing and accessories more comfortable and affordable.
   (C) Concerns about depleting environmental resources that need to be appreciated while they last.
   (D) Global awareness, efficient transportation and effective communication networks.

2. The trend to manufacture goods offshore is primarily a result of:
   (A) Social issues.
   (B) Environmental issues.
   (C) Political issues.
   (D) Economic issues.

3. Many issues influence trends in design and production. A recent trend is to consider the impact of the design, production and use of a product on the environment.
   (a) Discuss how environmental issues have influenced some designs. Use examples to support your answer.
   (b) Explain and describe how other issues have influenced the design and production of goods.

Answers Trends in Design and Production

Answer to Exercise page 42

Growing consumer awareness of the impact of design on society as a whole.

Answers to Review Questions page 46

1. (A) Social attitudes that encourage the seeking of self-fulfilment.
2. (D) Economic issues.
3. (a) As the question requires the student to discuss, make sure the positive and negative aspects are related to the environmental issue.
   (b) Issues to consider could include market demand, costs, social and ethical considerations, functional requirements such as durability and ergonomics, safety and aesthetics.

5 — Design Success and Failure

Chapter Overview

There are millions of designs around the world that have the potential to be tremendously successful but, for varying reasons, many are not commercially produced. Success or failure is not always a reflection of how well a design works or the benefits it will give to humanity. Many factors influence the success of a design.

Expected Outcome

On completing this chapter, students should be able to:

— critically analyse the factors affecting design and the development and success of design projects.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms

design failures
design successes

5.1 Design Success or Failure

The success or failure of a design is largely determined by whether or not it has produced a commercial profit. The 'best design in the world' is a failure if it does not return an income. Following are examples of designs that have been broadly classified as 'design successes' or 'design failures' though all have the potential for success. In some cases, specific factors have prevented designs from developing into commercial successes.

5.2 Design Successes

The Utility or the 'Ute'

The unique Australian utility was designed in 1933 as the direct result of a consumer making a request to the Ford Motor Company to design a car that would be suitable to transport both a family and farm animals. Lewis Bandt designed the utility vehicle based on the Ford Sedan. The passenger part of the vehicle was as comfortable as an ordinary sedan and the rear part was open, allowing the user to transport farm equipment and animals. A tarpaulin could also cover the rear part of the vehicle if the customer wanted the load protected. The 'ute', as it is commonly referred to, was, and still is, a marketing success. Ford began mass production in 1934 in Victoria and today the ute is probably the most popular vehicle used by Australian farmers and tradespeople.

The Café Bar

The Café Bar is an Australian invention developed by Neilson Associates. The automatic coffee-making machine dispenses coffee powder, milk powder, sugar and boiling water. The machine is extremely popular because it is simple, efficient and hygienic. Today, Café Bars are used around the world. Its design has been modernised several times to blend in with changing office environments.

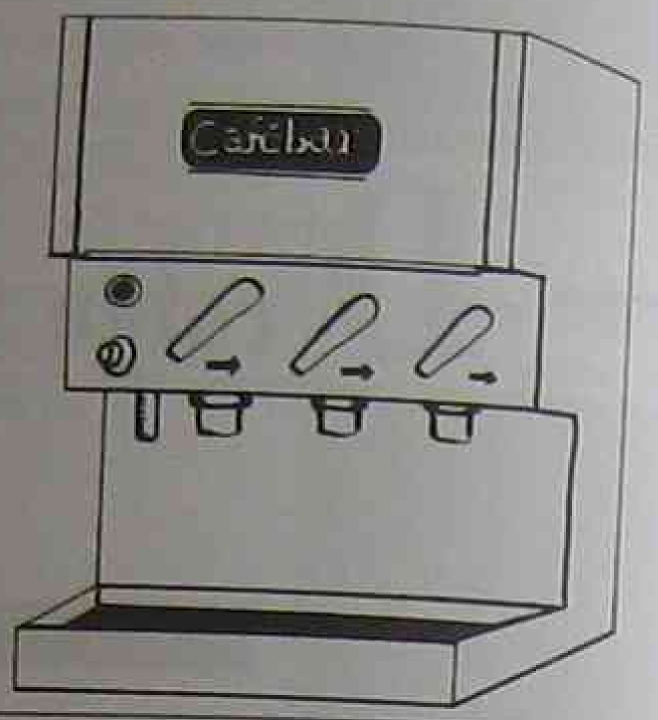


Figure 5.1 The Café Bar

The Black Box Flight Recorder

Dr David Warren, an Australian chemist, decided there was a need to develop a device to help investigators work out what had caused a plane to crash and developed the black box flight recorder in response to this. He produced a prototype combining a flight data recorder and a cockpit voice recorder but, unfortunately, the Australian Department of Civil Aviation and the RAAF rejected this design. Later the challenge was taken up by British and American companies. Today the black box flight recorder is standard equipment on all commercial aeroplanes throughout the world. Hence, while Warren's design was a failure, the final product is a tremendous success. The flight recorder stores information about the aircraft's altitude, speed and direction whilst the voice recorder stores conversations between the pilot, co-pilot and air traffic controllers. Both recorders were originally black, hence the name, but today they are bright orange so they can be easily identified amongst the wreckage.

The Wine Cask

Several Australian wine companies developed the wine cask. In 1965, Angoves marketed a cask with a resealable plastic spout. Next, Penfold's Wines introduced a table cask that consisted of an inner bag held in a cylindrical metal container with a tap. Today, the standard design is a laminated plastic bag in a cardboard box with a dispensing tap. The design works well because it is lightweight, easy to transport and it does not let any air into the bag so the wine does not go off. The design is also used for fruit juices and water.

The Bionic Ear

The Bionic Ear is a system that enables the profoundly deaf to sense and interpret speech and was originally conceived by Professor Graeme Clark of Melbourne. As a child he was often embarrassed by his own father's deafness, which made him determined to find a cure for this problem. Clark, with the help of electrical engineers, invented a prototype for the Bionic Ear, which transmitted coded speech patterns to the nerves of the inner ear. In 1978, after an eight-hour operation, a profoundly deaf adult received the world's first cochlear implant. Since then, the Bionic Ear has helped more than 10,000 people throughout the world.

The Ultrasonic Scanner

An ultrasound scanner is used to scan images from inside the body by sending ultrasonic (high frequency) sound waves to patients' organs. The receivers in the scanner pick up the echoes from the sound waves and create images from them. The scanner is useful for checking gall and kidney stones, breast and ovarian cysts, and examining the foetus in a pregnant woman. In the 1950s and early 1960s, Australian scientists pioneered the medical use of ultrasonic waves. George Kossoff and David Robinson built their first scanner in 1961. They also helped to design the transducer (the part of the scanner that is moved over the body) and the method of displaying the image.

The Automatic Totalisator

George Julius invented the world's first automatic totalisator. A totalisator is a machine that mechanically records bets and calculates odds and winnings. When the punter places a bet, a slip is given to them showing how much they will receive if they win. The information automatically appears on a display board. When the idea was originally conceived, a mechanical betting system known as the 'tote' was being used, which required three people to operate it effectively. The automatic totalisator was originally designed as a mechanical vote-counting machine but it attracted little attention from governments so Julius decided to convert it to a betting machine. The challenge was to make a machine that carried out simultaneous additions and gave instantaneous records. It needed to be capable of adding the records from a number of operators, all of whom might issue a ticket on the same horse at the same instant. Julius built the model in his spare time and the first order was for a machine at Auckland Racecourse in 1913. In 1917, George Julius founded a company called Julius, Poole & Gibson Pty Ltd. The basic design has been subsequently modified and adapted to suit the various needs of racecourses around the world though the original design was in use, in London, until 1987.

The Qwerty Keyboard

C.L. Sholes invented the Qwerty typewriter keyboard in the 1870s and it has been used in its original form ever since. The typical manual mechanism was built around 1900. As typewriters were built to last at this time, very few needed replacing. Legend has it that some typewriter dealers would buy up and destroy used machines in the hope of selling new ones. The keyboard has survived the development of touch-typing and has remained unaltered by the trend for ergonomic design. The design of the Qwerty keyboard is, in fact, quite poor in ergonomic terms. Several people have attempted to redesign the layout, as the keyboard requires finger stretches and contortions. Despite this, it still remains the standard keyboard.

Figure 5.2 The Qwerty keyboard

5.3 Design Failures

The Dvorak Keyboard

The Dvorak keyboard was developed by the efficiency expert August Dvorak in the 1930s. The Dvorak keyboard is different from the standard Qwerty keyboard, as the letters have been organised to basically correspond with their frequency of use. Dvorak also divided letters more evenly between hands, so one hand is not typing whole words. All the vowels are in the middle (home) row under the left hand, while the home row under the right hand has the five most common consonants (d, h, t, n and s). The result is that around 70 per cent of typing is done on the home row, allowing the fingers to stay in one area, whereas on the Qwerty keyboard only 30 per cent of typing is done on the home row. The aim of this set-up was to reduce aches and strains for regular typists.

The reasons for the Dvorak keyboard not becoming the standard are complex. When Dvorak patented his simplified design in 1932, the market was already saturated. Also, Dvorak introduced his keyboard in the middle of the Great Depression, an event that was closely followed by the Second World War. In addition, it was difficult and expensive to convert an existing typewriter to the Dvorak system in the 1940s (approximately equal to the cost of a new typewriter). Finally, people were comfortable with the Qwerty system, making it difficult to persuade them to consider any alternative. An interesting point to note is that a computer keyboard can be easily converted to the Dvorak layout by changing a file in the operating system. Microsoft actually pre-installs Dvorak in most versions of Windows.

The Leyland P76

Developed in the 1960s, the P76 was designed as a superior family car for the Australian market. Leyland believed Australians wanted a large, powerful family car with a big boot capacity. Unfortunately, the P76 was launched at the same time as the world fuel crisis of the 1970s struck, with OPEC raising crude oil prices dramatically. It was not the right moment for a large, petrol-hungry car to enter the market. At the same time, a reduction in import tariffs meant that small Japanese cars became cheaper and more readily available. Leyland also developed a reputation for poor quality products and unreliability and went out of business in Australia. Interestingly, the P76 is now an expensive collector's item which illustrates the cyclical nature of fashion in design.

Figure 5.3 The Leyland P76

The Ford Capri

The Ford Capri was developed in the late 1980s with over $300 million being invested in the design and development of a car for a niche market in North America. Initial sales were encouraging but weren't sustained and production ceased in early 1994. The failure was attributed to late changes in American laws regarding safety and pollution standards, which caused a last minute redesign and thus disrupted the marketing schedule. The 1990s recession also made a 'fun' vehicle less desirable. Finally, the car was promoted in the wrong market segment, being targeted at an older, wealthier, conservative demographic instead of younger, easy-going and fun-loving individuals.

The Automated Wool Harvesting System

The Automated Wool Harvesting System (AWHS) was designed to robotically shear large numbers of sheep safely and then class and bale the wool. Lack of funding and the recession caused the project to be abandoned in 1992.

Exercise

1. List the factors that contributed to the success and failure of the designs outlined in this chapter.
2. Use the ABC website (http://www.abc.net.au/) to find examples of relatively new designs. Look for key words such as science, technology and innovations. What factors may influence their success?
3. Identify two objects you use frequently and list the factors you think contributed to their success. Knowledge of their history may be useful in determining these factors and you may like to do some research to establish the rationale behind the designs.

☞ *Answers to Exercise, p. 52.*

Review Questions

1. Which of the following may contribute to the success of a new design:
   (A) Thorough market research, efficient design and the potential to be modified as consumer needs change.
   (B) The use of the design aligns with environmental and political trends.
   (C) The design is based on consumer needs, it has financial backing and it is launched in the right political environment.
   (D) All of the above.
2. A company that produces computer software has experienced massive growth since launching its products on the Internet. The success of these products is partially due to:
   (A) A growing interest in the use of the Internet to search for information and the absolute security of using a credit card to purchase goods.
   (B) The acceptance of the Internet as a consumer tool, its accessibility to most consumers and its ability to sell products via techniques that capture the user's attention.
   (C) The ability to use the Internet to obtain free software, and its accessibility to all consumers.
   (D) None of the above.
3. An individual is exploring the idea of designing and making household goods from recycled materials. They plan to sell the products through a 'party plan' business.
   (a) Identify the factors that may contribute to the success of these products.
   (b) Identify the factors that may contribute to the failure of the goods offered for sale.

☞ *Answers to Review Questions, p. 53.*

Answers to Exercise page 51

Successes

Utility

- Design was based on a consumer's request (a car that would be suitable to transport both a family and farm animals).
- Passenger part of the vehicle was comfortable.
- Rear part was open, allowing the user to transport farm equipment and animals.
- It was versatile, as a tarpaulin could also cover the rear part of the vehicle if the customer wanted the load protected.

Café Bar

- It was simple, efficient and hygienic.
- Its design has been updated several times to look modern and blend in with surroundings.

Black Box Flight Recorder

- Design based on a need to develop a device to help crash investigators work out what had caused a plane to crash.
- Stores information about the aircraft's altitude, speed and direction.
- Stores conversations between the pilot, co-pilot and air traffic controllers.
- Recorders are bright orange so they can be easily identified amongst the wreckage.

Wine Cask

- Result of a number of modifications to the original idea.
- Works well because it is lightweight, easy to transport and it does not let any air into the bag so the wine does not spoil.
- Multifunctional as it is also used for fruit juices and water.

Bionic Ear

- Is small and compact.
- Suitable for the profoundly deaf.

Ultrasonic Scanner

- Can scan images from inside the body.
- Is non-invasive.
- Useful for detecting gall and kidney stones, breast and ovarian cysts and examining the foetus in a pregnant woman.

Automatic Totalisator

- Efficiently records bets and calculates winnings and odds. The information automatically appears on a display board.
- Replaced a system that required three people to operate it effectively.
- Carries out simultaneous additions and gives instantaneous records.
- Adds the records from a number of operators simultaneously.
- The basic design has been subsequently modified and adapted to suit the varying needs of racecourses around the world.

Qwerty Keyboard

- Works more efficiently than alphabetically organised keys.
- Originally put on typewriters which were built to last so it was accepted through habitual, long-term use.
- Survived the development of touch-typing because it had saturated the market and people generally resist change.

Failures

Dvorak Keyboard

- Market was already saturated with the Qwerty keyboard when Dvorak patented his design.
- Dvorak introduced his keyboard in the middle of the Great Depression, which was closely followed by the Second World War, and consumers had other priorities at this time.
- It was difficult and expensive to convert an existing typewriter to the Dvorak system.
- People were comfortable with the Qwerty system.

Leyland P76

- A larger, petrol-guzzling car that was launched at the same time as the 1970's world fuel crisis.
- A reduction in import tariffs made small Japanese cars cheaper and more available.
- Leyland developed a reputation for poor quality and unreliability.

Ford Capri

- Changes in American safety and pollution standard laws caused a last-minute redesign, and hence disruptions to the marketing schedule.
- The 1990s recession made an impractical, 'fun' vehicle less desirable.
- Promoted in the wrong market segment.

Automated Wool Harvesting System

- Lack of funding.
- The recession caused the project to be abandoned.

2 and 3. Student response.

Answers to Review Questions page 51

1. (D) All of the above.
2. (B) The acceptance of the Internet as a consumer tool, its accessibility to most consumers and its ability to sell products via techniques that capture the user's attention.
3. (a) Factors that may contribute to success include:
   - Public awareness of the growing problem of waste disposal.
   - Acceptance of recycled products.
   - Ethically sound business idea.
   - Party plan allows flexibility as products can be made when an order is placed.
   - Low initial capital outlay.
   - Economical to use second-hand resources.
   - Low cost of marketing.

   (b) Factors that may contribute to failure include:
   - It may be difficult to obtain quality second-hand resources.
   - Promotion relies mainly on word of mouth.
   - The use of non-recycled resources has to minimal and justified.
   - Labour intensive.
   - May be difficult to ensure the design looks aesthetically pleasing when made from recycled resources.

6 – Historical and Cultural Influences

Chapter Overview

Today's design and production has been influenced by what has occurred in the past and by various cultural influences. Changing social trends, cultural diversity changing nature of work and technological change are examples of historical and cultural influences on design and technological development.

Expected Outcome

On completing this chapter, students should be able to:

— explain the influence of trends in society on design and production.

Source: Design and Technology, Stage 6 Syllabus, © *Board of Studies,* 1999.

Key Terms and Concepts

cultural diversity
nature of work
social trends
technological change

6.1 Historical Background

The historical development of design and the rate of production in Australia has been affected by periods of economic boom and bust. Australian designers have consistently exhibited innovation and some still lead the world with examples of outstanding design and creativity.

Australian historical periods may be divided into the following categories:

Before European Settlement (up to 1788)

Discoveries at Lake Mungo and the Willandra Lakes in New South Wales have shown Aboriginal occupation of Australia for at least 40,000 years, and possibly much longer. Australian Aborigines are generally accepted as having arrived in the north of the continent via a land bridge from New Guinea or over water from Indonesia. Whilst an Asian origin is probable, their exact origins are still uncertain.

The period 1760–1840 marked the Industrial Revolution in Britain. Food shortages, harsh penal laws and the displacement of people during the early stages of the Industrial Revolution added to Britain's criminal population. After the American Revolution ended in 1783, the British Government moved to establish a settlement in Australia as it could no longer ship convicts to America. In 1788 Captain Arthur Phillip led the First Fleet to Australia.

European Settlement and Pastoral Expansion (1788–1850)

Three major problems confronted the early leaders: providing a reasonable supply of food; developing an economic system; and producing exports to pay for imports from Britain. Land grants were given to ex-convicts and soldiers and there was unchecked pastoral expansion by the squatters.

Gold Rushes and Pastoral Growth (1851–1900)

The gold rush of the 1850s was centred in Victoria. Many people flocked to the area, partly because of the well-known and recent Californian gold rush. A band of miners protested the high cost of mining licences at the Eureka Stockade in 1884. Depression in the 1890s slowed growth and increased Australia's foreign debt.

Federation, World War I and the Great Depression (1901–1939)

In January 1901, Australia became a Federation and the resulting Constitution reflected both British and American practices. World War I (1914–1918) forced industries to make do with available resources, leading to many innovations. Australia sent more than 330,000 volunteers to war.

A national trade tariff system was imposed on many imported goods to protect local industries. In 1929, a collapse in the value of shares traded in the world's major stock market in New York triggered a severe depression.

World War II and the Post-war Boom (1940–1974)

When war came again in Europe, Australia dispatched its armed forces to assist in Britain's defence. The post-war 'baby boom' and an immigration policy that encouraged large-scale migration increased Australia's population significantly.

After the war, many countries began exporting commodities to Australia. Australian companies could not compete, so tariffs were imposed to protect local companies. This resulted in some very inefficient manufacturing techniques, out-of-date machinery and, in some cases, poor quality goods.

Internationalisation and Speculation (1975–1989)

During this period Australian industries competed locally and internationally, though in the mid-1970s there was a world recession. In the 1980s, Australian industries became less sheltered as tariffs on imports and other protection policies were lowered or phased out. The stock market crashed again in the late 1980s.

Recession and Recovery (1990–present)

A recession dominated the economy in the early part of the 1990s. During the course of the decade technology was embraced with unprecedented enthusiasm as e-commerce thrived and Internet usage grew dramatically. The Goods and Services Tax was introduced in 2000.

6.2 Cultural Influences

Australia is a culturally diverse country populated by people from a variety of ethnic backgrounds and culture is a major influence on a person's consumption patterns. Growing up in a particular society, people learn basic values, perceptions, wants and responses from the family unit and other institutions such as schools. These form the person's cultural identity. Western culture encourages people to value achievement, success, activity, involvement, efficiency, practicality, progress, material comfort, humanitarianism, youthfulness, fitness and health.

Within any culture there are subcultures or smaller groups of people with similar values. Catholics, teenagers and surfies are all examples of subcultures whose members often share common beliefs, preferences and behaviours. Whilst primary values have not really changed over the years, there have been many shifts in secondary values. Pop music, movies, celebrities, technology and economic circumstances have influenced values. Changes in values are reflected in areas such as sexual norms, the way people dress and the way people treat each other.

Extension

Describe how you think popular culture has influenced the way you dress, behave and consume.

6.3 Historical and Cultural Influences on Design and Production

These influences include:

- Changing social trends.
- Cultural diversity.
- The changing nature of work.
- Technological change.

These four influences are examined in detail b with each being related to the historical pe outlined in Section 6.1.

Changing Social Trends

Before European Settlement (up to 1788)

Aboriginal society was constantly developing tools and food sources and, through co networks, traded items such as quality stone (certain quarries) and also exchanged gifts, s and ceremonies. Complex social organisa included individuals' rights and obligations to the environment and other people.

European Settlement and Pastoral Expansion (1788–1850)

The penal colony nature of early white settle required strict military control of civilian life.

Gold Rushes and Pastoral Growth (1851–1900)

There was a rapid increase in the number of settlers during this period and these pe demanded a more democratic government.

Federation, World War I and the Great Depressio (1901–1939)

On 1 January 1901, the first law passed by the Australian Government was a policy of vi exclusion of non-European immigrants. This 'Wh Australia' policy remained essentially unchang until after World War II.

World War II and the Post-war Boom (1940–197

The price of crude oil increased, which promp consumer demand for energy efficient products.

Internationalisation and Speculation (1975–1989)

Increases in average disposable incomes during this period resulted in higher demand for leisure-related goods. Growing awareness of environmental issues led to innovations such as the Solahart hot-water system, which was developed to make solar heating economically viable for the domestic market.

In the 1980s it became popular to promote Australia's natural heritage and traditional Aboriginal art was commercialised and designers such as Ken Done increasingly used Australian themes in their work. Australian bush foods gained in popularity and were marketed in speciality stores and restaurants.

In 1984, Rainsford introduced the Safe-N-Sound baby capsule in response to consumers' concern regarding the safe transportation of babies in cars.

Recession and Recovery (1990–present)

There was an increase in consumer demand for convenience products due to increases in the number of women in the workforce and the number of single-parent families. This was coupled with a desire to spend less time on housework.

Health and dieting were major issues and many products were developed in response to this, bearing labels such as 'lite', 'low-fat', 'no cholesterol', 'reduced salt' and so on.

The state of the environment continued to be a major concern and Ian Kiernan launched the 'Clean-Up Australia' campaign in 1990 to encourage people to take responsibility for cleaning up rubbish in their own community. It was a tremendous success and led to the 'Clean Up the World' campaign in 1993.

The use of personal computers for work, leisure and study became very commonplace. Ethical issues surrounding medical procedures to assist human conception and cloning and genetic engineering were hotly debated topics in the 1990s.

Cultural Diversity

Before European Settlement (up to 1788)

Aboriginal culture dominated, although within this culture there existed many different subcultures.

European Settlement and Pastoral Expansion (1788–1850)

European migration to Australia began in 1788 when the British colonised Australia as a penal settlement to replace territory lost in the American War of Independence. The first voluntary migration program began in 1821 when assisted passages were offered to free settlers. In 1835 the 'bounty' system was introduced, whereby private employers could 'select' migrants and receive a government bounty for each person landed. This system created an imbalance of females over males and also introduced the first non-British migration since the arrival of the Aborigines.

Gold Rushes and Pastoral Growth (1851–1900)

The pattern of population growth changed dramatically when gold was discovered in Victoria and NSW in the 1850s. People migrated from Germany, Hungary, Italy, China, Poland, the USA and Scandinavia. This influx of cultural diversity led to changing consumption patterns and increased wealth.

Federation, World War I and the Great Depression (1901–1939)

World War I created the first feeling of mass national unity though there was rivalry between the English Protestant and the Irish Catholic communities. This had economic, political and nationalistic implications.

World War II, the Post-war Boom (1940–1974) and Internationalisation and Speculation (1975–1989)

In 1945 the Federal Government launched a formal program of population expansion through immigration to combat the shortage of labour. Included were people from Britain, Italy, Greece, Malta, Austria, Belgium, France, Germany, Switzerland, Spain, the Netherlands, Yugoslavia, Lebanon, Egypt, Portugal, Uruguay, Chile, Peru, Argentina and Turkey. There was a bias against Asians entering the country.

The prosperity of the 1950s encouraged the provision of free university education. In the 1960s, attempts were made to integrate Aboriginal peoples socially and culturally, including giving them the right to vote in 1967. In 1973, the Immigration Policy was reviewed to grant entry to people on the basis of Australia's national needs and for humanitarian reasons.

Australian society was no longer mainly Anglo-Irish and people from diverse cultures began to demand their own products. The variety of foods available from Australian shops increased, SBS television, community radio stations and foreign language newspapers catered for people of non-English speaking backgrounds and fashion influences became more diverse throughout the 1970s and 1980s.

Recession and Recovery (1990–present)

In 1993, the Government passed an Act allowing Aborigines and Torres Strait Islanders to file land claims.

The Changing Nature of Work

Before European Settlement (up to 1788)

Past studies of Aboriginal society generally concluded that it was a nomadic lifestyle but there is now a consensus that this was not generally the case. In areas where fresh water and food was plentiful, such as in the coastal regions of the east coast, Aboriginal populations were high and communities lived in semi-permanent villages. The main reason for moving communities was the eventual fouling of the vicinity of the village with the wastes of human habitation. The village would be abandoned as a matter of hygiene, allowing the camp refuse to decay, lose its smell and become part of the soil renewal process. This technological understanding of recycling waste and of when each camp was ready for reoccupation shows the organisation of Aboriginal society in these areas. Unfortunately for the Aborigines, these areas were the first grabbed by European settlers, forcing them off their lands and destroying their organisation.

Women, slowed down by caring for children, especially toddlers who were weaned late, did most of the collecting of foodstuffs such as shellfish, fruit and berries, fish (with hook and line) and roots. Men were more mobile and able to travel longer distances to hunt for game and fish. Men and women worked together at times, such as when fishing with nets.

In some areas there is evidence that Aborigines were in the process of abandoning their nomadic traditions at the time of European settlemen as in Victoria where sophisticated stone f have been found.

European Settlement and Pastoral Expansio (1788–1850)

Working conditions during this period involve hours (12–14 hour days), poor condition wages, no unions to fight for improvemen women and children often working as labourers.

Convicts were employed to carry out the physical labour on farms, work for the gover to provide infrastructure for the colonies and domestics in households.

Gold Rushes and Pastoral Growth (1851–190

People continued to work long hours, often hard manual labour.

Federation, World War I and the Great Depressio (1901–1939)

In 1910, the average working week was 52 ho Many workers were still working Saturdays wi penalty rates or overtime benefits and a signific proportion of the workforce were children aged 15 years. Mass production led to a division of lab and specialised skills and increased producti Unions were established to improve work conditions and wages.

A national trade tariff system was imposed on ma imported goods to protect local industries. In 19 a collapse in the value of shares traded in t world's major stock market triggered a severe depression which resulted in massive unemployment.

World War II and the Post-war Boom (1940–1974

In 1945 the war ended and one of the legacies t Australians was a wide range of technical sk gained from the huge demand for manufactu during the conflict. Secondary education had alm become universal and there were fewer children i the workforce. The post-war 'baby boom' increase the population.

In 1946, one week's annual leave was granted t Australian workers and this was extended to th weeks in 1963. In 1951, NSW introduced the first legislation in the world to provide for paid sick leave and long service leave. The Commonwealth Arbitration Court approved the 40-hour working week in 1947.

Internationalisation and Speculation (1975–1989)

In 1979, unpaid maternity leave was granted and unpaid paternity leave was granted in 1990.

Recession and Recovery (1990–present)

During 1990-91 many employers were forced to reduce working hours for employees in order to avoid large-scale retrenchments. Work became more flexible with increases in part-time positions and job sharing reducing the stress for workers and allowing them the opportunity for retraining and education.

Multiskilling, whereby one employee is required to develop diverse skills to carry out a number of jobs became increasingly in demand in the workplace. The use of technology such as computers became an essential element of many occupations.

In some industries workplace agreements replaced industry awards. Telecommuting, where a person works from home and is linked to the office via modems, facsimile machines and the telephone, became a more feasible work option as communication networks improved and social attitudes changed. The 'paperless office', where information is processed, communicated and stored electronically, has become much more commonplace.

Technological Change

Listed below are some of the more important innovations and advances in design and technology but note that not all of these were conceived or developed in Australia.

Before European Settlement (up to 1788)

Fish traps, built of stone and other materials, used natural water movement and river flow or tides to trap fish. In Victoria, a vast network of canals and ponds has been found which allowed eels to be brought across the mountains, stored and harvested at will.

Figure 6.1 Example of fish traps

Heavy, wide, meshed nets were used in wallaby and kangaroo drives, while finer ones were set in rivers and creeks to catch fish. These were made of various natural fibres, fur and even human hair. Spears varied from simple straight sticks with fire-hardened tips to elaborate designs with ornate or multiple heads. Heads could be attached with kangaroo tendons or tree and plant resins. As straight wood was not generally available, crooked wood was straightened by careful heating and bending so it could be made into spear shafts. Part of a shaft was often made from the flower spike of a grass tree (to keep it light) whilst the rest was constructed from hardwood for strength.

Woomeras (spearthrowers) were used to increase power when throwing a spear. They varied from narrow, like the spear, to broad, and often incorporated a shallow basin that could be used as a mixing bowl. Boomerangs varied across the continent and could be used for hunting or clapped together as musical instruments. Shields were either broad and made of softwood to take a blow, or narrow and constructed of hardwood for parrying. Various implements were made of stone, shell and bone while hooks were filed from shells and used for fishing.

Cooking was done on coals and in the ashes of fires and in ovens constructed of earth. Women gathered food using a traditional digging stick — a simple pointed stick with a fire-hardened end. Dilly bags or baskets were made from bark or plaited fibres and often waterproofed with gum. Bowls and dishes were made of wood, bark or large shells.

Rock painting demonstrated ingenious use of available materials. The most popular colours were red, white, black and yellow. Mostly pigments were used but paint was also mixed. Some areas had abundant supplies of natural pigment and colours were traded over great distances.

European Settlement and Pastoral Expansion (1788–1850)

The first Europeans brought tools and materials unsuited to the conditions of the Australian climate and hence innovation was born of necessity. Farming, building and manufacturing techniques were developed from knowledge of European practices and adapted to Australian conditions.

In 1819, Thomas Kent extracted tannin from wattle bark so leather goods could be cheaply processed and exported. In 1837, in the United States, the first telegraph was sent. A wheat-stripping machine was developed in 1843 in Australia. This enabled the cheap and efficient harvesting of large crops of wheat and it was also used in the United States.

Gold Rushes and Pastoral Growth (1851–1900)

The Coolgardie Safe was developed to prolong the life of food, particularly meat, by keeping it cool. It was a simple wooden box with gauze sides to keep flies out. The evaporation of water from wet hessian cooled the safe.

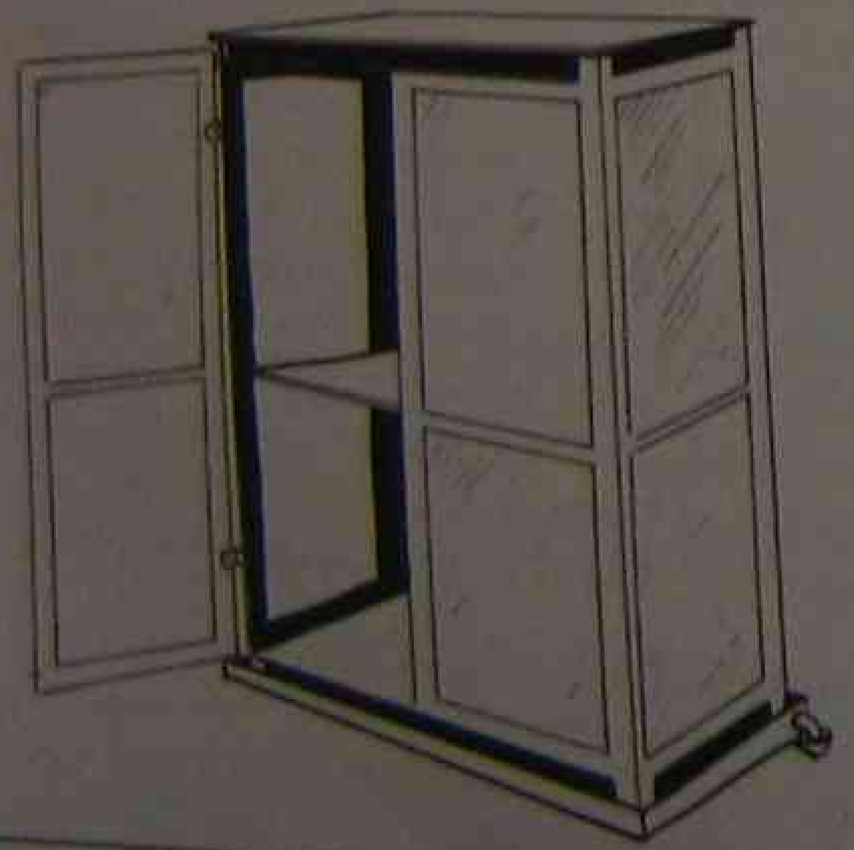


Figure 6.2 Coolgardie Safe

In 1857, James Harrison commercialised ice making and by the mid-1870s, ice factories were established in Australian cities. James Harrison also developed a method of deep freezing which enabled meat to be successfully transported by ship. During the 1860s–1870s, a new strain of Merino sheep was bred that enabled sheep farming in arid areas. Frederick Wolseley and his associates developed machine-driven shears for clipping sheep. In 1876, Alexander Graham Bell invented the telephone. In 1878, the Stump-Jump plough was developed, enabling farmers to plough land without having to remove stumps and surface roots first. Kodak developed the first hand-held camera in 1888.

Federation, World War I and the Great Depression (1901–1939)

In 1903, the Wright brothers travelled 40 metres through the air, for the first time in history, in a petrol-driven bi-plane. In 1906 the human voice was first transmitted by radio and Bakelite started developing plastics for commercial use in 1909. Henry Ford introduced mass production techniques for the Model T Ford in 1913.

In 1910, the Hume family manufactured concrete pipes using innovative methods and by 1939 the Hume's company had become one of Australia's largest manufacturing concerns, making a diverse range of products for local and overseas sale.

Cliff Howard built the first rotary hoe and by the 1920s he began manufacturing these and related products for Australian and overseas markets. George Julius designed an automatic totalisator in 1913 for use at racecourses. It mechanically recorded bets, calculated winnings and deducted charges. In 1926 the world's first demonstration of the television was given. Ford Australia designed and produced the 'utility' in 1933, a car with a cabin for comfort and a buckboard back to carry loads. The Douglas DC1 passenger aircraft also appeared in 1933. It was different from other aircraft in that it had a stressed aluminium skin that was strong enough to not need bracing wires and hence it had a streamlined look.

World War II and the Post-war Boom (1940–1974)

The Owen sub-machine gun was specifically designed for the Australian Army. It was easy to maintain, more reliable in wet, muddy conditions and cheaper to produce than other sub-machine guns used at the time. Howard Florey, an Australian scientist, led the team who made the first significant quantities of penicillin for large-scale use. This dramatically reduced the number of people dying from disease and infection.

From 1956 onwards television ownership rapidly grew throughout Australia, facilitating mass advertising. The Victa mower, designed in 1952, was unique in that it could cut grass at varying heights.

Figure 6.3 Victa mower

In 1955, Caroma Industries Ltd introduced the first one-piece injection moulded toilet cistern with all plastic parts. This overcame the corrosive effects of water on brass components. The Cold War between the United States and the Soviet Union sparked off the space race between the super powers. In 1957, the Soviets launched *Sputnik 1*, the first satellite to orbit the Earth and in 1960 a Soviet cosmonaut, Yuri Gagarin, was the first man in space. In 1969, the American, Neil Armstrong, became the first man to walk on the moon.

In 1960, lasers were developed and in 1964 IBM word processors were introduced. Christian Barnard performed the first heart transplant in 1967. Video-cassette recorders were introduced by Phillips in 1971 and soon became as commonplace in the home as the television. Electronics have resulted in some dangerous or repetitive jobs being carried out by robots and other machines.

Internationalisation and Speculation (1975–1989)

In 1976, the Apple computer was introduced and the first 'test tube' baby was born. Hand-held computer games such as Gameboy became very popular in the 1980s.

Recession and Recovery (1990–present)

The Commonwealth Serum Laboratories developed a snake venom detection kit, which reduced the incidence of inappropriate antivenin given to snake-bite victims. In 1990, the Night Golf System was developed whereby golfing products were dyed in fluorescent colours that glowed under ultraviolet light.

Internet use and communication through e-mail become common in households in the 1990s and it is predicted that Internet access will be as common as telephone access in the near future. DVD (digital versatile disk), a home entertainment medium, started to gain in popularity in the 1990s.

Exercise

1. Why do you think technology has changed more in some countries than others?
2. How have computers changed/improved since you have been using them?
3. Investigate your parents' perceptions of changes in computer technology.
4. What improvements do you think will be implemented in computers in the future?

☞ ***Answers to Exercise, p. 63.***

Review Questions

1. An example of a design that has been influenced by changing social trends is:
   (A) Pencil sharpeners.
   (B) Dual-flush toilet cisterns.
   (C) Cane baskets.
   (D) Leather and cotton gardening gloves.

2. A person's cultural identity may be derived from:
   (A) Consumption patterns, climate and environmental conditions.
   (B) Various institutions.
   (C) Family, friends, community, schooling and ethnic background.
   (D) Popular music, movies, celebrities and technology.

3. Australia's cultural diversity:
   (A) Is primarily attributed to the influx of migrants since early European settlement.
   (B) Was created in 1945 when the government launched a massive immigration policy.
   (C) Is due to the fact that many people accept 'foreign' cars, foods and customs.
   (D) Is a result of our changing value systems, increased population and increased number of people who enjoy the arts and the theatre.

4. Telecommuting is indicative of the changing nature of work as it:
   (A) Enables the employee to work more flexible hours, reduces time wasted in travelling to and from the workplace and utilises modern communication networks.
   (B) Ensures employees have communication via satellite networks and transport communication systems.
   (C) Uses technology to facilitate the rapid growth in working hours.
   (D) Encourages the employee to multiskill and retrain to use the available technology.

5. Technological change has a significant influence on designing and producing.
   (a) Explain how designing and producing may be influenced by changes in technology. Use examples to support your answer.
   (b) Discuss how changing social trends have affected technological changes in design and production.

☞*Answers to Review Questions, p. 63.*

Answers Historical and Cultural Influences

Answers to Exercise page 61

1. It is difficult to generalise but listed below are some points to consider:

- Social acceptance of technology is greater in certain countries.
- Some economies have massive national debt and therefore few resources to invest in technology.
- Some cultures have difficulty accepting change.
- Some communities are still very isolated and hence relatively unaware of the available technology.
- In some communities, the acceptance of technology is only for personal pleasure rather than for the benefit of the whole country.
- War and natural disasters keep some communities in upheaval and hence it may be difficult for them to appreciate or apply the benefits of various technologies.

2. and 3. Student response.

4. Suggestions include:

- Computers will become even more user-friendly.
- All day and everyday use of remote-controlled PCs.
- Integration of television, communication systems and PCs.
- Greater mobility of computers.
- Reduction in size of PCs.
- Reduction in cost of software and running costs.
- Note: Many of these so-called improvements have already been developed but are not readily available to the general consumer at a reasonable price.

Answers to Review Questions page 62

1. (B) Dual-flush toilet cisterns.
2. (C) Family, friends, community, schooling and ethnic background.
3. (A) Is primarily attributed to the influx of migrants since early European settlement.
4. (A) Enables the employee to work more flexible hours, reduces time wasted in travelling to and from the workplace and utilises modern communication networks.
5. (a) Examples could include:

- An improvement in tools, for example, the use of computer-aided design for the design of sails.
- Improvements in efficiency, for example, woomeras were used to increase the speed of spear throwing, the Stump-Jump plough made clearing land much quicker.
- Reduction in safety problems as machines and robots may be used to carry out dangerous tasks and simulations can be used to develop skills with innovations such as flight simulators.
- Less wastage due to more efficient processes, for example, mass production produces economies of scale.
- Communication occurs more efficiently and faster due to modems, facsimiles, telecommunication networks, fibre optic cables and satellite communication.

(b) Suggestions include:

- Social acceptance of technology has encouraged people to try out new technologies and many, such as mobile phones, computer games and answering machines, have become 'must haves'.
- Technology is now necessary in most areas of the workforce, especially the use of computers.
- There has been a greater push for environmentally-friendly products, hence many designs are more energy efficient or use less non-renewable resources. For example, electrical goods often have an energy rating to indicate to the consumer how environmentally friendly the energy consumption is.

7 – Creative and Collaborative Approaches in Designing and Producing

Chapter Overview

A range of creative and collaborative approaches influences the end results of design and production. A designer's thorough understanding of these approaches will result in more satisfying outcomes.

Expected Outcomes

On completing this chapter, students should be able to:

- investigate and experiment with techniques in creative and collaborative approaches in designing and producing
- use creative and innovative approaches in designing and producing
- justify technological activities undertaken in the Major Design Project and relate these to industrial and commercial practices.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

brainstorming
cognitive organisers
concept maps
co-operative structures
metacognition

7.1 Creative Thinking in Design

In Design and Technology you need to demonstrate a creative approach to your work. This means more than simply providing an artistic approach to the presentation of your folio. Your thinking needs to be creative and innovative. Lateral thinking and the ability to solve problems must be shown throughout the course in both your folio and Major Design Project.

Creative and Innovative Approaches to Design Practice

There are numerous ways to approach a design, but if the designer is to exhibit creativity or innovation they need to consider options beyond the scope of normality.

The world is full of ideas but only a unique person can take these ideas and develop them into innovations. Observation, research and a thorough investigation of existing ideas and technology will assist the innovator. Once an innovation is converted to prototype form, it is evaluated, tested and modified, often many times, until it fulfils the desired need.

The innovative part of a product or process is not restricted to products and manufacturing. New and emerging technologies and ideas for finance and management are constantly being developed. All of these play a role in innovation and, if it is appropriate, you should take the risk and use cutting-edge technology or styles to make your design a success. The quality of a design should be of a standard that reflects its cost and purpose.

Responding to Motivational and Inspirational Stimuli

How do we gather our initial ideas? We need to use and respond to inspirational and motivational stimuli. There are many different ways an innovator may be inspired to provide new ideas. Motivation may come from stimuli such as newspapers, magazines, journals, books, posters, billboards, television reports, fictional dramas, documentaries, live theatre, interviews, observations, photographs, music and aromas.

Responding to motivational stimuli can take many forms but will generally follow this pattern:

- **Recording** is where the raw response is tabulated, usually in written or graphical form.
- **Summarising the data** occurs when the data is broken down into essential components and unnecessary information removed.
- **Critical analysis** occurs when the results are analysed, often using a cognitive organiser such as De Bono's PMI.
- **Reflection** is the point where the results are considered in order to form an overall picture.
- **Drawing conclusions** occurs at the point where the designer decides whether or not to run with the ideas created by the stimulus.

7.2 Cognitive Organisers

> Why do we need to use cognitive organisers?
> Because they help us to think outside the square!

Cognitive organisers help designers to clarify their thinking. They enable them to work out what they already know and what they need to know, and help them to look at something from a slightly different perspective.

PMI

PMI is one example of a cognitive organiser. In Design and Technology there is often a need to evaluate and Edward De Bono designed a simple method of doing this known as PMI. Edward de Bono is one of today's greatest thinkers. A self-made millionaire, he has made his fortune teaching people how to think. He leads the world in studies of metacognition and is in great demand as a speaker. PMI works in the following way: designers complete a PMI by listing all of the **pluses**, the **minuses**, and any **interesting points** related to a concept, design or proposal. This analysis can be applied to a wide range of objects and ideas, as in the extension activity below.

Extension

Use a PMI to evaluate two texts that you may use for an HSC written exam.

Text 1: ______________________

Plus points:

Minus points:

Interesting points:

Text 2: ______________________

Plus points:

Minus points:

Interesting points:

Which in your opinion is the better text and how did you come to this conclusion?

You can use a PMI to evaluate designs that already exist for your next design brief or to research and evaluate new concepts such as digital television as an emerging technology.

Bloom's Taxonomy of Thinking

Benjamin Bloom is an American professor and his taxonomy of thinking helps us to see at what level we are working. It is based on his suggestion that, as our thought patterns develop, they become more complex. The more complex and higher levels of thinking that you display in your design projects and exam responses, the higher your marks will be.

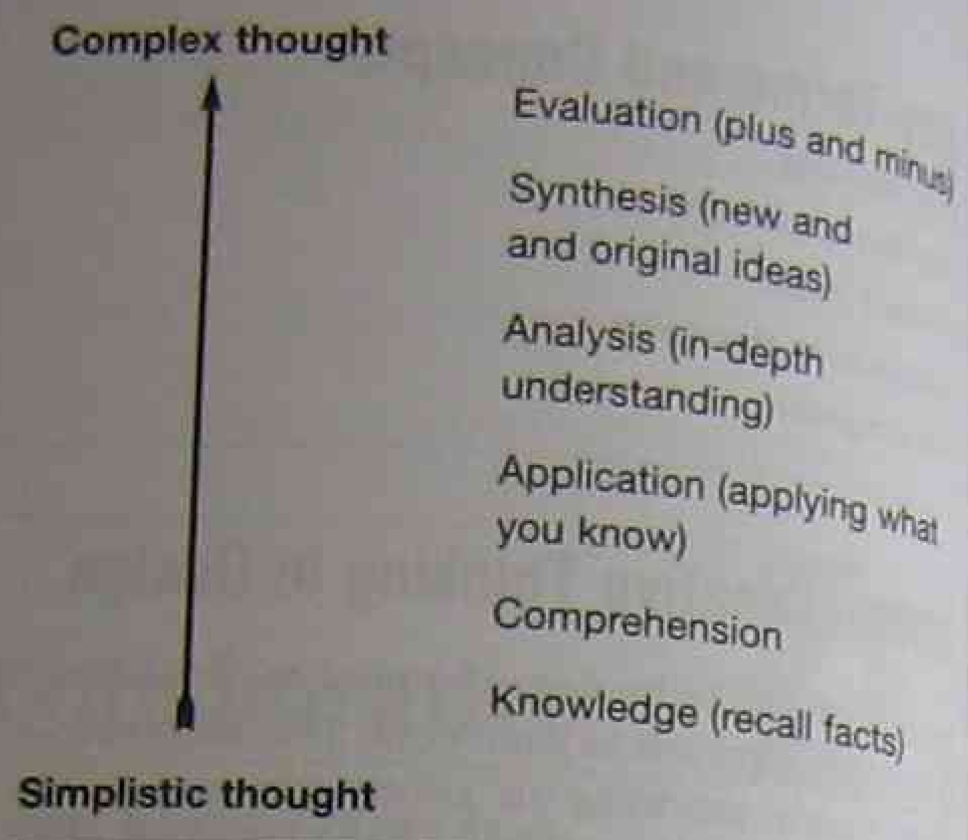


Figure 7.1 Bloom's Taxonomy of Thinking

When an HSC marker grades your MDP they are looking for an understanding and application of the higher order skills which, if present, will result in a good mark. The higher order skills are **analysis**, **evaluation** and **synthesis**. These skills are stressed in the HSC Syllabus for Design and Technology and those students who can synthesise, evaluate and analyse information in the HSC exam will be the ones who do well.

Exercise

At which level of the taxonomy am I thinking when I make the following statements?

1. (a) The project is made from wood.
   (b) The project is aesthetically pleasing.
   (c) The project is aesthetically pleasing and I made it from an exotic timber.
   (d) The exotic timber that I made my project from is rare.
   (e) I chose Western Red Cedar to make my project from because it is lightweight and this meant that my project could be transported easily upon completion.
   (f) I really like the project that I made and so do all of the people that I surveyed.
2. Write an evaluative comment about a project you are working on.

   For example, whilst my project is aesthetically pleasing, it could be improved by ....

☞Answers to Exercise, p. 70.

Brainstorming

This is when a range of ideas is gathered during a group discussion on a particular project, proposal or problem. All ideas are acceptable, are recorded and will be considered.

Extension

Gather a group of people and ask them the first thing that they think of when you use the word 'environment'. Write down all responses. Then, think of an environmental issue or problem and ask the same people for their ideas on the topic and write these down as well. When you have done this, you have completed a brainstorming session.

Concept Maps

When you are trying to come up with a design or perhaps collate information for a video review as part of design generation, it is easier to remember facts if they are related to each other. In this instance a concept map can be used.

A concept map of this chapter is illustrated in Figure 7.2 below.

Many people choose to draw their concepts rather than write them down. As the saying goes, 'a picture tells a thousand words'. You can use concept maps to summarise research in your Major Design Project or to summarise notes when revising a unit of work.

Think-Pair-Share

Often your teachers will ask you to think about a topic and share your ideas with the person sitting beside you. You will often find that they have different ideas to you and this may lead to you rethinking the topic and coming up with other ideas.

This process is useful at all times throughout a design project, as others will often see things you do not, particularly when you are working very closely on your design. If you make use of this worthwhile process, do not forget to document it in order to gain additional marks.

De Bono's Thinking Hats

Edward De Bono's Thinking Hats are an example of a co-operative structure which can be useful in generating design ideas. De Bono believes that arguing is a waste of time and that a lot of energy is lost when people's ideas and opinions conflict and no-one listens to anyone else. To overcome this problem he divided our thought patterns into six areas and suggested that in order to promote co-operative thinking structures, we all need to be on the same track. He calls this innovative thinking pattern 'the Thinking Hats'.

In using the hats, each person in the group tries to think along the same line at the same time and puts forward their point of view whilst considering and listening to that of others. The result is that the group follows a parallel path to a conclusion.

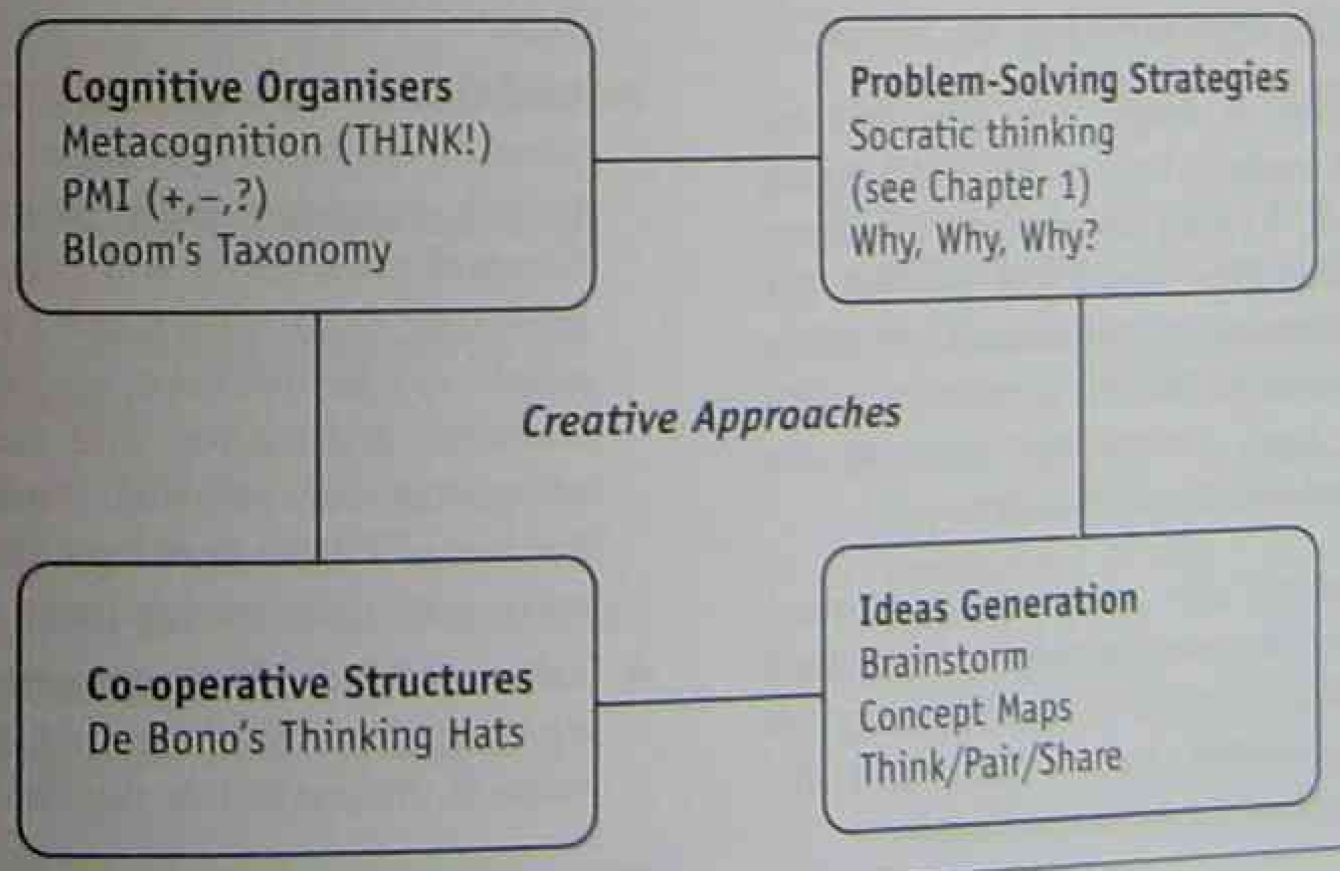


Figure 7.2 Concept map for this chapter

In order to use the Thinking Hats, one person explains that to direct the thinking for any given activity they will wear the **blue hat**, blue symbolising freedom and the sky. This person decides in which order the hats will be used and which hats are most appropriate. They allow the group 2–3 minutes to brainstorm ideas using each hat. The other hats are:

- The **white hat** which stands for 'factual information', white symbolising the blank page ready to be filled with ideas.
- The **yellow hat** symbolises sunny days and happiness. When told to put on the yellow hat, the group should list all the advantages.
- The **green hat** symbolises springtime and new growth and new ideas. It is often the last hat worn and is used to solve problems and suggest new approaches to an issue.
- The **black hat** is all that is dark and gloomy. It is worn to list all of the negatives.
- Red is the colour of blood, emotions and feelings. When emotions are high, it is a good idea to use the **red hat** early in the process.

7.3 Collaborative Approaches to Design

Design Teams

A **design team** is a group of people working together on a **design brief** given to them by a client. The team will share the vision and develop a design that fulfils the brief given to them.

To achieve success in design it is necessary for colleagues at all levels to have a sense of working together as a team. A strong design team co-operates to solve problems. They thoroughly research the design brief, understand the limitations and share ideas and build concepts in order to meet the brief's objectives. The team evolves and reshapes the concept and ideas until the brief is met.

The ideas generated are presented in a storyboard/prototype format to the client. If the client approves the design, specifics in manufacturing and marketing are examined and, if the client disapproves, it is back to the designing board.

Roles and Tasks of Members

The design team members are expected to thoroughly understand the design brief and the client's preferences. They will need to analyse appropriate research about the intended market, suitable emerging technologies and the product's intended use. Ideally, they will work together to develop a suitable design that will fulfill the brief and continue to work co-operatively in order to develop a way of presenting the designs to the client. This may involve a storyboard, a prototype, a model, an audio-visual display or a digital demonstration.

The role of **management** is to set goals and objectives to ensure that all required tasks are completed on schedule. They allocate resources in order to allow them to achieve the best possible outcome. They may or may not be the team leader. If they are not, they will rely on the leader to make managerial decisions and report to them on the project's progress at all stages.

Styles of collaborative management commonly used include:

- **Herzberg's motivation theory**. In the 1950s, Herzberg researched links between the attitudes of workers to their jobs and the rewards offered for their work. He found that levels of recognition motivated workers as well as providing personal growth and satisfaction.
- **Management by Objectives**. Team members regularly report to managers on past and current performances. Future goals and objectives are decided, as are ways to work towards achieving them.
- **Total Quality Management** (TQM). This style is based on the belief that improved quality means greater customer satisfaction, lower costs, increased productivity and long-term competitive advantage. TQM is everyone's responsibility and people, as a key resource, are invested in through education and training and placed in positions where they can put their knowledge to work. The aim of TQM is to reduce waste and error and make work more productive in the long term.
- **Value Added Management** is based on eliminating all processes that do not add to the value of the product or the service.

The role of the **team leader** is to ensure that each team member has a clear understanding of the design brief and is working as a functioning part of the team. The team leader should be a good communicator and human resource manager.

Modern trends in collaborative team leading include:

- **Autocratic**, where the management makes all of the decisions. For example, if a team were designing a new school emblem, the manager would decide on the size, shape, colour, wording and style and the team would do as they were told.
- **Democratic**, where the team is asked for their opinions on changes and these are taken into consideration at the decision-making stage. However, the final decision rests with the leader.
- **Collegial**, where the team are involved in decision-making from the beginning.
- **Laissez-faire**, where the team works independently with little intervention from management as long as the job is done properly.

Communication Within and Between Teams

The development of a sense of teamwork enables companies to operate efficiently and productively. This development occurs best when workers are committed to the project and their fellow workers. Each team member needs to be responsible for their own actions and people in teams need to be assertive, but not aggressive, flexible, and willing to negotiate and co-operate with other team members.

Communication in the workplace is a two-way process. Listening is just as important as speaking and effective communication should be positive. People need to use affirming statements that put others at ease. Communication can be both verbal and non-verbal, and a look, a smile, a friendly gesture or a wave is another way of reaffirming positive working environments.

Complex design briefs, such as a brief for a building, usually involve a number of teams from different design-related professions and it is important that there is effective communication between these teams to ensure the smooth progress of the project.

Review Questions

1. Collaborative decision-making occurs in many design situations. Which of the following techniques could be used in collaborative work:
   (A) Concept map, think-pair-share, De Bono's Thinking Hats.
   (B) Team building, autocratic decision-making and PMI.
   (C) Concept map, walk and talk, and solo design work.
   (D) Team building, De Bono's Thinking Hats and Bloom's Taxonomy.
2. Commercial design is often a collaborative process. The team leader's key role is to:
   (A) Generate financial plans to facilitate production.
   (B) Analyse market research.
   (C) Inspire concept sketches and generation of ideas.
   (D) Ensure an efficient management process is carried out.
3. You are a product designer and have been given the following brief: Design and produce a lightweight, all-weather jacket to be worn at a local co-educational primary school.
   (a) List and discuss the main design issues and the constraints to be considered before designing.
   (b) Sketch front and back views of your initial idea and clearly label the design features.
   (c) Explain **five** features that address the issues and constraints listed in part (a).
   (d) What are the long-term effects of people using this design on the individual, society and the environment.

☞*Answers to Review Questions, p. 68.*

Answers to Exercise **page 66**

1. (a) Knowledge
   (b) Comprehension
   (c) Application
   (d) Analysis
   (e) Synthesis
   (f) Knowledge

2. Evaluation. A sample answer would be: My project has the advantage of being lightweight, easily transportable and aesthetically pleasing, however I am concerned that the timber used is not readily available and I would consider using timber from a renewable source in the future.

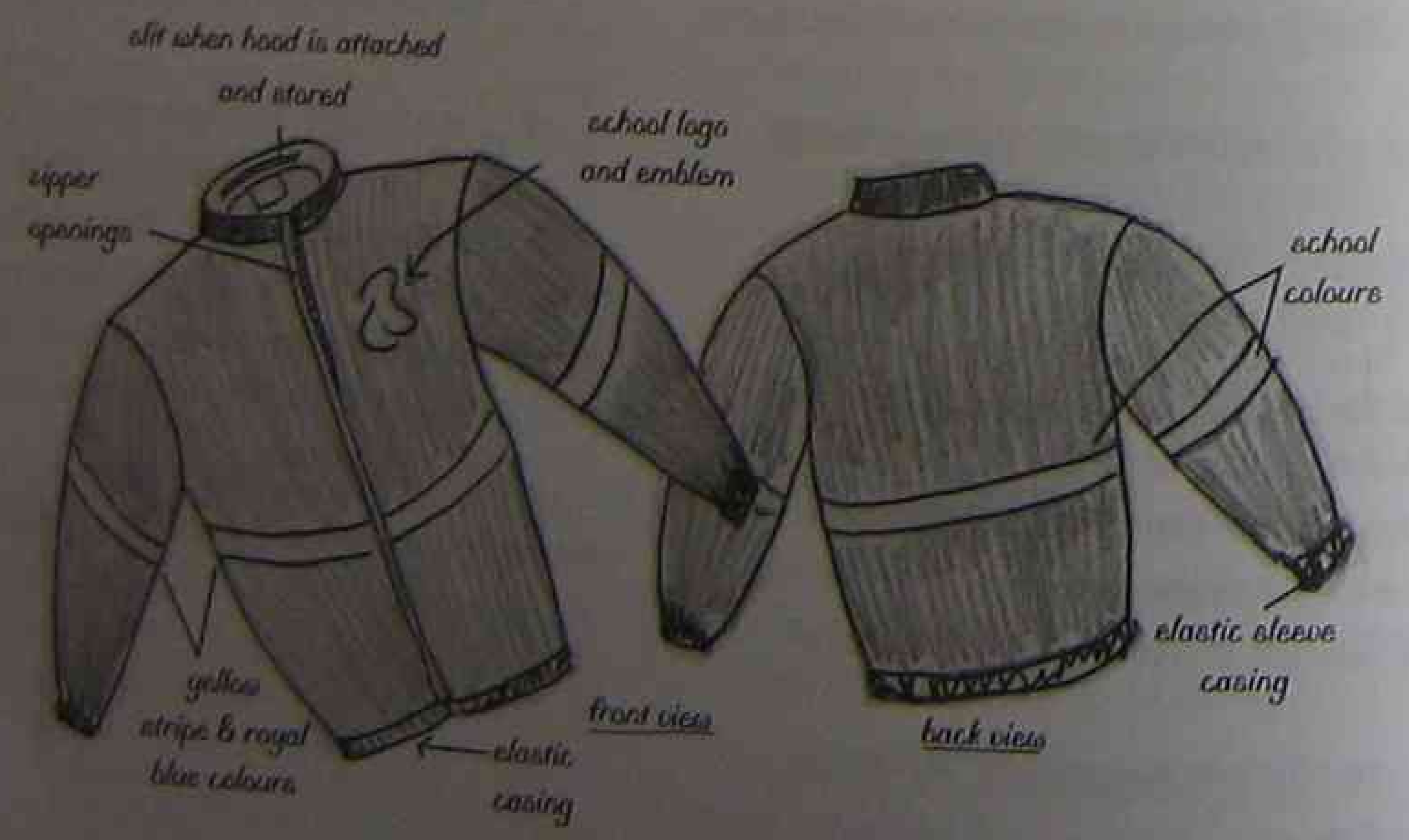
   A PMI analysis would identify 'advantage' as a plus, 'I am concerned' as a minus and 'I would consider' as an interesting point.

Answers to Review Questions **page 69**

1. (A) Concept map, think-pair-share, De Bono's Thinking Hats.
2. (C) Inspire concept sketches and generation of ideas.
3. (a)
   - Easy to clean — small children get grubby easily and often spill items on themselves. Schoolwork often involves the use of paints, coloured markers and other items that can stain clothing.
   - A quality product — colours must not run, zippers break or seams fray when the jacket is washed.
   - Comfortable — students will be wearing the garment regularly.
   - Low cost — not all parents are affluent and the jacket must be affordable if it is to be part of the school uniform.
   - Aesthetically pleasing — parents and students must like the look of the jacket. Colours and logo must represent the school and be displayed prominently.
   - Easy identification — jacket should have a tag for names and addresses so if it is lost it can be easily returned.
   - The design must not date quickly.
   - Should be lightweight and non-crushable so it can be put into a school bag.
   - It should be windproof and waterproof and ideally have a hood.

   (b) See illustration below.

   (c)
   - Easy to clean — made from polyester fibre that is hard-wearing and will not tear. It uses dark colours that hide the dirt and can be washed and dried overnight if necessary.
   - A quality product — uses dye-fast colours and strong zips.
   - Comfortable — lined with a cotton stretch fabric that is absorbent and provides some warmth.
   - Low cost — the materials used means that it can be produced at an affordable cost and the unisex design means it can be handed down to other children.
   - Aesthetically pleasing — the school logo encourages pride in the school and is also a form of advertising within the local community. The school-coloured stripes on the sleeve look good.
   - Easy identification — nametags are included on the inside of the jacket.
   - Design is a 'classic' style that will not date.
   - The polyester fibres are lightweight, non-crushable, non-absorbent, quick-drying and windproof. The hood fits into the top of the garment so it can be tucked away when not needed.



   (d) **The individual**: The design meets both the functional and aesthetic requirements of the design brief as outlined above.

   Society: The jackets will help keep students dry, warm and healthy. Reducing the risks of colds helps ensure a healthy population and reduces medical costs and absenteeism. The jackets may also help foster a sense of community spirit and pride in the school, leading to a reduction in vandalism and graffiti.

   The environment: Polyester is made from oil, coal and tar, which are non-renewable fossil fuels, and it is not biodegradable. However, the fibre is hard-wearing and will last a long time and thus the jackets can be handed down to others or recycled in charity shops. The cotton lining is made from a natural fibre. The use of this material helps our Australian cotton industry. Though cotton is biodegradable, it does wear out and the jacket may therefore have to be re-lined from time to time.

8 – Developing and Producing Design Solutions

Chapter Overview

The design process is used in the development and production of design solutions to meet needs and opportunities.

Expected Outcomes

On completing this chapter, students should be able to:

- examine design theory and practice, and consider the factors affecting designing and producing in design projects
- identify design and production processes in domestic, community, industrial and commercial settings
- use creative and innovative approaches in designing and producing
- identify a need or opportunity and research and explore ideas for design development and the production of the Major Design Project.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999

Key Terms and Concepts

constraints
design brief
design proposal
evaluation
limitations
parameters

8.1 Project Analysis

The use of project analysis will help to clarify goals and establish clear paths to devise solutions to meet needs and opportunities. Design and Technology students will find this particularly useful throughout the Preliminary and HSC courses.

8.2 Formulating and Analysing Design Briefs

A design proposal or brief is a clear statement describing a need that can be fulfilled by the development and manufacture of a product, system or an environment. A client will give a design company a brief when they want something designed. A good design brief will set both clear parameters and the direction for future research.

The design brief will have **limitations**, **parameters** and **constraints** that the designer must adhere to. Briefs may include information on cost, materials, techniques, size, weight, production and manufacturing and marketing. For example, when a client wants a home constructed on a block of land, the limitations could include how much money they wish to spend, the choice of materials to be used, the size and slope of the block of land, the preferred style of housing and so on.

As a Design and Technology student you are expected to write your own design proposal, which you should have been considering throughout the Preliminary year. Before you commence your design proposal you must consider some important issues. A good design solution is of a high quality and as innovative or creative as the brief allows.

The quality of your design, workmanship and folio must be outstanding for you to receive top marks. The project itself must be of a high enough quality that it is a saleable item, even in prototype form. You are expected to produce work of a quality expected from Year 12 students, and not just reproduce something that you manufactured in junior school. In order to reach this level of quality it may be best to work in an area where you already possess strong skills and interests. You may also need to attend classes outside of school at a TAFE or community centre to raise your skill levels. Given the level of quality expected, do not attempt a design proposal that requires skills you do not possess, unless you have a mentor who is prepared to spend many hours helping you.

The design solution must also be innovative and creative and can be an adaptation of an existing design or a completely new concept. It is important to show creativity throughout the entire design process and innovation in your initial ideas and in the development of concepts.

When developing a design solution to your brief there are likely to be many changes in direction as constraints and problems arise. Demonstrating that you dealt with and solved problems as they arose will assist your higher order thinking. It is important to learn from problems and mistakes, to document these 'glitches', and to try and use creative means to solve them.

Aesop, the ancient Greek writer of a well-known series of fables, said that 'it is easy to be brave from a safe distance'. In Design and Technology you are given the opportunity to take risks and develop completely new concepts, but do not get carried away as you are still expected to produce high quality work. Quality and creativity are the dual keys to doing well in this course.

Some students find it very difficult to know where to start when they are required to write a design proposal. If you are one of these students, the following may help — every time you encounter a problem that could be solved through design or hear someone complaining about something that doesn't work as well as it could, write it down. It has often been a response to a need or flaw that has resulted in an impressive and successful design solution. If you recorded three problems a week which could provide the basis for a design brief, by the end of the Preliminary year you would have approximately 90 problems to analyse! The types of problems you list may be simple or difficult, but they are all the foundation of valid design briefs.

Some problems may include:

- When I get into the car on a rainy day, how do I get my umbrella in without getting wet?
- When Dad is on the computer, how can I get my e-mail?
- Mum can't reach the top shelves in our kitchen and we have no room for a stepladder.
- I would like to get a job in graphic design when I finish school so how can I best increase my chances?
- There is no senior study at school. Is there anything I can do about this?
- It will soon be Mum's 50th birthday and I am responsible for making a wild and unique birthday cake.
- Dad's business needs a website but they can't afford a professional web master.
- I am going to my first masquerade ball this year and I have nothing to wear.
- My room is always a mess because I have to share it with my brother.
- Our school has a problem with bullying. What can be done about this?

When writing a design brief make sure that the solutions can be achieved and that the limitations and parameters are very clear.

8.3 Appropriateness of Design Solutions

Once the design proposal is clear the limitations and parameters must be identified. It is important to consider a number of possible design solutions. Lateral thinking usually provides design solution alternatives. Helen Kellar, a famous American woman who was visually impaired, was once asked if there was anything worse than being blind, and she replied 'having no vision'. A designer needs to have vision and be able to share that vision with the design team.

There are many ways to generate ideas for design briefs. Some designers gather their inspiration from nature. For example, the American space research body, NASA, was faced with the design task of creating a miniature vehicle that could travel over rugged terrain on Mars to collect soil samples. They used bugs as their inspiration and the vehicle that was used was a mechanical copy of a cockroach's movements.

Design teams usually use a number of collaborative approaches and cognitive organisers, as discussed in Chapter 7, including think-pair-share, brainstorming, mind mapping, sketching, observation and adaptation. In consultation with users, they examine existing products, explore ideas on the Internet, investigate emerging technologies and build prototypes.

The following factors all need to be considered when planning an appropriate solution to the design brief:

- project design specifications
- function
- safety
- cost
- materials
- method of manufacture
- appearance
- finish
- ergonomic considerations
- shape and size
- reliability
- maintenance
- environmental impact.

These factors are considered in more detail below.

- The **project design specifications** must be clear from the start and written into the design brief so that no confusion can arise. Both the designer and client must have the same understanding of what the design brief entails.
- The **functional qualities** will determine if the product does what it was meant to do and to what degree. If there are any faults in the functioning of the design solution then it is back to the drawing board. For example, you designed a water pistol, manufactured it and marketed it to be sold at Christmas. It was sold at a good price, held large volumes of water, was a great shape and colour, the trigger was ergonomically friendly for small children, it was made from cutting edge materials and it sold brilliantly. There was, however, a fault in the design and the water pistol only functioned for a limited time. People returned the object and asked for a refund, as the pistol did not function.
- **Safety laws** exist in Australia to protect the consumer. No matter how clever a design may be, if it does not meet the appropriate safety laws it will never reach the manufacturing stage. For example, if you were to design a gun cabinet you would need to research current gun laws so that the design solution would abide by them. The glass would have to be of a specific thickness and the locks of a certain type.
- The **cost** of the design must be clearly defined in the design brief. It is important to plan the budget carefully so the cost does not blow out of proportion.
- The **materials** used are important, particularly if the designer is environmentally conscious and considers a cradle to grave analysis. Designers have an ethical responsibility to future generations to use sustainable or renewable resources and materials.
- The **aesthetics** or **appearance** are important because if the design is not aesthetically suitable to the project then it is not marketable.
- The **processes** used and the **method of manufacture** must be suitable, efficient and cost effective. Testing and experimentation assist in the identification of the most appropriate processes.
- The **finish** is important because it will affect the aesthetics and final appearance of the design.
- The **ergonomic considerations** ensure the design is safe and comfortable for the user. Good ergonomic design may encourage correct posture and prevent future health problems.
- The **shape and size** of the solution will be determined in the design brief.
- **Reliability** is important if the solution is to be considered successful. The solution must work every time, as people do not want an unreliable product.
- **Maintenance** must be as simple a process as possible with easy access to all components.
- The **environmental impact** of the project needs to be considered. Are the materials from a renewable source, what happens to the waste and by-products produced during processing and so on? Long-term environmental impacts can affect the entire world and clever designers consider the environmental impact of their work. There has been global uproar about the deforestation occurring in Honduras as this process has worldwide effects on the environment. The cedar and mahogany forests are being cleared to make furniture to export to other more affluent countries. Now, however, Mexican designers are using a range of native timbers that were once thought to be unworkable. The bark on these trees is very soft and is being sliced and woven to make the backs and bases of furniture. These exotic timbers are not being totally cleared but logged at maturity with saplings planted to replace them.

8.4 Criteria for Evaluation

Once the design brief is clear, the designer needs to state the desirable criteria that will make the final solution successful. Both functional and aesthetic criteria need to be included in this list. In terms of your projects, the criteria must be achieved at a high standard before your project can be termed as being successful.

The stated criteria must ensure that the solution fits the design brief and abides by any limitations that are applicable. Limitations may involve a fixed budget or time schedule or demanding the specific use of certain ideas, tools, techniques or materials. The final evaluation of your Major Design Project will be undertaken in terms of the identified criteria for success. Therefore, before beginning work on your project you should list the criteria that need to be addressed by the solution, divided into functional and aesthetic considerations. Remember, the functional criteria includes information on what it will do and how it will work, whilst the aesthetic criteria refers to what it will look like. When writing your final evaluation you should comment on how your solution has fulfilled each of the criteria listed. Do not omit any as the markers may cross-reference to ensure that your solution does fit the design brief.

Factors to Consider

There are factors that you need to constantly check to ensure that you stay on track. As is often said, 'sometimes the inspiration gets lost in the perspiration'. It can be easy to lose sight of the problem that you initially set out to solve if you are not careful and you could find yourself getting 'lost' in all of the work that you are putting in.

Factors to constantly check include:

- Will my solution solve the problem?
- Is it of high quality?
- Has someone else done this before? If the answer is yes, then you need to continue the development of the design solution.
- Is the solution functional, reliable and safe?
- Is the solution aesthetically appropriate to the design project?
- Is the solution cost and time efficient?
- Are the materials, processes and finishes that I am using the most appropriate for this design?
- Am I making the most of the latest technology available to me?
- What are the factors contributing to the success of this design? How can I maximise the use of these factors?
- Are there any factors detrimental to this design? How can I overcome these difficulties?
- Have I considered, at every point, the effect on society and the environment?
- Is this a clever design solution?

Extension

Check your design proposal and then answer the following questions:

(a) Does your design brief identify a real problem and explore a need?

(b) Does it go on to state the areas to be investigated?

(c) What functional and aesthetic criteria did you list to evaluate the success of the project?

(d) Have you written a clear action plan?

(e) Do your time and finance criteria include proposed plans, actual plans and an evaluation column to explain the difference?

(f) Have you justified your resource selection in your design proposal?

Review Questions

1. When selecting materials, tools and techniques for a product, the following must be considered:
   (A) Quality, cost, size, environmental impact.
   (B) Availability, shape, finish, disposal.
   (C) Availability, cost, quality.
   (D) Sustainability, environmental impact, size.

2. A designer has decided to produce a new type of fishing lure. Once the design is finalised, how would the designer select the most appropriate tools for manufacture?
   (A) By building a prototype.
   (B) By reading all available information on construction.
   (C) By observing what tools other designers use.
   (D) By testing available tools for suitability.

3. Designers often use scale models. The main purpose of these is:
   (A) To show clients the aesthetics of the final design.
   (B) To test the suitability of all construction methods.
   (C) To test the accuracy of all design sketches.
   (D) To check that the design can be built.

4. Researching a design project involves:
   (A) Checking out ideas on the Internet.
   (B) Locating information on all aspects of the design, development and manufacture.
   (C) Evaluating the use of any emerging technologies and new ideas.
   (D) Asking friends and fellow professionals to evaluate the project on completion.

☞ *Answers to Review Questions, p. 77.*

Answers — Developing and Producing Design Solutions

Answers to Review Questions page 76

1. (C) Availability, cost, quality.
2. (D) By testing available tools for suitability.
3. (A) To show clients the aesthetics of the final design.
4. (B) Locating information on all aspects of the design, development and manufacture.

9 – Research Methodology

Chapter Overview

Design and Technology students need to conduct research to support their Major Design Project. Research is also a natural process carried out by commercial designers and may be used to support the development of a design and to modify and adapt designs to suit a particular need. Good research describes the situation being investigated, justifies the methodology, provides an explanation of the data collected, is analysed appropriately, communicated well and forms a basis for further action. It is important that the research conducted is relevant and ethical.

Expected Outcomes

On completing this chapter, students should be able to:

- use a variety of research methods to inform the development and modification of design ideas
- select and use appropriate research methods and communication techniques.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

data
ethics
experiments
information research
intellectual property
interviews
observation
plagiarism
qualitative research
quantitative research
questionnaires
research methods
statistical analysis
surveys
tests

9.1 Introduction

Research is a thorough investigation into a subject in order to discover information or facts. Knowledge of research methodology is essential if valid and relevant results are to be achieved.

9.2 Research Methods

There are four main types of research methods:

- **Descriptive research** explains or describes a current situation and may be carried out through interviews, surveys and analysis of data such as Census figures.
- **Historical research** is carried out to reconstruct events that have happened from past records, diaries, autobiographies and so on.
- **Experimental research** is research that occurs as a result of planned experiments.
- **Operational research** involves evaluating the performance of an operating situation such as assessing the environmental impact of manufacturing meat pies.

Sources of Data

The source of research, and hence the data collected, can be divided into two categories — primary and secondary data. **Primary data** is collected when research is conducted first-hand. It only exists because the researcher has collected it. **Secondary data** is obtained from other people's research. This information may be obtained from:

- Statistics, for example, Census data, health statistics, economic surveys, tourism surveys and ergonomic statistics.
- Mass media, for example, newspapers, television, radio, films, videos and magazines.
- Published material such as textbooks, journals and other non-fiction sources.
- Other sources such as the Internet, diaries, historical documents and photographs.

Researchers usually form a hypothesis before they start researching. A **hypothesis** is an idea or theory that researchers try to prove or disprove.

Qualitative and Quantitative Research

Research may be classified as either quantitative research, or as qualitative research.

Quantitative research gathers data that can be expressed in statistical or numerical form, such as experiments on water resistance, colour preferences, comfort and hours of use and so on, or can be measured by weight, size, income and so on. The results may be obtained through questionnaires or structured interviews. The results are often presented in statistical tables and graphs. Quantitative data is less subject to bias and is generally more objective.

Qualitative research examines people's feelings about some issue or event. The results may be obtained through participant observation, case studies, analysing diaries and personal documents or by conducting semi-structured and unstructured interviews. Qualitative research is sometimes susceptible to personal bias. The results are often presented in prose form, sometimes using direct quotes from the people questioned.

Exercise 1

Consider the question, 'How do you feel about the changes to the colour scheme of the bed-head design?'
How could you qualitatively analyse the results?
How could you quantitatively analyse the results?
What would determine the best analysis?

☞ Answers to Exercise 1, p. 91.

Surveys

A survey is when a person collects sample opinions or statistics in order to draw conclusions about an overall situation. Surveys vary in their scope and complexity though most involve the use of a questionnaire of some kind and some may also involve personal interviews.

Surveys are conducted to gather data at a particular point in time so that a researcher can:

- Describe the nature of existing conditions.
- Identify standards against which existing conditions can be compared.
- Predict the likely consequences of actions.
- Evaluate the effects of actions.
- Explain the relationships between specific events.

Before designing a survey, preliminary research of the topic must be carried out. Questions to ask about the topic include:

- What kind of information is required?
- How best can I get the information?
- How shall the sample be selected?
- What analysis will take place?

Exercise 2

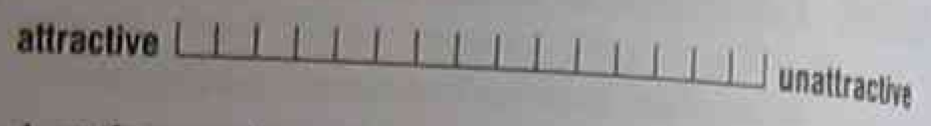
What problems might you encounter when conducting a survey as a student?

☞ Answers to Exercise 2, p. 91.

Questionnaires

A questionnaire is a printed question sheet and a tally sheet combined and is used to investigate a wide variety of phenomena. People's responses to questions can be counted and collated from an answer sheet. It may be filled in with, or without the interviewer being present. The questions should be pre-tested to ensure that they can be clearly understood. The two different types of questions used in questionnaires are pre-coded questions and open-ended questions.

Pre-coded questions have a limited range of responses. This type of question does not allow respondents to explain their views fully in order to develop or qualify their answers. There are two main types of pre-coded questions — those that use **scales** and those that require a **closed response**. The most common scale is the **Likert scale**. This scale gives the subject the opportunity to decide whether, and to what degree, the particular idea or element is desirable or undesirable, as in, strongly agree/agree/no opinion/disagree/strongly disagree. A **semantic differential** may also be used to record a response on a segmented scale such as when a respondent is asked to place an X to indicate their feelings. For example, the product was:



A **rating scale** requires the respondent to rate their opinion. For example, how tasty was the chicken? Excellent/Good/Average/Fair/Poor

Questions that require a closed response allow the respondent to choose an answer from a selection given, for example, yes/no, or (A), (B) and (C), or red/blue/green.

Open-ended questions do not have a pre-set choice of answers and allow respondents to freely express their own opinions and feelings. A free response question is usually used when an opinion or qualitative information is required. However, the information can be used for quantitative analysis if similar responses are grouped and counted. There are three main types of open-ended questions. **Completely unstructured questions** are very open, for example, what do you think about the proposed changes to the structure of the school's recycling system? With **word association questions** particpants are asked to write down the first word they think of after the stimulus word as in, Cola __________ Coca-Cola __________ Pepsi __________ and so on. **Sentence completion questions**, as the name suggests, ask the respondent to finish a statement. For example, the main reason I selected the fantasy costume design was because it ______________.

Remember that some questionnaires may require both pre-coded and open-ended responses.

When conducting a questionnaire, the researcher should ensure that all questions are:

- Relevant to the aim of the study.
- Short, clear, direct and unambiguous.
- Written in a language appropriate to the respondents' level of expertise.
- Designed to address one issue in each question.
- Designed to cover all aspects of the problem and ordered logically.
- Free from assumptions about the respondents.
- Free from bias, unnecessary emotion and not leading towards the answer the researcher wants.

Questionnaires are good to administer because:

- They do not have to be administered personally, hence they cost less and are not as time-consuming as personal interviews.
- The researcher can collect a large quantity of data in a relatively short time.
- If they are self-administered, they allow the respondent more time to think about the questions, the interviewer cannot bias the results and it is easier to address sensitive issues.
- If the questions are structured they can be easily processed using a computer.

Questionnaires may not be a suitable means to collect information because:

- The rate of non-response is often high.
- They are not as flexible as interviews as they limit the information a respondent can give.
- Similar types of people may respond, thus resulting in a limited range of views.
- Questions may be misinterpreted.

Exercise 3

Explain the difference between a survey and a questionnaire.

☞ Answers to Exercise 3, p. 91.

Interviews

Interviews are a method of collecting primary data whereby researchers talk to people face-to-face, by phone, by video link or through the Internet. Interviews may be formal and structured or informal and unstructured.

Formal and structured interviews have set questions and a structure. The interviewer asks the set questions and does not probe beyond the basic answers received. The questionnaire is pre-coded.

Informal and unstructured interviews allow greater flexibility in the dialogue. This type of interview is based on an open-ended questionnaire or it is simply a list of topics the interviewer wishes to discuss which may trigger off varied responses or further questions. The interviewer should try to put the respondent at ease in a relaxed, informal situation and encourage them to express their feelings and opinions. The researcher should also anticipate the responses they might get and have extra questions prepared. Questions that elicit a 'yes' or 'no' response should be avoided and the interviewer should be prepared to paraphrase a question to make it clear. It is a good idea to record the interview while it is taking place, or at least write a report as soon as possible after an interview while it is still fresh in the researcher's mind. This will help to reduce the loss of information that commonly occurs over time. The researcher can obtain a great depth of information through an informal interview.

Interviews are useful because:

- There is a good return rate.
- Sensitive or difficult questions can be rephrased.
- A good rapport may encourage in-depth responses.
- There may be less misinterpretation of questions.

Interviews may not be appropriate because:

- They are expensive and take up a lot of time.
- The interviewer may be unconsciously biased.
- The respondent may give the answers they think the interviewer wants to hear.
- Age, sex, ethnic or socio-economic status, and the personality of the interviewer or interviewee, may affect the responses.
- There may be some difficulty analysing the varying responses.

Exercise 4

1. Explain the difference between an interview and a questionnaire.
2. Observe a television interview and list the techniques the interviewer uses to ensure a successful interview.
3. Would an interview be a useful tool to assess a component of your MDP? If it is suitable, compile a list of questions you could ask. How would you record and analyse the responses?

☞ *Answers to Exercise 4, p. 91.*

Observation

Observation involves actual viewing and recording of an event in order to describe it. The situation may be natural or planned in some way. Observations should have a clear purpose and be systematic. Sheets for recording the data should be prepared in advance and should be easy for the observer to fill in. Observers must be alert and record any relevant behaviour. The data recorded must be factual and not interpreted, as this may bias results. A full record must be made of the situation that is being observed. The data researched through the observation method is quantitative as it tells 'how many' rather than 'why' or 'how'. There are two main types of observations — non-participant observation (or direct observation) and participant observation.

Non-participant observation occurs when a researcher observes a group or a situation without taking part in any way. The advantage is that the researcher can study people in their 'natural setting' without their behaviour being influenced and changed by the researcher's presence. The drawback of this type of research is that it is often not possible to understand what is really happening or to find out more by asking questions.

Participant observation allows the researcher to interact with the respondents and ask appropriate questions if required. It is more subject to personal bias.

Errors may occur in observations when:

- All of the data presented cannot be easily recorded.
- There is bias from personal views or experiences.
- The interviewer infers, rather than observes.
- It is very obvious that the individuals or groups are being 'studied'.
- The means of recording interferes with the observation.
- The people being observed are embarrassed or show-off to the observer.

Exercise 5

Devise an observation sheet to record a teenager's reaction to a recently created computer game. What are some of the difficulties that a researcher might encounter in this situation?

☞ *Answers to Exercise 5, p. 91.*

Tests and Experiments

A test is a standardised procedure for obtaining a response. There are many different types of tests that may be used in research and they may be formal or informal. An experiment is a test or trial that is used to test a hypothesis. In an experiment, a situation or environment is set up and subjects or objects are tested in that situation or environment.

The basic experimental process includes:

- Establishing an **aim**.
- Working out the most appropriate **method** and conducting the experiment.
- Collating the **results**.
- Drawing a **conclusion**.

Generally the enquiry is focused on only a few variables. Experiments attempt to identify relationships of **cause and effect** and the researcher should use a control. A **control** is a subject or an object that remains uninfluenced by the experiment. Experiments that occur outside the laboratory are generally referred to as **field research**.

Extension

Devise a series of relevant experiments to test the properties of the materials used in your MDP. Write up the experiments under the headings: aim, method, results and conclusions.

Statistical Analysis

Statistics is the science of collecting, organising and interpreting numerical facts (data). Statistics is interesting and useful because it is a means of using data to gain an insight into real problems. The hypothesis is tested through the research and a conclusion is drawn from the collated data. **Statistical analysis** involves classifying and interpreting numerical facts or data collected from the research. The conclusions that are drawn from the statistics prove or disprove the hypothesis.

One of the first steps of statistical analysis is to establish an overall pattern and spot unusual observations. This may be done using a graph as the researcher can easily summarise specific aspects of data, such as the average value of a variable, by numerical measures. The researcher needs to be constantly aware of where the data came from and what they hope to learn from it if they are to make valid conclusions.

Statistical analysis is based on a number of assumptions. These assumptions often involve the following terms printed in bold type. **Population** is the whole class about which conclusions are to be drawn. A **sample** is a selected number from the whole population. The findings from a sample are generalised to obtain conclusions about the whole population. A **random sample** allows the researcher to generalise about the population and should be chosen to allow every individual in the population an equal chance of being picked.

When data is analysed, there are several measurements that are calculated. The first is a measure for a central value from the data. Several measurements can be made including:

- **Mean** is the average of all data measurements made.
- **Median** is the half-way point in the data when it is set into an ordered arrangement.
- **Mode** is the data point with the highest frequency.
- **Midrange** is a quick estimate of the mean made by averaging the extremes of the data collected.

The amount of dispersion of the data is also measured using methods such as **standard deviation**, **range** (smallest and largest reading made) and **mean deviation**.

Exercise 6

List some problems that may be associated with the statistical analysis of data collected by students.

☞ *Answers to Exercise 6, p. 91.*

Information Research

Information may be collected from people, organisations, community groups, print and electronic sources, and libraries.

People are obviously an invaluable source of information. The people listed below may be good sources of information:

- People with expertise in the area being investigated such as a cabinet maker, baker or saddle maker.
- Teachers at school. Students may find it useful to access information from teachers throughout the school. Many teachers have expertise that is not directly related to their particular subject area.
- People who have experience in research techniques, for example, librarians, university lecturers, or authors.
- People who have access to relevant information such as a person who works in a chemist's shop, an engineering consultant or a day-care worker.

Data may be collected from:

- The general public, for example, people in shopping centres.
- Community organisations such as youth or church groups.
- People in specific roles such as general practitioners (doctors), politicians or bus drivers.
- Members of the immediate and extended family, including people who are not related but still considered 'family'.
- Peers or other students at school.

Organisations and community sources can provide excellent information. Information may be collected from business and voluntary organisations that have responsibility for, or deal with aspects of, the issue being studied.

Such organisations may include:

- Local councils for information on playground regulations for example.
- Community groups such as Meals on Wheels, Neighbourhood Watch or the Embroiderers Guild.
- Educational institutions such as TAFEs, universities and community colleges.
- Libraries, including council libraries, school libraries and libraries associated with other educational institutions.
- Government agencies such as Centrelink.
- Welfare organisations such as the Salvation Army, Lifeline or Mission Australia.

A variety of **print sources** are available to the student, including:

- books
- journal articles
- newspapers
- magazines
- pamphlets
- catalogues
- posters
- photographs and pictures.

Students may access a number of **electronic sources** to gather information including:

- computer files
- videos
- microfiche files
- CD-Roms
- cassettes
- television programs and radio reports
- Internet sites.

Extension

From a print source, select a piece of research on a topic that interests you and answer the following questions:

(a) What is the topic of research?
(b) Explain the method of research used.
(c) Describe how the data was collected.
(d) How did the researcher report their findings?
(e) How does the conclusion relate to the introduction?
(f) Do you think this is a good piece of research? Explain your answer.

9.3 Interpreting and Presenting Data

Interpretation of data involves discussion of the data. It should point to the significance of the information in respect of the questions posed. Interpreting the data involves clarifying it and presenting significant aspects, common elements, tendencies or averages, trends, unexpected results and relationships between items.

Data should be presented in a way that is appropriate to the information presented and the results should be clear and easy to read. Qualitative data is best reported in text or prose format, with properly structured sentences and paragraphs and with a number of headings and subheadings to guide the reader through the concepts. Quantitative data is usually reported in table, chart or graph format. These can include pie charts, histograms, and a range of graphs including pyramid, line, column or bar and can be generated using computer spreadsheets in an appropriate format, depending on the quantity and nature of the results. These formats allow comparison of many factors or samples as the following exercises show. Data presented in these forms should be clearly titled to allow the reader to quickly scan the information.

Tables list data in clearly labelled columns. They usually show the relationship between two or more factors. Units of measurement need to be clearly displayed.

Exercise 7

SOLID TIMBER SECTIONS

Timber grade	Width (mm)	Thickness (mm)
RS (rough sawn)	50 75 100 125 150 200 250 300	15 25 40 50 75 100
DAR (dressed all round)	41 66 90 115 140 185 231 281	12 19 33 42 66 91

Examine the table above and answer the following questions:

1. You are making a table with a top width of 450 mm. What sections of DAR could you use to make it?
2. What section of RS is used to mill to 66 x 33 DAR?

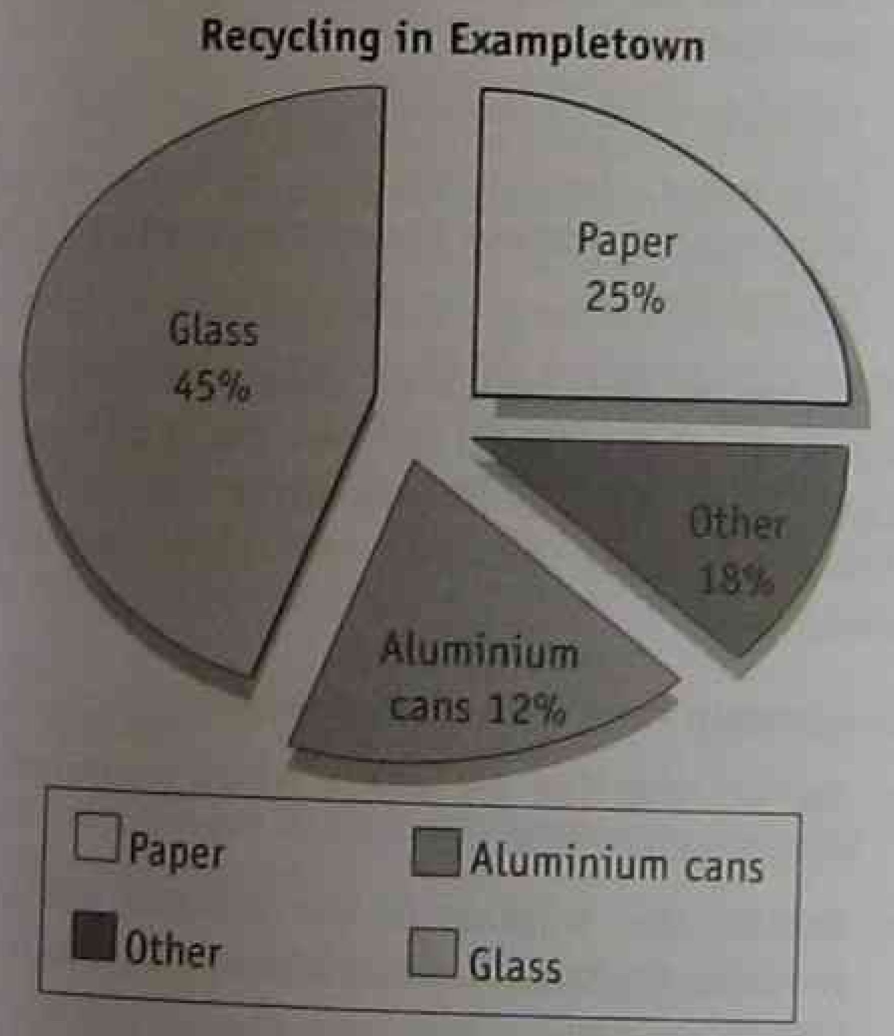
☞ *Answers to Exercise 7, p. 92.*

Pie graphs (charts) consist of a circle divided into parts, each part representing the value of a component or variable. Information is presented in a visual manner and it is desirable to have the numerical proportion represented as well. Pie graphs are really only appropriate when they do not contain too many slices — the greater the number of divisions in a pie graph, the more cluttered they become and the more difficult they are to interpret. They are usually colour-coded or shaded for easy reference.

Exercise 8

Examine the chart below and answer the following questions:

1. Which material is recycled most frequently in Exampletown?
2. What proportion of the total materials used do cans make up?
3. What materials do you think may be included in 'other'?



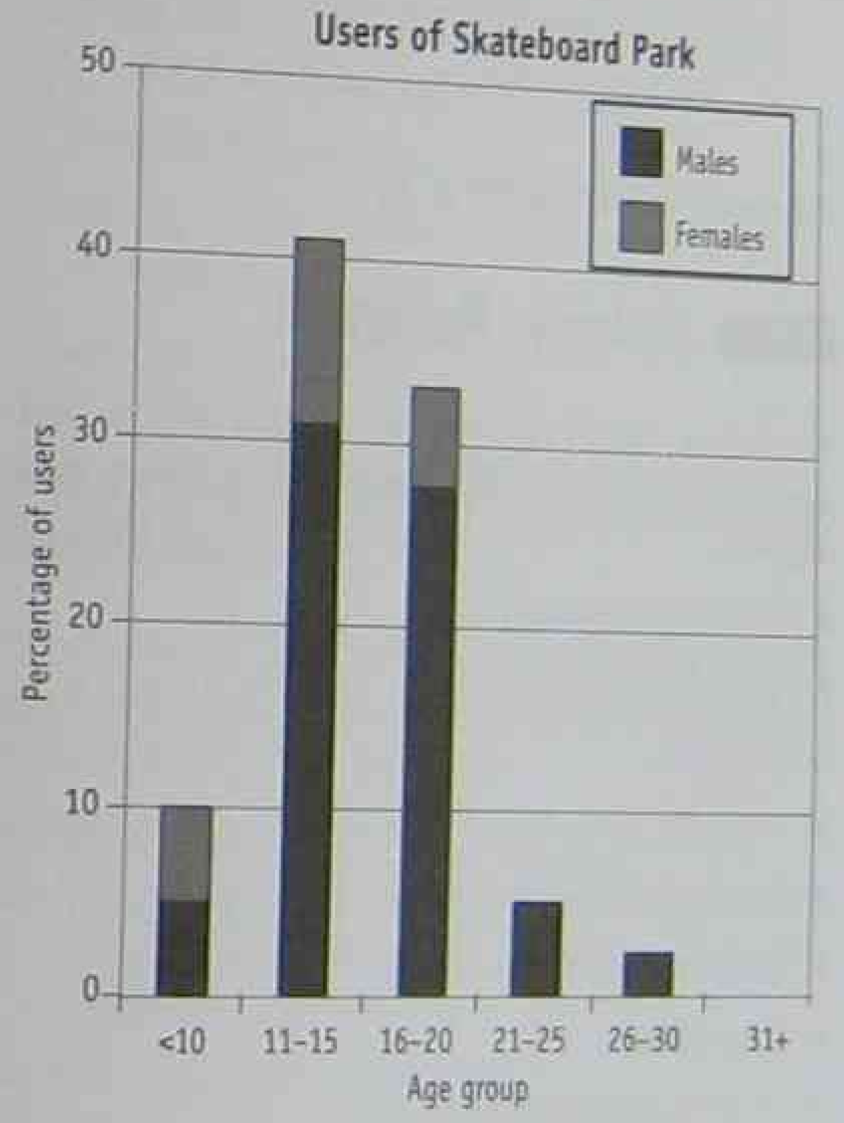
☞ *Answers to Exercise 8, p. 92.*

Bar graphs, column graphs and **histograms** are often used in preference to pie graphs. Bar graphs are drawn horizontally and column graphs are drawn vertically. As with pie graphs, they are used to present non-time data. The advantage of these graphs over pie graphs is that they can display more data without appearing cluttered. More than one piece of information can be shown on one column or bar, or sometimes two or more columns or bars are put in one category. For example, for a graph showing information by age group, there could be three columns — males, females and overall. A pyramid graph consists of two columns or bar graphs placed together, often forming a pyramid shape. They are useful for comparing two sets of data. Columns or bars may be drawn 3-dimensionally as tubes or prisms, or pictorially, as in columns drawn as piles of coins to represent the cost of different items.

Exercise 9

Examine the bar graph below and answer the following questions:

1. What percentage of Skateboard Park users are female?
2. What percentage of Skateboard Park users are under sixteen?



☞ *Answers to Exercise 9, p. 92.*

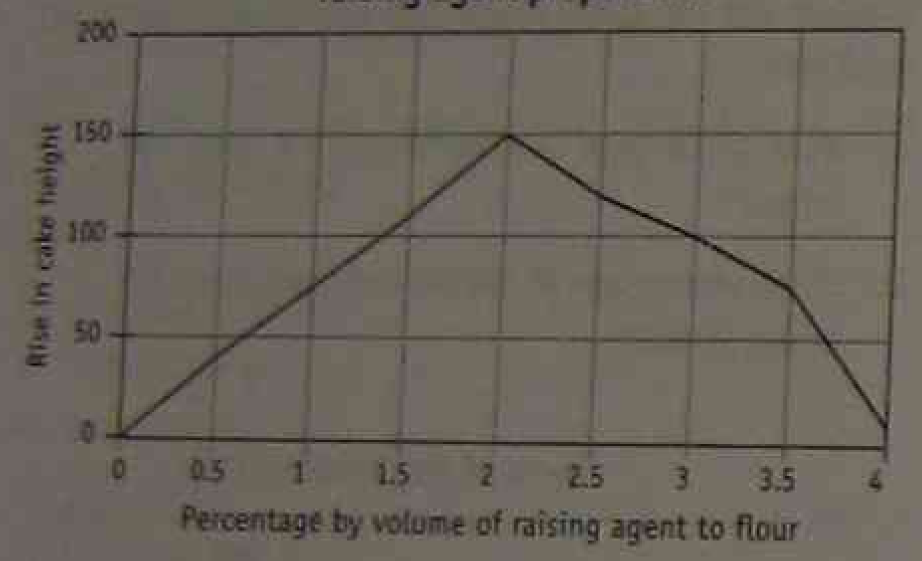
Line graphs show information in line form. They are particularly effective in showing changes or trends over time as more than one factor can be put on the graph. The factors are shown on horizontal and vertical axes, labelled to show what they represent. Again the use of colour or shading facilitates easier interpretation.

Exercise 10

Examine the line graph below and answer the following questions:

1. What is the optimum proportion of raising agent to gain maximum cake height?
2. If you used 1 cup of flour, how much raising agent would you need to gain maximum height?
3. What is the maximum height possible if the wet mixture height was 2 cm?

Rise in cake height for different raising agent proportions



☞ *Answers to Exercise 10, p. 92.*

9.4 Ethics in Research

There are numerous ethical considerations that should influence researchers. Some of these may include:

- Invasion of privacy.
- Confidentiality.
- Honesty.
- Integrity.
- Misleading information.
- Suppressing information.
- Prejudice.
- Validating information.
- Intellectual property including:
  - patents
  - trademarks
  - designs
  - copyright
  - circuit layout rights
  - plant breeder's rights
  - trade secrets
- Plagiarism.
- Tests on animals or people.

Invasion of Privacy

If a respondent is willing, invaluable information can be gained from primary research. It is important though, as a researcher, that the privacy of the respondent is maintained at all times.

Privacy may be invaded when a researcher:

- Asks too many questions.
- Takes up too much of the respondent's time.
- Publishes specific information about the individual.
- Is aggressive or rude.
- Interviews at an inconvenient time.
- Belittles a respondent because of their cultural, political or religious beliefs.
- Does not seek the appropriate permission to carry out the research from the organisation or the individual.
- Attempts to sell a product at the same time.
- Distributes the information to commercial organisations without the express permission of the respondent.

Most people feel positively about research and believe it serves a useful purpose and some people actually enjoy being interviewed and giving opinions. However, others strongly resent or mistrust researchers.

To **maintain trust** a researcher should:

- Explain who they are and to which organisation they belong.
- Explain the purpose of the research without revealing the hypothesis or information that may bias the results.
- Indicate what will be done with the results.
- Keep the results in a secure place.
- Discuss whether or not the response will be anonymous.
- Explain how the raw data will be disposed of once it no longer serves a purpose.

Exercise 11

Read this passage and then answer the question following:

> A magazine publishes a questionnaire about toiletry products sponsored by major suppliers of these products. Readers are requested to return the survey for a chance to win a holiday. There is a tiny statement at the bottom of the survey that says: 'I do not wish to receive any future offers by mail'. The respondent is required to tick the box if they agree with the statement.

Is there potential for invasion of privacy? Explain your answer. Is it ethical to assume that if the respondent **does not** 'tick the box' they are happy to receive mail offers? Explain your answer.

☞ *Answers to Exercise 11, p. 92.*

Confidentiality

If a researcher informs the respondent that the material collected is confidential, it is important that the researcher honours this statement. There have been many well-publicised incidents where personal information has turned up dumped in public places. Unwanted responses should be destroyed and the shredding of documents is a good way to do this. It is also important not to break confidentiality verbally. Many people in the past have been caught out chatting about a response and this may result in an embarrassing situation and also bring into question the researcher's integrity.

Exercise 12

Read the following passage and explain any potential problems you can see:

> A year after a researcher has completed his research, he finds completed surveys in a secure place. His five-year-old son asks if he could use them as scrap paper to draw on. He glances over the anonymous responses and decides that they could not be traced and therefore gives him permission.

☞ *Answers to Exercise 12, p. 92.*

Honesty and Integrity

To ensure the research is valid, the researcher must be honest with themselves and undertake the task with as much integrity as possible. The researcher must also be honest with the respondent without jeopardising the value of the research. The researcher must present the findings truthfully, regardless of whether the findings align with the researcher's hypothesis. The researcher must not, under any circumstances, falsify information.

Exercise 13

Read this passage and answer the questions following:

> A researcher believes that a netball logo she has designed has a positive impact on the psychological wellbeing of the local netball community. However, results of a survey do not support her hypothesis. The researcher knows she is right because she has spoken to many people who have told her so. The researcher thus feels justified in coming to a conclusion that supports her hypothesis.

1. Why is this unethical?
2. What could the researcher do to maintain the integrity of the research?

☞ *Answers to Exercise 13, p. 92.*

Misleading Information and Suppressing Information

It is important when conducting research not to bias the respondent, as the end result will be misleading. This may be avoided by:

- Not giving details of the hypothesis.
- Not asking too many questions on specific areas, hence providing more data on one area compared to another.
- Not asking leading questions.
- Giving respondents a reasonable choice of responses.
- Allowing space for comments.
- Not providing background information that supports the desired results.

The results of the research should be presented as truthfully and honestly as possible. The integrity of the results may be maintained through:

- Presenting all relevant findings, not just sections that support the hypothesis.
- Accurately disclosing bias, limitations (such as the nature and size of the sample), and any other factors which may have influenced the final results.

Withholding or suppressing information can lead to inaccurate results and thus invalidate findings.

Exercise 14

Read this passage and answer the question following:

> A survey conducted by a disposable nappy company asked the following question: 'It is estimated that disposable nappies make up less than 2% of landfill waste in the world compared to 21% taken up by beverage containers, waste paper and grass clippings. In your opinion, would it be fair to ban disposable nappies?'

Is this question misleading? Explain your answer.

Answers to Exercise 14, p. 92.

Prejudice

Prejudice is when an unfavourable opinion or feeling is formed without knowledge, thought or reason. We are all prejudiced about something and it is important to be aware of our prejudices. A researcher must be as objective as possible whilst conducting the research.

Validating Information

Whilst researching, students need to assess how reliable the source is.

The following questions are a useful guide to validating information:

- Is the material sponsored by an interest group?
- Is the author well-qualified on the topic?
- Does the author have practical experience in the topics written about?
- Is the source widely recognised as an authority on the subject?
- Does the material contain an obvious bias?
- Is the material unemotional?
- Are the issues treated impartially?
- Does the source make claims that cannot be verified?
- Do the conclusions relate to the information presented?
- Does the source give research and other references for further study?
- Why was the information presented?

Evaluating Websites

Students often fall into the trap of assuming that all information on the Internet is reliable. As with all forms of information, students need to assess the source. Internet sites can often be cumbersome and confusing and hence not very useful. The following questions can help students evaluate websites:

- Has the author left a contact address?
- Do you know when the page was last updated?
- Are the links current?
- Are the reference or resource links used in content development included?
- Is the host institution or business stated?
- Can you read meaningful information within 30 seconds?
- Do the image links have a text alternative?
- Are there alternative text pages offered when heavy graphics or frames are used?
- Do the graphics download quickly?
- Do all links work?
- Is it easy to navigate around the site?
- Is the site interactive?
- Is the site interesting?

Exercise 15

Consider the following and point out any potential problems. Explain your answer.

> A student uses extracts from popular magazines to provide the core of her secondary research.

Answers to Exercise 15, p. 92.

Intellectual Property

The products of a person's mind or intellect are called intellectual property and are legally protected. Copyright and circuit layout rights are automatically protected but all other forms of intellectual property must be registered. It is very important that researchers be aware of what is legally protected. Credit should be given if a researcher uses copyright material for study purposes and permission must be sought for use of other types of intellectual property. (Refer to Chapter 19 for more detail.)

Plagiarism

If a person presents another person's ideas, thoughts, images or material as their own they are guilty of plagiarism. It is the theft of another person's intellectual property. Students should familiarise themselves with the correct procedures for citing references, quotations and seeking permission when necessary.

Sometimes students may inadvertently plagiarise, often as a result of inexperience or poor note-taking. All intellectual property used in research should be acknowledged irrespective of the source. To avoid plagiarism, a student must cite the source of information in the body of their research (either as a numbered footnote or as an in-text reference) and list the cited sources **alphabetically** in the bibliography. To do this properly, a student needs to be careful about recording the source of each note that they make, be it from a book, a journal, a film, a television documentary, or on the Internet. If a direct quote is made, quotation marks must be used to indicate this. There are many different conventions used to cite sources but the basic information remains the same. Select one convention and use it consistently.

Listed below is an example of one convention each for a range of sources:

Books: Author (full name), title of the book (underlined or in italics), the edition (if not the first), place and date of publication, and page number quote or material comes from.

Articles: Author (full name), title of the article (between 'quotation marks'), name of the journal (underlined or in italics), volume and issue number, date/year of publication, and page number.

Film: Director (full name), title of the show or episode if a television broadcast (between 'quotation marks'), name of the film (underlined or in italics), producer, place and date of production.

World Wide Web sources: Name of the organisation providing the service, the title of the home page and its http://-address (this is the most important reference), the date of creation of that page (if known) or the date of your access.

A recent issue is one of plagiarism of information gained from electronic sources such as the Internet. If a person wishes to copy from the Internet they should first read the information carefully to see if there is a statement regarding copyright. If there is a statement, then the reader must follow the author's instructions. Material should not be indiscriminately copied. If there is no statement about copyright then a person may assume that they can print or download the material for research or study or if the copying is fair. However, this does not give the reader permission to distribute the information to others or use the material for financial gain. A person may use the information from the Internet to gain ideas and express these ideas in their own words without infringing copyright.

Extension

Check the Australian Copyright Council's web page (http://www.copyright.org.au) to source the latest information about copying from the Internet. This website is updated as changes occur.

Tests on Animals or People

In reality most products need to be tested by people. If a designer creates a chair, it needs to be comfortable for the target market. What the designer should be aware of is that testing should not have the potential to harm the tester.

Tests that involve animals must be thoroughly justified and should not involve cruelty in any form. Cruelty may occur as a result of the following:

- Infliction of pain.
- Creating a stressful or fearful situation for the animal.
- Creating a situation of frustration for the animal.

School students are generally **not** allowed to carry out tests on animals for research purposes. If a student wishes to be considered an exception then they must seek permission through the relevant bodies via the principal. There is a booklet available in schools called *Animals in Schools — Animal Welfare Guidelines for Teachers*, published by the NSW Department of Education and Training. It may be a useful reference if a student wishes to further investigate this area. A web search of the *Animal Research Act* may also be useful.

Review Questions

1. Material from the Internet:
    (A) May be used for study if the copying is fair, provided the author has not specifically stated otherwise.
    (B) Is not protected by copyright laws as it is in the public domain.
    (C) May be copied even if there is a statement declaring that the author wishes it not to be.
    (D) May not be copied or downloaded under any circumstances unless prior written permission is gained from the author.
2. Primary research:
    (A) Only exists because the researcher has collected it and used it to form the basis of their whole research.
    (B) May be obtained from Census data, economic surveys and tourism statistics.
    (C) Is obtained from mass media such as newspapers, television, radio, films, videos and magazines.
    (D) Can provide invaluable first-hand results that can be specifically designed to the researcher's requirements.
3. A company is designing a new school bag for students. It decides to use a questionnaire to survey students' needs and wants regarding this design. When conducting a questionnaire the researchers should make sure that all questions are:
    (A) Ordered logically, do not assume anything about the respondents and are free from bias.
    (B) In a language inappropriate to the students' level of expertise and understanding.
    (C) Addressed to more than one issue in each question and relevant to the aim of the study.
    (D) About colour, size, shape and durability.

☞ ***Answers to Review Questions, p. 92.***

Answers to Exercises

Exercise 1 page 80

Quantitative — the questions need to be divided into parts that can be statistically analysed such as 'Do you like the replacement of red with ochre in the routed flowers? Yes/No?'

Qualitative — use open-ended questions and draw conclusions about general preferences such as 'What do think of the replacement of red with ochre in the routed flowers? Please give reasons for your choice.'

Exercise 2 page 80

Problems could include:

- Inexperience.
- Difficulty selecting the sample and getting sufficient numbers.
- Personal bias.
- Poor structure and questions due to lack of experience.
- Difficulty working out the information required and how best to get it.
- Problems analysing the information.

Exercise 3 page 81

A survey is when a person collects sample opinions or statistics in order to draw conclusions about the overall situation. A questionnaire is a printed question sheet and a tally sheet all in one. Most surveys involve the use of a questionnaire of some kind.

Exercise 4 page 82

1. A questionnaire is a printed question sheet. It may be filled in with, or without, the researcher being present. An interview is carried out in person, although it may not necessarily be face-to-face. The interviewer usually uses a questionnaire to guide discussion or further questions.
2. Techniques include:
    - Clear instructions.
    - Simple questions.
    - Good eye contact.
    - Waits for a response, does not interrupt.
    - Reassures the interviewee.
    - Well-modulated voice.
3. Student response.

Exercise 5 page 82

Answer may include an assessment along the following lines:

Place an X to indicate a response to the following points:

☐ The game appeared

difficult to use |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| easy to use

Comments ____________________

☐ The hand controls appeared to be

uncomfortable |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| comfortable

Comments ____________________

☐ Comments about aesthetics

Colour ____________________

Shape ____________________

Size ____________________

Difficulties could include:

- Consistently rating the level of the responses.
- Biasing the response through body language or comments.

Exercise 6 page 83

Problems could include:

- Sample size may be small.
- Sample may be biased.

Exercise 7 page 84

1. 2 x 231 or 281 + 185 or 2 x 140 + 185
2. 75 x 50

Exercise 8 page 85

1. Glass
2. 12%
3. Plastics, oil, green waste, steel cans, other metals.

Exercise 9 page 85

1. 20%
2. 51%

Exercise 10 page 86

1. 2%
2. 2% of 1 cup (5 ml)
3. 5 cm (it has risen 3 cm plus the original 2 cm)

Exercise 11 page 87

If the respondent does not tick the box, their personal details may be sold to commercial organisations for promotional purposes. They may also have overlooked the box and the responsibility is put onto them to be active if they do not wish to go on the mailing list, which may not be ethical.

Exercise 12 page 87

If a researcher promises to keep the responses confidential then he or she should honour that promise. Although it is unlikely that confidentiality would be broken in this case, it would be safer to destroy the documents 'just in case'.

Exercise 13 page 87

1. The conclusion is not based on sound research and is unsupported.
2. Change the questions to be less biased or misleading if appropriate.

Exercise 14 page 87

The figures could easily mislead as disposable nappies are compared to three other items.

Exercise 15 page 88

The source needs to be validated before it is used as some of these magazines may present information that is biased or inaccurate.

Answers to Review Questions page 90

1. (A) May be used for study if the copying is fair, provided the author has not specifically stated otherwise.
2. (D) Can provide invaluable first-hand results that can be specifically designed to the researcher's requirements.
3. (A) Ordered logically, do not assume anything about the respondents and are free from bias.

10 – Marketing and Market Research

Chapter Overview

As the goal of all businesses is to make a profit, sound marketing practice is essential. Marketing must respond to discontent, social change, environmental concerns, and political and legal forces. A successful business organisation relies on long-term satisfaction of consumer needs and wants to maintain profitability.

Expected Outcome

On completing this chapter, students should be able to:

— use design processes in the development and production of design solutions to meet identified needs and opportunities.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

market groups
market research
market variables
marketing
marketing environment
marketing mix
marketing plans
marketing price
product management
promotion
SWOT analysis

10.1 Introduction

Marketing is the collective term that encompasses the planning, developing, pricing, promoting and distributing of goods and services to consumers. Marketing includes:

- Research to find out what the customer wants.
- Developing goods and services that deliver the key benefits that customers require.
- Working out how to perform better than competitors.
- Working out how best to reach the target market.
- Aiming to ensure a profit is made.

Design and Technology students may use market research to determine a need for their Major Design Project. The extent to which research is carried out will depend on the project and the intended market.

10.2 Marketing Plans and the Marketing Mix

Marketing Plans

Strategic marketing refers to the process that analyses, implements and evaluates the marketing of activities that will assist in the achievement of goals.

A **marketing plan** is a series of activities leading to the setting of marketing objectives and the formulation of plans for achieving them. A marketing plan may consist of the following steps:

- Mission statement or corporate objectives.
- Financial summary or marketing audit.
- Market overview.
- SWOT analysis, which is a statement of Strengths, Weaknesses, Opportunities and Threats that relate to the organisation.
- Assumptions.
- Marketing objectives and strategies.
- Programs, with forecasts and budgets.
- Identifying alternative plans and mixes.
- Programs and implementation.
- Evaluation, which occurs both throughout the whole process and at the finish.

Exercise 1

Why is a detailed marketing plan essential to the success of a business? Use the above points to guide your answer.

☞*Answers to Exercise 1, p. 100.*

Marketing Mix

The ways in which marketing elements are combined is often referred to as the **marketing mix**. The six interrelated elements of a marketing mix are:

- **Product**. The customer must want the product and therefore it must have a certain appeal that will give it an edge over competitors' products.
- **Position** refers to the market position or the area of the total market where the product will appeal.
- **Packaging** will influence the customers' initial reaction to the product.
- **Price**. If the price is too high the customer will not buy the product. If the price is too low the profit margin may not be enough to sustain the business. Potential customers may even avoid buying a low-priced product as they may feel it must be of poor quality if it is very cheap.
- **Promotion** informs the potential customers about the product and its benefits.
- **Place**. Efficient distribution of the product is essential. Customers will be discouraged if they are unable to obtain the product they want immediately.

Note: Many people refer to only four elements in the marketing mix: Product, Price, Promotion and Place. These are commonly known as the 'four P's of marketing'.

Exercise 2

1. Explain the significance of the two extra elements, position and package, in the marketing mix.
2. Interview the manager of a business and discuss the marketing mix they use.

☞*Answers to Exercise 2, p. 100.*

10.3 Market Groups and Variables

Market Groups

There are several terms used to describe market groups including:

- **Target market**. This refers to the group of people for whom the product is specifically intended.
- **Market segmentation**. In order to develop a product that is viable, businesses need to clearly identify which group of consumers they are aiming for. This group represents a section of the market, not the whole market.
- **Niche market**. This is a smaller market within a market segment that has particular characteristics that sets it apart from other groups.
- **Mass market**. This market includes everyone, not just specific groups.

Exercise 3

Why is it important for a market researcher to focus on a target market?

☞*Answers to Exercise 3, p. 100.*

Market Variables

Market variables refer to the variations within a market. They are often used to segment or divide the market into groups. The most common market variables are:

- **Demographic**, such as age, gender, income, education and ethnicity.
- **Socio-economic**, including income, education, religion, class and occupation.
- **Geographic**, such as country, city, state, suburb and climatic zone.
- **Psychological**, for example, personality type, ambitions, attitudes, values and standards.
- **Lifestyle**, such as sporting and outdoor activities, academic pursuits, family orientation and level of technology use.

10.4 Product Management and New Product Development

Product Management

Product management is concerned with ensuring the ongoing viability and profitability of a product. A successful business regularly reviews its products and modifies them in response to market trends. It will also remove unsuccessful products from the market before too much profit is lost.

There are three parts to product management:

1. **New product development** is essential for most large companies to survive.
2. **Product modification** occurs through the changing of features, quality or style.
3. **Product rationalisation** is about deciding when the product life cycle has ended. This may occur when a product fails to return a sufficient profit, is too expensive to modify, the competition is too great, or when innovations have made it redundant. As an old product is phased out a new product should be phased in.

Extension

1. Can you think of any products on the market that have been recently modified? How were they changed?
2. Name a new product that is on the market. Why was it introduced?
3. Name some products that have been taken off the market recently.

New Product Development

There are five stages to new product development:

1. **Exploring ideas**. New ideas are generated through research, suggestions by customers, suppliers, wholesalers and retailers, and from analysis of competitors' products, from employees' suggestions or from planning suggestions.

2. **Screening**. The ideas need to be analysed and those that are not suitable removed if they do not fit with the organisation's strategic plan.
3. **Business analysis**. The costs need to be calculated and initial financial projections must be made. If the idea is not financially viable it is abandoned.
4. **Development**. This involves the further development of the idea to produce a total product concept. A prototype or sample may be produced at this stage. A marketing strategy is also developed. Many new products do not get past this stage.
5. **Testing**. New products are tested to determine if they suit the intended purpose for which they were designed. Tests may be for quality, safety, durability and so on. The product may also be tested on a representative sample of the target market.

Exercise 4

Explain why many new ideas are not realised into commercial products.

☞ *Answers to Exercise 4, p. 100.*

10.5 Marketing Price, Promotion and Distribution

Price

Marketing price refers to a monetary value placed on a product and is determined by such things as the cost of the resources used, time and labour required for the design and production, packaging, promotion and distribution of the item, profit margin and competitors' prices. The price of some products is controlled by government regulations.

Exercise 5

Explain why the government may control the price of some products.

☞ *Answers to Exercise 5, p. 100.*

Promotion

keting promotion refers to the wide variety of thods used to inform and persuade the market of the product's merits. Advertising, personal selling and sales promotions are the major activities.

Promotion may take many forms including displays, word-of-mouth, billboards, blimps, aeroplane banners and sky writing, neon signs, trade shows, letterbox drops, web pages, free samples, sponsorship, use of the company logo, newspapers, magazines and so on.

Advertising is the most notable and easily identifiable form of promotion. There are seven steps in developing an effective advertising campaign:

1. Identify the target group.
2. Develop specific objectives.
3. Calculate the budget.
4. Decide on a key message.
5. Decide on the most cost-effective media.
6. Create the advertisement.
7. Evaluate the advertising campaign.

Extension

1. Develop a possible advertising campaign to promote a new health drink.
2. Collect a newspaper advertisement and analyse it in respect of how well the features of the product are promoted, how attractive the features are to potential customers and how effective you think the advertisement is overall.

Distribution

Marketing distribution refers to the channels through which a product will reach its market at the right time, and the system in place for physically handling and transporting the product through these channels.

10.6 Market Research

Market research involves gathering as much information as possible about a particular situation for analysis, in order for an effective marketing strategy to be developed. The more information a business has about a situation, the better equipped they are to make the right decision, and hence there are less risks attached.

The **purpose of market research** is to:

- Save money.
- Increase the chances of success.
- Determine if a proposition is viable.

Market research can apply to any part of the marketing process or any part in the product life cycle and is especially relevant when new products are being developed. Market research involves asking questions, of which some basic examples are:

- Does anyone else offer similar goods or services?
- Does a market segment exist for the new product?
- Approximately how big is the target market?
- What does the customer want?
- How much might the customer pay?
- Will demand change with a change in price?
- What is the best promotional method of reaching the target market?
- Is the target market growing, stagnant or declining, and why?
- Will customers buy the product from a catalogue, by direct mail, the Internet or from a retail outlet?
- How do customers perceive a similar product that has already been on the market for several years?
- Will a particular marketing strategy work?

Market research covers a wide spectrum of activities. Some small companies use professional market research firms, whilst larger companies often have their own market research departments.

The Market Research Process

The market research process includes:

- **Determining the objectives**. The organisation must clearly state the questions it expects the research to answer. Setting objectives will give the research a clear direction.
- **Determining data collection methods**. Once given the objectives, the researcher must determine the most suitable method for collecting data related to the question and/or problem.
- **Analysing the data**. The data must be collated and interpreted to determine any significant trends.
- **Preparing a report with recommendations**. The report should explain how the research was carried out, detail the findings, summarise the results and make recommendations. Findings are often displayed using charts and graphs as well as in prose form.

Exercise 6

Determine the probable market research objectives of the following situations:

(a) People aged between 40–60 are reading a magazine that was initially targeted towards 25–40 year-old women.
(b) A new range of designer furniture is not selling as well as anticipated.
(c) Blue ice cream is not as popular as other colours.
(d) Customers are complaining about the quality of a particular sewing thread.

☞ *Answers to Exercise 6, p. 100.*

The Market Research Report

A market research report consists of the following components:

- **Heading**. This simply provides the title, date and author of the report.
- **Introduction**. This is an outline of the scope and the purpose of the research. It also includes information about where and when the research was carried out and by whom.
- **Methodology**. This includes an outline of the methods chosen, details of the samples used and reasons why they were selected.
- **Analysis and findings**. The data is analysed and the results are collated. Limitations and possible shortcomings of the research are stated.
- **Conclusions and recommendations**. A summary of the main points is formed. Conclusions are reached and recommendations for possible actions are given and justified.
- **References**. A list of all publications referred to in the report is included.
- **Appendices**. Figures, tables or text that are too detailed for the body of the report are included in this section.

Extension

1. Conduct market research to identify needs and opportunities relating to your Major Design Project.
2. Write a report using the elements listed above.

Sources of Data and Information Gathering Techniques

Information may be gained from a multitude of sources including:

- **Primary sources** gained through interviewing existing customers, potential customers, competitors' customers and industry experts. This material may be gathered through mailed questionnaires, phone interviews, personal interviews or analysis of focus groups.
- **Secondary sources** such as government statistics, reference books, industry association magazines, websites, specialist publications, published reports, and competitors' literature.

A range of strategies may be used to gather information such as:

- Analysing demographics and the economic environment.
- Research into current laws and standards relating to the product.
- Observation and collection of data about similar or related competitive products.
- Surveys and interviews to find out the opinions of the target market.
- Seeking information from possible suppliers of raw materials.

When information is gathered it is then analysed and used to form the basis for planning marketing strategies. Refer to Chapter 9 for more information on this topic.

Exercise 7

Consider the following situations and select a method of data collection you could use to gather relevant information.

(a) A new brand of soft furnishings has been developed and the manufacturer wants to know whether the product is suitable for commercial marketing.

(b) A manufacturer of prepared Chinese meals wants to know the degree of consumer awareness surrounding their products.

(c) A computer software producer wants to know why consumers purchase their software in preference to their competitors' products.

(d) A hardware store wants to find out whether goods placed in a certain part of the shop will sell well.

☞ ***Answers to Exercise 7, p. 100.***

10.7 The Marketing Environment

As marketing does not take place in isolation from the rest of the world, businesses need to spend time working out how the environment will affect sales, or how they can best use what is happening in the world and people's lives for the purpose of making a profit. The **marketing environment** includes all factors that may influence the development of products and may include such factors as:

- Suppliers of resources to be used including raw materials, labour and energy.
- Marketing intermediaries who are used to distribute products.
- Competitors who produce the same or similar products.
- Demographics, which is the statistical study of human populations, distribution and trends.
- Economic conditions, which are influenced by interest rates, taxes, inflation, recession and unemployment. These factors ultimately affect the standard of living.
- Social and cultural forces.
- Political and legal forces, which are influenced by governments and pressure groups.
- Technological developments including teleconferencing, e-mail, fax machines, mobile phones, and so on.
- Ecological/environmental factors. These encompass factors within the natural world that influence the design, production and use of a product.

Review Questions

1. A group of enthusiasts are planning to set up a local European handball association. Which step would be the most important in the beginning stages of setting up this organisation?
   (A) Devising a financial plan.
   (B) Renting an office so all operations are centralised.
   (C) Establishing sponsorship deals.
   (D) Market research to determine the level of community interest.

2. A person wants to set up a patchwork business that aims to sell completed articles, fabrics and accessories and to conduct lessons. This business:
   (A) Will appeal to the mass market as everyone consumes textile products in some form.
   (B) Should focus on a specific target market, which can be easily assumed through general knowledge.
   (C) Will appeal to a niche market, as it is has particular characteristics that set it apart from other groups within a market segment.
   (D) Will appeal to the general public.

3. Market variables:
   (A) Are concerned with ensuring the ongoing viability of a product.
   (B) Must be identified if the mass market is to be reached.
   (C) Are often used to group market segments together.
   (D) May include factors such as demographics, geographic details and socio-economic status.

4. Organisations that have an effective marketing plan are more likely to be successful. The most important aspect of marketing is:
   (A) Targeting the market segment.
   (B) Advertising to gain maximum exposure.
   (C) Devising a plan for promotion.
   (D) The cost of producing, packaging, promoting and distributing the product.

☞ ***Answers to Review Questions, p. 100.***

Answers to Exercises

Exercise 1 page 94

To ensure all factors are considered. If all factors are not considered it is difficult to achieve commercial success. Use the marketing plan to guide your answer.

Exercise 2 page 95

1. The market position will influence the number of potential customers and their willingness to buy the product. Packaging will influence the customers' initial reaction to the product.
2. Student interview.

Exercise 3 page 95

Because the campaign can be specifically designed to appeal to the target group. It is too difficult and ineffective to appeal to all groups.

Exercise 4 page 96

There may be numerous reasons including:

- Insufficient funds.
- Economic, political or social environment does not support the idea.
- Poor management.
- Poor market research, for example, target market is too small.
- Production problems.

Exercise 5 page 96

It may be to protect industries, to benefit consumers via low prices or to raise revenue.

Exercise 6 page 97

(a) Find out why the market has changed and refocus the marketing campaign.

(b) Find out why it is not appealing to the target market.

(c) Find out consumers' perceptions of blue ice cream and determine whether it is profitable to continue production.

(d) Investigate the quality standards consumers expect from a thread.

Exercise 7 page 98

(a) Interview potential customers, competitor customers and industry experts. Conduct research using secondary sources such as government statistics, reference books, industry association magazines, websites, specialist publications, published reports, and competitors' literature. Analyse the demographics and the economic environment. Find out current laws and standards relating to the product. Observe and collect data about similar or related competitive products. Carry out surveys and interviews about the opinions of the target market. Seek information from a range of possible suppliers of materials.

(b) Interview both existing and potential customers.

(c) Interview existing customers.

(d) Interview existing customers, potential customers and industry experts. A short questionnaire may be suitable.

Answers to Review Questions page 99

1. (D) Market research to determine the level of community interest.
2. (C) Will appeal to a niche market, as it is has particular characteristics that set it apart from other groups within a market segment.
3. (D) May include factors such as demographics, geographic details and socio-economic status.
4. (A) Targeting the market segment.

11 — Communication

Chapter Overview

Effective communication is essential throughout all design and technological processes. There is a wide range of communication methods, all with their own strengths and weaknesses.

Expected Outcomes

On completing this chapter, students should be able to:

- communicate ideas and solutions using a range of techniques
- select and use appropriate research methods and communication techniques.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

- fibre optics
- graphic communication
- media
- tactile communication
- telecommunications
- verbal communication
- video conferences
- visual and audio communication
- written communication

11.1 Introduction

Communication is the process of sending and receiving messages. Effective communication will allow you, or designers, to clearly convey thoughts and ideas in portfolios to the examiners or to clients.

> 'What I think I must speak', William Shakespeare, *As You Like It*.
>
> 'If you think it, write it down', Advice for HSC Design students.

Messages need to be sent through verbal, graphical, visual, audio and tactile means. When communicating, there is a need to use a combination of these methods. As the great communicator Dr Samuel Johnson said, 'Writing is the only way the dead can communicate with us', and it is also the main way that candidates will communicate with their examiners.

11.2 Forms of Communication

It is necessary to achieve clear and thorough communication with the markers in your Major Design Project, and this can be best achieved via a range of communication techniques. Remember, quality and innovation in all things!

Verbal Communication

It is possible to communicate verbally with the markers, but a candidate may not have any personal contact with them. Verbal messages allow you to use speech to communicate and can be achieved by a tape or by placing the message into a section of a digital folio.

Verbal messages may also incorporate the inflection, pace and tone of speech. This is particularly useful when a video is being used to convey an idea or issue.

Written Communication

Here is your chance to impress the markers with your literacy skills, your higher order thinking skills and your use of technology. An appropriate use of technology is necessary. You can dazzle the markers with your word processing skills, your use of databases, spreadsheets, cognitive organisers, flow charts, Venn diagrams and pie charts. All of these should be of professional quality and appropriately presented with borders, headings and, if necessary, digital images.

It is important to only include relevant information and explain how it directly relates to your project. Important points can often get lost in a page of waffle, so do not hesitate to highlight an important point for the marker. Use the higher order skills of evaluating, synthesising and analysing to raise your marks. Recalling secondary information that you have gathered for other sources is a start but to gain better marks you must then explain how you can relate this information to your project.

Literacy skills are very important. Always check your work and get your teacher to recheck that what you have written makes sense. Ask the opinions of other people to see if your work needs to be reworded or edited. Check your spelling, punctuation and grammar and bear in mind that spell-check programs often use American spelling conventions and do not distinguish between homophones — words that sound the same but are spelled differently and have different meanings. It may take a little longer to sit with a dictionary and go through all the words you are not sure of but it may save you losing needless marks. Always try and use appropriate Design and Technology terms such as 'sustainable resources', 'emerging technology', 'collaborative decision-making' and 'cognitive organisers'. If the markers can see that you understand what a term is referring to and you have applied this knowledge to your project, your marks will improve. For example, you may recall factual information about an emerging technology but in order to gain marks you will need to explain how this technology is being used in the project (its relevance) and the benefits associated with its use.

Graphic Communication

This covers the arrangement of drawings, logos, icons and computer-generated sketches and images. Sketching is regarded as an art form as well as a clear way to convey and clarify ideas. A sketch will convey a message or an idea where words may leave room for ambiguity. For example, what do the following mean?

Figure 11.1 Examples of graphic communication

In folios there is a need to include a range of sketches. Firstly, include initial or rough sketches. These may simply be thumbnail sketches (see Figure 11.3). Then, include sketches to show the development of the project, for example, a new sketch for each time the product, system or environment altered. Do not forget to label sketches, particularly in relation to adjustments or improvements at each step. Beside each sketch you may choose to include a PMI (pluses, minuses and interesting issues associated with the design) which assists in evaluating the ideas.

Final sketches can include technical, rendered, fashion and computer-aided sketches. The use of appropriate conventions and standards for drawing diagrams must be followed as well as a justification of the chosen methods of communication. It is important to experiment with a range of techniques and forms to visualise and communicate ideas and solutions. The presentation techniques used must be suited to the needs of clients and design projects.

Many companies use a logo that symbolically represents the company to the public. A logo should clearly convey what the company is all about and it can be used as a basis for advertising. In many cases companies become known by their logos.

Visual and Audio Communication

Visual and audio communication is associated with providing maximum effect. A video is a good way of conveying the workings of an MDP, however, if using a video, be sure to allow enough time to shoot and edit a professional presentation. The style of speech used in video/audio presentations is usually more formal than that used in everyday speech. Viewing television documentaries can help you to 'hear' the differences, while watching them with the sound turned down can you help see the importance of selecting effective, relevant images.

Tactile Communication

Tactile messages are transmitted by our sense of touch, for example, we often get a feeling about someone when we shake their hand. The construction and production of samples and prototypes will give you a 'feel' for your design project and, in a similar way, markers will incorporate their tactile responses when examining and evaluating your MDP.

11.3 Elements of the Communication Process

The major elements of the communication process involve the **sender**, the **receiver**, the **medium** and the **message**. We gather information from the world around us by using the five senses — sight, hearing, taste, touch and smell — and of these, people rely mainly on sight and hearing to collect information. Communication is effective if it is pitched at an appropriate level of understanding and kept concise.

Communication involves sending messages, exchanging ideas and giving information and usually involves the following steps:

- To be effective the message must be clear, logical and easy to interpret when received.
- The message must be transmitted or sent. In a design portfolio, the rule is 'if you think it, write it down'.
- The message must be received and understood. For a message to be understood the receiver must be able to decode it.
- The information may be stored but the message must be responded to. This ensures that the sender knows that the message has been received.

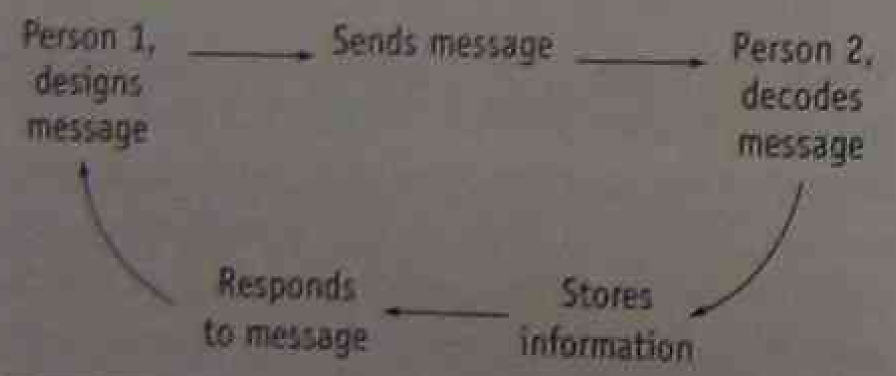


Figure 11.2 Steps in the communication process

11.4 Criteria for Evaluating Communication

The effectiveness of a message lies in its **clarity**, **presentation**, **ease of understanding** and **retention**. Each project requires the use of different methods to achieve effective communication. It is important to consider your target market and identify the 'triggers' to which the market will be most receptive. HSC examiners have a list of triggers that they will be looking for, based on the Design and Technology syllabus.

The level of language used and the subject-specific jargon and terminology can affect the clarity and appropriateness of a message. In many cases, appropriate terminology is expected. Information is most easily interpreted when it is logically organised into appropriate bundles. The MDP requires that these bundles of information be associated with every section as appropriate. They must be ordered in the same way as the criteria, so the examiner can logically follow through the process.

Exercise

1. List a set of criteria by which you can evaluate the success of a message.
2. Use these criteria to critically analyse the communication used in your Major Design Project.
3. Include additional communication methods to improve the presentation of your MDP.

☞ Answers to Exercise, p. 109.

11.5 Communication Media

It is important to communicate design ideas and solutions effectively by using a range of technologies. The mechanical and electronic communication used today has caused an information revolution and we are now able to communicate with people all over the world. Forms of communication media include:

- **Personal communication media**, which includes body language, speech, music, graphics and writing.
- **Mass media** includes movies, books, magazines, television and radio.
- **Mechanical and electronic media** includes computers, word processing, printing, desktop pubishing, audiotape, compact disks, telephones, i-phone (Internet phone), CB radio, facsimiles, modems, computer graphics and animation, film, video, photography, virtual reality, e-mail, Internet and Intranet usage and digital imagery. Much information that was previously only available in books, for example, encyclopedias, is now available online at a greatly reduced price.
- **Telecommunications** refers to the transmission and reception of messages using radio waves, light waves or electricity. Many forms of communication use these mediums and many are linked to telephone systems including fax machines, bulletin boards, the broadband Internet and e-mail systems, as well as computer Intranets. Currently a laptop computer can fit into a briefcase but the office of tomorrow is likely to be able to attach a telephone communications system to a handbag or a belt. Using systems such as this will allow visual and textual communication anywhere in the world.
- **Fibre optics**, through fibre signal carriers, provide 'isolated' Australians with the opportunity to access worldwide audio and video communication networks, research overseas information files and view entertainment online.

11.6 Visualising Solutions

When a designer is given a brief it is most important that they are able to present a visual solution to the client. This results in clear communication and a greatly reduced risk of misunderstanding. The presentation of the possible solutions must be suited to the clients' needs — for example, architectural sketches must be precise and accurate and should include views of the building from all aspects, measurements, direction of door openings, an indication of possible materials and so on.

A designer's initial solutions to a problem are usually graphic solutions. It is important that the designer produces a possible range of solutions that are of high quality and solve the design brief. Ways to demonstrate possible solutions include sketching, prototypes, models, simulations and storyboards. As a Design and Technology student you are expected to produce a range of superior quality solutions using a variety of techniques.

Sketches and Drawing

Types of sketches and drawings include thumbnail sketches, rough and developmental sketches, technical drawings, fashion sketches, exploded views, rendered and computer-aided drawing. These are examined in more detail below.

- **Thumbnail sketches** are miniature sketches of your initial ideas. The sketches are approximately 5 cm x 5 cm and are a quick expression of the first ideas that you come up with when confronted with the brief.

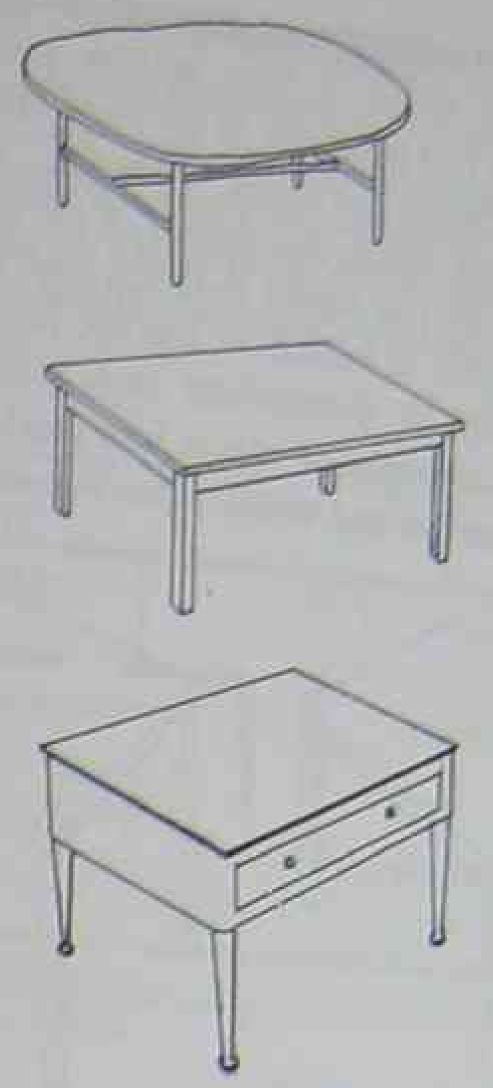


Figure 11.3 Samples of thumbnail sketches

- **Rough sketches**. As your ideas start to form, you will need to put them onto paper. As you sketch your ideas with more detail, but continue experimenting with them, you are preparing your rough sketches. Do not lose these, as they are necessary to demonstrate that you considered a number of options.

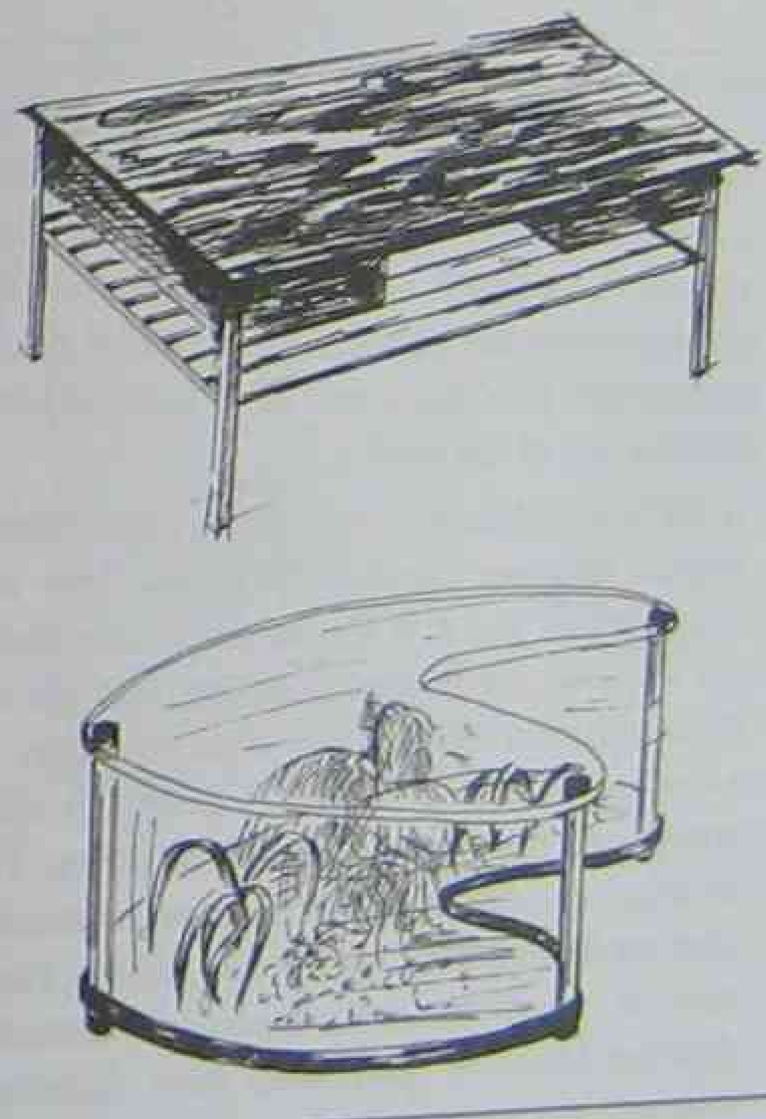


Figure 11.4 Samples of rough sketches

- **Concept development sketches**. Once you have decided which of your options you wish to explore it is necessary to do some investigation and research on tools, materials, ideas and processes. When this section of the research is completed you should re-sketch your developed ideas. This is known as concept development. You need to demonstrate each step in your design development, that is, how you have made modifications and added improvements.

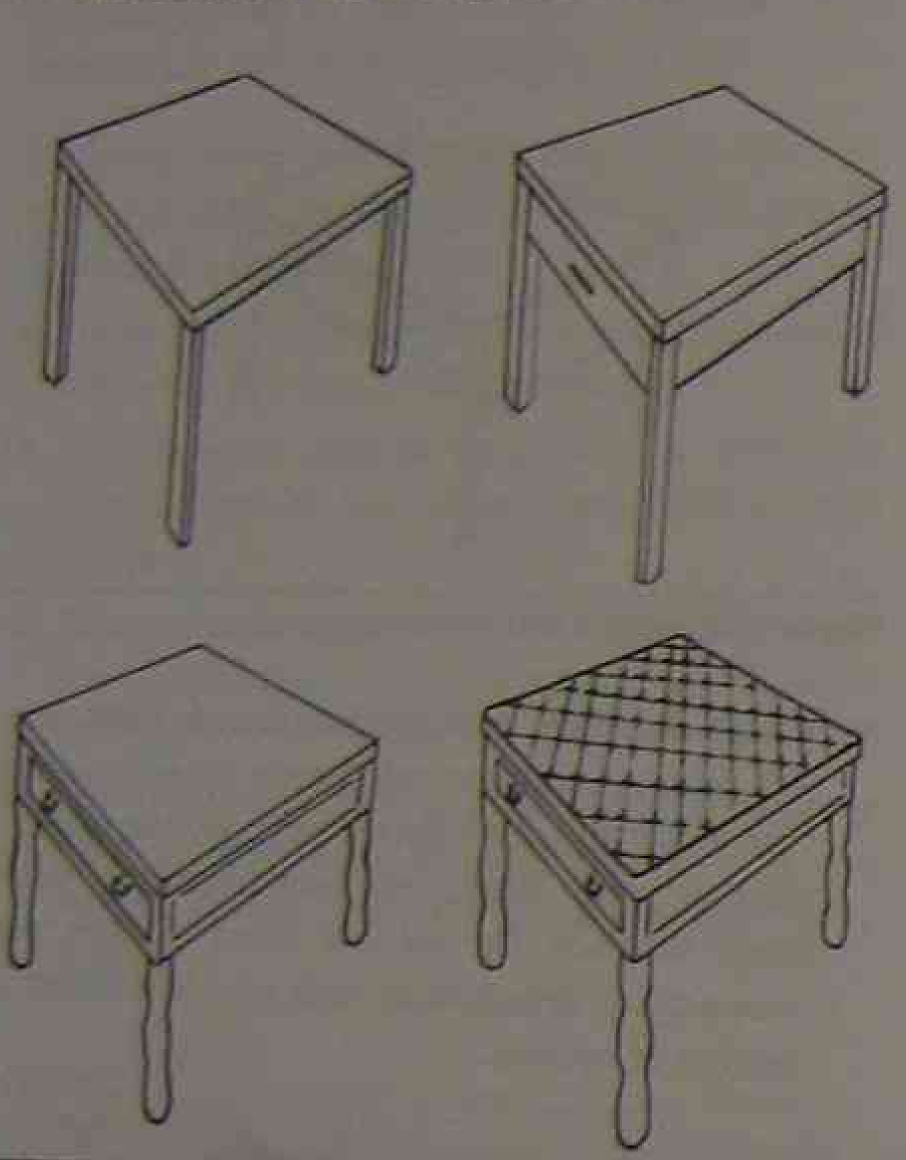


Figure 11.5 Samples of concept development sketches

- **Technical drawings**. Once the design is finalised a technical sketch may need to be made. This sketch will provide necessary information on measurements and may include a cutting list, if appropriate. This sketch will be at least A4 size, detailed and of top quality.

A technical drawing involves a specialised graphic language. Standards Australia lays out this language and it is standardised throughout the world by the International Organisation for Standardisation (ISO). This standardisation is necessary because of the rapid growth in technology and the globalisation of industries. The technical drawing standards that are commonly used are derived from AS1100 and AS1101. These may be found in most Australian technical drawing books or purchased from Standards Australia (www.standards.com.au).

There are many different types of technical drawings, including orthogonal, perspective, isometric, oblique and planometric drawings. Each is designed to illustrate the shape of an object on a flat drawing sheet. If you choose to use technical drawing as a communication media, you should research the various types and use the most applicable method following the standards set out by Standards Australia.

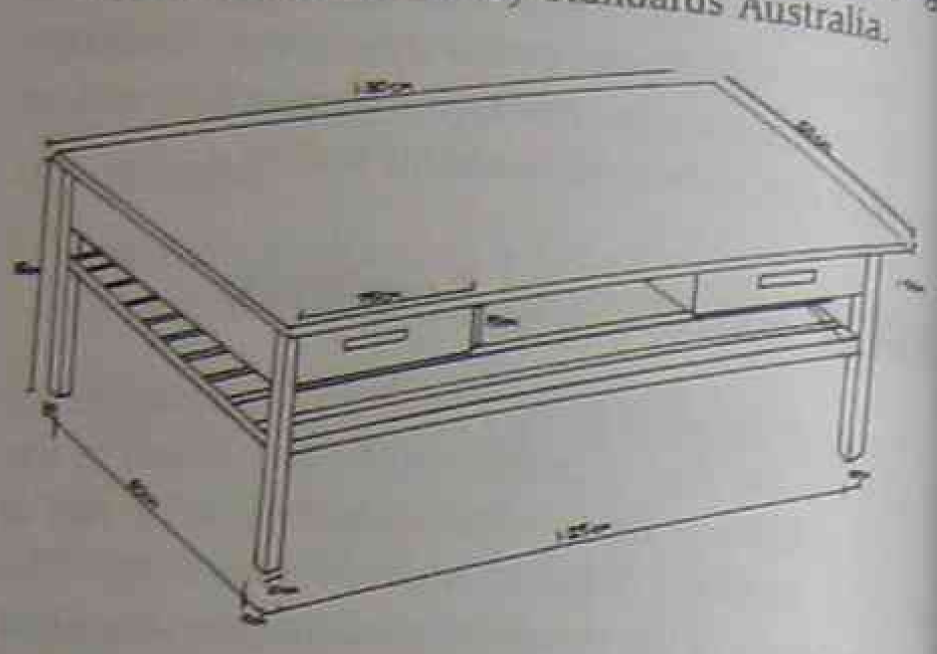


Figure 11.6 Sample of a technical drawing

- **Fashion sketches**. If you are sketching a textile item you will need to include a fashion sketch. This should show the front and back view of the item with all fashion features labelled. You may choose to include some possible fabric samples (swatches) to make the design from. Once again, this sketch should be at least A4 size, detailed and of top quality. This is illustrated in Figure 11.9 on the next page.
- **Exploded views**. It is possible that your design may be made using layers that have been joined together. If this is the case, an exploded view showing how the layers are attached is necessary.

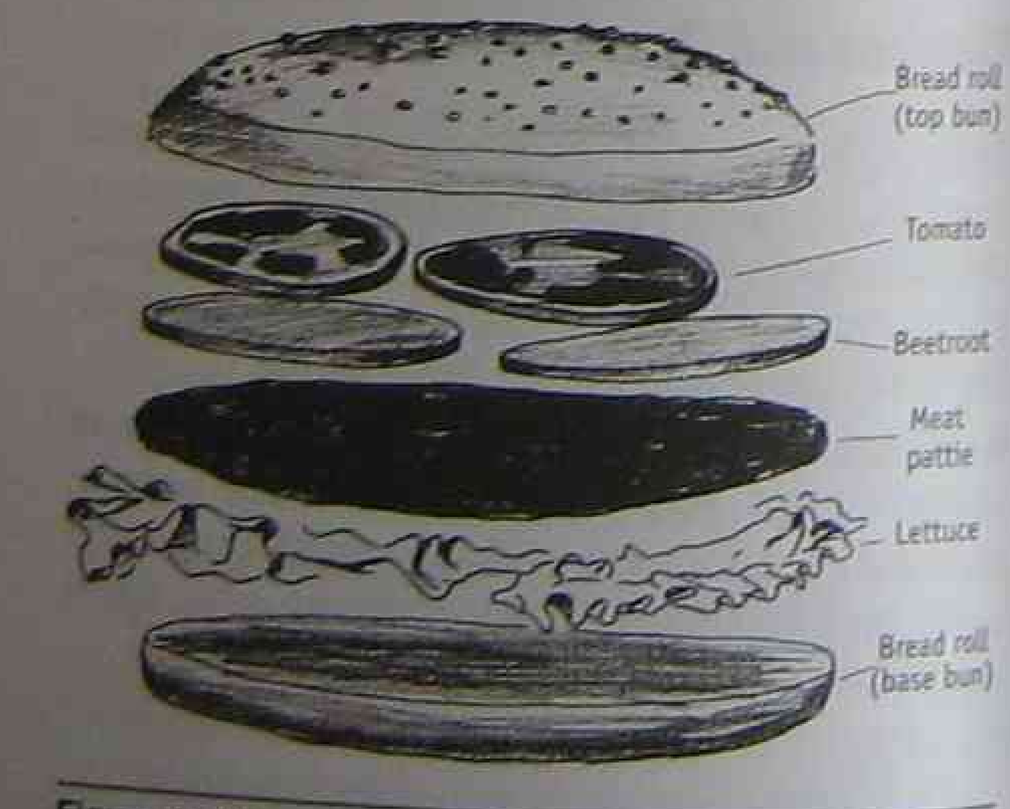


Figure 11.7 Sample of an exploded view

- **Rendered sketches**. Rendering is a technique that allows designers to produce a quality sketch via the use of shading to give a 3-D effect. This technique takes time to perfect but is a good tool to use. A technical drawing teacher at your school may be able to help you with this if you ask for assistance.

Figure 11.8 Sample of a rendered sketch

Computer-Aided Design (CAD)

A range of CAD and computer graphics packages are available. These computer software packages allow designers the opportunity and advantage of placing their designs on the computer and, for the HSC, it is your opportunity to utilise another form of technology.

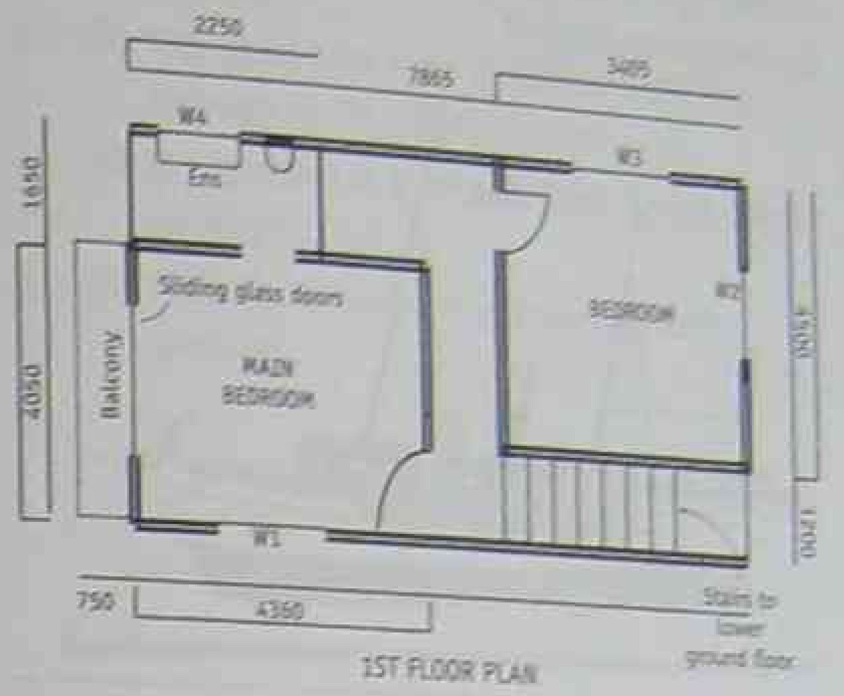


Figure 11.10 Sample of a CAD drawing

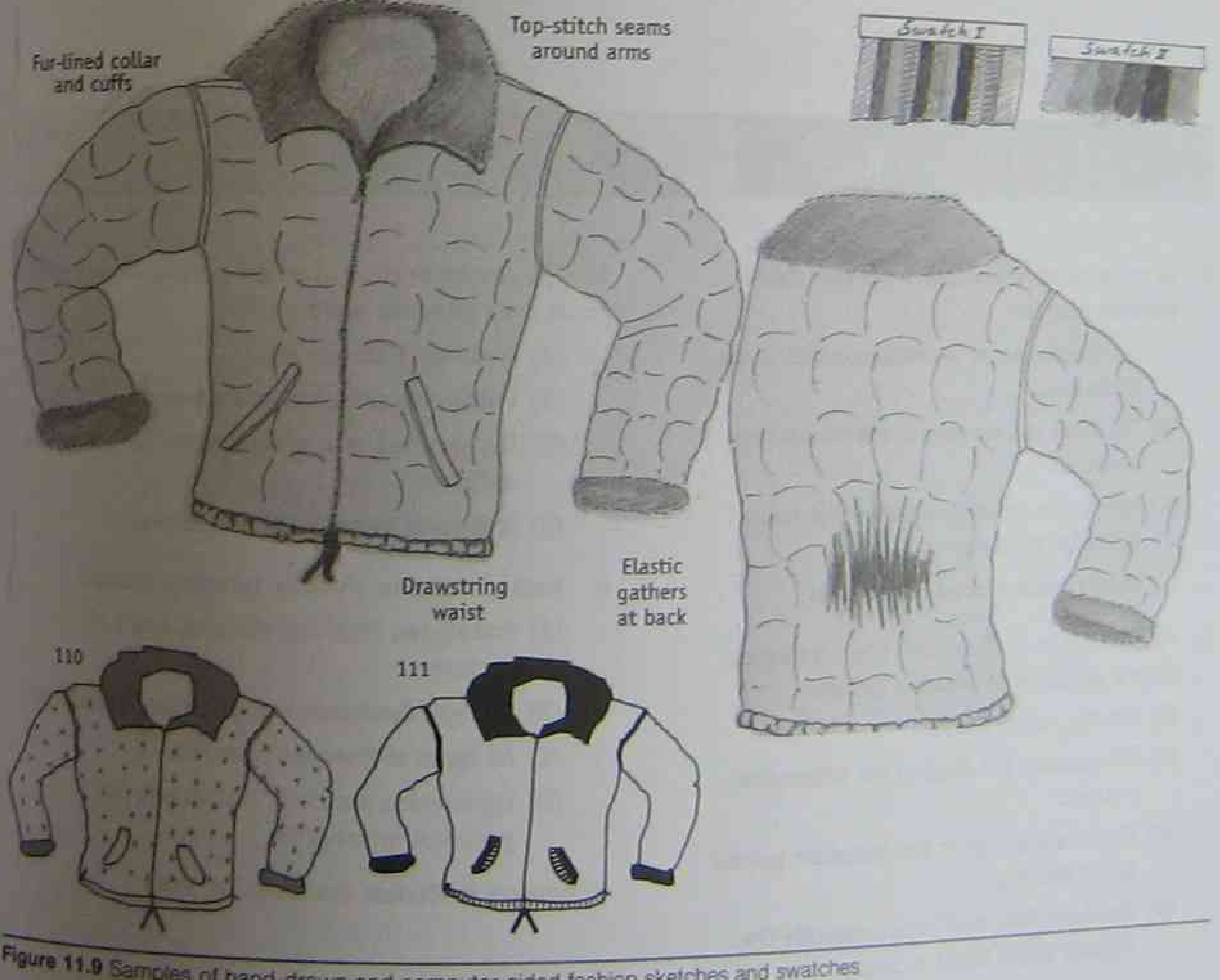


Figure 11.9 Samples of hand-drawn and computer-aided fashion sketches and swatches

11.7 Presentation Techniques

Prototypes and Models

These are miniature samples of your ideas and they may or may not be working models. The purpose of a prototype is to represent in 3-D form and to scale the design or product.

Figure 11.11 Sample of a model/prototype

Demonstrations

As a designer it may be necessary to demonstrate how your design will work and to do this you will need to manufacture and demonstrate a working model. In the HSC, **you must demonstrate the working of your project**. If you cannot do this in person it is possible to get a peer to do the demonstration for you, though you risk your peer not being able to get your design to work. As an alternative it might be better to make a video of the actual working product, system or environment. If a video camera is not available you may use a storyboard.

Storyboards

A storyboard is a series of sketches or photographic evidence that illustrates how the design solves the design problem. Some students may use a series of photographs in their MDP. These photographs will need to be accompanied by an explanation of what is occurring in each image.

Review Questions

1. To communicate graphically, a designer should primarily consider:
   (A) The functional and aesthetic qualities of the media used.
   (B) The detail and accuracy of the information presented.
   (C) Appropriate technical sketches that follow Australian standards.
   (D) Using computer-based technologies.
2. Major factors to be considered when evaluating graphic design communication include:
   (A) The size, colour and font.
   (B) The accuracy and detail of the information provided.
   (C) The standards used in the Australian graphic design industry.
   (D) The visual form used to communicate the message to the target audience.
3. The communication of a new product design idea is most effective when:
   (A) Given on a storyboard.
   (B) Multimedia presentations are used.
   (C) It is pitched at a suitable level for the target audience.
   (D) It is clear, concise and interesting.
4. Methods used to visualise solutions include:
   (A) Prototypes, freehand sketches and CAD packages.
   (B) Surveys, databases and graphical information.
   (C) All types of freehand sketches.
   (D) Ergonomics, sketches, multimedia and graphical information.

☞ *Answers to Review Questions, p. 109.*

Answers Communication

Answers to Exercise page 104

1. Factors include appropriateness of chosen message, clarity of message and ease of interpretation.

2. and 3. Student response.

Answers to Review Questions page 108

1. (B) The detail and accuracy of the information presented.
2. (D) The visual form used to communicate the message to the target audience.
3. (C) It is pitched at a suitable level for the target audience.
4. (A) Prototypes, freehand sketches and CAD packages.

12 — Computer-Based Technologies

Chapter Overview

Computers are used in almost every area of our lives. Computer-based technologies may be used to develop, communicate and present design ideas and processes. Knowledge of computer-based technologies will assist students to discriminate in the choice and use of these technologies for designing and producing.

Expected Outcome

On completing this chapter, students should be able to:

- evaluate and use computer-based technologies in designing and producing.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

Apple Macintosh computer
computer-aided design (CAD)
computer-aided engineering (CAE)
computer-aided manufacturing (CAM)
computer drafting
computer graphics
computer-integrated manufacturing (CIM)
computer modelling
computer simulation
databases
decision support systems
electronic mail (e-mail)
expert systems
intelligent systems
Internet
multimedia
networks
numerical control (NC)
personal computer (PC)
spreadsheets
virtual reality
voice input
word processing

12.1 Introduction

Computer-based technologies are an invaluable asset to design and production and are used extensively in both commercial and private situations. There are many different types of computer-based technologies and new technologies are constantly being developed and introduced into our lives. These new and emerging technologies soon become old and established technologies.

12.2 Types of Computer Systems

The standard computers that most people are familiar with are called personal computers and are often referred to as **PCs**. They used to be called IBM-compatible computers, as IBM developed the original personal computer and the software was compatible with the IBM product. The other main type of personal computer is the Apple Macintosh or **Mac**. The Mac was the first computer to use icons, thus making it very user-friendly. Most PC and Mac software is now compatible, that is, it may be used on both platforms. Personal computers generally look the same and have similar functions. The main components include a central processing unit, disk drives, monitor, keyboard and mouse. PCs are mostly used for word processing, accounting, spreadsheets, databases and communication, via the Internet and e-mail. They can also be used for playing games, watching video clips and listening to music.

Mainframes are used for data processing. Government departments, large businesses and scientific organisations use mainframes. Mainframes may be used for banking, by insurance companies and by airlines. A mainframe is an extremely large computer and is more powerful than a thousand ordinary personal computers. They are powerful enough to be used by many people at the same time from numerous individual terminals. Supercomputers are more powerful than mainframes and there are only a small number of them in the world. Computer companies rent them out by the hour at a very high cost. Supercomputers can carry out complex calculations very quickly.

A **laptop** is a portable computer that may be folded shut. The screen is contained within the lid. Laptops can be powered by battery or through an electrical supply. A **notebook** is a computer the size of an A4 piece of paper or notebook, as the name suggests, and only a few centimetres thick. It has limited memory and is useful for jotting down notes.

Palmtop computers fit into the palm of an adult's hand. They are small, lightweight and relatively expensive. Some palmtops have the same capabilities as an ordinary PC, while others have limited memory. Some are capable of running simple word processing and sending and receiving e-mails.

12.3 Computer-Based Technologies in Design and Production

Computer-based technologies may be used in design and production for a number of functions, including:

- modelling
- research
- simulation and graphics
- communication
- presentation.

These functions are examined in greater detail below.

Modelling

Computers are used extensively to aid design development by producing accurate, low cost models that may be easily manipulated and accurately analysed. These models may be computer-generated and thus created and manipulated on the screen or they may be created as a prototype in real form, using computer-generated specifications, and tested in the real world.

Computer modelling is advantageous because it may be used to:

- Accurately depict the design's form from a variety of angles on a computer screen, which can then be analysed by the designer.
- Create computer-generated models of products in operation thus showing the mechanical or electrical behaviours of the product. This type of model may also be viewed on the computer screen.
- Create a functional prototype or model that may be tested externally by integrating the use of computer-aided design (CAD) and computer-aided manufacturing (CAM) systems.

Computer-aided design (CAD) uses a computer and special graphics software to aid in product design. The CAD software eliminates the laborious drafting that was previously required and allows the designer to dynamically change the size of some or all of the product and view the design from different angles. The design database can also be reviewed by other designers or design engineers, which can save a great deal of time and improve processes. For example, if a support bracket was required for a new product, the design engineer could review the database to see if any existing products used an appropriate bracket. This not only decreases the overall design time but also increases the reliability of the new product by using a proven part.

Computer-aided manufacturing (CAM) is the use of computers to control production equipment. CAM production equipment includes software-controlled drilling, lathe and milling machines as well as robots.

Numerical control (NC) is a form of programmable automation in which numbers control a machine. It was initially applied to the machine tool industry. The process is based on converting component drawings and machine cutting paths to a numerical code. This code is then transmitted to computer numerical control (CNC) machinery, which then cuts and shapes the component using the codes. Some schools have CNC lathes and other related machinery. A student may also outsource the manufacture of some components of their MDP using CAM processes.

Computer-integrated manufacturing (CIM) is the total integration of the manufacturing process using computers. Using CIM concepts, individual production processes are linked so that the production flow is balanced and optimised and products flow smoothly through the factory. In a CIM factory, automated design processes are linked to automated machining processes that are linked to automated assembly processes that are linked to automated testing and packaging.

Research

Designers and students may conduct research using a variety of sources (refer to Chapter 9). Computer-based technologies can be used as a tool to aid the research process or they may be used for processing and presenting the collected data. Computer technology is an invaluable asset for Design and Technology students in conducting the research necessary for completing the Innovation Case Study and the Major Design Project.

The **Internet** is a worldwide network of computers connecting millions of users via existing telecommunications infrastructure. Users of the Internet can get access to vast amounts of information on many subjects, communicate with other users anywhere in the world via electronic mail, send and receive computer files and remotely connect to, and use, other computer systems and services. The Internet provides information via:

- **Electronic books (e-books)**. These are books that may be downloaded for reading offline.
- **Electronic libraries (e-libraries)**. These are specialised websites covering a range of educational areas.
- Multimedia educational material.
- Encyclopaedias or knowledge systems.
- **Mailbot** is an e-mail server that automatically sends out response information via e-mail to anyone requesting generic information.
- **Mailing lists** are virtual forums where e-mail messages are delivered to the people who subscribe to the list. Some mailing lists are moderated so people can send messages to the moderator, who in turn decides whether to post the message. A person joins a mailing list by sending a message to a specific e-mail address. Each person subscribed to a list receives a copy of everyone else's e-mail on the list, thus allowing a virtual forum where people can communicate on a set topic. Mailing lists are a good way to ask for help about a research topic.
- **News groups** are online discussion groups and there are thousands of news groups on every conceivable topic of research.
- **Internet relay chat (IRC)** enables direct conversations between Internet users.
- **Video conferencing** is a form of teleconferencing whereby people from geographically distant locations can see and talk to each other using video cameras and monitors. It can be an excellent way to share ideas and carry out brainstorming activities and is achieved via the Internet and a PC.

Database software enables a researcher to store a large amount of data. This data can be cross-referenced, retrieved and manipulated to produce information. There are many different types of databases that can assist research including:

- **Personal databases** are offline databases that may be used for a variety of tasks such as cataloguing references or Internet sources.
- **Distributed databases** are online databases that store copies of the data files in different locations on the network. This allows users to have faster access to the data but requires the database management system to periodically update all the database files to make sure they have consistent data.
- **Search engines** are online databases of websites. They may be used to connect a researcher to their topic area. Different search engines are suitable for different types of searching including:
  - ▸ Question searches which answer questions such as 'How do you ...?' or 'When did ...?', for example, www.ask.com
  - ▸ Boolean suits searches for information buried in extraneous data, for example, www.looksmart.com.au
  - ▸ Keywords suit searches for key words or simple phrases, for example, www.google.com
  - ▸ Metasearch. This search engine looks through numerous search engines to find a reference that might be indexed in only a single comment, for example, www.metacrawler.com
  - ▸ Directory search suits unstructured searches where a researcher wants to find out what is available on a topic, for example, www.yahoo.com

Spreadsheet software is based on the traditional accounting worksheet. The user can develop personalised reports involving the use of extensive mathematical, financial, statistical and logical processing. Researchers may use spreadsheets for a variety of purposes including statistical analysis of research data and production of graphs, tables and charts. They may also generate predictions once sufficient information has been input.

Simulation and Graphics

Computer-assisted simulation is increasingly being used in industries where it is too dangerous or too expensive for people to practise on the job. For example, simulations are used in chemical and nuclear power plants, and in the aircraft and maritime industries.

Computer-generated graphics can be of a very high quality and extremely accurate in depiction. Graphics are useful for a variety of applications in the area of design and production.

Computer simulations are used to model the real world or some set of real conditions so that they can be manipulated and studied more easily. Simulations are an artificial creation on screen of some form of real life. Simulations are intelligent learning environments that are interactive and reactive. Simulations are useful because they provide for a scenario or set of events, allow clear options for participation, provide a range of plausible reactions to responses to the scenarios and give guidance for completion of the scenario. Good simulations present a believable set of circumstances, reasonable response options and a revised set of circumstances based upon the ongoing interaction with the user.

Computer-aided engineering (CAE) is the use of computers in drafting, design analysis, numeric control (NC), tool and mould design, quality control (QC) and process planning. CAE involves the use of computers to test product designs. Using CAE, engineers can, for example, test the design of an aeroplane or bridge before it is built. Sophisticated programs are available to simulate the effects of wind, temperature, weight, and stress on product shapes and materials. Before the use of CAE, prototypes of products were built and subjected to testing that often destroyed the prototype.

Computer drafting is the process of using a computer to carry out manual drafting functions. It replaces the T-square, measuring and marking tools, and the drawing board. A drafting program consists of drawing tools, text, dimensioning tools, layering features, symbol libraries and a database. The design is created with the use of a keyboard, mouse and a digitiser pad. This system uses a cursor (stylus) on a pad to locate points and a light pen, which is used to point to areas on the computer screen. Computer drafting is more flexible, more accurate and less time consuming than manual drafting.

Decision support systems assist people to make decisions by providing information, models and analysis tools.

Intelligent systems receive data from the environment, react to that data and produce an intelligent response. Uses of intelligent systems include creating chess opponents and for medical diagnosis.

Expert systems provide information and solve problems that would otherwise require an expert experienced in the particular field. They are designed for use in highly unstructured settings such as medicine and share investment. The main advantage of expert systems is their low cost compared with the expense of paying an expert or team of specialists.

Virtual reality (VR) creates surroundings that seem real, but only exist as electronic signals inside the computer. The user wears a headset that contains two screens, one for each eye. The brain combines the screen images to create a 3-dimensional scene. The headset plays stereo sounds, one into each ear, which the brain combines for a surround sound effect. Some VR systems have gloves, shoes and even whole suits with sensors to detect the user's movements and change the images and sounds to reflect these. The user can move through virtual environments and grasp virtual objects. VR systems are used to train people in difficult and dangerous jobs such as surgery, piloting an aeroplane or fighting fires. They are also used extensively in the entertainment industry.

Computer graphics refers to the production of pictures, patterns and diagrams by a computer. Graphics may be very simple such as those produced in drawing programs or the use of clip art, or they may be as complex and detailed as the graphics used in multimedia presentations such as cartoons, movies and simulations.

Extension

Use the Internet to look up and work through a simulation in an area of personal interest. Evaluate the simulation in respect of:

(a) Was there a pre-test before you started the simulation?

(b) Was user feedback provided throughout the simulation?

(c) Did the simulation accommodate varying levels?

(d) Did the user generate a personal record?

(e) Was it easy to navigate?

(f) Did it achieve its aim?

Communication

Computers may be linked via cables thus forming a **network**. This means that communication may be shared. Networks may be established between two computers, between computers in different rooms and between computers across the world. A modem using telephone cables is used to connect computers via the Internet.

Electronic mail (e-mail) is a communication system whereby messages are transmitted to, and received from, other computer users via a modem or some other communications device. Networks may be established using a LAN (Local Area Network) or WAN (Wide Area Network). New systems are in place to make this process even faster but they are more expensive to use.

Voice input is sometimes referred to as voice or speech recognition. Voice input allows the user to enter data and issue commands to the computer with spoken words. Most systems require the user to train the system first by speaking the words that will be used a number of times. As the words are spoken, they are digitised by the system allowing for computer recognition. In voice-controlled word processing systems, spoken words can be used to control such functions as single and double-spacing, choosing type styles and centring text. The major advantage of voice input is that the user does not have to key, move or touch anything in order to enter data into the computer.

Presentation

Word processing software on PCs allows people to create, edit, store, retrieve and print documents.

Desktop publishing is a combination of hardware (PC, laser printer and scanner) and software that together provides near-typeset quality output in a variety of sizes, styles and fonts. This technology can integrate, or combine, graphics and text to produce a professional-looking page.

Multimedia computers give information in many forms (or media) including words, still and moving pictures, sound effects and music. They are also interactive, which means that the user can take part in the program using a mouse, keyboard or joystick. Most multimedia computers have a CD-Rom drive. Multimedia presentations can be the most powerful form of presentation as they actively engage the audience. Games involve a specialised use of multimedia. For some games a console with a joystick may be used. **Hypertext** is also used in multimedia presentations and is an interactive system of information browsing and retrieval that allows a user to click on a link to go to related information. Every time a person clicks on a link on a web page they are using hypertext. It is frequently used for presentations via software such as Microsoft PowerPoint.

Multimedia input devices may include:

- **Digital Still Camera.** A digital still camera uses an electronic sensor array to capture the image and store it in electronic memory. It has a lens and shutter assembly similar to that found in any conventional camera but a digital camera does not use film. Some cameras have a fixed amount of storage, while others have interchangeable memory modules. Some cameras store the images on a standard 3½-inch floppy disk. All memory is non-volatile, which ensures that the information is safe for up to a year, even in the event of battery failure. There are many advantages of using a digital camera for presentation — they capture and process an image rapidly, and, as they can be used to capture a number of images of a particular subject, the most appropriate may be quickly selected and the rest easily deleted.
- **Digital Video Camera.** In the digital video system, pictures and sound are converted into digital signals and recorded onto tape. The image can then be connected to a VCR or PC for playback and, with the appropriate software, the image may be edited and manipulated using a PC. Digital video images can be used for multimedia presentation packages to create an interesting and engaging presentation of many aspects of design and production.
- **Scanners** include a variety of devices that read printed codes, characters or images and convert them into a form that can be processed by the computer. Scanners may be used to copy photographs, text documents, drawings, paintings and so on. This tool is useful as the images can be manipulated and integrated into various computer documents thus facilitating a quality presentation.
- **Microphones** may be used to record sounds such as voices or music. A sound card is used to transform the sounds into audio.
- **Compact Disks Read Only Memory (CD-Rom).** A CD-Rom stores computer data and cannot be written over with new data like a floppy disk or hard drive. CD-Roms are typically used to store

programs, text, images, audio and video. Designers and design students may find CD-Roms useful for presenting folios and supporting documentation as they have a large capacity. About 650 megabytes of data can be stored on compact disk.

- **Compact Disk Recordable (CD-R)** is a CD that can be used to record information, including sounds.
- **Compact Disk Rewriter (CD-Rewriter)** is a peripheral device that can record data on a CD-R disk. This machine facilitates the production of audio CDs and CD-Roms. The slang term for a CD rewriter is a '**CD burner**'.
- **Digital Versatile Disk (DVD).** A DVD looks almost identical to a CD-Rom but it has a larger storage capacity. A DVD is potentially double-sided with multiple layers and uses advanced compression schemes.

Review Questions

1. Computer-based technologies may be of benefit because they:
   (A) Often provide data that can be accurately manipulated and reproduced.
   (B) Are always time-saving and simple to use.
   (C) Allow for up-to-date information processing and presentation.
   (D) Can produce information that appeals to the younger generations.
2. Computer simulations:
   (A) Are not used by a wide cross-section of the community because most people are not engaged in dangerous occupations.
   (B) Are an effective way to give the user an experience that is similar to real experiences.
   (C) Are used in design and production to assist the presentation of an idea.
   (D) Can create excellent communication networks.

Answers Computer-Based Technologies

Answers to Review Questions

1. (A) Often provide data that can be accurately manipulated and reproduced.
2. (B) Are an effective way to give the user an experience that is similar to real experiences.

13 — Management

Chapter Overview

Everybody manages their lives to some degree, but some people manage their lives more effectively than others. Students need to actively engage in quality management if they are to be successful. Knowledge of the management process and related concepts will help students to make effective choices in order to achieve set goals. Effective management of resources will ensure the successful completion of the Major Design Project. Management techniques and tools are used in industrial and commercial settings to achieve goals and increase profits.

Expected Outcome

On completing this chapter, students should be able to:

- use a variety of management techniques and tools to develop design projects.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

evaluation
goals
management
management styles
needs
project management
resources
standards
values
wants

13.1 Introduction

Management is a process that involves the planned use of resources to achieve goals. It is a dynamic process that involves ongoing evaluation and may be carried out by individuals or by groups of people. Management practices are used in commercial organisations to improve profits and can be applied to any kind of organisation — domestic, industrial or commercial.

There are a number of different management models but they all have similar components. The management process consists mainly of the following activities:

- **Planning** or devising a scheme.
- **Organising** what has to be carried out.
- **Implementing** a plan of action.
- **Evaluating** the results in respect of the goals set.

The level to which each step is carried out will determine how successful the management process has been.

Planning

A plan is a scheme of action with a definite purpose. Planning involves setting, clarifying and prioritising goals. It also involves identifying and selecting available resources. Planning helps to prevent failure and it facilitates an awareness of opportunities for future development. Large organisations will develop a mission statement to focus planning activities. The mission statement is a simple statement that encompasses the basic philosophy of the organisation. For example, a golf club's mission statement may be to provide good service and a friendly atmosphere.

A **strategic plan** is used to plan strategies to achieve broad organisational goals. A **tactical plan** is developed to overcome short-term problems. An **operating plan** is developed by managers to accomplish their job requirements.

Organising

This involves arranging what has to be done, who will do it, when it will be carried out and where the process will take place. Plans are often modified at this stage.

Implementing

This is where the plan is put into action. Some minor changes or revisions may have to occur at this stage.

Evaluating

Evaluating occurs both throughout and at the end of the management process. It involves examining what has happened and how well the goals have been met. Recommendations may be made for future planning.

Extension

Think back to the last time you organised a social occasion. Did you work through the management process? Would the outcome have improved if you took the time to consciously plan the event?

13.2 Factors Affecting Management

Management skills may be divided into three different categories:

1. **People skills** involve understanding how people think and feel, an ability to communicate effectively, negotiation skills and network-building skills.
2. **Thinking skills** involve problem solving and lateral thinking skills as well as an ability to see the 'big picture'.
3. **Technical skills** involve knowledge of production and support services.

Exercise 1

Categorise the following processes as either people skills, thinking skills or technical skills:

(a) Ability to communicate well.
(b) Knowledge of how a good is manufactured.
(c) Mathematical knowledge.
(d) Ability to solve problems.
(e) Ability to negotiate outcomes.
(f) Knowing how to motivate people.

☞ *Answers to Exercise 1, p. 128.*

To manage effectively, a person must be able to perform a variety of mental processes and then **act** on the decisions made. Management requires the following skills:

- Setting priorities for needs and wants.
- Identifying available resources.
- Clarifying values.
- Setting goals.
- Setting standards.
- Seeking possible alternatives.
- Evaluating the costs and benefits of each alternative.
- Making and implementing decisions.
- Preparing task descriptions and sequencing.
- Evaluation throughout the process and of the final result.
- Documentation.

A person's ability to master these skills will ultimately affect how well they can apply the management process. These skills are examined in greater detail below.

Setting Priorities for Needs and Wants

As needs are those things a person cannot do without and wants are those things people would like, but are not necessary to sustain life, a manager must determine what they perceive as more important. Ranking or prioritising goals will help a manager determine what is more significant and this will aid in the more efficient use of time and energy. For example, if a student needs to get more sleep then this should take priority over wanting to socialise with their friends. If a commercial organisation needs to move beyond the break-even point and make a profit, this should take priority over wanting to refurbish the office.

Identifying Available Resources

Resources are those things we use to achieve goals. They may be **human** (time, energy, skills or knowledge) or **non-human** (tools, materials, libraries or fuel). Resources are interrelated and interchangeable. It is important that the manager is aware of the range of resources available so that they can use them to their advantage. For example, if a student is creating a patchwork quilt they need to be aware of the skills they possess, the range of specialised materials and tools required and how they can obtain professional help at various stages if necessary. All of these factors are resources that can be used to complete the project. The student should also be aware of how to substitute one resource for another if required. For example, money may be used to replace a lack of skill by employing someone to mechanically carry out the quilting process. A large organisation may find it more economical to subcontract small, specialised jobs rather than using existing staff to perform tasks they have few skills in.

Exercise 2

Solve the following problems for students who need to manage their resources:

(a) Not enough money to complete the project.
(b) Cannot find suitable hardwood in correct colour.
(c) Wool wadding is too expensive.
(d) Cannot find a suitable glossy finish for a poster.
(e) Computer software will take three months to arrive.

☞ *Answers to Exercise 2, p. 128.*

Clarifying Values

Values are beliefs about what is good or desirable. They are ideals that govern the way people think and/or feel things should be. Examples include the importance a person or organisation places on health, friendships, freedom, security, wealth, safety, job satisfaction, family life, religion and happiness. Values influence and control goals, standards, and decisions made. Values may be grouped into the following categories:

- **Moral values** such as honesty, integrity and tolerance.
- **Material values** such as the desire to have money, a large house, a pleasant lifestyle and certain types of clothing.
- **Aesthetic values** such as valuing beauty, music, art and certain types of food.
- **Social values** such as co-operation, friendships, privacy and effective communication.
- **Cultural values** including customs, family traditions and religion.

Clarifying values involves working out what is really important to the individual. For example, a person may value financial security and put aside money for a 'rainy day'. Another person may choose to put considerable time, effort and money into a hobby such as model-making and hence there is little money left for emergencies. The values that large organisations hold are a reflection of the personal values of upper management. Some of these organisations may organise family days, Christmas parties or provide financial incentives, all to support the values they hold.

Setting Goals

Goals are the desired end towards which a person is willing to work. They are the targets that direct an individual's or organisation's activities and energy. Goals reflect needs, wants, values and standards. Goals may be grouped into the following time frames:

- **Short-term goals** are those that are achieved within a week or so. It is often necessary to realise short-term goals before long-term goals can be achieved. A short-term goal may be to find out what computer software is available to create a web page.
- **Long-term goals** may take years to achieve. For example, if a person wants to build a boat it may take them years to develop the necessary skills and have the financial resources at their disposal in order to achieve this goal. A commercial organisation may wish to expand their operations offshore. This will not occur unless current operations are successful and the necessary research has occurred to justify this move. Obviously these processes take time.

Goals may be ranked according to priorities. They should also be realistic for the person or organisation trying to achieve them.

Setting Standards

A standard is a measure used to determine whether or not a goal has been achieved. For example, an individual may have completed blackwork embroidery using a mixture of traditional and modern stitches but may not be pleased with the overall aesthetic effect. Their personal standards have not been met. An organisation may set the goal to make a profit of $500,000 in a certain financial year. This forms an easy benchmark for determining whether a goal has been realised.

Seeking Possible Alternatives

As there is always more than one possible course of action, research may be required to determine the various alternatives. This research may take many forms such as gaining information through a brainstorming activity, researching on the Internet or seeking expertise from people with the required skills and knowledge. It is important for all organisations and individuals to look beyond the obvious if they are to make the best possible decisions.

Evaluating the Costs and Benefits of Each Alternative

While some alternatives may appear more suitable than others, it is usually not possible to see the true potential of each alternative until it is analysed in respect of costs and benefits. Comparing choices may even require further research. The degree to which the alternatives are analysed will depend on how complex or significant the decision is in respect of realising the goal. A SWOT analysis is a method used to evaluate alternatives. This involves looking at the strengths and weaknesses as well as the opportunities and threats of each alternative.

Making and Implementing Decisions

A decision is made based on the costs and benefits analysis of the possible alternatives. When a decision is made, it is important to determine what exactly will be done, who will do it and when it should be implemented and completed. Many organisations develop policies and procedures to guide the implementation of decisions. Policies are statements about the courses of action that have been adopted by an organisation. They are the rules set out by the organisation. For example, a procedure is a particular course of action that is set out in sequence, that is, there is a procedure for employees wishing to take annual leave.

Task Descriptions and Sequencing

What exactly needs to be done can be outlined in a task description. This should reduce the problems that can occur through miscommunication and is especially important when a task has been allocated to a person who has not been involved in the decision-making process. The logical sequencing or ordering of tasks to achieve goals minimises time, energy and other resource wastage.

Evaluation

Evaluation is necessary to determine how the process is going and whether or not goals are being realised. Evaluation involves questioning the results in respect of standards, values and resources used. Evaluation must be made throughout the process and also of the final result.

Documentation

Accurate records are useful as a reference tool for complex decisions and they can also provide the basis for future decisions. Relying solely on memory is not very sound and is a poor business practice. Many organisations expect ongoing reports and scheduled weekly meetings to monitor progress. Documentation and meetings also enable individual managers to assess their progress in light of the big picture, which in turn promotes the more efficient realisation of the larger goals.

13.3 The Decision-Making Process

Decision-making is the process of selecting between various choices and it occurs in each step of the management process. The steps of the decision-making process are as follows:

1. Recognising a problem.
2. Seeking alternatives, options or choices.
3. Analysing alternatives, options or choices.
4. Choosing between alternatives, options or choices.
5. Implementing the decision.
6. Evaluating the action and the result.

13.4 Management in Commercial and Industrial Settings

Within commercial and industrial organisations there are many levels of management. Organisations have either a vertical or horizontal management structure. This relates to the span of control of the managers at each level.

Vertical structures have more levels of management and communication is directed downwards through these levels. Vertical structures are usually drawn as a **pyramid model**. This traditional **hierarchical structure of management** divides management into three broad levels — top, middle and lower:

- **Top level managers** spend more time planning and organising than middle managers.
- **Middle managers** are more involved in leading the implementation of the management process. They need good technical skills.
- **Lower level managers** need good people skills.

This pyramid model involves specialist departments headed by managers who are technically qualified in their particular area and who work independently.

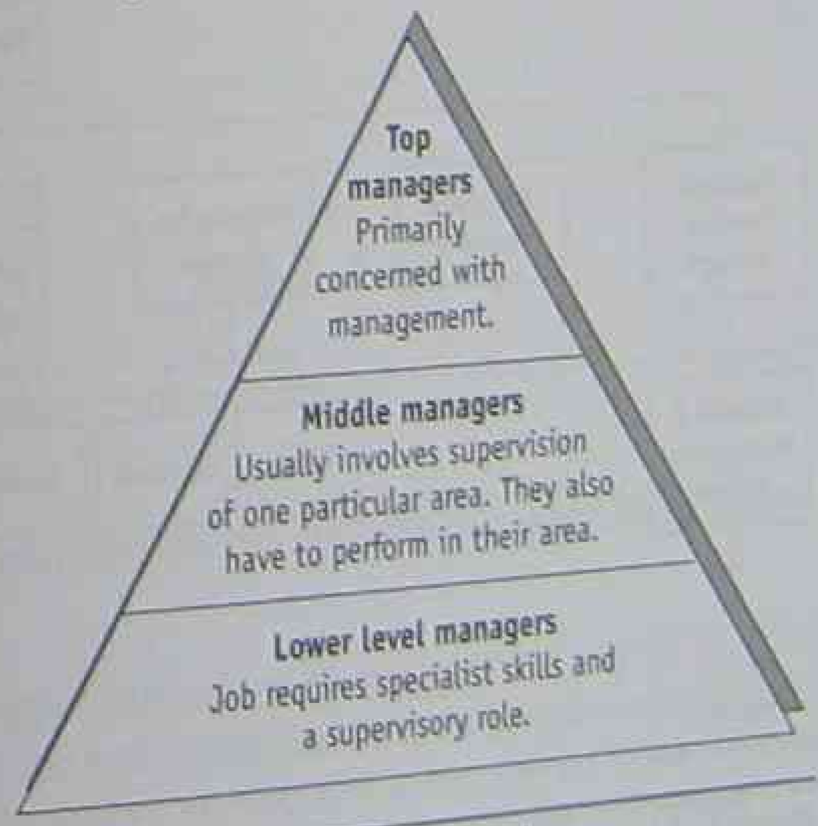


Figure 13.1 The levels of management

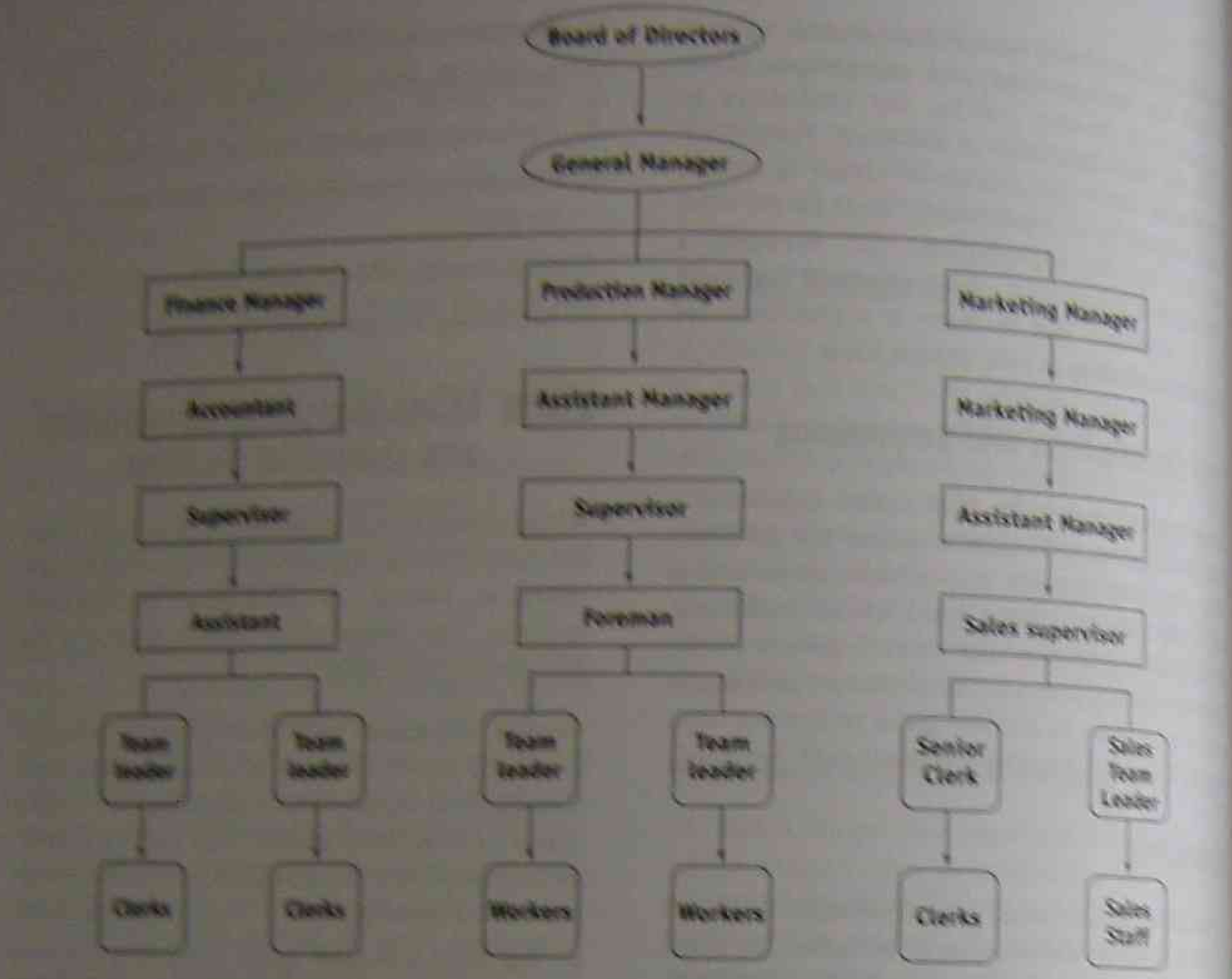


Figure 13.2 A hierarchical management structure

Horizontal structures have fewer levels, larger spans of control for managers, and tend to allow for greater horizontal communication. This model, with its **flatter structure of management**, is increasingly replacing the traditional model. There are fewer layers of management between the workers and the top management.

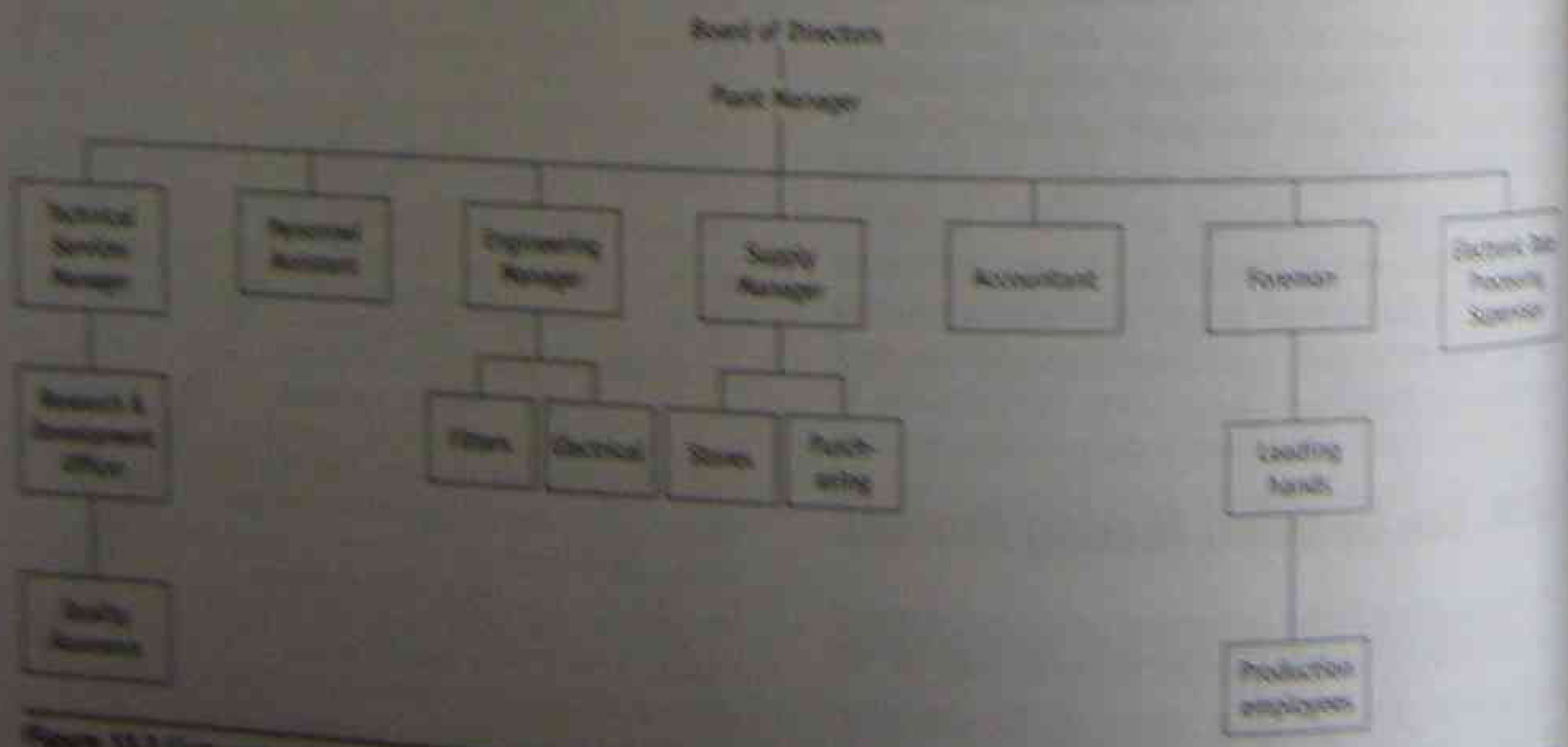


Figure 13.3 Flattened management structure

Management models may also be depicted as **molecules**. These molecule models are often used in preference to pyramid type structures, as it is easier to depict relationships between various roles at different levels. Remember also that management functions and characteristics differ between organisations.

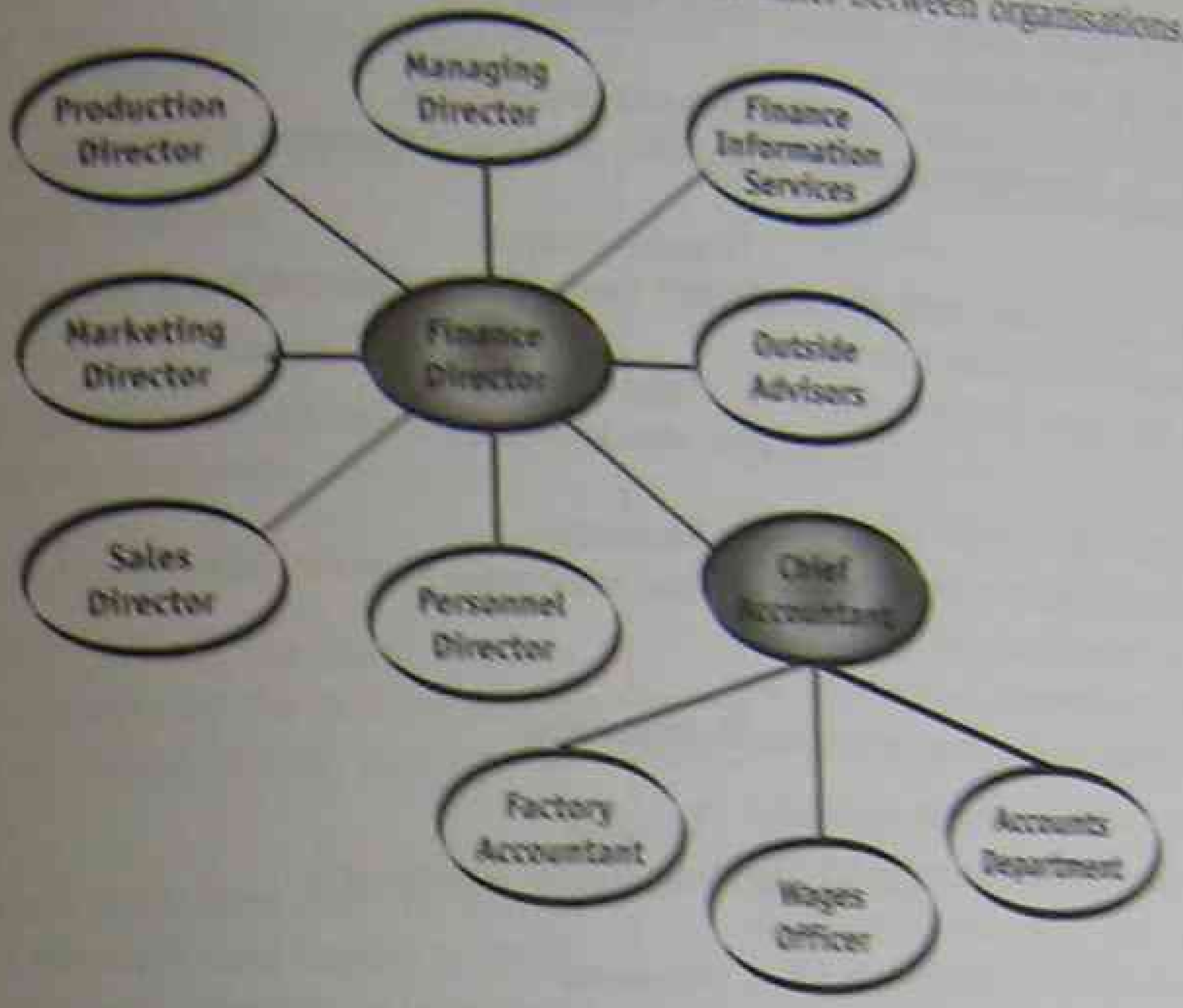


Figure 13.4 Molecular diagram showing the relationships between the Finance Director and other people at various levels.

Larger organisations tend to have complex vertical structures, long chains of command and a controlling Board of Directors. Directors are senior to managers. They are led by the Managing Director and have responsibilities to their shareholders, to the government, to the community, to employees (and the trade unions who represent them), and to customers. In larger organisations more work is delegated. This involves dividing jobs into various tasks and allocating these to people who are capable of completing them.

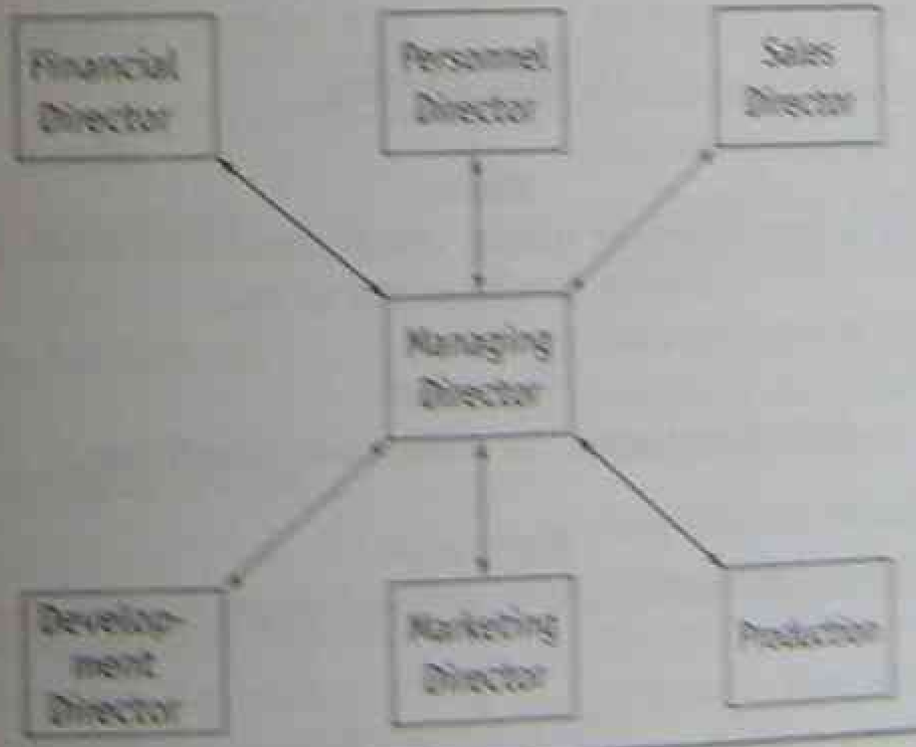


Figure 13.5 A central management team

Smaller organisations usually have relatively simple structures, owners are often managers and communication is usually informal and direct.

A good commercial or industrial manager will involve employees throughout the management process. This may be done by encouraging input into general decision-making and goal setting, and developing skills and knowledge through training, acknowledgement of achievements and by communicating freely. Managers are also expected to monitor the actual performance of employees and the organisation overall to ensure goals will be met.

Applying the Management Process within Commercial or Industrial Organisations

1. Planning

Research and Development
(Investigate products, production, consumer preferences and so on.)

Financial Analysis
(Will it be profitable? How will it be financed?)

Sales Plan
(Who, what and how?)

Resources
(Human and non-human.)

2. Organising

Facilities
(Offices, machines, factory, warehouse.)

Personnel
(Team approaches, training, recruit specialised staff.)

Buying
(New materials, facilities and equipment.)

Services
(Utilise financial institutions, maintenance, security, recycling and disposal of waste.)

3. Implementing

Making
(Aiming to meet targets for quality, rate of production, costs, profits, working conditions and so on.)

Promotion
(Information about the product and advertising.)

Distribution
(Must be available quickly and in sufficient supply to meet demand.)

4. Evaluating

Profit
(Did it generate sufficient profit?)

Process
(Was the process managed well?)

Product
(How could it be improved?)

Commercial and Industrial Project Management

Project management may include the following activities:

- Considering and interpreting the plans.
- Determining the work activities.
- Classifying and grouping work activities.
- Assigning and delegating authority.
- Establishing the chain of command from the alternative approaches available.

These are discussed in more detail below.

Considering and interpreting the plan requires technical expertise to determine the most profitable and rational course of action, taking available resources into account.

Determining the work activities may be carried out in two ways. The manager may choose to divide the tasks into specialist tasks (division of labour), or they may group the job into specific projects (project principle).

Classifying and grouping work activities requires consideration of the tasks involved (the job description) and the employee abilities required (job specifications) and is called **job analysis**.

Assigning and delegating authority involves four steps:

1. Determining the expected results.
2. Assigning the work to the subordinate employee.
3. Giving the subordinate the authority to accomplish the task.
4. Holding the employee responsible for the results achieved.

Establishing the chain of command from the alternative approaches available involves the manner in which authority, responsibility and accountability are delegated within an organisation.

13.5 Management Theories and Styles

Management Theories

- **Robert Owen** (1771–1858) believed that a manager's best investment was in people.
- **Charles Babbage** (1792–1871) emphasised the division of labour principle.
- **Frederick Taylor** (1856–1915) showed that careful observation of particular jobs could identify the most productive way of completing each task. This was considered to be scientific management.
- **Henri Fayol** (1841–1925) believed that good management was based on principles that could be taught rather than on skills that came naturally.
- **Elton Mayo** (1880–1949) discovered that special attention from managers and the development of bonds between employees in work groups could be the most important influence on how productive workers became.
- **Abraham Maslow** (1908–1970) argued that employees have needs that they wish to be satisfied. If all levels of needs are satisfied through the work then motivation levels will be higher.
- **Behavioural theories** involve management that understands the needs of people. Communication is very important.
- **Quantitative theories** involve the application of scientific methods to solve managerial problems.
- **Systems theories** appreciate the entire organisation and its component parts, including internal and external forces.
- **Contingency theories** emphasise that there is no approach to management that will work in all circumstances. The management style should therefore adapt according to the situation.
- **Management by objectives** involves setting all people in an organisation goals to achieve and then assisting them to reach them.
- **Total Quality Management (TQM)** is an approach to management that aims to continually improve the quality of performance of all aspects of the processes, products and services of an organisation. TQM philosophy stresses that everybody should do his or her task correctly the first time. It emphasises team activity, encourages pride in performance, develops more informed and supportive managers and supervisors and hence leads to a positive workplace environment. Poor quality may be demonstrated through customer returns and complaints, stops and delays in production processes, excessive wastage of materials, poor use of equipment, unproductive

sales, job dissatisfaction and increased employee absenteeism.

- **Value Added Management** is a variation of TQM and is based on continuous improvement, identification and elimination of waste and the complete creative involvement of all employees. The work team is a major concern.
- **Process re-engineering** involves becoming more competitive through simpler, leaner, more productive processes. Process re-engineering usually involves downsizing, which is removing any unnecessary management and activities, and empowering ordinary employees so that they take on management functions.

Management Styles

Autocratic leadership:

- Takes on all decisions.
- Requires that employees obey and follow all instructions.
- Allows little opportunity for employees to use their initiative.

Democratic leadership:

- Encourages ideas from employees and follows suggestions.
- Adjusts views to support a consensus.

Collegiate or committee leadership:

- The manager does not use their position or authority to influence the decision other than setting broad limits on what the decision could involve.
- Allows sufficient time for full consideration of all ideas.
- Allows the group to reach a decision.

Laissez-faire:

- Few limits are imposed.
- Employees are basically free to function as they wish.

Responsibilities of Managers

Managers have a responsibility to a variety of stakeholders including customers, employees, other organisations, creditors, owners, suppliers, the government, society, the environment and future generations.

Managers have the responsibility to:

- Manage change.
- Consider social justice.
- Consider ecological sustainability.
- Comply with the law.
- Follow codes of practice.

Financial Management

The sound management of finances is critical for the survival of any commercial or industrial enterprise. Financial accounting involves analysing the financial position of a business by studying its sales, purchases, overheads and so on. Monthly statements of profit or loss need to be assessed regularly to determine potential profitability.

A **budget** is a financial plan for the future. A budget includes a statement of anticipated results based on needs, historical spending patterns and operating expenses.

There are many different types of budgets including:

- **Sales budgets**, which show the relationship between anticipated sales and profits.
- **Production budgets**, which predict the costs of production influenced by variables such as resources, technology and skills.
- **Expense budgets**, which are devised to anticipate the cost of particular components such as advertising, employment or training.
- **Capital expenditure budgets**, which are useful in predicting the costs of resources such as new machinery and buildings.
- **Cash budgets**, which show the flow of cash in and out of an organisation.

Organisations and industries aim to make money and companies must determine at what point they can cover losses and start to make a profit. This is called the **break-even point**.

Review Questions

1. Worker motivation contributes to production output. A management plan to promote motivation would have:
   (A) Workers participating in decision-making.
   (B) A laissez-faire style of management.
   (C) Strictly controlled communication avenues.
   (D) No consideration for employees' needs.

2. Total Quality Management involves the commitment of everyone in an organisation to excellence and to a process of continuous improvement. An important factor in Total Quality Management is that:
   (A) An organisation attracts a bigger market.
   (B) All workers are involved in the process.
   (C) Long-term goals are developed.
   (D) An autocratic style of management is used.

3. Commercial and industrial project management is primarily concerned with:
   (A) The time it takes to design and finish tasks.
   (B) Researching the cost effectiveness of the whole project.
   (C) Determining the work, classifying and grouping work activities, delegating authority and establishing a chain of command.
   (D) Ensuring the project reaches the marketplace on time and below budget.

☞ *Answers to Review Questions, p. 128.*

Answers to Exercises

Exercise 1 page 119

(a) People skills.
(b) Technical skills.
(c) Thinking skills.
(d) Thinking skills.
(e) People skills.
(f) People skills.

Exercise 2 page 119

(a) Reassess priorities and maybe use cheaper or second-hand resources.

(b) Research whether wood stain would produce a similar effect on an alternative piece of equipment.

(c) Investigate a cheaper alternative that produces similar properties, for example, polyester.

(d) Research and go to libraries, ask professionals and so on.

(e) Use waiting time to complete other essential tasks, or conduct some research to find out whether there is any other software available that will produce similar results.

Answers to Review Questions page 127

1. (A) Workers participating in decision-making.
2. (B) All workers are involved in the process.
3. (C) Determining the work, classifying and grouping work activities, delegating authority and establishing a chain of command.

14 — Manufacturing, Production and Technology

Chapter Overview

Manufacturing and production is driven on a commercial basis by profit. Individuals may create products, systems or environments for their own pleasure or they may be driven by a specific need. Some of the factors that influence manufacturing include the scale of manufacture, planning procedures, resources available and the profit motive.

Expected Outcomes

On completing this chapter, students should be able to:

- identify design and production processes in domestic, community, industrial and commercial settings
- investigate a range of manufacturing and production processes and relate these to aspects of design projects
- justify technological activities undertaken in the Major Design Project and relate these to industrial and commercial practices.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

- automation
- batch production
- competitive edge
- custom production
- enterprise bargaining
- flexible manufacturing systems
- job specialisation
- just in time
- manufacturing
- mass production
- off the job training
- on the job training
- production
- quality assurance
- robotics
- technology
- workplace teams

14.1 Introduction

Australia is a free enterprise economy and within this economy organisations convert inputs such as labour, skills, raw materials, money and knowledge into outputs such as products, systems and environments. When this process works well the economy thrives and prospers and the standard of living improves.

Commercial manufacturing and production is of benefit to the economy as it:

- Can provide opportunities for investment.
- Can help redistribute wealth.
- Creates employment.
- Creates training opportunities.
- Encourages new products and innovations.
- Generates trade opportunities.

14.2 Organisational Structure

The structure of an organisation may be identified in a number of ways including:

- **Structure of management** such as hierarchical, partnership or sole proprietor.
- **Workforce profile** including number of workers, gender, roles, skills, unions, ethnicity, welfare, training, wages and conditions.
- **Physical environment** including buildings, noise, machinery, pollution, ease of movement, ergonomics of workplace.

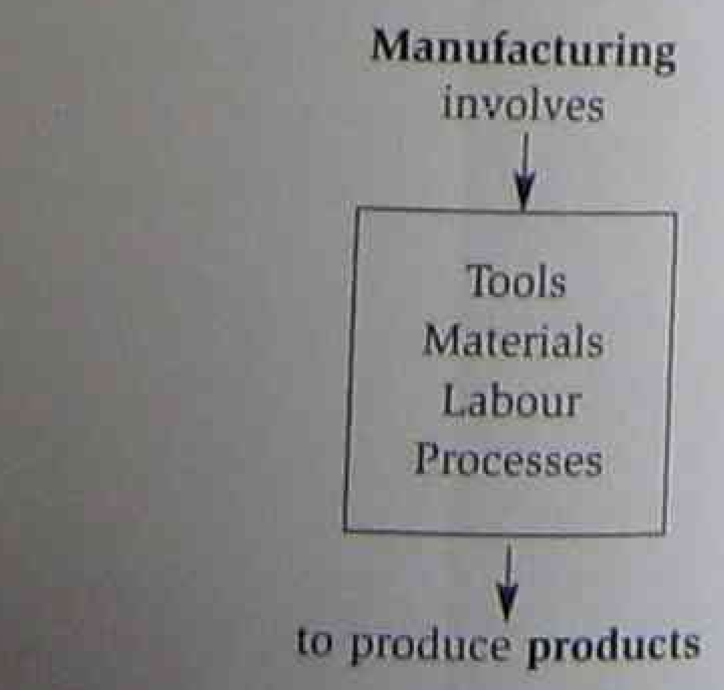
Levels of Operation

There are many different levels of operation in organisations within Australia including:

- **Size**, for example, small, medium or large.
- **Ownership**, for example, sole proprietor, partnership, companies, franchises and so on.
- **Market role**, for example, wholesale or retail.
- **Type of activity**, such as manufacturing, mining, construction, wholesale and retail trade, transport and storage, finance, property, business and community services, recreation, personal services and so on.
- **Industry sector**, such as primary, secondary or tertiary.

14.3 Manufacturing and Production

Manufacturing refers to the making of anything. It may involve large-scale concerns or the generation of one-off products. **Production** refers to making goods by any action or operation. The cost of tools and materials, availability of resources and market demand determines the production techniques used.



Design and the Manufacturing Process

Design will greatly influence the manufacturing process and designers should take into consideration how products will be made. Often a design will be modified many times by many people to accommodate the practicalities of the manufacturing processes.

Goods may be designed for the consumer in the following forms:

- **Ready to use**, where a product is ready to use once it leaves the retail outlet.
- **Designed for assembly**, where the design allows for easy assembly by the consumer.
- **Designed for disassembly**, where products are made so that they can be taken apart, reused and/or recycled. This form of design has resulted from concerns about dwindling resources.

The Manufacturing Process

Manufacturing must be planned if it is to operate efficiently. There are many steps involved in planning a manufacturing system and each system will vary according to the product made. The general steps are as follows:

1. **Identifying the customer demand** is necessary to ensure the product is purchased once it is manufactured (see Chapter 10 for more details).
2. **Designing the product**. The method of manufacture must be taken into account at this time
3. **Product details are finalised** by engineers, working drawings are made and product details and costs are calculated.
4. **Prototype is built and tested.**
5. **Marketing plan is developed.**
6. **Production sequences** are planned for efficiency.
7. **Parts and materials are chosen, ordered and stored.**
8. **Plant layout is organised.**
9. **Tooling-up for production** is the process of making sure tools are set up to do specific jobs.
10. **Jobs are planned and workers trained.**
11. **Trial runs** are held to discover any unforeseen problems.
12. **Full scale production.**
13. **Quality control measures** are implemented throughout all processes.
14. **Product is packaged and shipped** to sales outlets.
15. **Product is sold** to the consumer.

Extension

Compare and contrast the manufacturing process stated above to the process you went through when you designed and made a product. There should be obvious differences and similarities. Your process may also be ordered differently.

Manufacturing Techniques

Manufacturing may be carried out by individuals and by large and small organisations. The planned system of production may take many forms. As technology changes and trends, which influence consumer demand, develop, manufacturing techniques will adapt to accommodate these changes.

There are three basic manufacturing techniques:

- **Custom production** (**or one-off production**) is where a special order is placed and one person or several people work on one product at a time. They do all the processes on the product until it is finished. For example, a person may want a customised boat mast manufactured and installed on an existing boat. The buyer would go to a mast manufacturer, who does customised work, and convey their specifications. The manufacturing process is tailored to suit the customer's demands. Design and Technology students are also often involved in custom production when they design and make a product based on a need.
- **Batch production** (or **job-lot production**) is used when only limited numbers of a product are wanted. The company takes orders from individuals or other companies for a specific number. The machines are set up for this number and the products are made. After the products are finished, a new order for a different product is taken. The machines are then set up for the new product and production continues.
- **Mass production** refers to producing goods in large quantities. Henry Ford developed the first system of mass production for his Model T Ford motor car whereby parts were standardised for easy assembly. In this type of production, all elements are broken down into single operations

and people are assigned specific and often repetitive jobs. Machines and usually a conveyor system, for moving parts around the manufacturing plant, are set up in positions where they will remain for long periods of time. Once production starts, each worker does one job continually so they can specialise and work efficiently. A limited number of jobs may be rotated to reduce worker fatigue. Mass production has made goods more affordable. Today, machines often carry out the repetitive tasks created by mass production processes. As goods are produced in large quantities, quality is usually assessed throughout the whole manufacturing process, as well as by a certain amount of random sampling and testing.

Manufacturing Methods

The three basic techniques of manufacturing may be used in combination with other manufacturing methods such as:

- **Flexible manufacturing systems (FMS)** allow variations to the product design at the manufacturing stage, depending on specific customer requirements. This process is assisted by using computer-based technologies to make adjustments in the production process.
- The **just in time (JIT)** method has become a common production process in manufacture. It is a technique whereby a company produces and distributes only what consumers' need, when they need it. It is a cost efficient system because only the minimum required stock is held.

Factors Affecting Manufacturing and Production

Many factors influence manufacturing and production, including:

- The selection of processes appropriate to a need.
- The development of appropriate skills.
- The development of appropriate techniques.
- Project analysis, that is, learning how the product is made.
- Cost considerations including overheads (all costs that are not material or labour costs).
- Available resources including tools, labour, buildings and so on.
- Timing, which refers to the time taken for production, as well as the appropriateness of the product for the intended market.

14.4 Technology

Technology is the knowledge and creative processes that assist people to use resources to solve problems. People use, apply and modify technologies. Many people think of technology as objects made to make our lives easier such as computers, cars, microwave ovens, telephones and so on. However these items are the **products of technology**. Technology also involves knowledge and skills, processes and culture.

Technologies Used in Industrial and Commercial Settings

In order for an organisation to survive it must make efforts to be competitive and thus make a suitable profit. Technology can be used to maintain the competitive edge by implementing some of the following initiatives:

- **Development of a market plan.** A marketing plan must be developed for new and existing products if they are to be successful (see Chapter 10 for more details).
- **Diversification of product range.** A diversity of products may improve profitability. If a product is available on the market in many forms it may be more readily accepted. Consumers may also try new products if the manufacturing brand already has goods that are proven in respect of quality and reliability. Diversification may be carried out through:
  - ▸ **Line extensions,** which are additions to the product line in the same product category by manufacturing different sizes, models or flavours.
  - ▸ **Brand leveraging,** which is introducing a new product under an existing brand name.
- **Reducing the product range.** If there are too many products in a range and insufficient market demand to meet production, the organisation will need to cut back on the range of products manufactured.
- **Expansion of the organisation** may allow for more efficient production processes as larger volumes of resources such as raw materials, labour, machinery and equipment may be processed, thus reducing time, energy and costs.
- **Management restructuring.** A flatter system of management may work more efficiently by allowing greater scope for employee input. Refer to Chapter 13 for more detail on management structures.
- **Enterprise bargaining** is the system whereby employees negotiate working conditions with employers and it may result in improvements in productivity and hence profits.
- **Quality assurance** is a term applied to all processes in the workplace that are capable of leading to continuous improvements in quality. It maintains that standards and fitness for purpose are ensured from the beginning of the production process until the good is handed over to the consumer. **Quality control** is a set of procedures for the evaluation of a product as it evolves. Quality may be influenced by the original design, the source of raw materials, manufacturing techniques, management methods, worker training and skills, warehousing procedures, distribution methods, and consumer follow-up service.
- **On the job training.** Employees may need to be taught new skills on site when and if the need arises. Training can improve productivity, reduce injuries, increase job satisfaction and develop new skills. Training may range in formality from informal training via a co-worker to formal training through an external provider.
- **Off the job training.** Employees may be required to participate in training away from the workplace at TAFEs, universities or through private providers.
- **Job specialisation** involves workers doing set tasks. As the worker becomes more familiar with this task they become more efficient.
- **Workplace teams** involve workers being part of a group of people who share common goals and value each other's contributions. Workplace teams facilitate communication between workers and management, provide avenues for problem solving and allow a greater ownership of the consequences of actions for members of the team.
- **Mechanisation** involves the use of machinery to aid the production process. Greater investment in machinery usually results in fewer employees who tend to be highly skilled. Mechanisation increases the quantity of goods produced.
- **Automation** is the use of mechanical and electronic devices to take the place of human effort, observation and decision. It involves automatically controlling mechanical processes. The process is self-moving and self-acting. Automation can lead to greater efficiency.
- **Robotics** may be used to carry out precise, repetitive and often dangerous tasks. The robot used in manufacturing is usually a powerful one-armed manipulator with an appropriate gripping tool. It is most often a six-axis robot that is fixed either to the factory floor or to the machine it serves, although it can be mobile. A mobile robot in a factory is usually an Automatically Guided Vehicle (AGV) that moves around the factory floor in an automated fashion. The robot is controlled from a powerful computer that is usually located nearby. This computer's cabinet contains all the logic components and amplifiers needed to run the robot. The computer is generally also connected to other computers in the factory with high-speed communication lines. Most factory robots can repeatedly pick up work pieces and tools that weigh over one hundred kilograms and place them within about 1 mm of the desired location. They can move the loads at a speed of about 1 metre per second and put them down as gently as required. Grippers or robot hands of every description allow all manner of objects to be manipulated and controlled.

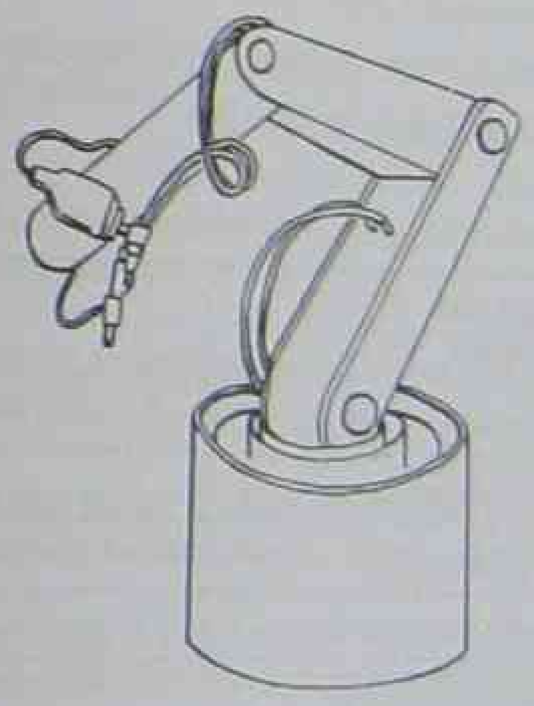


Figure 14.1 Example of a robot

- **Computerisation** is used throughout most manufacturing processes. Some examples include computerised stocktaking, record keeping, accounting, networking between organisations, computer-aided manufacturing (CAM), computer-integrated manufacturing (CIM), computer-aided design (CAD), computer-aided engineering (CAE), expert systems and so on. Refer to Chapter 12 for more detail.

1. An organisation must maintain its competitive edge if it is to survive in the marketplace. Methods that could be used to ensure this may include:
   (A) Management restructuring, on the job training and mechanisation.
   (B) Employment of external assessors to ensure employees are carrying out their job correctly.
   (C) Reducing the quality of the product and flooding the market.
   (D) Reducing the cost of the product by reducing employees' incomes.
2. Increasing the use of machinery in a factory tends to:
   (A) Result in fewer, though highly skilled, employees.
   (B) Increase labour costs.
   (C) Reduce job specialisation.
   (D) Lead to boredom and job-related injuries.
3. Quality assurance involves:
   (A) Assessing products as they come off the production line.
   (B) Making sure employees have adequate training in all aspects of their job.
   (C) All processes in the workplace that are capable of leading to continuous improvements in quality.
   (D) Using meetings to help employees recognise practices that will result in quality production.
4. Quality manufacturing is primarily influenced by:
   (A) Innovative technology.
   (B) Effective marketing strategies.
   (C) The training and level of expertise of the workers.
   (D) The ability of an organisation to obtain expensive resources.
5. Give a brief outline of both the innovation you have studied and your Major Design Project. Using the chart provided below, compare and contrast technologies and processes used in your MDP to production of an innovation in an industrial or commercial setting.

☞ *Answers to Review Questions, p. 135.*

Processes and Technologies	Innovation	Major Design Project
Manufacturing technique		
Deciding product range		
Size of organisation		
Management system		
Enterprise bargaining		
Quality assurance		
On the job training		
Off the job training		
Job specialisation		
Workplace teams		
Mechanisation		
Automation		
Robotics		
Computerisation		

Answers to Review Questions page 134

1. (A) Management restructuring, on the job training and mechanisation.
2. (A) Result in fewer, though highly skilled, employees.
3. (C) All processes in the workplace that are capable of leading to continuous improvements in quality.
4. (C) The training and level of expertise of the workers.
5. Sample answer using: Innovation — lace-making process using spun-bonded webbing and MDP — series of hats based on a theme.

   The processes are quite similar in some ways, as the production of the lace was not on a large scale, but there were distinct differences as the design project was not as streamlined. Many of the processes were developed as the project progressed. Future production of the hats may result in processes and technologies that align more closely with the lace manufacture.

Processes and Technologies	Innovation	Major Design Project
Manufacturing technique	Batch production based on commercial demand/JIT.	Custom/flexible.
Deciding product range	Range has increased as customer demand has increased. Now producing multi-colours and more 3-D effects.	Limited range.
Size of organisation	Production is integrated into a large-scale manufacturing plant. Without this support the production would not be viable.	One person.
Management system	Flattened management system.	Sole operator.
Enterprise bargaining	No evidence of enterprise bargaining.	Not applicable.
Quality assurance	QA measures are strictly followed as the market is competitive and the product appeals to higher income earners.	Modified QA measures are in place so the product is of a good standard.
On the job training	Initial training was on the job.	Training occurred throughout the process by learning new skills during problem-solving process.
Off the job training	Not applicable as the process is unique.	Studied D and T at school and completed a hat-making course at evening college.
Job specialisation	While in production, only two people are involved.	Specialised in the manufacture of the majority of the project. Got help from a commercial embroidery company for one component.
Workplace teams	Not used.	Not used.
Mechanisation	Specific machinery was used for cutting, forming, construction and packaging.	A domestic sewing machine and overlocker were used.
Automation	Production was not automated.	Production was not automated.
Robotics	Not used.	Not used.
Computerisation	Design specifications were calculated using computer software. Production was computer controlled.	Computerised sewing machine was used for the construction and decorations. A PC was used for design, research and supporting documentation.

15 – Safety Issues

Chapter Overview

Everyone has the right to be safe and everyone has the responsibility for maintaining a healthy and safe working environment. There are a number of laws and organisations influencing health and safety issues that have an impact on design and production.

Expected Outcomes

On completing this chapter, students should be able to:

- use resources effectively and safely in the development and production of design solutions
- explain the influence of trends in society on design and production
- select and use resources responsibly and safely to realise a quality Major Design Project
- justify technological activities undertaken in the Major Design Project and relate these to industrial and commercial practices.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

Codes of Practice
duty of care
hazards
legislative requirements
litigation
Occupational Health and Safety (OH&S)
regulations
risk assessment
risks
safety
standards

15.1 Introduction

Safety is a basic need that should be satisfied. Throughout the various stages of design and production safety hazards should be minimised. The safe disposal of the product and by-products should also be considered.

Materials that may produce potential safety problems include dusts, glass, metal filings, potting mix, paints, dyes, inks, fixers, finishes, cleaners and so on. Many processes also pose potential safety problems such as operating machinery, for example, tractors or overlockers, carrying out various cutting and sawing processes, heating and joining processes and so on. Tools can be dangerous if they are used incorrectly or recklessly. Correct training will help to minimise dangerous situations.

Safety problems affect the designer, manufacturer and user. They also have the potential to affect other people who may just be associated through proximity or who live in a related community. Safety is everyone's problem.

The designer's approach to health and safety issues may be influenced by the following factors:

- Moral, legal, ethical and professional responsibilities.
- Function and aesthetics.
- Costs of design and production.

Safe working practices are determined by the nature of the workplace. The general principles that apply to all workplaces include specific training, clear procedures and continuous monitoring. Part of this may include actions such as locking up poisons, obeying safety rules, and wearing protective equipment as appropriate.

15.2 Consumer Rights and Responsibilities

Consumer Rights

Consumers have a number of rights that are protected by law. These include the right to:

- Expect a certain quality, performance and level of safety standards.
- Be protected from misleading and deceiving marketing practices.
- Be given accurate information when buying or using goods and services, including any information which is required by law.
- Have clear safety instructions on potentially dangerous products.

Consumer Responsibilities

A consumer has the responsibility to:

- Check goods carefully before buying them.
- Read guarantees and warranties.
- Read and carefully follow safety instructions.
- Check that goods can be serviced reasonably and conveniently.
- Check that goods meet the advertising promise.
- Know what they need and can afford.
- Compare prices.
- Not sign documents without reading them carefully.
- Know where and how they can seek redress if needed.

15.3 Safety Issues at School and in the Workplace

Safety Issues at School

Students have a responsibility to ensure they strive to maintain a healthy and safe environment by:

- Complying with health and safety instructions given by those in authority.
- Taking action to avoid, eliminate or minimise hazards.
- Correctly using personal protective equipment.
- Not wilfully placing the health and safety of themselves or others at risk.
- Seeking information and advice if they are unsure about safe procedures and/or the correct use of equipment.
- Reporting all accidents or potential health and safety problems.
- Being aware of the location of first aid equipment, fire extinguishers, fire blankets and other health and safety equipment.
- Being familiar with emergency and evacuation procedures.

Safety Issues in the Workplace

Hazards are anything that can potentially cause harm to anyone working within an organisation.

A **risk** is the likelihood that a potential hazard will result in injury or loss. **Risk assessment** is the process used to help manage the risks to health and safety that may arise in the workplace.

Risk management includes the following processes:

- Identifying hazards.
- Assessing the risks.
- Eliminating or controlling hazards.
- Ongoing monitoring and reviewing of hazards.

Hazards may be identified through a variety of techniques such as:

- Hazards analysis, where each stage of the operating procedure is analysed for potential hazards.
- Workplace inspections.
- Injury and incident investigations.
- Safety reviews.
- Day-to-day observations.

Exercise

1. Draw up and complete the following chart for at least 10 hazards and risks.

Potential hazards and risks in your school. (These may refer to the use of materials, tools or techniques.)	**Devise an appropriate control strategy to eliminate or minimise the problem.**
For example, the risk of getting particles in an eye while using an electric saw.	Wear eye protection.

2. Look up WorkSafe Western Australia at http://www.safetyline.wa.gov.au and answer the following questions:
   (a) What are the three ThinkSafe SAM steps to prevent accidents?
   (b) Investigate one area of safety related to your MDP and work through the module. For example, if you were making a tree house for a disabled person you would complete the Building and Construction Module.

☞ *Answers to Exercise, p. 142.*

15.4 Legislative and Related Issues

Legislative Requirements

Legislative requirements refer to what must be done to satisfy the law. There are a multitude of Federal and State laws and regulations in relation to health and safety and there are penalties for organisations and individuals that are found guilty of breaching these laws. For example, penalties of up to $22,000 for individuals and up to $110,000 for companies may be imposed for breaches of the safety laws under the *Fair Trading Act* 1987.

Key Terms

Regulations provide a basic guideline for dealing with specific health and safety issues in greater detail than the *Occupational Health & Safety Act* (OH&S Act). They set standards to be achieved for the management of particular hazards such as noise, chemicals and manual handling and emphasise a process of identifying, assessing and controlling the risks. For example, one regulation made under the OH&S Act is the *Hazardous Substances Regulation* 1996. This regulation covers the identification, assessment and control of risks related to hazardous substances in workplaces throughout NSW, including schools. Another regulation affecting design and technological processes in schools is the *Dangerous Goods Regulation* 1978 which outlines the requirements for the use and storage of dangerous goods in the workplace.

Codes of Practice are practical documents that assist people to implement safe workplace procedures. They set out advice to employers on how they can achieve the minimum acceptable level of performance in a particular area and are produced by WorkSafe Australia. Codes may be used by a court as evidence of an employer's failure to implement their duty of care responsibility.

Duty of care refers to the duty of key people in ensuring the health and safety of people in the workplace. There is an expectation that everything that is practically possible is done to ensure this.

Standards are published documents that set out, in detail, specifications and procedures that ensure that a product, process or service consistently performs in the way it was intended to. Standards provide social and economic benefits such as improvements in safety, efficiency, quality, reliability, interchangeability, conformity and convenience. The process for developing a standard is as follows:

1. A request is made for a standard to Standards Australia.
2. The request is assessed in respect of community, economic and national benefit.
3. A technical committee is formed to deal with the standard.
4. A draft standard is made and assessed.
5. The draft is published and made available for public comment.
6. The draft is modified if necessary.
7. The committee votes on the final draft.
8. The standard is published.

The Occupational Health and Safety Act 2000 (NSW)

This Act aims to reduce the high level of workplace injury and to ensure employers consult with their employees to make certain the workplace is safe and without risk. The purpose of the OH&S Act is to protect employees and the general public and its primary aim is to protect the health, safety and welfare of people in the workplace environment. It is based on the premise that all employees and other people at a place of work have the basic right to protection from unsafe and unhealthy working environments. This Act replaced the *Occupational Health and Safety Act* 1983 (NSW).

The Act aims to:

- Ensure the health, safety and welfare of all employees.
- Protect other people at the workplace, such as visitors.
- Promote a working environment that suits employees' physical and psychological needs.
- Provide a framework for protection that uses regulations, Codes of Practice, standards and joint consultation.

Occupational health and safety works best when the principles of health and safety are incorporated into the organisation's overall plans and strategies. This works best when both employers and employees participate in the processes.

OH&S Committees

The aim of OH&S committees is to raise awareness of occupational health and safety amongst employees. The basic procedure for forming an OH&S committee is as follows:

1. Employees must vote in favour of forming the committee.
2. The employer is informed.
3. A meeting is held to discuss the make-up of the committee. There cannot be more representatives from the employer than there are employee members.
4. A method is determined for electing representatives. Nominations are called for and an election is held.
5. First meeting is held. Committee members may then organise to participate in accredited training.

This committee should then:

- Develop an OH&S policy and related programs.
- Establish a training strategy.
- Set up a consultation mechanism.
- Establish a hazard identification and workplace assessment process.
- Develop and implement risk control.
- Promote, maintain and improve these strategies.

Key Organisations

The **National Occupational Health and Safety Commission (NOHAC)** (http://www.nohsc.gov.au) is a national body that leads and co-ordinates efforts to prevent workplace injury, disease and death. It is made up of Government, employer and employee representatives. WorkSafe Australia was the NOHASC's corporate title but this is no longer officially used.

Standards Australia International Limited (SA) (http://www.standards.com.au/) is a private organisation that sets standards in consultation with overseas standards bodies and relevant Australian working parties. They do not have the force of legislation unless specifically called up in legislation. Standards Australia was formally known as the Standards Association of Australia.

The **NSW WorkCover Authority** (http://www.workcover.nsw.gov.au) is an organisation responsible for managing the State's workplace safety. It administers OH&S, rehabilitation and workers compensation, and tests and licences specific qualifications such as those related to the use of cranes and explosives.

The **Workers Compensation Advisory Council of NSW** advises the Government bodies responsible for workers compensation and OH&S policy and legislation.

The **Occupational Health and Safety Council of NSW** advises both the Workers Compensation Advisory Council and the WorkCover Authority on any matters relating to occupational health and safety.

The **National Safety Council of Australia** (NSCA) (http://www.safetynews.com) is an independent body that promotes health and safety across Australia. It is a non-profit, member-based organisation. The Council provides training and consultancy services and also publishes two OH&S magazines.

The **NSW Department of Fair Trading** (http://www.fairtrading.nsw.gov.au) is a Government department that seeks to promote an equitable trading environment for consumers and businesses in NSW by providing information, monitoring marketplace practices and formulating strategies to reduce illegal trading activities. The department is committed to ways of reducing safety problems that consumers may face and as part of this commitment they provide an information service on buying safe products.

The **Fair Trading Tribunal** is an inexpensive and informal way of resolving disputes. It has four divisions — consumer claims, home building, commercial claims and the motor vehicles division.

Extension

1. As the Occupational Health and Safety legislation will be being updated over time, use the Internet to find out if there have been any recent changes to this Act.
2. Use the Internet to research the legislative functions of WorkCover.
3. Find out how your school handles hazardous substances and dangerous goods to comply with the *Hazardous Substances Regulation* 1996, *Dangerous Goods Act* 1975 and *Dangerous Goods Regulation* 1978. Have these OH&S laws had an impact on you as a Design and Technology student?
4. Investigate some current news articles about OH&S by accessing the NSCA website. List some of the costs and implications of poor safety procedures. You may like to search through the archives to gain a more thorough understanding.
5. Use the Department of Fair Trading website to find four examples of potentially unsafe products. Summarise the safety regulations that must be adhered to if the product is sold to consumers.
6. The *Fair Trading Act* 1987 is an extensive and detailed Act. Read through the Act and list some of the areas it covers. (The Act may be found on the NSW Consolidated Legislation web page http://austii.edu.au)

Litigation Trends

Litigation refers to the process of using the legal system to contest points of law. Australia is following the United States trend where many people are taking individuals and organisations to court over safety issues. This has put extra psychological and financial pressure on the individuals and organisations involved in maintaining safety.

Extension

Research a product that has failed and caused injury to a person. Investigate reasons for the failure, the implications of the failure and describe any legal action that was taken as a result. Newspaper archives and *CHOICE* magazine may provide some valuable case studies for this exercise.

Review Questions

1. The *Occupational Health and Safety Act* 2000 (NSW) is a:
   (A) Legislative requirement that protects the health, safety and welfare of people in the workplace environment.
   (B) Requirement that protects the safety of people in the workplace environment and is entirely controlled by the employees.
   (C) Law based on the premise that all employees and other people at a place of work will always be protected from unsafe and unhealthy working environments.
   (D) Legislative requirement that asserts employees must set up an OH&S committee.
2. When designing a child restraint for a motor vehicle the most important consideration is the:
   (A) Safety and legal requirements.
   (B) Comfort and non-flammable characteristics of the materials.
   (C) Quality and strength of the unit.
   (D) Cost of materials and manufacture.
3. An OH&S committee should:
   (A) Organise all members to participate in accredited training.
   (B) Hold meetings to discuss the publicity campaigns and educational strategies.
   (C) Develop a policy, establish a training strategy, set up a consultation mechanism, establish a hazard identification and workplace assessment process and develop and implement risk control.
   (D) Manage all OH&S issues.
4. An employee notices that the fumes produced when using new ink in the printing process appears to give some people headaches. They should:
   (A) Discuss this issue with their doctor to find out the most appropriate medication for fume-induced headaches.
   (B) Raise the issue with the OH&S officer.
   (C) Contact the union and recommend a stop-work meeting until the issue is addressed.
   (D) Tell the employer to place a warning sign over the printer.
5. For a design you have studied or created, recall how health and safety factors have influenced the use of materials, tools and techniques related to the project.
6. Everybody has the right to be safe. With reference to a design you have studied, discuss how legislative requirements, including OH&S, have influenced the design.

☞ ***Answers to Review Questions, p. 142.***

Answers to Exercise page 138

1. Student response.
2. (a) (i) Spot the hazard.
   (ii) Assess the risk and work out the likely possibility of the hazard hurting someone.
   (iii) Make the following changes as necessary — elimination, substitution, isolation, safeguards, safest way to use and appropriate protective equipment.
   (b) Student response.

Answers to Review Questions page 141

1. (A) Legislative requirement that protects the health, safety and welfare of people in the workplace environment.
2. (A) Safety and legal requirements.
3. (C) Develop a policy, establish a training strategy, set up a consultation mechanism, establish a hazard identification and workplace assessment process and develop and implement risk control.
4. (B) Raise the issue with the OH&S officer.
5. and 6. Student response.

16 — Evaluation

Chapter Overview

Evaluation throughout the design production and at the end of the process is essential if the project is to be a success.

Expected Outcomes

On completing this chapter, students should be able to:

- evaluate the processes and outcomes of designing and producing
- evaluate the processes undertaken and the impacts of the Major Design Project.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms

evaluation

tests

16.1 Ongoing Evaluation

The most important thing to note about evaluation is that it is not something that you do at the end of your Major Design Project, rather it starts the moment you begin the project and, in theory, never ends.

Dr Ron Sinclair, an expert educationalist and university lecturer, has stated in his published research on classroom pedagogy (the art or function of teaching) that 'we don't really learn anything from experience, only from reflecting on the experience', and this is true for designers. It is important to examine the process as well as the end product in order to ascertain what contributed to the success or failure of the design.

If we fail to provide ongoing evaluation, then we fail to learn which of the steps contributed to the design solution's success and, in turn, which steps will be transferable to future design projects.

One the design brief is clear the designer needs to state the desirable criteria that will make the final solution successful. The criteria are a list of what you expect the solution to look like and to do and how it will work.

Once the brief has been clearly stated and the desirable functional and aesthetic criteria listed, the next step is to design and develop possible solutions that will be refined until the project fulfils the brief. The development of these ideas, and the decisions as to which materials, tools and techniques to use, will require much thinking, research, experimentation and testing. It is most important to document every idea, thought and process tested and used, as this provides evidence of how decisions were made, and your use of higher order thinking. In addition, documenting tests and experiments can provide information for future design tasks.

It is important to evaluate throughout the process and remember, if you think it, write it down! Jean Bacdrillard, a Canadian technological communications expert, said in discussing the impact of Internet usage in schools that 'we live in a world where there is more and more information but less and less meaning'. When you are completing your testing make sure that all tests are relevant and relate directly to the design brief. Do not just test for the sake of testing. If you remember the question 'When should I evaluate my MDP?' and the answer, 'All of the time', you will stay on track.

16.2 Criteria to Evaluate Success

In listing the criteria that will make the final solution successful, you need to include both functional and aesthetic elements. The stated criteria must ensure that the solution fits the design brief and abides by any relevant limitations. Limitations may include a fixed budget, a tight time schedule or a requirement for the specific use of certain ideas, tools, techniques or materials.

The final evaluation of your MDP should be written in terms of the identified criteria for success. It is important that the criteria are not only met, but met at a high standard.

Analysing Criteria for Evaluation

As stated above, the criteria needs to be divided into functional and aesthetic elements. Functional criteria includes information on what it will do and how it will work, whilst the aesthetic criteria refers to what it will look like.

For example, if you were to design a mailbox, the criteria may include the following:

Aesthetic:

- Made from timber, for example, to match the house.
- Fits in with the surrounding environment.

Functional:

- Able to withstand a range of weather conditions.
- Is stable and will not fall over.
- Protects the mail from the elements.
- Is large enough to hold papers and small parcels.
- Can be locked.

When writing your final evaluation you need to comment on how your solution has fulfilled each of the criteria listed. Do not omit any as the markers may cross-reference to ensure that your solution does fit the design brief.

16.3 Implementation of Design Solutions

Always include evidence of testing and experiments performed and write them up in a consistent format. The following example relates to the testing and evaluation of three different types of seams for a business shirt.

Experiment 1: Seam Finishes

Aim: To determine the most effective seam finish on the chosen fabric for a business shirt. This will be tested by completing a French seam, an overlocked seam and a zigzag seam, and then comparing their appearance and launderability.

Appearance is important in order to produce a high quality item and in terms of aesthetics and marketability.

Launderability is important because the garment will be frequently worn and laundered and must therefore be durable.

Procedure for manufacturing a French seam:

1. Stitch 'wrong' sides of fabric together, 7 mm from edge.
2. Trim, turn and press French seam.
3. Stitch seam together 7 mm from edge, reversing at each end.
4. Trim, turn and press.

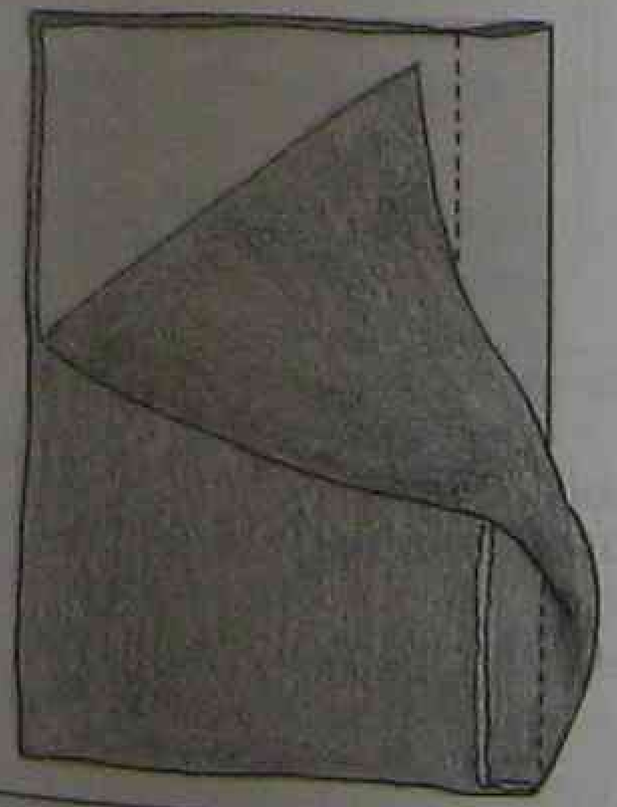


Figure 16.1 French seam sample

Procedure for manufacturing an overlocked seam:

1. Stitch fabric together using a straight stitch 1.5 cm from the edge, reversing at each end.
2. With both sides together, overlock the edge of the fabric. The overlocker trims the unwanted edges.

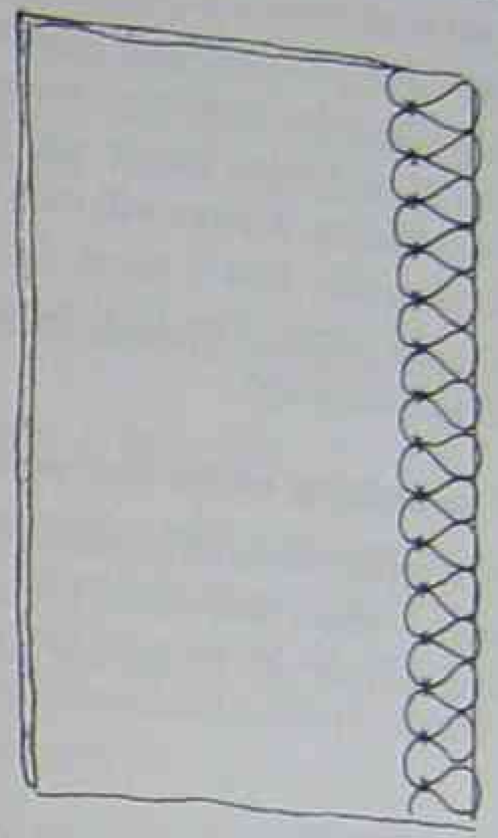


Figure 16.2 Overlocked seam sample

Procedure for manufacturing a zigzag seam:

1. Zigzag along the edge of the fabric.
2. Stitch fabric together using a straight stitch 1.5 cm from the edge, reversing at each end.
3. Press seam open.

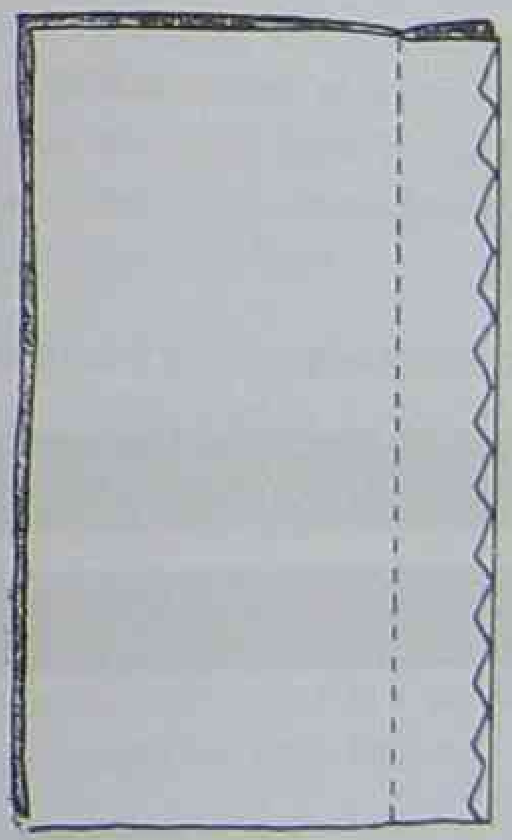


Figure 16.3 Zigzag seam sample

Procedure for testing appearance:

The three textile experts at the school will be requested to examine the three samples and score the appearance, with 3 being the best score and 1 being the worst. These scores will be totalled to ascertain which seam produced the best appearance with the results represented on a bar graph.

Procedure for testing launderability:

All three seam samples will be laundered in the washing machine in cold soapy water and any differences in the seam tension or evidence of the fabric puckering or fraying will be noted. This will be anecdotal evidence. A score will then be allotted to each of the seams, with 3 being the best score and 1 being the worst. The final scores will be represented as a bar graph.

Procedure for deciding on the best seam finish:

The scores for appearance and launderability will be added together to give a final score. The seam finish with the highest score will be the one used on this fabric.

Marks for appearance:

Teacher 1	Scores
French seam	2
Overlocked seam	3
Zigzag seam	1

Teacher 2	Scores
French seam	3
Overlocked seam	2
Zigzag seam	1

Teacher 3	Scores
French seam	2
Overlocked seam	3
Zigzag seam	1

Results for appearance:

Anecdotal evidence/marks for testing launderability:

French seam: Trimmed too close to edge and seam has started to pull away. Has also started to pucker. Score = 2.

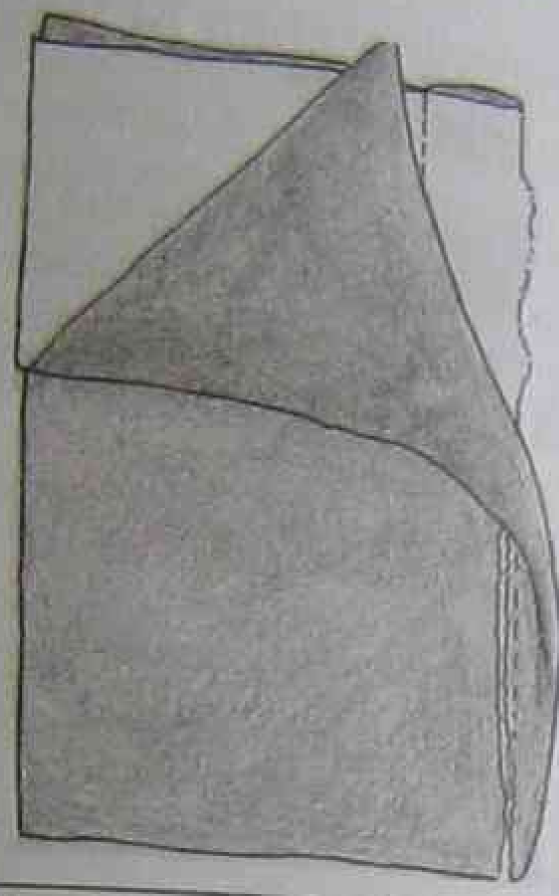


Figure 16.4 French seam sample

Overlocked seam: Seam has good tension. Has twisted a little due to not having the correct tension on all threads whilst stitching. Easy to overcome. Score = 3.

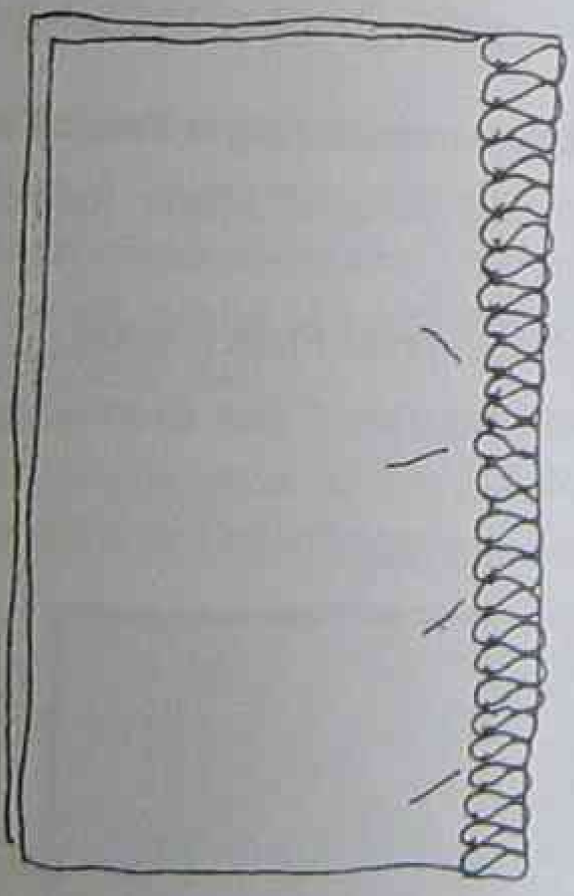


Figure 16.5 Overlocked seam sample

Zigzag seam: Seam has started to fray after one wash and is not suitable. Score = 1.

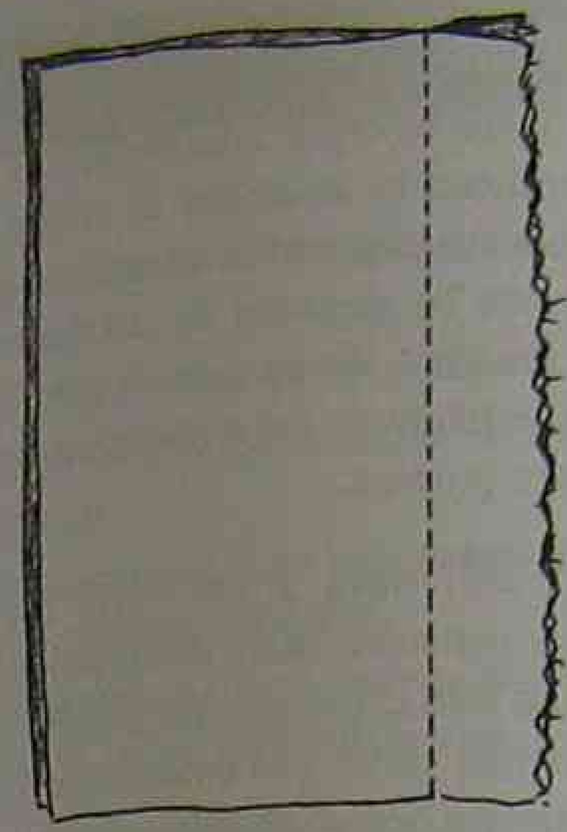
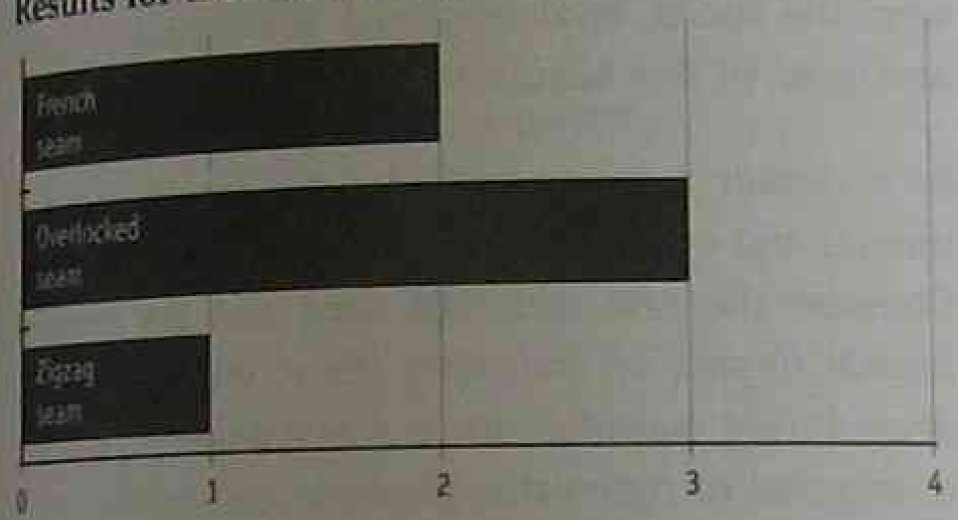


Figure 16.6 Zigzag seam sample

Results for launderability:



Overall best seam	Total scores
French seam	7 + 2 = 9
Overlocked seam	8 + 3 = 11
Zigzag seam	3 + 1 = 4

Conclusion

From the experimentation it was concluded that:

1. The best seam finish for appearance was the overlocked seam.
2. The best seam finish for launderability was the overlocked seam.
3. The best seam finish overall was the overlocked seam.

Therefore, the overlocked seam will be used.

It is necessary to provide evidence of the testing carried out and this may take the form of practice samples, photographs, videotape or digital images as well as written evidence. Remember, use common-sense and do not perform tests without valid reasons.

16.4 Final Evaluation

Your ongoing evaluation must be apparent throughout the folio. It might be a good idea to colour-code all evaluation so it stands out for the markers and it will then also be obvious in your student diary. All students need to keep a weekly diary which details what was completed each week, as well as any intended plans and also relevant comments on decisions made. This is evaluation.

For example:

Design and Technology, Major Design Project Diary.
Week 1, Term 2, Date 30/4

Work completed: I have completed my design brief idea, some secondary research and written a design brief that I will be working on for the HSC. I have listed my functional and aesthetic criteria, and limitations to the project.

Work to do next: I am going to sketch some of my ideas and research the function of unusual ingredients in food. I am especially interested in the physiological function of ingredients such as MSG.

Decisions made: Decided to work in the 'Food' area with my design brief as this is the area that I want to work in when I finish school. If I do a good job, I can use my folio to help me at job interviews.

Your diary can be used to provide the marker with valuable information but it cannot be written after the event. It must be written as the project develops to be effective. Try to set aside 15 minutes once a week to update your diary. Remember, evaluation is worth 15 marks for your MDP.

It may be helpful if you can get a written evaluation of your project completed by a recognised professional in the area that you have worked in. Having a mentor who can guide you through the difficult components of your project and write a complete evaluation of your project could be of enormous benefit. However, remember that a **mentor is there to assist you, not do the work for you.**

16.5 The Impact of the MDP

You may choose to survey a range of the project's end users to justify the comments you make in this area. An appropriate text type to use would be a critical analysis. You must comment on all of the following:

- Explain to what degree this project satisfies the original need in your design brief.
- How well does it meet with the established functional and aesthetic criteria?
- Comment on the relationship between the aesthetics and the function.
- What were some of the problems that arose and how did you go about solving them?
- How did you use the project limitations to your advantage?
- What factors contributed to the success of this project?
- What factors contributed to the failure of sections of this project and how were they overcome?

Compare your product with existing products in society and explain clearly why yours is the superior product. How have you improved on what currently exists? Explain how this project may benefit people in society and address the wide-ranging implications of mass production.

Consider the implications of your design on designers, raw material usage, occupational health and safety, processes and manufacturing, by-products and waste, pollution, and the product's effects on industry and employment.

Every product has a life cycle. It enters the market as a new commodity, and hopefully gathers sales, thereby making the manufacturer a profit. It will usually then reach a plateau for a period of time. The time it takes to reach and remain on a plateau will be determined by its ability to satisfy consumer needs, the advertising and marketing used and the ease that it can be replaced by a better and more marketable product. When sales begin to decrease, the product is likely to be replaced by a new and perhaps better product.

The product will have a life cycle but a clever designer will consider both durability and obsolescence in the initial design and should also try to consider potential social and environmental benefits. If these factors are not taken into account, there may be considerable social and environmental costs. For example, the costs are still being counted for the atomic bomb that was dropped on Hiroshima. What were the social, environmental and ethical benefits and costs of this occurrence?

In a similar manner, consider the social, environmental and ethical benefits and costs of your MDP. Consider the raw materials used and the environmental impact of extracting these, energy conservation during manufacturing, waste disposal, the use of recycled or renewable products and so on.

Complete a flow chart of a cradle to grave analysis of your MDP to assess the impact of each of the activities undertaken in the development of your design on the individual, society and the environment. Then, by describing each step in the flow chart, you can translate this information into a written evaluation.

Review Questions

1. The key function of evaluation, as used by designers, is to:
(A) Minimise the number of mistakes.
(B) Ensure the efficient selection of appropriate resources.
(C) Experiment and draw conclusions that will apply to design projects.
(D) Ensure that the best solution has been reached via an efficient process.

2. Evaluation is essential to the success of any design project. The best time to do an evaluation is:
(A) Near the end of the project.
(B) Near the beginning of the project.
(C) Throughout the project.
(D) At the very end of the project.

3. In relation to the design brief, the role of evaluation is to:
(A) Ensure that every aspect of the brief has been addressed.
(B) Ensure that the solution will make money for the client.
(C) Test possible tools, materials, techniques and ideas.
(D) Establish an accurate financial plan.

Answers Evaluation

Answers to Review Questions

1. (D) Ensure that the best solution has been reached via an efficient process.
2. (C) Throughout the project.
3. (A) Ensure that every aspect of the brief has been addressed.

17 – Innovation and the Factors that Impact on the Success of Innovation

Chapter Overview

Australians are known to be great innovators but unfortunately many of these innovations are not developed into successful commercial ventures. The success of an innovation is influenced by a multitude of domestic and global factors.

Expected Outcome

On completing this chapter, students should be able to:

— analyse the factors that influence innovation and the success of innovation.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

copyright

creativity

emerging technologies

entrepreneurial activity

innovation

patent

17.1 Introduction

Australians have historically demanded a high standard of living, which has in the past relied upon our primary industries. However, modern Australia needs to encourage and promote innovation and make the best use of advances in technology. It is often said that Australia is good at invention but poor at realising inventions into innovative products. Few individuals, companies or industries are willing or able to regularly invest the time, energy and resources required to successfully develop ideas into reality.

Innovation involves a change to established product designs and manufacturing, and to marketing or organisational structures. Innovation is when something new or different is introduced. An innovation is often based on discoveries or inventions that are then changed and improved.

Innovation refers to:

- Material objects, for example, a mousetrap, Velcro, safety pins.
- Knowledge of operating practices, programs, skills, attitudes, experience and so on.
- Organisations and industries, for example, genetic engineering, pharmaceuticals, space technology.

The term 'invention' **is commonly reserved for an original concept or discovery**. It consists of the first ideas, sketches or development of a product, system or environment. Inventions are believed to:

- Depend on an intuitive flash of insight.
- Be encouraged by a sympathetic social ethos and awareness on the part of the most creative minds in those fields that are most in need of new discoveries.
- Not always dependent upon advanced technological training, though they are more likely to emerge from such a background.
- Be only minimally dependent on phases of the economic cycle, though encouragement is likely to be greater and the inventions more likely to be successful if the economic conditions are favourable.

Creativity involves originality of thought or expression. It is the product of something that is new. Creativity in design is distinctly different from innovation in design in that it is not based on the improvement of an existing design, but displays something original and unique. Creative and innovative designs ultimately aim to change what people do, experience or value.

Innovation is the end result of many factors including:

- Imported technology.
- Local research.
- A culture that welcomes and exploits new ideas.
- Financial support for new ideas.

Innovation in Australian industries may result in:

- **Improved economic outcomes** such as:
  - Survival and growth of organisations.
  - Increased employment.
  - Increased exports leading to national prosperity.
  - Value adding to commodities by further processing and differentiation.
  - Improved skills in the workforce via reskilling and multiskilling.
- **Social and cultural changes** such as:
  - New ways of working, including part-time, telecommuting and so on.
  - More opportunities for leisure.
  - Greater access to facilities and information.
  - Changing perceptions and values.
  - Reduced working hours.
- **Environmental changes** such as:
  - Environmental monitoring and protection.
  - New standards of safety, performance and quality.

Exercise

Explain the difference between creativity and innovation.

☞ *Answers to Exercise, p. 159.*

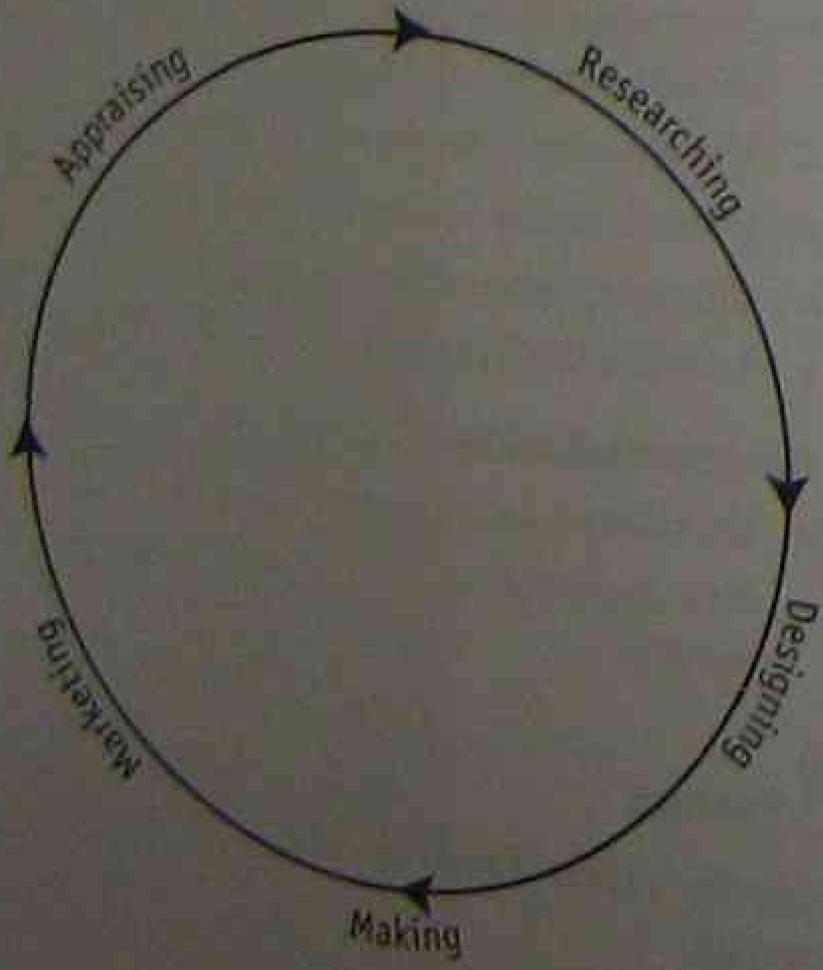
17.2 Processes Undertaken to Develop an Innovation

The most common model of how products or processes are created is known as the **linear model of innovation**. This model treats the innovation process as a sequence from basic research, through applied research, to experimental development and hence deployment. Despite the attractiveness of the linear model, innovation involves many complex and sophisticated interactions that are not indicated in the model. In any successful innovation these activities overlap and are repeated many times as the innovation is improved, updated or extended. Knowledge gained from carrying out each of these activities will influence other activities, especially the appraisal of ideas to improve, update or extend the innovation.

The steps of innovation may be detailed as:

1. **Appraising** existing, and new, needs and wants of consumers.
2. **Researching** ideas for the innovation that might meet the desired criteria.
3. **Designing** a product, system or environment that will meet the identified needs and the legal registering of the innovation.
4. **Making**, assembling, finishing and packaging the innovation.
5. **Marketing**, distribution, sales and servicing of the innovation.

The process of innovation may be represented as a circle of overlapping activities that are repeated many times.



The most comprehensive approach to innovation is **system innovation**. This involves developing all the elements needed to carry out production or another function. A traditional example of system innovation is the 'turn-key' approach, where all the purchaser has to do is turn a key and the system is expected to work. Consumers are demanding the turn-key approach when purchasing more sophisticated innovations such as computer systems.

To develop an innovation into a commercial success a designer will generally work through the following steps:

1. **Identifying a market opportunity**. When developing an innovation it is essential to first identify a market opportunity. In order to do this it is necessary to research the market to ensure that the perceived need actually exists.
2. **Obtaining and managing resources**. A continual flow of the necessary resources for an innovation is a must if it is to be successful. Resources may include people, skills, knowledge, energy, finance, time, tools and materials. If any of these resources are in short supply throughout the research and development phase, the entire project is put at risk.
3. **Research and development**. Primary and secondary research, and testing and experimenting of the design must be carried out to develop the product, system or environment. Intensive redesigning should occur using the latest suitable emerging technologies in order to develop the best solution to the design situation.
4. **Protecting intellectual property**. The designer needs to ensure that others do not steal, copy or manufacture their design. The designer has specific rights and responsibilities and protection of intellectual property may be formally sought through IP Australia.
5. **Product design** will evolve and change over time as research and testing is carried out and new technologies become available.
6. **Obtaining resources/supplies**. Once the product design is finalised, the next step is to ensure resources are available in order to move into the manufacturing phase. A continual flow of the necessary resources is essential for a design to be successful. If any of these resources are in short supply manufacturing cannot continue and the entire project is put at risk.

7. **Manufacturing** is the process whereby the design is made. Research into the necessary resources and manufacturing processes, timing of production runs and calculation of production costs will assist this process to run smoothly.
8. **Promotion**. Advertising, in its many forms, is needed to inform people that the innovator has designed and manufactured a desirable product that will help to make their lives a little easier or more enjoyable.
9. **Distribution, sales and service**. A marketing plan is instrumental in the product's success. This needs to be well thought out and documented, and timing is important. For example, in 2000 Dick Smith Foods had a distribution problem because the advertising campaign for Dick Smith peanut butter reached its peak but distribution was held up by a legal challenge from another food company. People had heard about the 'Aussie' product and wanted to buy it but it was not yet available on the shelf.

17.3 Success of an Innovation

Obviously not all innovations are successful. Some of the possible reasons why they may not succeed include:

- The idea may not be good enough.
- There were not enough resources available to help realise the idea.
- Well-established and comparable or competing solutions already exist.

Innovators often have some of the following personal characteristics:

- Intelligence (but not necessarily genius).
- Burning curiosity.
- A high degree of autonomy and self-sufficiency.
- Resilience.
- Non-conformist attitudes.
- Ability to take risks.
- Hard-working.
- Intuitive and creative.
- Not afraid of apparent contradictions.
- Not predisposed to reach premature conclusions.

The success of innovation is determined by:

- Its users.
- The organisation(s) introducing it.
- The region, industry or nation where it was introduced.
- Other regions, industries and nations.

Successful innovations do not result from a one-off effort, bur rather repeated cycles of incremental improvements and enhancements made to improve quality, safety, appearance and other aspects that establish an advantage over competing products or processes.

Factors critical to success in any innovation include:

- **Effort and risk-taking**. Successful innovation is always attributed to a huge amount of effort and time. Innovation is often the result of necessity and adversity and the ability to take risks and think creatively is not innate in all people. An innovator needs to put in the effort and have confidence in their abilities.
- **Managing all of the elements of the innovation.** Successful innovators regard the innovation process as a complex series of steps that overlap at times. Every element must be managed carefully as the mismanagement of one step could be financially catastrophic, and could influence the success of the innovation. A designer should oversee and manage every step intricately.
- **Seeking out other sources of innovation**. By thoroughly researching, testing and experimenting and using cutting-edge technology, a designer can help make their design a success.
- **Integration of all elements of innovation**. A collaborative approach between researchers, designers, manufacturers and marketers will contribute to the success of the product. All these elements overlap and should be integrated throughout the project.
- **Continuing improvements**. Once a company achieves a competitive advantage through an innovation, it can sustain it only through continual improvement. Competitors will eventually overtake a company that stops improving itself.
- **Sustained investment**. In any successful design, ongoing success will depend on sustained and

cumulative investment in physical facilities, research and development and marketing. Assets in the form of a good reputation, strong customer relationships and specialised knowledge also need to be continually worked on.

- **Analysis of successful innovation**. Innovation is a means of increasing productivity, reducing unit costs and gaining a competitive edge over the competition. In order to analyse a successful innovation, a designer must evaluate the design criteria and ensure that all these have been reached. Functional and aesthetic aspects of the design need to be evaluated along with the short- and long-term effects on society and the environment.

17.4 Factors that Influence the Success of Innovations

Factors that impact on the success of innovations include timing, available and emerging technologies, cultural, political, economic and legal factors, and marketing strategies including demand and product promotion. These factors are often interrelated.

Timing

Most successful innovations occurred in times of economic prosperity that afforded people the freedom to invent. That is not to say that great inventions and innovations have not occurred during times of economic depression, but an innovation is more likely to be successful during times of prosperity.

When management or a consumer perceives a need, there is likely to be a demand for innovation. This is called **demand-pull** innovation. If the timing is wrong and there is no real need for the innovation then the design is unlikely to be successful.

Available and Emerging Technologies

A technological discovery or invention can provide the stimulus to initiate the innovation process, for example, the laser, which became the basis for the compact disk data storage technology. This is called **technology-push** innovation. New technologies, especially in the areas of biotechnology, genetic engineering, synthetic materials, information technology and the new manufacturing technologies such as robotics, have given great impetus to innovation.

Cultural, Political, Economic and Legal Factors

It is not enough to just have the technology for innovation to occur — the cultural environment must also be right. The cultural environment consists of institutions and other forces that affect society's basic values, perceptions, preferences and behaviours. For an innovation to be successful it needs to be socially accepted. Innovations require a new way of doing things or new things to do, and are dependent on people accepting the uncertainties, costs and effort that accompany these changes.

Innovation within a company is often generated through the **expectation of innovation**. There are often jobs and promotion prospects on the line and the organisation and its employees therefore have a strong vested interest in the innovation. The innovation, which has been pushed from below by researchers and pulled from above by management, acquires a certain momentum in terms of the mass of personnel and hardware involved and the pace at which it is moving.

The political climate is a strong factor in determining how successful an innovation becomes. The political environment consists of laws, government agencies and pressure groups that influence and limit various organisations and individuals in a given society.

Often a certain degree of disharmony or at least competition may be a powerful stimulant for innovation. Australian involvement in world wars (coupled with isolation from traditional suppliers at such times) has been a major stimulus to the local development of technology. Many technological developments have been in response to the pressures of actual or threatened war.

The state of the economy will also influence the potential success of an innovation. Australia is classified as a **modified market** economy. This means that a price mechanism operates within a framework of government controls. The government concerns itself with the production of goods and services, the distribution of income, the regulation of markets and firms, and with the management of the economy. Inflation, depression, unemployment, poverty and international political problems will influence how buoyant the economy is and how willing it is to invest in innovation.

Funding innovation may be considered risky as it usually requires a considerable investment of time and money, either from previous profits, or from external funding sources such as loans, grants, commissions, share issues, licences or royalties. The resources required to produce a marketable invention are typically only a small proportion of the resources needed to implement a successful innovation.

The types of laws that may have an impact on innovation include:

Administrative law, which deals with how government departments work and their rights and duties towards private citizens.

Criminal laws deal with behaviour that is seen as damaging towards the whole community.

Industrial laws deal with the relationships between employers and employees.

Contract laws deal with agreements made between people, such as between those keeping a trade secret.

Marketing Strategies

A marketing strategy is the approach used to achieve a marketing objective. For example, a marketer may decide to produce a high quality product for a niche market, predicting small sales, but implementing a high profit margin in order to make the innovation economically viable. The promotion of this product would be specifically targeted to people with large disposable incomes.

17.5 Agencies that Influence Innovation

IP Australia http://www.ipaustralia.gov.au

IP Australia is the Federal Government agency that grants rights in patents, trademarks and designs. It aims to ensure that Australians benefit from the effective use of intellectual property, particularly through increased innovation, investment and trade. IP Australia incorporates the Patent, Designs and Trademarks Offices.

Patents Office http://www.ipaustralia.gov.au

Applications for patents are filed at the Patents Office of IP Australia. The Patents Office assesses whether an invention is new and if it meets the legislative requirements.

Patent and Trademark Attorneys

People with a registrable form of intellectual property in the form of a patent or trademark can use a patent or trademark attorney to prepare applications for registration. These attorneys can also advise clients on the general management of their intellectual property.

Australian Copyright Council

The Australian Copyright Council is an independent non-profit organisation. The Council aims to assist copyright owners to exercise their rights effectively and inform the community about the importance of copyright. It also researches, identifies and seeks to change laws to improve the effectiveness and fairness of copyright legislation and foster co-operation among the relevant people affected by copyright. The Council's activities and services include writing and publishing a range of publications, organising and speaking at seminars about copyright, consulting, advocacy and giving free legal advice.

Council of Small Business Organisations of Australia (COSBOA) http://www.cosboa.com.au/

COSBOA is an organisation representing small and medium enterprises. It aims to assist their development by initiating, participating in, or overseeing projects that may benefit small businesses. It also prepares and presents submissions to governments and other relevant organisations.

International Council for Small Business http://www.icsb.org/

This is a non-profit international organisation that integrates the activities of organisations and professionals who deal with small business. It creates and distributes information and actively stimulates research into relevant areas.

Australian Securities and Investments Commission (ASIC) http://www.asc.gov.au

The Australian Securities and Investment Commission is one of three Government bodies that regulate financial services. It is responsible for making sure that trading is honest and fair. It protects markets and consumers from manipulation, deception and unfair practices and it also promotes Australia's business reputation abroad. The ASIC encourages risk taking and supports the growth of international trading through the free flow of capital in a well-informed market.

Standards Australia (SA) http://www.standards.com.au

Standards Australia is a company that promotes, publicises, and develops standards. These standards help to improve efficiency and enhance the quality of products.

Australian Competition and Consumer Commission (ACCC) http://www.accc.gov.au

The Australian Competition and Consumer Commission was formed in 1995 by the merger of the Trade Practices Commission and the Prices Surveillance Authority. The Commission administers the *Trade Practices Act* 1974 and the *Prices Surveillance Act* 1983 and has additional responsibilities under other legislation. It prohibits anti-competitive conduct in virtually all businesses across Australia.

WorkCover Authority of New South Wales http://www.workcover.nsw.gov.au

This organisation manages workplace safety, injury management and workers compensation systems. The Authority is responsible for ensuring compliance with workers compensation and occupational health and safety legislation.

Entrepreneur Business Centre http://www.ebc.com.au/right_frame/franchising/franchising_main.htm

This organisation provides advice and resources for the small business owner.

Small Business Institute of Australasia http://www.sbi.com.au/

This organisation provides advice and services such as consultancy and training to small businesses.

Australian Centre for Innovation and International Competitiveness (ACIIC) http://www.aciic.org.au/

The ACIIC is a group of consultants who operate nationally and internationally to develop strategies, manage projects, develop policies, identify technological futures, design online communities, carry out futures analysis, devise technology and innovation strategies, design e-commerce projects and conduct presentations and workshops.

Extension

1. Due to the nature of government organisations and the changing political scene it is quite possible that the agencies that influence innovation and the success of innovation have changed their name and/or varied their role recently. Investigate each organisation to establish the most current information.
2. Brainstorm with a friend how these organisations could influence innovation and the success of innovation.

17.6 Entrepreneurial Activity and Its Influence on Innovation

An **entrepreneur** is a person who can efficiently and effectively organise and manage enterprise. They make decisions and bear risks with the view of making a profit.

The Nature of Entrepreneurial Activity

The entrepreneur performs three basic functions:

- **Decision-making**: The entrepreneur controls the firm and makes decisions that are fundamental to its nature, operation and continued existence.
- **Innovation**: The entrepreneur applies new techniques to the production process, undertakes the production and distribution of new and improved goods and services, and introduces new forms of selling and organisation to the firm.
- **Risk bearing**: In making decisions the entrepreneur necessarily takes and accepts risks and these risks often come from uncertainties. The uncertainties may be due to anticipating the marketplace or by introducing innovations.

Role in Design and Technological Activity

Entrepreneurial activity is necessary to encourage design and technological activity. The entrepreneurial procedures necessary for production include:

- Establishing the **marketing opportunity** for the design.
- Organising **financial backing** for the development of the design.
- **Protecting the final design** by securing design registrations and patents.
- Organising the **supply of components, raw materials and labour**.
- **Manufacturing** of the design.
- **Advertising** the product to the target market.
- Organising **sales, distribution and servicing**.

Agencies that Affect Entrepreneurial Activity

The key agencies that affect entrepreneurial activity are:

- **Government agencies**, through laws, incentives, subsidies and so on.
- **Commercial agencies**, through the buying and selling of goods.
- **Industrial agencies**, through WorkCover, workplace agreements and awards.

Management and Entrepreneurial Activity

The fundamental difference between a manager and an entrepreneur is the type of decisions made by each. The entrepreneur has the responsibility of basic policy decisions that set the future course of the business firm whereas the decision-making of the manager is usually concerned with day-to-day routine matters.

17.7 Case Study of an Innovation

The Moller Skycar

The Skycar is a personalised vehicle that can take an individual from their driveway and transport them anywhere they want to go, at any time. It is the commuters' dream of the twenty-first century and may mean the end of traffic jams forever.

Dr Paul Moller foundered Moller International in 1983 in order to design, develop, manufacture and market the personal vertical take-off vehicles. The single most important emerging technology was the development of the Rotapower engine, a Wankel rotary engine. This engine is now produced and marketed by Freedom Motors.

The Skycar takes off like a helicopter, yet flies like a jet. Moller uses a Vertical Take-Off and Landing system (VTOL). The engines swivel so that on take-off the thrust pushes the aircraft upwards. The engine then swivels horizontally to drive the aircraft forward. Past efforts to develop a flying car have resulted in expensive aircraft in which a minor component failure has resulted in catastrophic results.

The Skycar is better than past designs with similar intentions because:

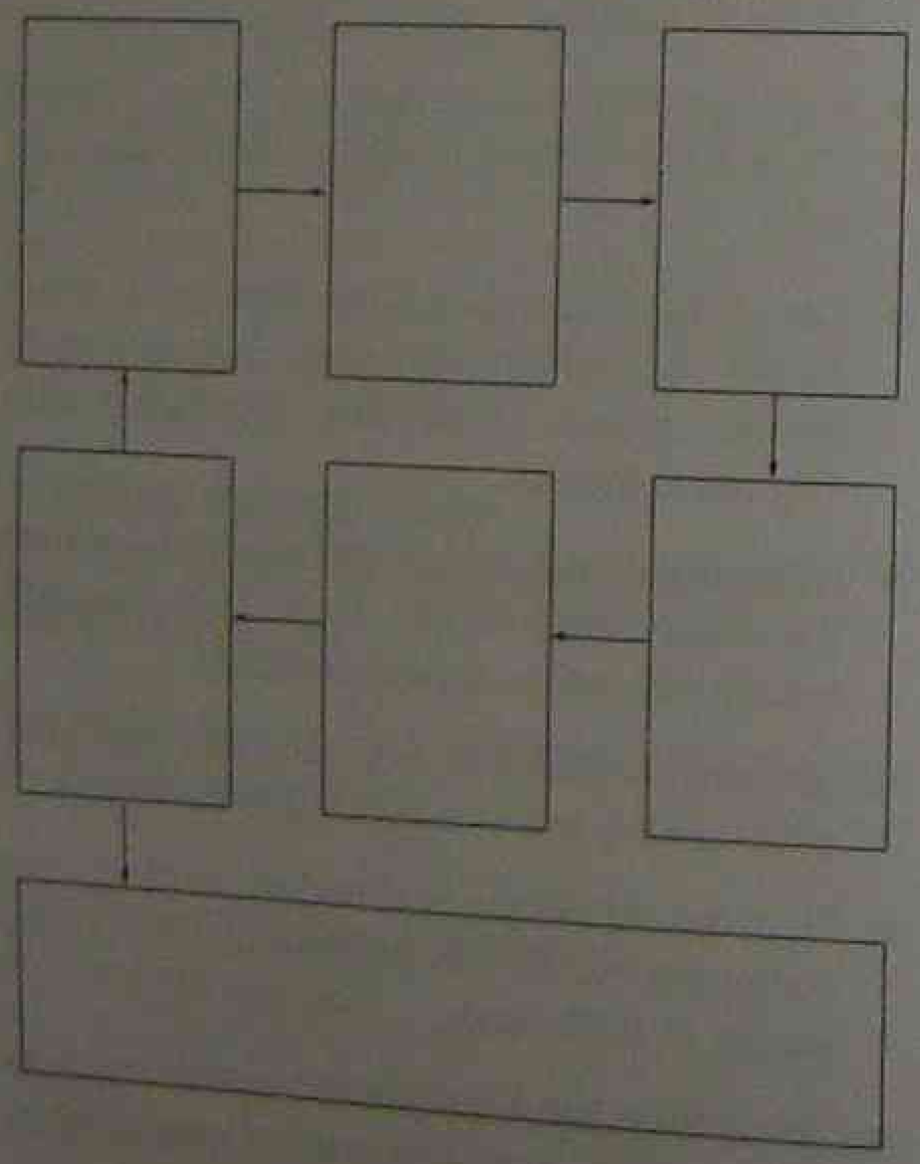
- Moller has made over 150 hovering and low-speed flights, which are the most important elements of any VTOL system.
- It has been clocked at 650 km per hour.
- Its 960 horsepower engine runs on standard automobile fuel.
- It gets 6 km to the litre — most large cars average 10 km to the litre.
- It is larger than the average car — 5.4 m long and 2.7 m wide — but it is smaller than a small aircraft.
- The Skycar is currently being displayed at motor shows throughout Australia, however commercial release is pending negotiation with aviation authorities.
- Early models may cost as much as $A1.4 million but Moller believes that mass production will reduce this cost to around $A95,000.
- Airborne commuters will not need extensive pilot training as a computer pilots the Skycar.
- To avoid potentially fatal mid-air accidents, the computers would use pre-programmed courses similar to traffic lanes.
- The vehicle has a low environmental impact in terms of noise, emissions and fuel consumption.

- Total ownership over the life of the vehicle, including purchase price, operating and infrastructure costs, are reasonably low and will compete with motor vehicles.

If Moller's vision comes to pass, commuters will no longer be tied to working in cities as they can travel much further in the same time. Moller believes that at some time we will use that great resource we call 'the sky'.

Extension

1. Go to Moller's Internet site at www.moller.com/ and answer the following questions. Hint: Read the FAQ (Frequently Asked Questions) pages.
   (a) Name the innovation.
   (b) Who is the inventor?
   (c) When and where was it invented?
   (d) Why was it invented, that is, what was the need?
   (e) Provide a clearly labelled sketch or a detailed description of the Skycar and the Rotapower engine.
   (f) What is innovative about this design? How does it fulfil the original need?
   (g) Use a flow chart to list and describe the processes undertaken to develop the Skycar (as an example of innovative design practice).



   (h) Describe how the following factors have contributed to the success of the Skycar:
      i. timing
      ii. available technologies
      iii emerging technologies.
   (i) List the factors affecting the development of the Rotapower engine (the emerging technology) that allowed this innovation to occur.
   (j) What criteria were used to evaluate the use of this emerging technology?
   (k) What is the impact of this emerging technology on society and the environment?
   (l) What is the impact of this emerging technology on this innovation?
   (m) How have the following factors influenced the design:
      i. cultural factors
      ii. political factors
      iii. economic factors
      iv. legal factors
      v. marketing strategies including size, demand and product promotion?
   (n) What ethical and environmental issues needed to be considered?
   (o) How is the technology sustainable?
   (p) Describe how the designer protected his intellectual property.
   (q) In relation to this design, identify the rights and responsibilities of the designer.
   (r) Did this designer use the Patents Office?
   (s) Did this designer use the Small Business Council?
   (t) What was the nature of the entrepreneurial activity?
   (u) What was the role of the entrepreneurial activity?
   (v) Which agencies (government, commercial or industrial) affected the entrepreneurial activities?

Review Questions

1. A designer has developed a new computer software program. Factors that will influence the commercial success of this design include:
   (A) Registering it for copyright.
   (B) Timing, and cultural and legal factors.
   (C) Financial backing and the long hours put into the promotion of the product.
   (D) Having a high degree of autonomy and self-sufficiency.

2. IP Australia's key role is to:
   (A) Prohibit anti-competitive conduct.
   (B) Prepare and present submissions to governments on behalf of small business.
   (C) Assist copyright owners to exercise their rights.
   (D) Grant rights in patents, trademarks and designs.

Answers Innovation

Answers to Exercise page 151

Creativity involves originality. It is the product of something that is new. Innovation in design is based on the improvement of an existing design.

Answers to Review Questions

1. (B) Timing, and cultural and legal factors.
2. (D) Grant rights in patents, trademarks and designs.

18 – Emerging Technologies

Chapter Overview

In our world of technological change there are numerous emerging technologies which have an impact on design activities.

Expected Outcome

On completing this chapter, students should be able to:

- critically assess the emergence and impact of new technologies, and the factors affecting their development.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms

emerging technologies

innovation

18.1 Emerging Technologies

Products that create a new need or satisfy an existing one in a totally new way whilst using established product designs are known as innovations. An emerging technology refers to a new or developing material, tool or technique and is often used to create a new design. Examples of new and emerging technologies include:

- Genetic technology.
- The rotary engine used in Paul Moller's flying car (refer to Section 17.7, page 157).
- A project to extend the shelf life of seafood.
- Satellite and digital technology.
- Telecommunications using impulse transmission and software radio.
- Clever components and microchips.
- Photovoltaic cells.

The use of these technologies in varied processes should result in unlimited innovative ideas and designs.

The written paper in the HSC examination requires students to complete an innovation case study, but without understanding the associated emerging technology there is a danger that the depth of understanding will be limited. Be sure that you have a thorough understanding of any associated emerging technology.

Extension

Consider the following questions when analysing an emerging technology:

1. What factors have affected the development of the technology? By analysing the historical development of the technology it should be possible to identify the factors that have contributed to its successful development. Some of these may have a cultural bias, which is also an important factor.
2. List the criteria to be used to evaluate the technology and the innovation. Include both functional and aesthetic criteria. Functional criteria refers to what you want the product, system or environment to do whilst the aesthetic criteria refers to what you want the design to look and feel like.
3. What will be the impact of this idea on society and the environment? You are expected to include information on the environmental, financial, social, ethical and legal implications.
4. What will be the impact of this emerging technology on the range of innovations that will follow?

18.2 Case Study: Mobile Phones

The following is a sample answer for students studying first-, second- and third-generation mobile phones as their innovation and Code Division Multiple Access (CDMA) technology as their emerging technology.

Factors Affecting the Development

The first Australian mobile phone connections were made in March 1987 and it took twelve months to attract 25,000 users. These were predominantly car phones that cost $5000 to install. Portable phones were attached to power packs carried in briefcases, weighed about 5 kg and cost $5000. They were nicknamed 'lunchboxes'.

Hand-held mobile phones appeared in the late 1990s and cost around $3000. They were known as 'bricks' because they typically weighed 1 kg — as much as a bag of potatoes. Talk time was limited to 1 hour and Internet access and fax capabilities were unheard of.

By 1992 handsets were available from $1500 and in 1995 there were 200,000 mobile phone connections in Australia. In the final quarter of 1999 there were 7,557,584 mobiles connected. The lowered cost of the handset had contributed to the success of this innovation.

In December 1999, Wireless Access Protocol was launched and on 1 January 2000 the analog network was replaced with digital and Code Division Multiple Access (CDMA) technology, which will enable users to receive Internet content on their mobiles.

Philips' new phone uses voice-command technology in its computer voice recognition software. Your voice can even tell the phone to make the text larger on the screen. The Samsung Watchphone, available December 2000 for a cost of $15,000, is about the size of a matchbox and weighs 39 grams. In the final quarter of 1999 over 500,000 new connections were made. The Australian Mobile Telecommunications Association has said that the figure equates to 36.5 per cent of Australians using mobile phones. In December 2000, Telstra alone signed up 280,000 customers and it was claimed that by December 2001 over 65 per cent of Australians would be using mobile phones.

The weight and size of mobile phones has been reduced by 90 per cent over the last ten years and the price has also dropped significantly. Australians have been seduced by the latest craze in mobile phone technology — text messaging. Optus has found that there is an enormous demand for this method of communication. Marketing has shown that users find it 'hip' to communicate in this manner and more than 17 million messages are sent every week, both formally and for fun. Consumers who were annoyed by the noise of mobile phones found this a quicker and quieter option. This text option is called Short Message Service (SMS).

Some of the techniques and abbreviated words include:

ATB = all the best,
B = be,
BCNU = be seeing you,
CUL8R = see you later,
GR8 = great,
H8 = hate, L8 = late,
LUV = love,
NE1 = anyone,
OIC = oh I see,
PCM = please call me,
PPL = people,
RUOK = are you OK?,
UR = you are,
WAN2 = want to,
:-) = smiley face,
;-) = winking face,
:-o = surprised face,
:-(= sad face,
d:) = baseball cap,
:@) = pig.

Australians have developed a level of reliance on this technology as the mobile phone is now regarded an important communication tool for both the private and business user, especially with the range of communication services available on the average handset. Wireless mobile technology that glows, beeps or vibrates to alert a wearer when mail is received will be a part of the future. The technology may take the form of a watch, necklace or a hand adornment.

Criteria for Evaluation

Functional Criteria

This includes:

- **Reduced weight of handsets**, achieved by reducing the weight of phones from 5 kg in the 1980s to a mere 39 g in the year 2000.
- **Reduced size of phones**, achieved by reducing to the size of a matchbox that can be worn as a watch or a piece of jewellery.

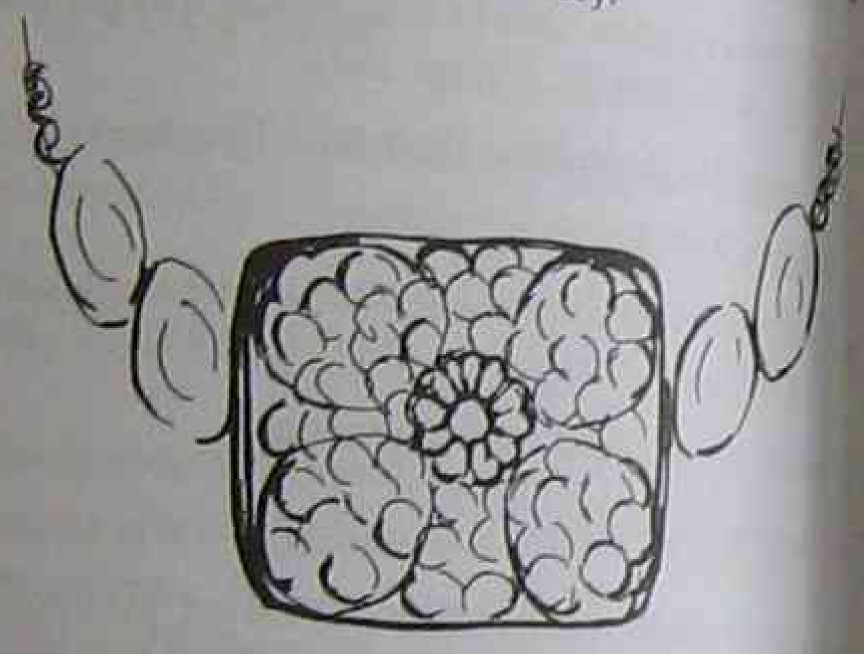


Figure 18.1 Necklace Phone

- **Reduced cost of the phone**, achieved by offering free phones and free talk time as compared to the 1980s when it cost around $3000 to purchase a telephone.
- **Reduced cost of calls**, achieved by developing a number of telephone plans that suit different people's needs. There is now a prepaid plan where people can purchase a card with a limited amount of dollars available and then spend the card at their leisure. These are available in a range of amounts.
- **Easier to carry**, achieved by moving away from the idea of carrying a phone and toward the idea of attaching the communication system to one's body as an adornment, making it the perfect status symbol for a technophile.
- **Increased function of communication systems**, achieved by using CDMA technology, which allows users to receive Internet content on their mobiles.

Aesthetic Criteria

This includes:

- **Millennium appearance**, achieved by using modern, stylish and lightweight materials and designs that have a techno appearance.
- **Range of styles**, achieved by designing and producing a range of styles, shapes, dials and buttons.
- **Range of colours**.

Impact on Society and the Environment

Ecological Implications

There is much debate about the radiation emitted from mobile phones and the associated health risks. Swedish researchers found significant health problems in those using mobile phones for more than 1 hour per day including headaches, dizziness, fatigue, loss of concentration, memory problems and heat sensations. The electromagnetic energy that fuels a cell phone is pulses of microwaves from the antenna, and human brains may absorb up to 60 per cent of this energy. This is near the top end of international safety recommendations.

In April 2000, Australian researchers challenged British findings that mobile phone hands-free devices can increase the radiation directed at a user's brain. They claim that there is still no reason to assume that any kind of mobile phone use is either completely safe or dangerous. Local scientists suggested that, unlike the past actions of tobacco companies, mobile phone companies should be more forthcoming in releasing their own research into the effects of radiation emissions. Research conducted jointly by scientists from the University of Sydney and doctors at Sydney's St Vincent's Hospital has found that hands-free kits reduce energy emissions by as much as 50 per cent.

Economic Implications

In the 1980s a handset cost $5000 but now companies offer free phones, free talk time and a number of telephone plans that suit different people's needs. The price of the handset and the calls are able to be negotiated in a plan, but once a commitment is made there are hefty fines for those who want to change plans midstream.

Prepaid phones are now available at a cost of $99 for the handset, and the card, used to pay the cost of telephone calls, is purchased in advance at a cost of $10, $30, $50 or $80. Prepaid plans offer incentives such as free monthly access, bonus prepaid cards and discounts for calling other mobiles using the same plan. The lowering of costs and the introduction of call packages has put mobile phone usage within the financial reach of many Australians.

Social Implications

It is becoming a social norm to own a mobile phone, but this is causing a culture swing for Australians and there are some decisions to be made. Consider the following:

- Is it acceptable to have an important conversation interrupted by your friend answering their mobile?
- Is it acceptable to sit in an exclusive restaurant and spend the evening listening to the jingling tunes from telephones all around you?
- Is it acceptable to take a mobile phone to a movie or leave your phone on when in a lecture because something is important to you? Should people leave their mobile phones on when visiting hospitals and elderly people?

On the positive side, encouraging a teenager to carry a mobile can assure a parent that their child is just a phone call away and, if assistance is needed, this is also reassuring for the adolescent. Mobile phones can also be an important asset for elderly people and those who have limited mobility, whilst commuters may be able to complete work during travel.

Ethical Implications

Despite the issues mentioned above, is it acceptable for students to carry a mobile phone to school? Also, is it acceptable for schools to ban them from being taken into the classroom if students play with them? If they are banned, then whose responsibility is it to replace the phone if it is stolen from a student's bag whilst in class? Is it acceptable for a worker to take their mobile phone to work and answer personal calls during work hours when they are technically on the company's time?

At what age should people have their own mobile phones and what responsibilities should be placed on them. For example, who is responsible for the cost of calls, when will they have access to it and what happens if the phone is stolen or lost? These and many more questions are being raised as mobile phones become more common in our society and they are the types of issues students need to consider when discussing the ethical implications of an emerging technology.

Legal Implications

There is a growing debate about the information on phone plans that is being given to consumers when they sign up. Young people are running up huge bills which could be avoided if they had been given advice on which plan to take. There have been cases where people accumulate large debts on mobile phones and then change companies and purchase new plans when they are disconnected. When the debt finally catches up with them, they are being forced into bankruptcy court.

Parents are complaining, when they get mobile phone bills of $2000 to $3000 that their children have run-up, that they were unaware of this debt but they are still legally responsible for it. It appears that at present mobile phone companies are willing to sign up anyone who can purchase a plan but consumer watchdog organisations are attempting to have protection laws put in place for young people. Many people who have been in this situation are refusing to give up their mobile phones and are now taking up prepaid options.

Impact on Innovation

Mobile communication technology has evolved along a logical path from the first-generation analog products to the second-generation digital wireless telecommunications systems to the third-generation complete Personal Communications System (PCS). This latter development will encourage the use of the mobile phone as a 'lifestyle portal'. It will be known as third-generation mobile communications systems (3G systems).

The drawback of existing mobile phones is that they are not capable of supporting the kind of services that consumers will demand in the future. There is a trend towards the globalisation of the world's economy and it is desirable that global communications continue to grow. Today's cellular phones are still too slow to support high quality audio and video, video conferencing or fast Internet connections.

3G systems have been designed to provide wireless access to the global telecommunications infrastructure through both satellite and terrestrial systems. The new communications device, as well as being voice-activated, will include improvements in batteries, integrated circuits, flat screens, cameras and speaker verification systems.

The emerging technologies that will make these innovations available to us are the use of impulse transmissions and software radio. These are two areas with vast potential for mobile phone technology.

The Future

The mobile boom has lead to the current second-generation mobile service. The continued global mobile boom and the desire for broadband communications 'anywhere, anytime', has provided the motivation for the development of the third-generation mobile communications systems. The 3G system offers a way to provide global communication via global broadband services, such as multimedia applications and high speed Internet access. 3G systems will consist of a satellite and a terrestrial component integrated together. These systems will have smaller handsets and enable fast interactive services.

The phenomenal growth in the mobile communications industry is one of the world's success stories. The global market for mobile communications is set to grow to around 2.4 billion users by 2015. Wireless access is fast overtaking fixed access to global communications.

The success of 3G mobile phones depends on market forces — that is, the promised services must be delivered at an attractive price. As previously mentioned, research into the health implications of using mobile phones is still inconclusive. The use of emerging technologies such as blue tooth, software radio and the new satellite telephone systems are the way of the future but are not commonly used by the everyday consumer because of their huge expense.

Will prices of these communication devices reduce to make them more accessible to the everyday consumer? That will depend, ultimately, on consumer demand.

18.3 Examples of Emerging Technologies

Sensational Foods

Every day, advances are being made in almost every aspect of our world. In September 2000, Sensational Foods, a Port Stephens-based company, received funding of $1.3 million for the research and development of a seafood-packaging project. Once completed it is expected that the project will extend the shelf life of fresh seafood. The project involves building a pilot plant, carrying out supply chain evaluations and extensive research. The project will create increased markets because of improved food safety and the extended shelf life of fresh seafoods. The company is one of the Hunter Region's fastest growing businesses and employs more than 30 staff. The research will benefit Australia's growing aquaculture industry, which should profit from the extra market opportunities that an extended shelf life will provide.

The Human Genome Program

We are currently mapping the blueprint of life. The Human Genome program should, by the year 2002 at the latest, have mapped what every piece of information on our DNA does. The effect of having this information will have an enormous impact on the future. The former United States President, Bill Clinton, claimed that within five years a genetic map of a newborn child could be given to its mother. This could identify potential future health problems at birth, thus greatly reducing an individual's risk of contracting certain genetically predisposed illnesses.

One of Australia's leading medical researchers, Dr Karl Kruszelnicki, claims that 'Children today will be either the first generation to live forever or the last generation to die.' Greater knowledge of genetics could mean that we will be able to stop the ageing process. Current research has allowed us to grow a human ear on a mouse's back. It is believed that within 15 years, paraplegics will be able to re-grow stem cells that will enable them to walk again.

Space Colonies

NASA scientists are claiming that within 40–50 years there will be a human colony on Mars with stopping off platforms, like a space motel, on the way.

Transportation

Supersonic passenger jets will fly from Sydney to London in half the time and be twice the size of 747s with room for a restaurant on a lower level. However, the sonic boom created will mean that these planes will not be allowed to take off over large cities on a regular, frequent basis. There is every possibility that they will be computer-controlled, thus removing the need for a windscreen! For information on Paul Moller's Skycar, refer to Section 17.7, page 157.

Computerised Refrigerators

A man from the Central Coast of New South Wales has designed, patented, manufactured and is now selling a refrigerator with a computer screen built into the front of the door. The computer maintains a shopping list by scanning items as they diminish. It also acts as a communications centre by providing Internet access, an entertainment centre for games and a workstation for children on which to do their homework, or for family members to produce documents.

18.4 The Ethical Implications of Emerging Technologies

The Australian humanitarian, Dr Fred Hollows, stated that 'The presence of sick people lessens me as a human being'. While there is inequity between rich and poor and sick and healthy people, should this be where our use of emerging technologies be concentrated? Where would you, as a designer, begin?

18.5 Innovation and Emerging Technology Websites

General Sites

Radio Australia's Innovations Site

http://www.abc.net.au/ra/innovations/default.htm

This site contains broadcasted transcripts from the ABC Network's weekly radio program on innovations. The stories highlight Australian design, inventions, engineering and research expertise. Each week there is a new topic, while previous topics are available in the 'Archives' section. A very interesting site with lots of resources.

CSIRO Australia

http://www.csiro.au/

This is the Commonwealth Scientific and Industrial Research Organisation (CSIRO) website. The CSIRO researches just about every aspect of Australian life, including agriculture, minerals and energy, manufacturing, communications, construction, health and the environment, finding ways to improve our quality of life and economic performance. This site has many useful sub-sites — the 'Features' site has an innovations site for students, while the 'Research Division' and 'International Activities' pages are also worth visiting. As the site is Australian-based, it is extremely useful for identifying specific innovations and technologies being developed here.

designboom — Design Magazine

http://www.designboom.com

This online magazine is a celebration of the current architectural, industrial and interior designers and their work. It includes interviews, related articles and clips on interesting new designer products around Europe.

Discovery.com

http://www.discoverychannel.com

This website is based on cable television's Discovery Channel. It expands on some of the channel's television programs with video images and website links. The site is full of innovative and new technology and offers a range of educational resources.

Emerging Technologies: Insights for Industry

http://emertech.wharton.upenn.edu/ET%20Tech%20
html

This site is from the Mack Center for Technological Innovation at the University of Pennsylvania. It describes new and emerging technologies for industries such as biometrics (scanning of body parts for identification, e.g. scanning the eye's iris), cars of the future, and human genetics and medicine.

HowStuffWorks

http://www.howstuffworks.com

This is an excellent website encompassing a wide range of technologies. It has an abundance of facts, figures and diagrammatic representations of machinery and tools, plus plenty of useful links to other sites. The search system is very user-friendly — you can type in basic keywords to locate relevant information. It is not limited to an industrial focus as it includes financial, societal and cultural aspects as well, although keep in mind that it is from an American perspective.

Innovations (Products)

http://www.innovations.com.au/

Online catalogue of innovative products, including electronics, furniture, kitchenware and appliances.

Innovations (Questacon)

http://www.questacon.edu.au/html/innovations.html

This is all about Australian innovation, from home innovations to agricultural and medical innovations. It has a good education section and covers most of the Australian innovations over the last century.

The Innovation Journal

http://www.innovation.cc/

The Innovation Journal is an independent, Internet-based journal for public sector (government) design and innovation. It provides articles, case studies, book reviews and news about government design issues.

Innovative Australia (Australian Department of Foreign Affairs and Trade)

http://www.dfat.gov.au/facts/innovative/fs05.html

This site offers a diverse range of Australian innovations and is a good starting point if you are looking for an invention to investigate further. Includes a brief historical account of each listed innovation.

Powerhouse Museum

http://www.phm.gov.au/

The Powerhouse Museum is a good place to visit online but a better place to visit in reality in Ultimo, Sydney. The Museum hosts DesignTech, the annual exhibition of HSC Design and Technology design projects, in February–March each year, and also offers seminars for HSC students. The website provides information on technology and innovations and is updated regularly. There is a section specifically devoted to Australian innovations which provides information on past, present and emerging technologies. The Museum's shop also contains a number of books on innovations that are very useful.

Virginia's Center for Innovation Technology

http://www.cit.org/

An interesting site which is continually updated to display the latest developments (almost daily) in innovative technology being developed in the US state of Virginia. The site is easy to navigate and offers a range of technology topics, although it is focused mainly on Virginia's interests which is a limitation on the information available. Another of the Center's sites is Innovation Avenue at http://www.innovationavenue.com/ which offers information to technology developers in Virginia.

Agricultural Technology

Ruddweigh

http://www.ruddweigh.com.au/

Ruddweigh is a company which develops electronic weighing systems for agricultural purposes. Ranging from livestock weighing systems to grain and machinery, their products are intended for a variety of agricultural activities. The site also contains links to sites which develop agricultural software programs.

Automotive Technologies

Gasoline Direct Injection Engine

http://web1.mitsubishi-motors.co.jp/inter/technology/gdiselect/select.html

Mitsubishi's GDI engine aims to significantly cut carbon dioxide, nitrous oxides and unburnt hydrocarbon emissions from vehicles, and Mitsubishi claims it is able to reduce fuel consumption and carbon dioxide emissions by 20%. This site explains how the new engine works and its benefits.

Holden Special Vehicles

http://www.hsv.com.au

This site is dedicated to the design of motor vehicles for special purposes such as racing.

Hybrid Electric Vehicle

http://www.mitsubishi-motors.co.jp/inter/technology/env_08.html

Mitsubishi is developing an experimental electric vehicle. This site explains how the engine works from batteries, the car's specifications and its environmental benefits.

Volkswagon of America

http://www.vw.com

This site is dedicated to the design of motor vehicles for Volkswagon, and includes a whole network for news, jobs and technical literature.

Biomedical Technology

AbioCor Implantable Replacement Heart

http://www.abiomed.com/prodtech/Fabiocor.html

http://www.heartpioneers.com

The AbioCor artificial heart was designed as an alternative to heart transplantation for patients whose hearts are irreparably damaged or who suffer from heart disease. The device has an internal motor and moves blood through the lungs and to the rest of the body, simulating the rhythm of a heartbeat. After it is implanted, the 'heart' does not require any tubes or wires to pass through the skin — it is powered by a series of coils which do not pierce the skin. The first artificial heart implantation was performed in 2001.

actionbioscience.org — Bioscience Issues

http://www.actionbioscience.org

This is the website for BioScience Productions and it aims to educate and inform scientists, students and the general public about issues in bioscience, such as biodiversity, the environment, evolution and genetic research. The site describes itself as a 'non-commercial, ad-free educational website'. This is a good starting point for issues in biotechnology.

Bionet

http://www.bionetonline.org/English/default.htm

This is an outstanding site offering information, techniques, ethics and links. It is aimed at students and encourages informed dialogue on emerging biomedical technologies, including stem cell research, prolonging human life, HIV research and gene technology. The site features videos, quizzes, online debates, interactive games and a range of links to explore different angles of each issue, plus up-to-date news on the latest developments.

Biotechnology Australia

http://www.biotechnology.gov.au

Biotechnology Australia is a collaboration of five Commonwealth Government agencies. The site contains links to other related sites, both local and international, and displays information, community issues and industry viewpoints. The 'What's New' section is updated every three months so the information displayed there is up-to-date. This site is an excellent starting point for research and information for students and teachers.

Biotechnology: Mohawk Innovative Technology Inc.

http://www.miti.cc/biotechnology.html

MiTi® is an American product development company which has branched into the biotechnology field by developing artificial internal organs, biosensors and nanotechnology for biological uses. It is hoped that organs and limbs will be able to used to replace body parts that are damaged, worn out or not in good working order.

New and Emerging Technologies

http://www.wa.gov.au/tiac/directions/paper3/paper3.html

This site contains a paper on biotechnology and other developments written by Ron Johnston from the University of Sydney. It is focused on developments in Western Australia, but contains some useful overviews of how biotechnology, nanotechnology and geomatics (remote sensing/mapping) are being used in research and development.

The Retinal Implant Project

http://rleweb.mit.edu/retinaweb/

This site examines the emerging technology of eye and retina implants which aims to assist people who suffer from degeneration of the retina. The implant would rest on the inside surface of the retina, close to the optic nerve which carries signals to the brain. This use of an implant to bypass the damaged areas of the retina mirrors the successful cochlear implant, which has restored useful (though not normal) hearing to some deaf patients. This site contains information on the types of eye problems that could be treated with the implant, as well as details about the mechanism of the implant and how it works.

Ventracor — The Heart Company

http://www.ventracor.com/

This website is a great resource if you are studying a unit on biotechnology. Ventracor is involved in developing mechanical heart devices, specifically a 'Left Ventricle Assist Device' called 'VentrAssist' which is implanted into the body to assist patients suffering congestive heart failure. The website is easy to use and follow. There is an excellent brochure available which shows diagrams of the implant and describes its function and what it does to assist the body. Its use of technology is impressive — visitors are able to download videos which show the 'VentrAssist' in action and can view a picture of the device in close-up.

Communication Technology

Mobile/Cellular Technology

http://www.mobilecomms-technology.com/projects/cdma2000/

This site looks at the recent code division multiple access (CDMA) technology on mobile phones.

Computer Technology Innovation

Bell Labs

http://www.bell-labs.com/

Offers a range of information about developments in computer technologies, including wireless technologies and computer software. Their news features give up-to-date news on latest developments.

Computer Software and Computers (CompInfo)

http://www.compinfo-center.com/compinfo/pages.nsf/webpages/topicist2.htm

This is a comprehensive computer information centre – simply click on what you want to find out about a computer, including software, e-commerce, operating systems, artificial intelligence and robotics.

Corning.com

http://www.corning.com/

Corning was one of the first companies to develop fibre optics, and their website offers information on the history of fibre optics and their range of uses.

Intel Innovation in Education

http://www.intel.com/education

The Intel Corporation develops and manufactures microprocessors and other computer parts. This educational site has a variety of information on computers, parts and how computers are used in different fields, plus a good search facility that enables you to find what you are interested in.

Robots Alive! Almost Human

http://www.pbs.org/safarchive/4_class/45_pguides/pguide_704/4574_human.html

Rodney Brooks, specialist in artificial intelligence at MIT in the US, is creating and constructing a robot that will mimic a human being. This website gives a range of educational resources and activities to start you thinking about artificial intelligence and its applications.

SPYGY

http://www.spygy.com/

This website displays information about a mini-PC that the Thai company SPYGY is developing and describes the problems involved in developing such small technology. The site contains many pictures of new and emerging computer technologies, and you can see just how small these computers can actually get. A good innovation study if you are interested in computer technology.

Environment and Energy Technology

ActewAGL Education Site

http://www.actewagl.com.au/education/default.cfm

This site provides a good basic introduction to electricity, gas and water supply, and gives information about innovations such as wind turbines and hydropower. The site includes interactive features and animated diagrams.

Alternative Technology Association

http://www.ata.org.au/

This Australian site looks at sustainable energy alternatives and the effect of technology on the environment. The Association provides information for businesses about using renewable energy sources such as the sun, wind and water. The site includes media releases on relevant topics and content listings from the Association's magazine, *ReNew*.

Australian Greenhouse Office

http://www.greenhouse.gov.au

The Australian Greenhouse Office is a government organisation which looks at ways of reducing greenhouse gas emissions. The 'Latest news and information' section details new innovations and programs, while other sections provide information on environmental solutions for homes, businesses, industries and transportation.

Hot Rock Energy for Australia's Future

http://hotrock.anu.edu.au/

This website contains information on a renewable energy called geothermal energy. Geothermal energy uses heat from the Earth to drive turbines that produce electricity. The project being researched in Australia is known as 'Hot Rock Energy' and is being conducted by the Australian National University in Canberra. See also http://www.geodynamics.com.au/IRM/content/ for more information.

Hybrid Toilet System

http://www.gough.com.au/HybridToilet.asp

The hybrid toilet system is an innovation that allows sustainable management of sewage waste through an organic breakdown cycle which does not require access to sewerage systems. This makes it useful and environmentally safe in rural areas where sewerage systems are not accessible.

Nova – Science in the News – Environment Topics

http://www.science.org.au/nova/envir.htm

This is a database maintained by the Australian Academy of Science. Scientific articles provide information regarding advances in a number of scientific fields including the environment. The articles are well-written and use glossaries to explain difficult scientific terms. This site is a good example of science and technology being used to address a wide range of problems faced in society.

Advanced Technology Watercraft

http://www.solarsailor.com/

This website is an excellent site focusing on solar power, wind energy and the relationship these two factors have with movement, specifically for watercraft. Mainly focusing on hybrid power (a combination of wind, sun and fossil fuels), the site also discusses social and technological issues involved in further developments and also highlights future ideas and plans. There are excellent pictures and diagrams to support the written material, plus brochures and information kits which can be printed from the site. It is updated on a regular basis and there is an archive of all the company's news dating back to 2000.

US Department of Energy

http://www.energy.gov/

This site is a good source of general information on energy technology.

Flight Technology

The AirBike

http://www.geocities.com/alliedaerobiker/

Allied Aerotechnics are developing a personal aircraft which uses vectored thrust, generated by a ducted fan, to achieve both vertical and level flight. This page has limited information but certainly shows the direction of the future.

HyShot Scramjet (ABC Science Online)

http://www.abc.net.au/science/slab/hyshot/default.htm

Scramjets are types of rockets which are fuelled by oxygen and hydrogen and do not expel toxic exhaust like traditional rockets. This website gives a quick history of the Woomera rocket range and explains the world's first successful scramjet test carried out by the University of Queensland HyShot program in June 2002. It also lists a number of potential uses for the scramjet in the future.

Moller International

http://www.moller.com

This is the website of Moller International. The site features information on the history of the Moller Skycar, testing, technology and frequently asked questions. The site also has videos for sale about the M400 Skycar, and some great links (such as http://www.freedom-motors.com/ which supplies the latest rotary motors to power the Moller Skycar). The site also provides the history and evolution of their motors, environmental information and details on engine efficiency. (See also ZAP! site, below.)

Rotorcraft

http://www.internetage.com/rotorcraft/

This website has a great variety of links for rotorcraft and VTOL (vertical take-off and landing) information.

Scramjets (Popular Mechanics)

http://www.popularmechanics.com/science/aviation/2001/
/hyper-x/print.phtml

This page looks at the US scramjet Hyper-X program before it had completed a successful scramjet flight. It looked at reasons for scramjet technology including how it could be used to get payloads into space much more efficiently than the rockets can today. It also looks at military uses such as ballistic missiles but goes on to say that the technology can quite easily be used in civilian areas like commercial flights between distant cities.

ZAP! Electric Vehicles

http://www.zapworld.com/news/mollerzap.htm

ZAP (which stands for 'Zero Air Pollution') is a US company which develops electric vehicles with the aim to make them affordable options for people all over the world, including developing countries. This particular article contains information about the alliance between ZAP and Moller to develop and manufacture the Moller M400 Skycar.

Genetic Technology

Cloning and the Creation of Human Body Parts (Radio National Health Report)

http://www.abc.net.au/rn/talks/8.30/helthrpt/stories/
s53436.htm

This site is a transcript of a radio discussion between a presenter, a transplant surgeon, a representative of the Australian Health Ethics Committee, a representative of an American biotech corporation and a university professor in the area of stem cell research. The primary focus is ethical issues through a discussion of emerging technologies and its implications. Also discussed are the implications of foetal cell use and government intervention. It is easy to read, offers a good Australian perspective and the discussion is well-balanced. The Health Report site also provides numerous links to other sites, books and organisations.

Gene Therapy

http://biotech.about.com/cs/genetherapy1/index.htm

This site has a series of links to other sites on human gene therapy. There are basic overviews, scientific information, the current progress and information on the future potential.

Genetically Modified Crops and Food (American Medical Association)

http://www.ama-assn.org/ama/pub/article/2036-3604.html

This is a report by the Council on Scientific Affairs discussing the technology of genetically modified foods and the utilisation of transgenic crops. It discusses the capabilities of incorporating genetic engineering into plants, and raises a number of issues about this form of technology and whether it will be safe for the environment and human consumption.

Stem Cells

http://biotech.about.com/cs/stemcells/

This website has links to a range of websites about stem cell research, its market opportunities, the politics of the issues and more.

Human Organ Cloning

http://www.grin.net/~cturley/ADHOC/Human.Organ.Cloning.html

The advantages to growing human tissue from a patient's own cells and then transplanting it is that the body doesn't reject its own tissue. Are these innovative and emerging technologies the early steps towards immortality? See also *New Scientist*'s page at http://www.newscientist.com/hottopics/cloning/ for the latest updates on cloning and stem cell research.

Organic Federation of Australia

www.ofa.org.au

The Organic Federation of Australia is an industry-based association and their site displays information on markets, equipment and the latest research. It offers a newsletter (by subscription) to keep the industry informed of issues and developments. The site also offers links to other Australian and international sites. This is a good site for obtaining an industry perspective.

Historical Innovations

American Inventors and Inventions

http://www.150.si.edu/150trav/remember/amerinv.htm

This page discusses many inventions and innovations such as the telephone, the artificial heart and the light bulb, to name a few.

Hills Industries Ltd

http://www.hills.com.au/

The story and history of the company which invented and developed the Hills Hoist rotary clothesline.

The History of the Invention of the Transistor

http://www.pbs.org/transistor/

The transistor was THE invention of the twentieth century. The development of the transistor at AT&T (an American telecommunications company) was the birth of the age of telecommunications as we know it today. This site looks at the history of the transistor and has links to teaching material and information for students studying technology.

Industrial Designers Society of America

http://www.idsa.org/

The Industrial Designers Society of America (IDSA) is dedicated to communicating the value of industrial design to society, business and government. The website contains in-depth resource and information areas, including a section called '100 Years of Design' that gives details about many of the world's great inventions and how they were designed.

Hospitality Industry Technology

Children at the Table

http://www.stratsplace.com/rogov/children_at_table.html

This site looks at the effects of children dining at restaurants and how restaurants can implement innovative strategies to accommodate families. These include using specialised equipment and menus, customer service and the ramifications of having specialised areas allocated to children for dining. This is a useful resource for discussion on innovation in restaurants and cafés.

Hard Rock Cafe

http://www.hardrock.com

This site has great visual aids if you are trying to design a cafe layout and includes pictures from Hard Rock Cafe restaurants all over the world. There is a history of how the cafes were formed, from the first ones to the chain's most recent additions.

Sheraton Hotels' New Web-based Customer Service System

http://industry.java.sun.com/javanews/stories/story2/0,1072,49373,00.html

If you have ever been to a resort, hotel or motel and been disappointed with the room, food, cost, cleanliness, outlook, atmosphere, service or manners of those being paid to look after you, you will know that the only options for you are to remain a dissatisfied customer, confront the manager or leave a note which the cleaning staff will probably toss into the recycling bin. However, IBM and Nexaweb Technologies have provided an alternative for Sheraton Hotels in the US — a customer response system called 'Star Guest' which enables customers to place problems and complaints into a computer system. The personnel and maintenance staff at the hotel are able to respond immediately to resolve the complaint or problem and ensure these problems do not occur again.

INNCOM: Energy Management Systems for Hotels

http://www.inncom.com/

INNCOM is a US company which develop computer systems and wireless technology for hotel and motel staff and guests. Their innovations include central monitoring systems, lighting controls and devices such as electronic 'Do not Disturb' buttons and motion sensors which allow staff to determine if guests are inside their rooms.

Just-in-time Housekeeping System

http://www.hp.com/hpinfo/newsroom/feature_stories/2003/03hotel.html

A relatively new technology for the Housekeeping sector, this hand-held communication system allows a manager to assess where the housekeeping staff are up to and find out if rooms are ready for occupancy. Each housekeeper carries a pocket PC as they clean rooms and can communicate their progress and location using the stylus and touch screen. They can also receive updated instructions through the PC. Guest request and additional services can be dealt with faster and create guest satisfaction which will result in return guests to the hotel.

Marine Technology

Aquarium Links

http://w3.gorge.net/cannon/aqua.html

Provides a list of links to US aquarium websites.

Living Ocean International

http://www.livingocean.com.au

This company designs and constructs public aquariums and oceanariums, as well as manufacturing general aquaculture and other marine equipment. Their site provides extensive links to other sites in the area of marine biology, marine biotechnology and aquaculture.

Northwest Marine Technology

http://www.nmt-inc.com/

This company designs tags that can be implanted into live fish and other aquatic animals so scientists can track them and research their habits. Images and information are available for each different type of tag, and the Links page provides further links to marine technology sites around the world.

Space Technology

NASA Education Site

http://www.nasa.gov/audience/forstudents/9-12/features/index.html

There is plenty of information on technological developments for space exploration on this extensive website. The NASA site is constantly updated and includes interactive features, news updates and links to other resources.

Moon Base

http://www.ux1.eiu.edu/~imsa2/alexandra/lunar1.html

Log onto this site for insight into a new, emerging technology – living on the moon! The site supplies information about the issues associated with living on the moon and explains in detail some facts about this innovation, such as how to create artificial gravity, what the moon base will be like and even how school would occur on the moon. Follow the 'Bibliography' link to learn more. This is an interesting emerging technology to study, and there are plenty of Internet sites with information about it.

Sporting Technology

Aluminium Surfboards

http://www.tritonfoundation.org.au/User/Showcases.asp?Showcase=56

Information about the new aluminium surfboard and its designer, Ron Hasted. The aluminium skin on the board makes it more durable while retaining its ability to bend in the surf.

American Society of Golf Course Architects

http://www.asgca.org/

Provides information on designing golf courses, including issues about environmental impact and a 'Developer's Handbook'.

Clyde Johnston Designs, Inc.

http://www.clydejohnston.com/

Clyde Johnston Golf Course Architects design innovative golf courses which focus on aesthetic considerations and environmental suitability. The site provides a range of general information on the design of golf courses.

Classic Yacht Design

http://www.classic-yacht-design.com

The website of the late yacht designer Daniel Z. Bombigher displays a variety of modern yacht designs with detailed pictures with measurements and a detailed outline of the fit-out of each yacht.

Full-Body Swimsuits

http://www.ausport.gov.au/fulltext/2000/sportsf/s111424.htm

This is the transcript of a radio program entitled 'Design Innovation: Good or Bad for Sport?' which discusses the controversy surrounding the innovation of the full-body swimsuit in competitive swimming. The science behind the invention is explained, and the tension between new design innovations and the need to preserve fairness in sport is discussed.

Textile Technology

Australian Wool Innovation

http://www.wool.com.au

Read about the innovations in wool. Follow the link to 'Innovation Radio' and click on 'Browse the archive' to see transcripts of interviews and programs about new innovations.

Lycra® Innovations

http://www.lycra.com/Lycra/innovation/retail/spotlight_on_innovations.html

This website is a great one if you are interested in textiles and fashion design. It outlines ways that the fabric Lycra can be used to obtain fashion originality. It notes information about the company DuPont, who are trying the innovation of including Lycra in jeans to make them softer.

Velcro USA

http://www.velcro.com/

Velcro's hook and loop fasteners have been around for over 40 years. This site explains the many products the company has developed and provides information

Review Questions

1. An emerging technology is one that:
   (A) Has been used for many years.
   (B) Is very expensive.
   (C) May increase the number of innovations.
   (D) Requires a lot of fossil fuels.

2. Emerging technologies usually arise because:
   (A) Everyone needs new ideas.
   (B) They are needed to make an idea work more efficiently, economically or independently.
   (C) They are needed to make an idea more functional.
   (D) They are needed to make an idea into a reality.

3. (a) Identify an emerging technology and explain how its development has been influenced by each of the following:
   (i) Historical developments.
   (ii) Cultural diversity.
   (iii) Environmental issues.
   (iv) Manufacturing processes.

   (b) For the emerging technology that you chose, attempt to identify two positive and two negative impacts of this technology on the environment, the individual and society.

Answers Emerging Technologies

1. (C) May increase the number of innovations.
2. (B) They are needed to make an idea work more efficiently, economically or independently.
3. Student response.

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19 – Ethical, Environmental and Social Issues

Chapter Overview

A design is not produced in isolation from the rest of the world. Society as a whole is becoming more aware of ethical, environmental and social issues that affect design and technological activities. The impact of a design must be considered from conception to its ultimate demise. As well as numerous responsibilities, designers also have rights that are legally protected.

Expected Outcomes

On completing this chapter, students should be able to:

- explain the impact of a range of design and technology activities on the individual, society and the environment through the development of projects
- explain the influence of trends in society on design and production
- evaluate the impact of design and innovation on society and the environment
- select and use resources responsibly and safely to realise a quality Major Design Project.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

copyright
cradle to grave analysis
designs
environmental impact
ethics
intellectual property
patents
plagiarism
rights
sustainable technology
trademarks
trade secrets

19.1 The Impact of Design Activities on the Individual, Society and the Environment

Personal Values

A value is something that is important to us. As humans we each value different things — money, freedom, flora and fauna, other people, convenience, technology and so on. Personal value systems will determine the degree of importance that people place on environmental and social issues. In order to convince people that these issues are important, education about causes, consequences and preventative actions is necessary.

Design example

Many people value an uncluttered environment. An Austrian architect, Gustav Peichi, concealed a potentially ugly building development associated with a telecommunications site by locating most of the buildings underground. Rooms are positioned around central holes in the ground, which form courtyards lit by natural light.

Cultural Beliefs

Cultural beliefs are formed by groups of people living and interacting together. These beliefs are transmitted from one generation to another. A person's heritage is where they originally define their value system. For example, if a community of people have relied on the felling of trees for their livelihood, then they may choose not to see the problems associated with deforestation as part of their lives. In other words, for them, day-to-day living may be more important.

Sustainability

The Bruntland Commission (the World Commission on Environment and Development published in 1987) defined sustainable development as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs'.

The implication is that for development to be sustainable it must take into account not just the economic factors but also the environmental and social factors and must assess the long-term consequences of actions as well as short-term results.

For industry, the implications of sustainable development include taking a much longer-term view of investment decisions and taking all the true external costs of activities into account. Such approaches are made difficult by the short-term focus of financial and shareholder interests in many countries.

The concept of sustainable development, or 'green growth', only exists in most countries as a philosophical ideal. However it is being increasingly used as a guiding principle.

Safety and Health

Safety is the state of being free from injury or danger. Health may be described as a state of physical, mental and social wellbeing. It is not just looking and feeling physically fit. Although the designer must consider both of these issues, the degree to which they influence the design will depend on resources available, particularly financial implications.

Design example

A textile factory in Denmark produces cotton fabric using environmentally friendly processes. These processes reduce some of the health and safety problems often associated with cotton processing and fabric production. The fabric is specially designed to minimise the need to use chemical additives, and throughout the dyeing and finishing process pollution is minimised by the use of sophisticated purification and monitoring systems.

Community Needs

Communities consist of groups of people who share similar customs and who usually live in the same area. Communities will put pressure on designers to meet their needs. For example, increased public concern about pollution has forced designers to create a huge range of pollution abatement technologies.

Design example

In 1990 a UK company stopped selling furniture made from tropical hardwoods and introduced a range of furniture made from rattan, obtained from sustainable plantations in Indonesia. This change was in response to consumer demand. It also benefited the local community as it provided long-term employment without harming the forest.

Individual Needs

As people become more educated about environmental and social issues, the designer must respond to their concerns if they are to please the customer.

Equity

Equity refers to that which is fair or just. In our world there are many things which are not fair or just. Many people do not have adequate food, water, shelter or sufficient resources to maintain a reasonable lifestyle and many people are struggling just to survive. On the other hand, there are some extremely wealthy people who have ample resources. A designer, and those commissioning designs, should consider not just the profit margin but who will benefit. Some examples of design to improve social equity include appropriate housing and products for developing countries, and products for the handicapped or the elderly.

Design example

A solar lantern was designed for use in remote areas of Africa. It converts sunlight into electricity using solar cells, providing the equivalent of a 40-watt light for up to four hours. It is lightweight, portable and requires very little maintenance.

Economic Factors

Many governments, companies and consumers place economic efficiency above environmental considerations and often purchase designs that are economically rather than environmentally viable. A clever design should be both.

Exercise 1

Evaluate the design of a McDonald's burger packaging in relation to environmental and social issues.

☞ *Answers to Exercise 1, p. 189.*

19.2 The Impact of Design and Innovation on Society and the Environment

Ethical Issues

Ethics are moral principals by which we judge right or wrong, good or bad. They are the rules of conduct recognised by our society. Laws passed by governments support some ethical values, while others are accepted and generally practised by the whole community. The term 'ethics' is now widely used throughout the community including the government, business, education, legal, manufacturing and design sectors. There has been a utopian (perfect world) view in the past that all design and technology is in everyone's best interest, but this is not always the case. Ethical issues must be considered if a design is to be accepted by the market and/or the community.

Ethical and Environmental Considerations of Designers and Society

There are numerous ethical considerations that influence designers. Some of these may include:

- Assessing the impact of the design on the consumer.
- Protection of intellectual property.
- Privacy.
- Exposure to the undesirable.
- Advertising of designs.
- The right to alter natural order.
- Whether designs should be tested on animals and humans.
- Environmental impact.
- Sustainable technology.
- Minority groups.

These issues are looked at in greater detail below.

Assessing the Impact of the Design on the Consumer

The designer may consider safety, ease of use and built-in obsolescence. The designer may also consider if anyone will really benefit from the design, will it make someone happy or is it just another created need? Designs may be created for a higher moral purpose, such as to improve equity within our society.

Design example

Mobile phones have gained tremendous popularity in recent years, as they have become more compact, reliable and affordable. They are promoted as 'essential' parts of modern living, yet there have been studies linking constant use of mobile phones to certain health problems.

Protection of Intellectual Property

The designer needs to be aware of patents which can be legally enforced, thus giving the patent holder exclusive rights to the invention.

Design examples

When Kambrook developed the electrical powerboard, it neglected to patent the idea, hence losing millions of dollars to companies that copied the design.

IBM developed the Personal Computer, but did not patent it. Now a host of companies produce IBM 'compatible' PCs, making them the most popular type of computer in use today. IBM now only has part of the market share for the product it developed.

Privacy

There are certain inventions and uses of technology which have the potential to invade privacy such as computer databases, security monitoring devices and sophisticated communications systems.

Privacy is of particular concern in the public sector as specific personal details are collected and stored as a matter of course. The *Privacy and Personal Information Protection Act* was passed by the NSW Parliament in 1998 to provide protection of personal information held by public sector agencies. The Act imposes obligations on agencies in their collection, storage, use and dissemination of personal information.

Design example

E-mail (electronic mail) is a tool used by many computer users to send messages between two or more computers. It is easily accessed by computer hackers and is a known source of computer viruses, some of which can shut down whole networks in a short space of time.

Computers enable 'data matching programs' to exist whereby certain agencies are able to cross reference personal information such as tax file numbers, income details, marital status and so on.

Exposure to the Undesirable

Some designs enable exposure to information, pictures and experiences that would not otherwise be possible.

Design example

Pornographic sites on the Internet are accessible to all ages of users and this poses ethical and practical questions about government regulations and society's attitudes.

Advertising of Designs

Some designs are forcefully advertised, especially to the young and impressionable. There are advertisements that are offensive to certain subcultures such as migrants, Aboriginal people, women, the elderly, homosexuals and the disabled. Subliminal messages (messages that the consumer is not conscious of hearing or seeing) may also be considered unethical although the effectiveness of subliminal messages is debatable.

Design example

Coca-Cola is heavily marketed towards young people. Nutritionally speaking, it has very few benefits and many negative effects if consumed in large quantities.

The Right to Alter Natural Order

Some people believe that designs should honour the concept of natural order. For example, genetic engineering and the selection of foetuses through genetic identification do not honour this concept. Society's view on these issues is varied as people come to terms with new technology and concepts that until recently were just science fiction.

Design examples

Tomatoes are now genetically modified with flounder genes to improve their keeping qualities. Some prawns are genetically modified with strawberry and banana genes.

Monsanto genetically engineered soya beans so they would be resistant to a Monsanto-produced herbicide, allowing crops to be sprayed with it so weeds would be killed but the crops would be unaffected.

Whether Designs Should be Tested on Animals and Humans

There has been a trend towards minimal testing on animals and many companies promote the fact that their products are not tested in this manner.

Certain testing on humans may be harmless, while other forms will always remain controversial. All an[illegible] (including human) testing is strictly con-[illegible] government regulations.

Design example

Many cosmetic companies display the words 'This product has not been tested on animals' on their goods. This statement is often used as a marketing ploy and does not necessarily mean that the ingredients, as opposed to the final product, have never been tested on animals.

Environmental Impact

Designs have been modified and created because of concerns about the impact humans have on the environment through using both renewable and non-renewable resources. Eco-design refers to designs that have specifically taken into consideration minimal environmental impact throughout the life cycle of the product, system or environment. This has also become a major marketing tool.

Design example

Roads are now designed and constructed after an EIS (Environmental Impact Statement) is carried out. Roads have been re-routed and altered because of rare and endangered flora and fauna or significant Aboriginal cultural sites.

Sustainable Technology

Designers may choose one design over another depending on whether the resources used in design and production are conserved while still meeting production requirements.

Design example

Philippe Starck, in the 1980s, designed stacking chairs with legs that were screwed rather than glued on. This facilitated recycling, as parts could be dismantled into different components.

Minority Groups

Some groups in our society require special design attention such as the disabled, the elderly and isolated communities. Often these designs are only required in small quantities and so can be expensive or of low profitability.

Design example

Eat/drink cutlery was designed in the 1980s for people with limited strength. The knife functions through pressure applied with the arm rather than pressure from the wrist as in conventional knives.

Exercise 2

1. *What is the purpose of the Privacy and Personal Information Protection Act 1998?*
2. *Investigate the Australian Institute of Computer Ethics (AICE) website at www.aice.swin.edu.au. Why do you think there is a need for such an organisation?*

☞ Answers to Exercise 2, p. 180.

19.3 Background to Environmental Issues

The Greenhouse Effect or Global Warming

Gases in the atmosphere insulate the Earth, preventing some of the sun's heat escaping into space, which has resulted in the warming of the Earth. To avert global warming there is a need to reduce the emissions of carbon dioxide, preserve the Earth's oxygen-producing forests and develop alternatives to fossil fuels.

The designer's responsibility is to design products and buildings powered by alternate power sources and to manufacture energy-efficient product designs for everyday use.

The Ozone Layer

The ozone layer (12 km above the Earth's surface) forms a protective shield against ultraviolet radiation from the sun. If the ozone layer thins or breaks there will be climatic changes and changes to the ecosystem.

The ozone is broken down by the use of chlorofurocarbons (CFCs). These are gases used as blowing agents when Styrofoam is made, as propellants in aerosol cans, as refrigerants, and as packing insolvents for cleaning electrical components. The designer should ensure that CFCs are not used, as there are alternatives available.

Tropical Deforestation

Between the 1960s and the 1980s over 300 million hectares of rainforest were lost. Many were felled and some died due to the effects of air pollution. If the current rate continues, it is estimated that all rainforests will disappear by about 2080.

The effects of deforestation include the destruction of many species of animal and plant life and the disruption of local climates, possibly leading to desertification due to changes in rainfall. Desertification will lead to losses of habitat for local people and it is a contributory factor to the greenhouse effect. Designers could choose to not use any tropical wood unless it is proven that it is from a sustainable source.

Waste

Developed countries produce a billion tonnes of industrial waste (garbage) each year. Most of this ends up in landfill sites (where space is simply running out), some is incinerated (which can release toxic gases into the air) and some is simply dumped at sea (causing damage to marine life).

The designer's decision could be to produce less waste. Designers have a crucial role to play in this area and can really make a difference. They can increase the life cycle of a product, reduce the amount of material used, use biodegradable materials and so on. In addition, they could also design for reuse, recyclability and for remanufacture.

Water Pollution

The growth in population and the increasing use of large volumes of water for industrial purposes means that there is not sufficient clean water to meet demand. Water pollution creates huge problems for wildlife and many rivers in northern Europe have ceased to 'exist' because of pollution. Pressure is increasing for industry to aim for a closed loop waste management system where no harmful substances are emitted, but this is not always practical. Designers can use their design skills to reduce the need for harmful emissions and develop pollution abatement equipment.

Design example

Carlovers, the Ultimate Car Wash, is an example of an organisation that has focused on providing an environmentally friendly service. Used water is recycled on site, thus reducing the amount of pollutants in our waterways. The car wash also utilises energy-saving features.

Resource Consumption

The conservation of natural resources and the responsible management of renewable resources are at the centre of the concept of sustainable development. Designers' decisions have an impact on this in three ways through:

- The choice of materials.
- The energy used throughout the processes.
- Creating a reduction in the need to consume.

Noise

Although noise pollution is not life threatening, it causes discomfort to people. In heavy manufacturing there is a need to work on noise reduction to reduce the incidence of industrial deafness. Noise from motor or air traffic is of concern to people living nearby and the noise from domestic machines such as lawn mowers can be an irritation.

A designer's decision relates to the choice of materials and construction techniques used, as these will greatly affect the noise given off by any design.

The Cradle to Grave Approach

Assessing the environmental impact of a product can only be done if consideration is given to its effect throughout all stages of its life cycle. A designer's decision in using this approach is to acknowledge that environmental issues may emerge at any stage, including raw material extraction, ingredient processing, manufacturing, distribution, use and disposal.

The cradle to grave form of assessment provides a useful framework and checklist to ensure that every aspect of the product has been considered.

19.4 Sustainable Technologies

One of the problems associated with the introduction of technology is anxiety about the availability of resources. There is a growing world concern about depletion of non-renewable resources. Historically, when new technologies were introduced, there was little thought given to the use of resources. The Earth seemed infinitely large and there were always new areas to open up, explore and exploit. Today the picture has changed. The population has grown rapidly and industrialised countries are using up resources at a rapid rate. Society is beginning to realise that some of the resources we depend on are finite. Coal will last longer than oil but it too will run out eventually. High-grade energy sources, such as fossil and nuclear fuels, are effectively not renewed from extraterrestrial sources such as the sun. These sources of energy are **non-renewable**.

The need for greater use of **renewable energy** is clear. Fossil fuels, besides being finite, are also significant polluters. Burning coal and natural gas to generate electricity in Australia contributes to almost half of our annual emissions of carbon dioxide (CO^2), the major greenhouse gas. Switching to power stations run by sources of renewable energy, for example, solar or wind, which have very low environmental impacts, would greatly reduce this. Also, unless renewable technologies become widely used in developing countries as well, their greenhouse gas emissions will greatly increase, swamping any reductions made by more developed countries such as Australia. Less than 15 per cent of Australia's electricity demand is met by renewable energy sources.

Sustainable technology is a technology that meets production requirements while still conserving natural resources. Sustainable technologies use environmentally friendly resources, mostly those that involve renewable energy sources.

Renewable energy is energy from resources that will not diminish or can be replaced as we use them, within a time span relevant to humans.

Some sources of renewable energy include:

- hydro (water)
- solar
- wind
- biomass

- tidal
- wave
- geothermal.

These are discussed in more detail below.

Hydro

The energy created by the flow of water has been used for hundreds of years in devices such as water mills. With electricity, the 'modern' energy source, moving water is used to generate the power. Water turbines are attached to generators to produce a steady and reliable flow of electricity. Hydroelectric schemes are used to store electricity for later use. Excess electricity from other power stations can be used to pump water back uphill to the top reservoir. The energy stored in the water can then be released when the water is allowed to flow downhill through the hydroelectric generator.

Hydroelectricity is a renewable energy source that does not generate pollution or contribute to the greenhouse effect but the creation of the system has a devastating effect on the local environment. Some of the environmental ramifications include silting of dams, destruction of farming areas, townships and wildlife habitats, and killing of fish in local rivers when dam water is released. As a result of environmental concerns not many new hydroelectric schemes are being built. An alternative to the large schemes is a system whereby generators are installed in existing dams and rivers to divert part of the natural river flow through a turbine. This method does not require the construction of large dams and thus minimises the environmental impact.

Solar Energy

Solar energy, or energy from the sun, is in plentiful supply in Australia. It may be used through a **solar thermal** system to heat water, air or oil for domestic and industrial uses or through a **photovoltaic** system (solar panels), which directly converts sunlight to electricity.

A range of **solar thermal** technologies are used throughout the world to harvest the sun's energy. A flat plate solar collector may be used for domestic hot water systems. Solar energy is also used to heat either water or oil (which is then used to heat water) to produce steam to generate electricity. The solar energy is often concentrated by the use of parabolic mirrors.

Photovoltaic systems use high purity silicone semiconductors. Energy from the sun (or artificial light) causes electron movement in one direction only which causes a current to be produced. The electricity produced by photovoltaic cells is direct current. Large cells are currently expensive to produce, as single silicone crystals need to be grown. However, smaller cells are often used in calculators and other small electrical gadgets.

Solar energy is a renewable resource that has some disadvantages in that it is available only during the day and the availability varies with the season, location and weather.

Wind

Moving air causes the vanes of a windmill to turn. Whilst these have traditionally been used in Australia to pump water, modern mills incorporate an electric generator. Wind generators have been constructed or are planned for Sydney (Malabar), Newcastle (Koorangang) and the Southern Highlands. In the Netherlands and Denmark, wind farms used for the production of electricity are a common sight. Locations are selected on the frequency of the site being exposed to winds of appropriate strength.

Biomass

Biomass is the name given to all plant and animal matter. Biomass energy is obtained from plant or animal material, waste from agricultural, industrial and forestry products, and human or animal wastes. Biomass energy originally comes from solar energy through photosynthesis. Plants gain their energy from the sun and animals get their energy from the plants or other animals they have eaten.

Plant material can be used directly (for example, burning wood for heating or cooking) or indirectly by converting it to a liquid or gaseous fuel (for example, alcohol or biogas). Animal matter can also be used to produce fuels, such as biogas from animal manure.

Wood fuel is popular across the world but it is causing the rapid depletion of forests, adding to greenhouse gases and creating visible pollution in some countries. **Alcohol fuels** such as ethanol and methanol can be used to fuel engines. Ethanol can be made from materials that contain sugars, starch or cellulose such as cereals, sugar cane, sugar beet, wood and kelp. Ethanol is currently used to supplement or substitute petrol in cars. Methanol can be produced from wood and other biomass, which is why it is known as 'wood alcohol'. Methanol can also be used to fuel engines.

Biogas is produced when animal waste or other organic material rots in the absence of oxygen. This can happen when rubbish has been buried underground. It also happens in the digestive system of humans and other animals when bacteria break down food in the intestine. Biogas is also known as 'swamp gas' or 'marsh gas' and can be burned like natural gas or LPG to provide heat for homes, commerce and industry. Up to 65 per cent of biogas is methane — the main gas found in natural gas. Biogas can be made commercially by mixing livestock manure with water in a heated chamber. Bacteria, present in the manure, break it down thus producing biogas. Biogas energy can be used to power furnaces, heaters and engines and to generate electricity. In some areas, biogas generators are being used to make electricity by burning the gas produced at old garbage dumps.

Plant oils obtained from peanuts, vegetables, olives, canola, sunflowers and so on have the potential to replace diesel fuel. At this stage the use of plant oils as a major energy source is not economically viable but as technology improves, and fossil fuels become scarcer and more expensive, there may be a place for them in the future.

Tidal

Tides are produced by the gravitational influence of the moon and sun on the water of the Earth. Every day, in temperate areas, there are two high and two low tides. Water depth may vary by up to two metres while in tropical areas tidal fluctuations can be much greater. Spring tides are when the variation between high and low tides is greatest, neap tides when least. Spring tides are associated with the full moon, that is, when the moon is on the opposite side of the Earth to the sun.

While tidal flows occur on every body of water on the Earth, the flow is really only useful as an energy source where the water moves through a constriction such as a channel to a coastal lake or a narrow entrance to a bay. Both incoming and outgoing water can be used to generate electricity. Water flow is not constant and may stop at high and low tides (slack water). Flow depends on tidal variation and is greatest midway between tides.

Wave

Waves are caused by wind blowing over bodies of water. The size of waves depends on the speed of the wind, how long it has been blowing and the distance of water it blows over (the fetch). Types of waves include **chop** — caused by short-term local winds, **wind swell** — caused by long-lasting local winds, and **ground swell** — caused by strong, distant winds, such as a cyclone which could be hundreds or even thousands of kilometres away. Large ground swells carry the most energy. As a wave passes a point in the ocean, water particles move in a cyclic path, rising and then falling as each wave passes. Waves are produced in many parts of an ocean and travel from different directions. When they reach a common point in the ocean some waves cancel each other out, whilst others combine to produce large waves. These large waves come in 'sets' separated by periods of smaller waves.

Wave energy has been captured using a turbine to generate electricity as the rising and falling water levels caused by waves push air from and into the space above the water. Sites for wave generators need to be exposed to the open ocean to capture all available swell, and thus risk damage from storms and salt water corrosion.

Geothermal

The source for this energy comes from the Earth's molten centre. Geothermal energy occurs in several forms:

- **Low grade** is when the water reaches the surface below its boiling point (20–80°C) and is often used as a heat source for building and swimming pools.
- **High grade** is when the water or steam reaches the surface super-heated at high pressure (> 100°C). This can be used to generate electricity via a turbine.
- **Hot dry rocks (HDR)** can be used as an energy source if water is fed to the rocks (between 3 and

6 km below the surface) and is given a return path that allows the steam produced to turn a turbine.

Nuclear Power

Nuclear power is sometimes portrayed as one of the best alternatives to fossil fuel consumption. Whilst some forms of nuclear power have existed for several years, others are still being studied.

Nuclear fission is the break-up of large atoms to produce energy. Small amounts of fuel yield enormous amounts of energy, reducing transportation costs and ensuring current reserves will supply energy needs for thousands of years. The most common fuel for this is uranium. In standard nuclear reactors, enriched uranium is used (uranium with a greater amount of U235 compared to U238 than is found naturally). This greatly adds to the cost of the process and, in addition, highly radioactive (and therefore dangerous) by-products are created.

Fast-breeder reactors do not require enriched uranium and also use the plutonium produced by other reactors. These reactors also produce dangerous radioactive substances.

Thorium fuel reactors are currently being researched. Thorium is a much more common element than uranium and is readily available in large deposits throughout the world. It has the advantage over uranium that radioactive waste is not as big a problem, but it does need the ignition energy of a uranium or plutonium fission to start the nuclear reaction.

Nuclear fusion is when light atoms such as hydrogen or lithium are fused together. This is the form of energy that powers the sun and other stars. The most common reaction is the fusion of two deuterium (an isotope of hydrogen containing a neutron) atoms to form a helium atom. Whilst the nuclear reaction can be produced, for example, in the H-bomb, harnessing the energy safely is still being researched. Whilst there is a finite amount of fusionable material on Earth, it still offers the possibility of an almost inexhaustible energy supply.

Extension

1. Find out from your electricity supplier the source of their energy.
2. Investigate 'green energy' options for consumers from this supplier.
3. Using the Environmental Defender's Office's (EDO) website, www.edo.org.au, find a link to your local government environmental information site. Investigate an environmental issue that has been addressed in your area.

19.5 Protection of Intellectual Property

Intellectual property refers to **property of the mind or intellect**. Intellectual property is legally protected and a designer must be aware of this. Credit should be given if a person uses copyright material for study purposes. Permission must be sought for the use of other types of intellectual property.

Protecting intellectual property is essential if research and development is to remain the property of the designer. It is a means to ensure that the financial gain from the design goes to the creator of the intellectual property. Patents, trademarks, registered designs, copyright, circuit layouts, plant breeds and trade secrets are legally classified as intellectual property.

The Commonwealth Government administers legal protection of intellectual property. Copyright and circuit layout rights do not have to be formally registered but all other forms of intellectual property must be. Legal protection is granted by the following government agencies:

- **IP Australia** — administers patents, trademarks and design rights.
- **Attorney General's Department** — administers the legislation for automatic rights to copyright and circuit layout rights.
- **Plant Breeder's Rights in Agriculture, Fisheries and Forestry Australia** — administers plant breeder's rights.

Legal protection of intellectual property is covered under common law and consumer protection (fair-trading) legislation in the *Trade Practices Act*.

Patents

A patent is a temporary (20-year) monopoly granted to a patentee by the government once an application is approved. A patent is taken out on new or improved products or processes. A patent enables the owner to gain exclusive commercial advantage from their product or process. Artistic creations, mathematical models, plans, schemes or other mental processes cannot be patented. The legal protection of intellectual property in the form of patents encourages people to continue to research, to develop new and innovative products, exploit new technology and promote the transfer of technology to Australia.

Most countries have patent processes similar to the Australian system. If a person wants to protect their invention in several countries they need to file an international patent application under the Patent Co-operation Treaty (the PCT).

Design example

Many Australian icons have been patented including the Victa lawnmower (1955), the Hills Hoist (1956), Cochlear's bionic ear (1978), and Dynamic Lifter (1986).

Trademarks

Trademarks differentiate the goods and services of one organisation from another. A trademark can be a logo, picture, word, letter, phrase, shape, number, feature of a package or even a sound or smell. It may also be a combination of these. A registered trademark gives the owner the exclusive legal right to use, licence or sell within Australia the registered goods and services. Trademarks are recognised as a valuable marketing tool as they enable the public to identify a certain quality and image with goods and services bearing the trademark.

Designs

Design refers to the shape or appearance of finished products. When a design is registered it prevents other people from using it without permission. Design registration is used to protect the visual appearance of manufactured products for industrial or commercial use. Designs that are mainly artistic works are covered by copyright legislation. They are not [illegible] design registration.

Design examples

Speedos were registered as a design in 1976.

In 1994 Ken Done registered a bed linen design displaying typical Ken Done artwork.

Copyright

Copyright protects written material, artistic work, music, dramatic works, computer programs, compilations, films, sound recordings, broadcasts and published editions. In Australia copyright is protected under the *Copyright Act* 1968. Copyright protection is free and automatic. A work is protected automatically from the first time it is written down or recorded. Copyright lasts 50 years after the creator's death.

The copyright notice (©) does not have to be put on copyright material for it to be protected but it does serve the purpose of reminding people that the work is covered. Any person who wants to use copyright material needs the copyright owner's permission. Failure to get permission is an infringement of copyright. The exceptions to infringement occur when material is used by reviewers, students, libraries, educational institutions and government bodies. In these cases certain procedures must be followed.

If a person uses copyright material for **research or study** they do not infringe copyright if the use is fair. When copying text or printed music it is considered fair to copy less than 10 per cent of the total pages or one chapter if the work is divided into chapters. There is no legal requirement, at this stage, to acknowledge the source, but a person may be in breach of the law if they suggest the material is their own. Hence it is obvious that acknowledgement of the source is good practice.

Circuit Layout Rights

Three-dimensional electronic circuits in products or their layout designs are automatically protected. Circuit layouts are usually complex and are often worth considerable money. Circuit layouts may be used in many electronic devices that we use every day such as heart pacemakers and personal computers.

Plant Breeder's Rights

Plant breeder's rights gives the grantee exclusive marketing rights to a new plant variety, or its produce, for a period of 20 years (or 25 years in the case of tree and vine species). New plant varieties may be protected once plant breeders register the variety. The rights enable a person to direct the production, sale and distribution of the new variety, receive royalties from the sale of the plants, or sell the rights.

Trade Secrets

Confidential information or trade secrets can also be legally protected. A trade secret is both a type of intellectual property and a strategy for protecting intellectual property. A trade secret strategy is appropriate when it is difficult to copy the construction, manufacturing process or formulation from the product itself. A **confidentiality agreement** is often entered into as well, to stop employees from revealing the secret. This is usually a signed document outlining the trade secret and it provides legal evidence of what was agreed on.

Plagiarism

Plagiarism occurs when a person presents another person's ideas, thoughts, images or material as their own. It is the theft of another person's intellectual property and it is against the law to plagiarise. Plagiarism can be avoided by acknowledging the source of the intellectual property.

Extension

1. Visit IP Australia's website (http://www.ipaustralia.gov.au) and determine how you could protect the intellectual property associated with your Major Design Project.
2. (a) Find out how the 'copyright notice' is cited for all materials including sound recordings.
   (b) Fully investigate the procedures you should follow when copying from the Internet. You may like to access the Australian copyright website at http://www.copyright.org.au.

19.6 Rights and Responsibilities of Designers

Human inventiveness and human consumption of products invented by others has increased rapidly over time. Standards of living have risen as a result and designers today are encouraged, through consumer expectations, to consider the ramifications of their design and how it fits into society as a whole. Gone is the technological utopianism when there was a general belief that innovations were always in everyone's best interests. Today, designers have an ethical responsibility to consider conspicuous waste, environmental factors and the exploitation of vulnerable and minority groups. In other words, design is not just carried out for the sake of design — the human factor is also important. Designers must respond to changing expectations if they wish to remain relevant, and employed!

Rights of Designers

Laws protect the rights of designers. A designer has the right to:

- Legal protection of intellectual property by the relevant means.
- Legal redress if intellectual property is used without permission.

Responsibilities of Designers

A designer has the responsibility to consider the implications of following the design process, the production of the design and the use of the design. Designers should:

- Accept a professional obligation to further the social and aesthetic standards of the community.
- Act in keeping with the honour and dignity of the profession.
- Not consciously assume or accept a position in which personal interests conflict with professional duty.
- Act in the client's interests within the limits of the designer's professional duties.
- Not work simultaneously on assignments that are in direct competition without informing the clients or employers concerned.
- Treat all knowledge of a client's intentions, production methods and business organisation as confidential.
- Try to reduce any potential safety hazards associated with the design.
- Aim to create minimal environmental impact through design, manufacture and use.
- Not use other people's intellectual property without permission.
- Not encourage or engage in the invasion of privacy.
- Not unnecessarily harm any human or animal.
- Not hide details that may be significant to the consumer.
- Be aware of the needs of minority and disadvantaged groups.
- Have an awareness of consumer rights including:
  - the right to safety
  - the right to choose
  - the right to be informed.
- Improve the world through their design.

Extension

Use the Internet to investigate the role of the following organisations in protecting consumer rights:

(a) Australian Competition and Consumer Commission at www.accc.gov.au

(b) Department of Fair Trading at www.fairtrading.nsw.gov.au

(c) Australian Consumers' Association at www.choice.com.au

(d) Whistleblowers Australia at www.whistleblowers.com.au

(e) Consumer Affairs Division at www.treasury.gov.au/consumer

Review Questions

1. A designer needs some music to play during the credits of a promotional video. What are some ethical considerations in the use of the music?
   (A) Finding and acknowledging the source of the music.
   (B) Making sure the music is not plagiarised from a previous source.
   (C) Strictly controlling the use of the music.
   (D) Placing a copyright notice at the end of the video to protect intellectual property.
2. How could a washing machine be designed to reduce its impact on the environment?
   (A) By reducing small component parts and using an easy to clean lid.
   (B) By reducing the size of the washing bowl to minimise water consumption.
   (C) By making the plastic components out of easily recycled plastics.
   (D) By improving the efficiency of the machine in respect of power consumption and water usage.
3. What is meant by sustainable technology?
   (A) Technology that uses only renewable energy sources.
   (B) Technologies that use environmentally friendly resources and conserve non-renewable resources while still meeting production needs.
   (C) Technology that can be sustained over a long period of time irrespective of trends or fashions.
   (D) Technology that uses recycled materials over a long period of time.
4. A renewable resource is one that:
   (A) Comes from high-grade energy sources such as fossil and nuclear fuels.
   (B) Cannot be replaced within a time frame relevant to human beings.
   (C) Will not diminish or can be replaced within a time frame relevant to human beings.
   (D) Can be easily recovered or recycled.
5. Designers can play a significant role in the recycling of products. How may a designer assist consumers in the recycling process?
   (A) By designing products that may be reused several times.
   (B) By ensuring that the products are made from materials that are readily recycled in most communities.
   (C) By minimising the number of different materials used in a design.
   (D) By labelling the components that may be recycled.

☞ ***Answers to Review Questions, p. 188.***

Answers | **Ethical,** Environmental **and** Social Issues

Answers to Exercises

Exercise 1 page 177

Personal values: Do you value the relatively low cost, the eye-catching design on the packaging or the convenience of the shape?

Cultural beliefs: How does it fit in with your beliefs about the environment, the use of technology or any other belief that may be passed from one generation to another?

Sustainability: Does the packaging use sustainable resources? Is it harmful to the environment?

Safety and health: Does it protect the food from contamination within the range of normal use? Is the product clean? Could you harm yourself when you use the package?

Community needs: Have McDonald's developed the packaging to suit community expectations about recycling and waste minimisation?

Individual needs: Are you happy with the packaging?

Equity: Does the packaging work as well for people with disabilities such as arthritis, or the elderly?

Exercise 2 page 180

1. The *Privacy and Personal Information Protection Act* 1998 has two main purposes:
   - It establishes the office of the Privacy Commissioner.
   - It provides for the protection of personal information held by public sector agencies.
2. The problem of computer use and abuse is enormous. Computer use is growing rapidly in all sectors of our society for both legal and illegal uses. The AICE is a central body that addresses issues of ethics and computers. It provides independent assessment and also comments publicly when appropriate.

Answers to Review Questions page 188

1. (A) Finding and acknowledging the source of the music.
2. (D) By improving the efficiency of the machine in respect of power consumption and water usage.
3. (B) Technologies that use environmentally friendly resources and conserve non-renewable resources while still meeting production needs.
4. (C) Will not diminish or can be replaced within a time frame relevant to human beings.
5. (B) By ensuring that the products are made from materials that are readily recycled in most communities.

20 – Case Study of an Innovation

Chapter Overview

A mandatory requirement of the syllabus is for students to study innovation and emerging technologies. As part of this study students conduct a detailed case study of an innovation. Information gained from this case study may be used to support the exploration and development of a student's Major Design Project.

Expected Outcomes

On completing this chapter, students should be able to:

- critically analyse the factors affecting design and the development and success of design projects
- relate the practices and processes of designers and producers to the Major Design Project
- explain the influence of trends in society on design and production
- evaluate the impact of design and innovation on society and the environment
- analyse the factors that influence innovation and the success of innovation
- use creative and innovative approaches in designing and producing
- select and use appropriate research methods and communication techniques
- critically assess the emergence and impact of new technologies, and the factors affecting their development.

Source: Design and Technology, Stage 6 Syllabus, © Board of Studies, 1999.

Key Terms and Concepts

case study
creativity
cultural influences
design
emerging technology
entrepreneurial activity
environmental issues
ethical issues
historical influences
innovation
research methods

20.1 Introduction

The case study provides students with an opportunity to:

- Relate aspects of the content material to a detailed study of an innovation.
- Identify and analyse factors contributing to the success of an innovation.
- Discuss ethical issues relating to the innovation.
- Discover the impact of the innovation on Australian society.
- Conduct detailed research using appropriate methods.
- Produce a relevant and useful report.

20.2 Content Areas

The case study should refer to:

- Designs and design practice (see Chapter 4).
- Creativity (see Chapter 8).
- Factors which may impact on successful innovation (see Chapter 17).
- Entrepreneurial activity (see Chapter 17).
- The impact of emerging technologies (see Chapter 18).
- The impact on Australian society (see Chapter 17).
- Historical and cultural influences (see Chapter 6).
- Ethical and environmental issues (see Chapter 19).

20.3 General Information

The case study is an in-depth study of an innovation. It is a relatively time-consuming activity that addresses all of the content areas outlined above. The results should be a useful investigative report that demonstrates critical thinking and analysis using appropriate research methods.

Background

Industry is important to the economic viability of any country. Australia must be able to produce saleable items for overseas markets or it has no income. The balance of trade within Australia compares our exports with our imports. Industry presence within Australia is directly related to this balance and the wealth of our country.

The entrepreneur Dick Smith explained this to the people of Australia in 1999–2000 when he began manufacturing a range of Australian grown, owned and produced food products. He challenged the Australian people to 'keep the money in Australia'. Dick Smith and his investors aimed at a 12-month profit of $A15 million only to find that they made this amount in just a three-month period. This profit margin has allowed the company to diversify and extend their product range.

The Dick Smith Food Company began by releasing 'Aussie' Vegemite and peanut butter and had many battles with Kraft Foods before the former product was released onto the market. The company now provides a range of products that includes Helicopter jelly, Dick Head matches, biscuits, cheese, toppings and drinks. For additional information on this company look up the website www.dicksmithfoods.com.au.

Innovation involves a change to an established product's design, manufacturing, marketing or organisational structure. It is something new or different and may involve a material object, knowledge, an industry or an organisation.

Emerging technologies are new and/or improved materials, products, systems and environments. They are usually more efficient and cost effective than current technologies in a similar field.

Innovation is often linked with an emerging technology because as new technologies emerge, people learn to use them in diverse ways and this often results in enormous innovation.

Selecting an Innovation to Study

When choosing an innovation to study it is important that you select one that has been well documented and that you have access to. This allows you to thoroughly research every aspect of the innovation. If there is not a reasonable amount of available information, it can be difficult to adequately address the content areas.

While conducting their MDP students can employ the processes they used in the investigation of their case study. In other words, even if the innovation is not directly related to the MDP, the same procedural framework can be applied.

A relatively recent innovation is preferable, as it is likely to be more relevant to you as a student and should also be easier for addressing social issues and emerging technologies. You should not rely on one source for all your information and you should try and use as many different types of research as possible. Students may use primary or secondary research or a combination of these. Students should be able to comment on their choice of research and justify why they chose that particular method.

Secondary research is when you use information that has been gathered by other people. You can use books, magazine and journal articles, pamphlets, the Internet, videos, photographs and digital images. It is important when gathering material from secondary sources that you summarise the information in your own words and from your own understanding. Evaluating the information and drawing your own conclusions will enhance your higher order thinking skills.

Primary research is when you gather the information first-hand. You may interview, survey, question, visit and observe, write to or e-mail people to gather data on any aspects of the study that you feel are relevant. This first-hand information can be very helpful when you are trying to formulate your own conclusions.

The investigative report should be of a high quality. You should try and get someone to proofread it before submission. The report should be written in the third person. For example, write that 'the data would suggest …' rather than 'I think …'. Students should avoid using colloquial, slang or sexist terms and emotive language.

Source of the Case Study of an Innovation

Students may use a variety of sources to research the selected innovation. See Chapter 9, Research Methodology, for more details.

Students will find examples of innovations by:

- Reading textbooks from a variety of subject areas such as computing, social sciences, technology, design, art, history, mathematics and so on.
- Reading reference books.
- Viewing television documentaries, lifestyle programs or the news. Transcripts of these are often published on the Internet.
- Reading newspapers, including supplements. In some cases these may also be found on the Internet.
- Reading biographies.
- Reading reviews in newspapers and magazines.
- Reading journals (libraries will often conduct searches for you).
- Viewing CD-Roms.
- Searching on the Internet.
- Joining chat groups.
- Registering an e-mail address with relevant groups.
- Viewing catalogues.
- Interviewing people in the relevant industry.
- Participating in work experience or work placement.
- Visiting sites and doing field research.

The Written Report

As with all reports or documentation, your research must be presented in a concise manner. It must be informative and supported by appropriate graphics. You must consider all of the following aspects when researching an innovation:

- Designers.
- Trends in society on design and production.
- The impact of design and innovation on society and the environment.

- The use of creative approaches.
- The development of new technologies and their impact.
- The factors that influence innovation and the success of innovation.

Suggested Research Questions

Students may like to use the following questions to form the basis of their case study:

- Name the innovation.

Designs and design practice

- Name the designer and state what position and qualifications they hold.
- When was the design created?
- Where was it created?
- Why was it invented (what was the key motivation)?
- What was the need?
- Describe the research that was conducted to support the innovation.
- What market opportunities were identified?
- How were the ideas generated or developed?
- What factors limited the development of the innovation?
- Did the designer consider any other possibilities?
- What is innovative about this design?
- Provide a clearly labelled sketch, photograph and/or a detailed description of the innovation.
- Analyse the function and aesthetics of the design.
- Analyse the quality of the design.
- Analyse the durability of the design.
- Record and analyse the plan (action/time) used to guide the progress of the design development.
- List, explain and give reasons for any tests or experiments that were used to develop the innovation.
- What resources were used to develop the innovation?
- Explain why the design is so successful.
- Are there any problems with the design?
- What are the limitations of the design?
- Were ergonomics a consideration? If so, explain why.
- Describe the role of ongoing evaluation in the design process.
- Identify the critical stages of evaluation in the development of the innovation.
- How does the innovation fulfil the original need?
- Compare and contrast technologies used in the production of the MDP to activities of design and production used for the innovation.

Creativity

- What aspects of the design are creative?
- Use a flow chart to list and describe the processes undertaken to develop the innovation.
- Explain how the ideas have been adapted and developed to form the finished innovation.
- Did the designer use any motivational stimuli to develop their innovation?
- What creative thinking processes did the designer use to create the innovation?

Factors that impact on the success of innovation

- Analyse the timing of the innovation.
- How have available technologies impacted on the innovation?
- Explain how cultural factors have influenced the innovation.
- How have political, economic and legal factors impacted on the innovation?
- What marketing strategy was used to promote the innovation?
- What is the market size for the innovation?
- Describe the demand for the innovation.
- How is the innovation promoted?
- Name the agencies that have been used to support the innovation.

Entrepreneurial activity

- How has the entrepreneurial activity influenced the success of the innovation?
- Describe the management structure that has supported the innovation.
- Were any legal or ethical issues of note taken into consideration by the entrepreneur when developing the innovation?
- How have agencies such as government, commercial and industrial agencies influenced the innovation?

The impact of emerging technologies

- Analyse the impact of emerging technologies on the innovation.

The impact on Australian society

- What impact has the innovation had on Australian society? Consider social, global, political, economic, environmental, technological, legal and marketing factors.

Historical and cultural influences

- Have changing social trends influenced the development of the innovation? Explain.
- What impact has cultural diversity had on the development of the innovation? Explain.
- Has the changing nature of work had an impact on the development of the innovation? Explain.
- Has long-term technological change had an impact on the development of the innovation? Explain.

Ethical and environmental issues

- List and explain the ethical issues considered during the design and production of the innovation.
- How did the designer protect their intellectual property?
- Did issues such as copyright or plagiarism present any challenges to the designer?
- List and explain the environmental issues considered during the design and production of the innovation.
- Were sustainable technologies used in the design and production of the innovation?
- Is the innovation an environmentally sustainable technology? Explain.
- Analyse how the design and production of the innovation uses energy, considering various energy sources.
- Comment on the environmental impact of the energy consumption.
- Is the design recyclable or reusable?
- How safe is the design to the designer, manufacturer and user?
- Is it easy to dispose of?
- Will the design become obsolete in the near future? Explain your answer.
- Do a life cycle analysis of the design.
- What does the designer perceive as their 'rights' as a designer?
- What does the designer perceive as their 'responsibilities' as a designer?

20.4 Writing the Research Report

A report usually comprises the following features in the following order:

- Title page.
- Contents page.
- Abstract or summary.
- Acknowledgements.
- Main body of report.
- References/bibliography.
- Appendixes.
- List of figures and tables.

These are examined in more detail below.

Title Page

The title page consists of the title of the report, the author's name and name of the student's school and the date of publication.

Contents Page

This should be accurate and logical. There should be major headings and some students may choose to use sub-headings for each part. The page numbers should be easy to identify. A sample contents page is reproduced on the next page.

Abstract or Summary

The author should give a brief background to the research, outline the methods used, and discuss the main findings.

Acknowledgements

This section is used to thank any organisations or individuals who have helped with the research.

Main Body of Report

This is the most important part of the research. Students need to put the results of the questions into prose form. The body should contain an introduction, body and conclusion. Each of the content areas should be addressed and they should form major headings, for example, 'Ethical and environmental issues' is a major heading.

Table of Contents		Page
Abstract		(i)
Acknowledgements		(ii)
1. Introduction		1
2. Designs and design practice		5
3. Creativity		6
4. Factors which may impact on successful innovation		7
5. Entrepreneurial activity		8
6. The impact of emerging technologies		9
7. The impact on Australian society		10
8. Historical and cultural influences		11
9. Ethical and environmental issues		12
10. Conclusion		15
References		16
Appendixes		
Appendix 1	Research questions	18
Appendix 2	Raw responses	21
List of Figures and Tables		
Creativity flow chart		6
Life cycle analysis		14

References/bibliography

A reference list includes only those sources referred to in the text while a bibliography includes all sources you may have looked at but did not necessarily use in the report. Teachers usually guide students as to which list they would prefer. See Chapter 9 on Research Methodology for citing references or compiling a bibliography.

Appendixes

Appendixes contain information that is relevant to the project but not suitable to put in the report, for example, a copy of the questions used for research and the raw responses given. Each item should be clearly labelled and numbered.

List of Figures and Tables

Each chart, table and illustration should be listed and numbered following the table of contents. You can use the checklist below to ensure that you have studied your case study in enough depth and refer to Figure 20.1 which presents the checklist in diagrammatical form.

Designers

- Designer's practice.
- Processes used by the designers.

Trends in society on design and production

- Historical development and the influence on design.
- Cultural diversity and the influence on design.
- Global, social, political and economic influences on design.
- Changing social trends.
- The changing nature of work and its influence on design.
- Technological change.

The impact of design and innovation on society and the environment

- Ethical considerations.
- Environmental considerations.
- Use of sustainable technology.
- Protection of intellectual property including patents, copyright and plagiarism.
- Designer rights and responsibilities.

Use of creative approaches

- *Responding to motivational stimuli.*
- *Creative thinking.*
- *Processes undertaken to develop innovation.*
- *Success of innovation.*
- *Adaptation and development of ideas.*

The impact of new technologies and their development

- *Use of emerging technologies.*
- *Factors affecting their development.*
- *Criteria for evaluation.*
- *Impact on society and the environment.*
- *Impact on innovation.*

Factors that influence innovation and the success of innovation

- Timing.
- Available and emerging technologies.
- Cultural, political, legal and economic factors.
- Marketing strategies including size, demand and product promotion.
- Role of the Patents Office.
- Role of the Small Business Council.
- Nature of entrepreneurial activity.
- Role of entrepreneurial activity.
- Agencies which affect entrepreneurial activity.
- Management.

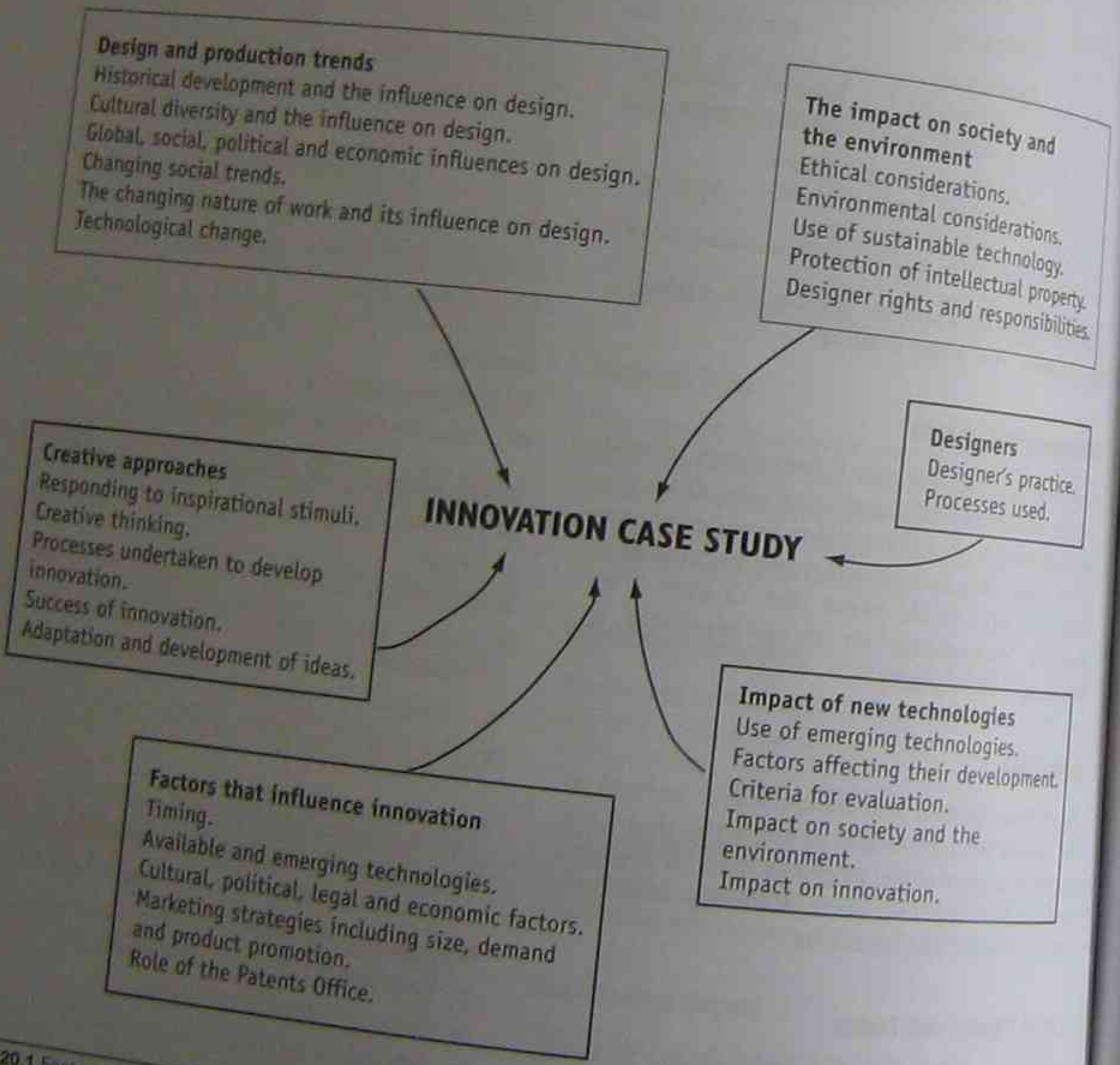


Figure 20.1 Factors to consider in the Innovation Case Study

Review Questions

Students should note that no answers are given to the following review questions as students need to apply them to the particular innovation they have chosen.

(a) Explain how functional and aesthetic factors have influenced an innovation you have studied.

(b) Define the term 'ethics'. Discuss how the designer of an innovation you have studied addressed a number of ethical issues.

(c) Quality versus cost effectiveness is an issue faced by many designers. Describe the quality of an innovation you have studied and explain the influence of cost on quality.

(d) Evaluation is a critical element within the whole design process. With reference to an innovation you have studied, analyse the role of evaluation in influencing the design's success.

(e) Explain the difference between the terms 'new' and 'emerging' technologies. With reference to an innovation you have studied, discuss the influence that new and emerging technologies had on the success of the innovation.

(f) Marketing is a significant factor that will contribute to the success of an innovation. With reference to this statement, and an innovation you have studied, justify the marketing strategies used to promote the innovation.

(g) Describe the function and role of **three** agencies that have impacted on an innovation you have studied. Justify your selection.

(h) Discuss **two** environmental issues that impacted on the design and production of an innovation you have studied.

(i) Analyse the life cycle of the innovation.

(j) With reference to an innovation you have studied, describe in detail some of the health and safety issues that influenced design and production.

(k) What is entrepreneurial activity? How has entrepreneurial activity influenced the success of an innovation you have studied?

(l) Australian society is influenced by a number of changing social trends. Discuss in detail how **two** social trends have influenced the success of an innovation you have studied.

21 – The Major Design Project

Chapter Overview

The Major Design Project is worth 60 per cent of the external assessment of the HSC Design and Technology course. Clever planning, management, design, production and evaluation will help students maximise their marks.

Expected Outcomes

On completing this chapter, students should be able to:

- identify a need or opportunity and research and explore ideas for design development and production of the Major Design Project
- select and use resources responsibly and safely to realise a quality Major Design Project
- evaluate the processes undertaken and the impacts of the Major Design Project
- use a variety of management techniques and tools to develop design projects
- investigate a range of manufacturing and production processes and relate these to aspects of design projects.

Source: Design and Technology, Stage 6 Syllabus, © *Board of Studies, 1999.*

Key Terms and Concepts

action plan
criteria to evaluate success
design folio
environment
evaluation
finance plan
product
project development
project management
project proposal
project realisation
system
time plan

21.1 The Major Design Project

Your MDP is worth 60 out of 100 marks for your HSC and it is a very important part of this subject. It is important to try and gain as many marks as possible as they are like 'money in the bank' in terms of your eventual overall mark. The aim of the MDP is to provide students with experience in seeing a design challenge through to completion. Each student is expected to use and document the design process to design, research, manufacture and evaluate. Students have a choice of completing a product, system or environment for their MDP.

A **product** is something that can be touched and has a purpose. Some examples include:

- A textile garment or item.
- An item of food.
- A piece of furniture.
- A fashion accessory.
- A game.
- A musical instrument.
- Sports equipment or accessories.
- Computer graphics, software or animation.

A **system** is a series of steps that are followed in order for something to occur. This process should make the work easier, more efficient or cheaper. Some examples include:

- An electronic surveillance/security system.
- A process of transporting a particular item, for example, round hay bales.
- A process for serving food.
- A process that if followed changes people's behaviour.
- A fitness regime.

An **environment** is a space that needs adaptation or redesigning. Some examples include:

- Redesign of recreational areas such as parks or sporting fields.
- Adaptation of a house for a disabled person.
- The development of a room or outdoor area in a home.
- A clubhouse for an association.
- A plan of housing or cities.
- A theme park.

You are free to select from any of these three areas and you must complete both the practical project and the folio to gain maximum marks. The project will be marked by a team of examiners who will spend approximately 20 minutes examining your project. The examiners give every student the opportunity to do well by providing a checklist of all aspects of the project that will be marked — be sure that you have completed every level and demonstrated your use of higher level thinking skills.

21.2 Selecting a Major Project

The most difficult part of a Major Design Project is getting started, as you have to find a product that will demonstrate quality workmanship and creativity.

In order to demonstrate **quality workmanship** it is a good idea to work with a material or resource that you have some experience with and where you have previously developed some skills. For example, if you have studied wood techniques or textiles and design in Years 9 and 10, it may be a good idea to continue working in this area. You can choose to combine a number of materials, thus demonstrating that you are multiskilled and able to produce quality work with a variety of resources. If you choose to work with a material that you are not familiar with, it may be a good idea to complete some work experience or training in this area or seek the assistance of a mentor or teacher to assist and direct you.

Your project will need to be **innovative and creative**. *This means that it must have some degree of originality. Your design can be your own unique idea or it can be an existing idea that has been modified to suit a specific need. It is very important to not simply reproduce an idea, but to ensure that your design possesses unique features.*

Although the MDP cannot be started until the HSC course begins, you should start considering possibilities throughout Year 11. Do not be afraid to discuss these ideas with your teacher as you may decide to do a training course at TAFE during Year 11 to help you with your MDP. Because many students are unsure where to begin, it can be useful throughout Year 11 to note three problems that you observe each week. By the end of Year 11 you will have a large number of problems from which to choose a MDP solution. Remember also that a clever project may result in a career in the area related to the design. Finally there is one important rule to remember, the KISS principle, which stands for 'Keep It Simple Son', with 'son' being a generic term.

Folio Layout

It is advisable that the major and minor headings for your MDP correlate with the examiners' checklist. Major headings such as 'Project proposal and development', 'Project development and realisation' and 'Project evaluation' should be used as title pages to divide sections. Minor headings still need to be large and placed at the top of the page. Each heading and accompanying text must commence on a separate page.

21.3 The Project Proposal

The project proposal is worth 15 marks and it **must be included in your folio** as it sets the stage for the marker. Your proposal needs to be clearly divided into three sections as detailed below.

Identification and Exploration of the Need

The need must be clearly defined and it needs to be real! In this section you will have to explain what the need is and why you are doing this particular project. The need may be a personal one or it may be community based. Some examples of design situations and briefs are listed below:

- **A bus shelter**. Every day, my friend and I wait for the special bus at our local bus stop to take us to school. Claire, my friend, is in a wheelchair. Her wheelchair does not fit into the shelter so she gets wet on rainy days. The other people waiting get embarrassed and upset when this happens. I intend to design and build a prototype of a bus shelter which council could build to replace the existing one. I will then submit my ideas, plans, prototype and letters showing community support to council.
- **Being a cultural instrument**. I am an Aboriginal student who is very proud of my heritage. I enjoy both traditional Aboriginal and modern music and I have been developing my metalworking skills at TAFE for the last year. I hope to use these skills in my MDP. I would like to design, experiment with and manufacture a metallic musical instrument. I want to be able to use it to play both traditional and modern music.
- **Future career path**. I am an engineering student who wishes to follow engineering as a career path when I finish school. There is one engineering firm in the small town where I live and next year they are going to offer one apprenticeship to a HSC-level student. The competition for this position will be very fierce and my best friend, whose uncle works for the firm, is also intending to apply. My MDP will be something that I hope will impress the firm and help me gain the apprenticeship. I have surveyed many of the young people in my town and they have expressed a strong desire for somewhere to ride their skateboards so they can do something other than hang around the shops. I have successfully applied to council for funds to support my plan, pending their approval of my final submission, for the design and manufacture of a skateboard ramp in one of the town parks.

Areas of Investigation

The areas of investigation must be clearly identified and the limitations of the design brief, such as size, dimensions, costs, weight and so on, included. Areas for investigation need to be listed along with an explanation of how you will investigate them and the sources you intend to use. You may choose to include information on possible materials and applications and you must show a direction away from the problem/s towards possible solutions. Some areas you may investigate are detailed below:

- **Folio layout**. Explain the different ways you are considering laying out your folio. This could include style of presentation as in hand- or computer-written, fonts, point sizes, use of colour and so on.
- **Folio materials**. This can include a range of materials including size and type of folder, type and colour of paper, type of ink, pens and so on and can also include an investigation of the costs involved and environmental factors.
- **Folio skills and techniques**. This can include word processing, publishing, computer-aided drawing and painting, graphs and charts, lettering and headings, photocopying, scanning and the use of manipulated images obtained from a digital camera.
- **Prototypes and models**. You could investigate materials and techniques required for constructing prototypes and models as well as the reasons for using them.
- **Project materials**. This could include a listing of the materials required and their sources. You could also describe the most appropriate materials and detail their desirable characteristics.
- **Project testing and experimentation**. You should name and justify all tests and experiments to be carried out. Remember that only relevant tests can be awarded marks. For example, a flammability test to be carried out on a possible wedding dress fabric can only be relevant if it is explained that there will be a large number of candles at the wedding and thus the bride-to-be is concerned about flammability. In this example it would also be a good idea to test ways of removing wax from the material.
- **Project skills and techniques**. You need to list both the skills you will need to develop and how you intend to do this. This could include attending classes, practising and experimenting, working with a mentor and so on.

Real evidence of every aspect of this investigation must be provided throughout the folio. The markers will be looking for evidence of investigation and cross-referencing with the management section of your folio. They will check to see that you have investigated every element that you said you would and if you have not, they will consider this as evidence of poor time management.

Criteria to Evaluate Success

This is where you need to consider exactly what it is you wish to achieve, otherwise how will you know if you have done a good job? You need to convince the markers that you have successfully completed your design brief and the evaluation criteria will show both yourself and the examiner that this has been achieved.

Do not forget to use both functional (what it does) and aesthetic (how it looks) criteria as well as project-specific criteria. You may choose to refer to the elements and principles of design (refer to Chapter 2) to describe your criteria. You must state both major and minor desirable qualities and suggest how you will evaluate your success.

Once you have decided on the criteria you intend to use, you need to explain how the evaluation will occur and who will be doing it. It is a good idea to get a professional in the relevant field to evaluate your MDP if possible. For example, if your MDP involved producing a book, then a written evaluation from an author or a publishing company would be appropriate. If you have manufactured a product, then an evaluation from a designer or craftsperson would be needed. If you manage to sell a design or plan, this would provide an excellent opportunity to show external evaluation.

Extension

Read through your project proposal and then answer the following questions.

1. Briefly outline your proposal and design brief.
2. What is the need that makes this proposal real?
3. Explain why you have chosen this project.
4. Complete the following table:

Area to be investigated	How I will investigate it

5. List the criteria that you will use to evaluate your MDP.
6. Who will be involved in the evaluation process?
7. How will they complete an evaluation?
8. Is all of the above information written in your folio? If the answer is no, add the information to the folio.

21.4 Project Management

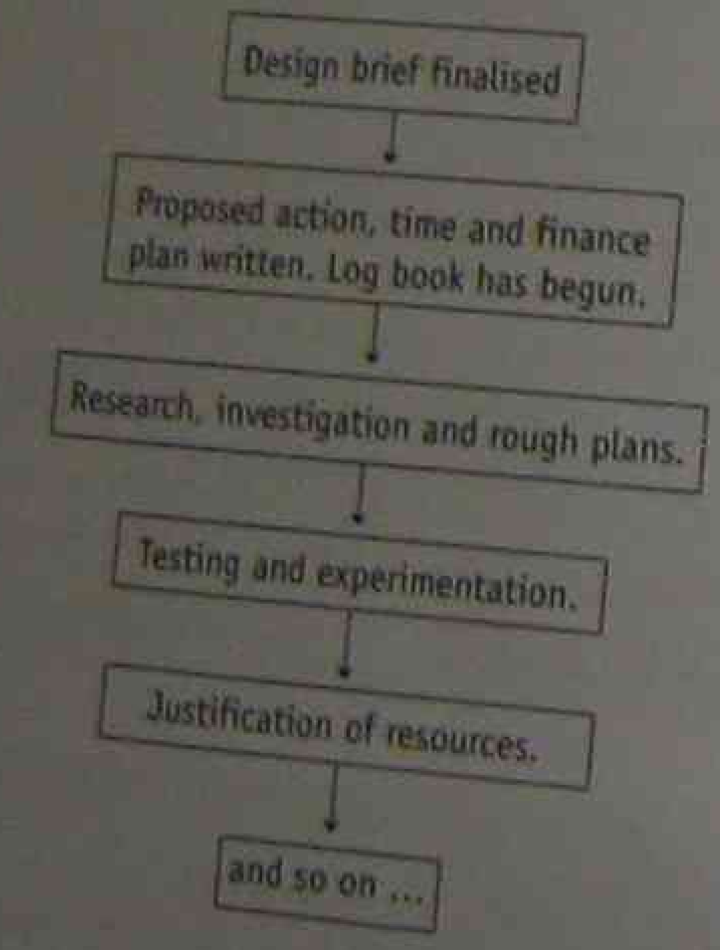
This is where you explain to the examiners how you organised your project. Management needs to be planned ahead and **ongoing documentation** needs to be included as you work through the process.

Action, Time and Finance Plans

In this section you will need to include action, time and finance plans and their application and evaluation.

Action Plan

This is an outline of what you intend to do from the beginning to the end of the project. An example of an action plan may include a flow chart similar to the one below, with project-specific detail added.



Time Plan

Proposed time plans must be included. If these were written before your MDP was in progress you will need to align them with the actual plans of what happened and provide constant evaluation of why there is a difference between the two. For example:

Proposed time plan	Actual time plan	Evaluation
Term 1, Week 2 Complete the tenacity and tensile strength test on ...	Term 1, Week 6, Completed strength tests on ...	University lecturer was on leave and I had to await her return to complete testing.

Finance Plan

When doing a finance plan, be sure you research the costs thoroughly. **Do not guess** at costs. Get quotes from suppliers and include these in your plan as well as the names of the suppliers and the date you obtained the quotes. A portion of a sample finance plan is supplied below.

Proposed Finance Plan

Costs		Supplier
D & T subject fees	$20	High school
A3 folio	$20	K-mart
A3 paper	$10	K-mart
Raw material costs		
and so on ...		

The total proposed cost of my MDP is $____

Your actual financial costs may vary from your proposal. If this occurs, treat it as an opportunity to demonstrate ongoing evaluation. If applicable, you could demonstrate your technical skills by using a spreadsheet that shows a progressive balance. This will give you the chance to show why there is a variation in the costs for reasons such as products needed were on sale, inflation caused a price increase, a relative provided you with some materials for free and so on. An evaluative comment such as 'I was able to save money ($...) on the (timber, fabric, food) because of ...' demonstrates higher order thinking skills and could improve your marks.

To prove that your financial records are accurate, keep all receipts and include them in your folio as evidence of your actual financial costs.

Selection and Use of Ideas and Resources

In this section you need to select appropriate resources and identify their use in the MDP as well as explaining why you chose to use them. You will also need to justify the selection and use of other resources related to the solving of any problems that arose.

Resources can be divided into two types — human and non-human. **Human resources** include people, skills, knowledge and attitudes. **Non-human resources** include all items that are used to help achieve the MDP. You need to identify and list all resources that will be used and demonstrate where in the project you have chosen to use them. You will also need to explain why you chose this particular resource over other similar products available. This justification needs to be more involved than 'it was aesthetically pleasing' as justification shows higher order thinking and a strong argument for why you chose the resources you did will result in higher marks.

21.5 Project Development and Realisation

This section is worth the greatest percentage of marks and thus your folio needs to be clear, concise and logical. You will need to demonstrate a mastery of cognitive organisers (refer to Chapter 7) and you may use flow charts, concept maps, sketches, photographs, digital images, written procedures, a log or diary, letters, interviews and written information.

Evidence of Creativity and Innovation

Innovation can be shown through creativity, a new idea, a modification or improvement to an existing idea and through evidence of problem solving. You may demonstrate innovation and creativity through the use of ideas, materials and/or techniques.

You will need to do three things in this section — explain **why** and **how** your idea is different and explore any similar existing ideas and documentation. You may choose to use sketches as a means of communicating in this section.

Consideration of Design Factors

You must analyse a range of design factors and explain how they are used in your folio. These may include:

- Functional and aesthetic aspects of the design.
- Ergonomics.
- Use of energy.
- Safety considerations.
- Costs.
- Comparison with existing products.
- Ethics.
- Quality.
- Durability.
- Strength.

Documentation of Research

Evidence of both primary and secondary research is required here and a range of research techniques should be employed to support the project. However, gathering information is only a small part of the marks allotted to the research section.

You can gather your information from a wide range of sources but be careful not to plagiarise. Make sure you reference all the information you get, whether it be from books, journals, or off the Internet. It is important to realise that the better candidates will do more than just gather reams of information — they will explain how this research was used in the making of the MDP. For example, an article explaining a simple research technique may be included in the research section. To increase marks it would be expected that the student would reference the article, highlight the major points and explain how, where and why this technique was used.

Extension

Name at least four research techniques that you used in your MDP. What did you learn from this research? Have you stated where the material came from and explained how you used it in your project? If you answered no, you will need to add this information to your folio. Remember though to **only add relevant information** — do not pad this section.

Evidence of Testing Design Solutions

Experimentation and testing can be carried out in many different ways but it must be done for a reason that has a direct relationship with the MDP. Testing must also be carried out on the same types of materials that will be used in the project. Reasons for testing and experimentation can be to improve your skills, to assist creativity and innovation and to see if ideas will work. Documentation of these procedures is required.

Many students choose to include samples and prototypes showing innovative problem solving and design solutions. Consideration needs to be given to how the conclusions from your testing will be presented in your folio.

Extension

What type of testing and experimentation did you use in your MDP?

Application of Conclusions

In this section you need to document how you used the information you gathered during your research and testing. More successful students will explain how they changed sections of their MDP because of the conclusions drawn from the experimenting processes, if applicable.

Extension

How did you use the results of your testing and experimentation?

Use of Communication and Presentation Techniques

The use of good communication and presentation techniques will help you get your message across to the markers. Remember that the quality is more important than the quantity. Communication needs to be clear and concise and utilise higher order thinking skills. The relevant use of a range of technological skills will be highly regarded and the inclusion of models and prototypes is encouraged.

Evidence of Practical Skills

Evidence of ongoing application must be included in your folio. This means that you must prove to the markers that this was your project and that you did the work. You may use logs, diaries, photographs, work reports and storyboards. The inclusion of a clear and detailed procedural text is strongly recommended as is the use of a log, regularly signed and dated by your teacher, and supported by photographic evidence of the steps in the project's development. Be careful with photographs as they can often tell the marker more than the folio does. For example, if you claim you did all the work at school, do not include a photograph of your Dad helping you in the shed at home!

Industrial/Commercial Practices

An industrial setting involves a manufacturing workshop environment whilst a commercial setting is any other business. In this section you need to clearly explain the similarities and differences of the materials, tools and techniques that you used in comparison with those used in a commercial or industrial setting. Remember to discuss OH&S regulations, Australian standards and the protection of intellectual property.

21.6 Evaluation

Evaluation is an ongoing procedure that must continue from the very first thought to the final presentation. Evaluation is important because it has been said that 'We don't really learn anything from experience, only from reflecting on experience' (Robert Sinclair, 1996). Remember that evaluation considers both the most and least important qualities.

Record of Evaluation Procedures

You must keep a clear evaluative record of all processes and decisions made throughout the MDP. In this section you can list all areas where ongoing evaluation occurred and state the relevant page numbers. It is also a good idea to colour or highlight (with the same colour or method) all evaluative comments to make it easier for the markers to identify the ongoing evaluation.

Application of Evaluation

In this section you need to explain how you have used an evaluative comment to improve the MDP. For example, you started manufacturing with a particular technique and machine that proved acceptable but you then found were unable to use the chosen machine for some reason. You discovered that you could not get the same results on a substitute and thus had to change either your technique or machine. In this example, you evaluated, made a decision and changed direction. All elements of this evaluation and its outcome must be apparent in the MDP.

Analysis and Evaluation of Aesthetic and Functional Properties

Here you must analyse your design and state to what degree your aims have been achieved. You need to analyse both the functional and aesthetic qualities. To analyse the functional properties you may consider the following questions, as applicable:

- Is it a quality product?
- Is it safe?
- Does it work as expected and intended to?
- Is it long-lasting and durable?
- Is it made from the most appropriate materials?
- Has the target market been considered?
- Is it easy to use? Are there any instructions needed for appropriate and safe use?

To analyse the aesthetic properties you may consider the following questions, as applicable:

- Is it an attractive design?
- Is it likely to appeal to the target market?
- How could you improve the look of the design?

It may also be useful to analyse the aesthetics of a design in respect of the elements and principles of design. To help you analyse and evaluate your design, you could relate the above questions to the list on Consideration of Design Factors on page 193, as applicable to your particular project.

Final Evaluation

You will need to state if the need in the project proposal has been met and then you must evaluate the impact your MDP will have on society and the environment. When evaluating your design in respect to society you must consider if it will make people healthier, safer, more aware, happier, wealthier, have more leisure time, enjoy increased status, or possess greater skills, knowledge or understanding.

In relation to the environment, consider all of the ecological issues. What environmental effects might your design have? Will it be sustainable, recyclable, will it increase or reduce pollution? Does it have a planned obsolescence? Have you done a cradle to grave analysis? Have you reflected on the criteria to evaluate success and so on?

Relationship of the MDP to the Project Proposal

In this section you must document two questions:

- Did I do what I said I would in my proposal?
- Did I do a good job on the MDP?

You should obtain written evaluations from experts in the same area as your MDP who will need to sign and date their evaluation. You may also include information on how you could improve the design if you were to make another.

Students' Log/Diary

All students and their teachers are required to keep a log of the progress of the MDP. This could be kept in the form of a diary and teachers should sign and date it to confirm that each aspect of the work was completed by the appropriate date. The diary does not have to be a part of the folio and may be presented as a separate book. Bear in mind that the markers may request to see a teacher's and/or student's log to check that progress was constant.

21.7 Checklist for MDP Success

Before submitting your MDP for marking, ensure that all of the following points have been considered and covered:

- **The folio and MDP need to be integrated.** When your project is being marked, the evaluators will examine a section of the folio and then examine the relevant element of the project. All work will be cross-referenced so it is essential that the folio provides a comprehensive record of the MDP.

- **Colour-code and/or label the folio.** This will assist the markers in their allocation of marks. If each section of the folio, such as the proposal, the project management and so on, is in a different colour it will make your folio clearer.
- **Evaluation must be ongoing.** Evaluative comments can also be colour-coded so the markers can see your use of ongoing evaluation.
- **A good MDP is of excellent quality and involves innovation.** The quality of both your project and folio must be of a Year 12 standard and must demonstrate a high level of skills and techniques and the use of innovation.

When considering quality in your MDP and folio you should:

- **Consider the range of skills you will demonstrate.** It is a good idea to work within an area where you already possess some skills and also use a mentor or appropriate teacher to help you demonstrate the level of expertise that will be expected.
- **Experiment to achieve quality work.** If it is worth doing for your MDP, then it is worth doing as well as you possibly can. Just as you need to edit and refine your folio, so you need to practise the skills and techniques you will use in your MDP. Experimenting via the use of prototypes, samples and different techniques encourages creativity and should result in high quality work and thus high quality marks.
- **Take time to give attention to detail.** It is the markers' job to examine all aspects of your MDP so you need to spend time making sure everything is as perfect as you can make it. This is why you need to work on your MDP throughout the entire year.
- **If it is not right, try to rectify it.** It is likely that despite your best efforts problems and errors will arise in your MDP. This is normal in design and it is your job to solve these problems. You may need to experiment to decide which approach will be best and all of this must be documented and evaluated. Experimenting, evaluating and documentation in relation to problem solving will result in better marks.
- **The timing of the MDP is crucial.** Good quality work cannot be achieved if you run out of time. You are given eleven months to work on the project and the examiners will expect the standard of your MDP to reflect this amount of time. You cannot possibly reach a high standard with a project thrown together in the last weeks or even months. Remember that time lost can never be regained.

21.8 Presenting the MDP

Even though the presentation of the MDP is not worth any marks, it does set the stage for the markers. It shows them what you were trying to achieve and is therefore very important and must be carefully planned. The MDP needs to be displayed appropriately and should be:

- Simple and informative.
- Displayed with suitable accessories such as storyboards, props and so on.
- Interesting and different.

Audio-visual presentations need careful planning and you will need to allow plenty of time for making, processing and editing. As an exercise, list some ways that you may be able to display and present your project.

Remember to:

- Use your time wisely.
- Record everything.
- Evaluate throughout.

Some helpful hints include:

- Be as creative as possible.
- Include samples of materials considered and used.
- Include rough work, handwritten comments and working drawings that relate to the development of the project. Remember, if you think it, write it down!
- Label all sketches.
- Explain any models that you use.
- Only include the relevant sections of any brochures or pamphlets used.
- Explain all points.

- Know the rules!
- Remember that markers are there to give marks when they can, not to take them away.

Extension

Under the following headings, list anything that you need to improve on your MDP before it is submitted.

General Points

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The Proposal

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Project Management

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Project Development and Realisation

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Evaluation

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22 – The Written Examination

Chapter Overview

Students should familiarise themselves with the structure of the written HSC examination paper as well as the outcomes it is likely to assess. A well-prepared and confident student is more likely to achieve good results.

Expected Outcomes

On completing this chapter, students should be able to:

- recall the structure of the paper
- recognise and apply the key words used in the examination paper
- practise specimen questions
- identify measures that may be implemented to improve the chance of a good result.

Key Terms

- account
- analyse
- apply
- assess
- compare
- contrast
- critically analyse/evaluate
- describe
- discuss
- evaluate
- explain
- identify
- justify
- outline
- recall

22.1 General Information

The Design and Technology HSC written paper is worth 40 per cent of the final examination mark. The paper is based on the syllabus and a variety of outcomes are tested each year. Every year a different set of outcomes is tested, although there may be some overlap from year to year. The paper is structured so that students' responses can be matched to all levels of performance. This basically means that there are some simple questions and some questions that require higher order thinking.

It is important that students concentrate on answering exam style questions as well as completing their Major Design Project to the best of their ability. Questions in the written exam are based on the content areas Innovation and Emerging Technologies and Design and Producing. Students will also be able to draw on the experiences they have gained whilst completing their MDP and case study to answer some questions. Students are given 90 minutes to complete the paper.

22.2 Structure of the HSC Paper

Students need to be familiar with the structure of the paper so they can develop a strategy to maximise marks in the given time. The paper is divided into three parts:

Section I (worth 10 marks)

In Section 1:

- There are **ten multiple choice questions**.
- All questions are compulsory.
- All questions are of equal value.
- Questions are to be answered on the answer sheet provided.

Section II (worth 15 marks)

In Section II:

- There is **one question** made up of a number of short, structured response parts.
- The question is compulsory.
- The question must be answered in the space provided on the examination paper.

Section III (worth 15 marks)

In Section III:

- There are **three structured extended response questions** (not essay questions).
- Where students have a choice of questions, the questions will have a similar structure so they can be compared with other questions.
- All questions are of equal value.
- Students should only do **one question**.
- The question must be answered in a separate writing booklet.

Directions to Candidates

Make sure you read the 'Directions to Candidates' as some words may change slightly from year to year. Students should look at past papers to familiarise themselves with the structure and directions to candidates. It is important that students are not only familiar with these directions, but also know how to respond to them. Be aware that the Design and Technology syllabus changed in the year 2000 and any past paper prior to this will reflect a different syllabus.

Instructional Words

Instructional words have been standardised across all HSC subjects. Very often the key or 'instructional' word is at the beginning of the sentence. It is important that the meaning is well understood.

The following are some of the common key words used in Design and Technology exams, with explanations of the kinds of responses they require. The Board of Studies has developed a glossary of key words that have the same meaning across all HSC subjects.

- **Account** — account for, state reasons for, report on. Give an account of, narrate a series of events or transactions.
- **Analyse** — identify components and relationships between them; draw out and relate implications.
- **Apply** — use, utilise, employ in a particular situation.
- **Assess** — make a judgement of value, quality, outcomes, results or size.
- **Compare** — show how things are similar or different.
- **Contrast** — show how things are different or opposite.
- **Critically (analyse/evaluate)** — add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to analysis/evaluation.
- **Describe** — provide characteristics and features.
- **Discuss** — identify issues and provide points for and/or against.
- **Evaluate** — make a judgement based on criteria; determine the value of.
- **Explain** — relate cause and effect; make the relationship between things evident; provide why and/or how.
- **Identify** — recognise and name.
- **Justify** — support an argument or conclusion.
- **Outline** — sketch in general terms; indicate the main features of.
- **Recall** — present remembered ideas, facts or experiences.

Source: Board of Studies, 1999.

Extension

1. Go through the previous chapters and define the key words and concepts in your own words. Reread the chapter or check the glossary if there are terms you do not fully understand.
2. Read past examination papers and write down terms that you are not truly familiar with. Research the meanings.
3. Access the Board of Studies website and identify the Glossary of Key Terms and the corresponding explanations at http://www.boardofstudies.nsw.edu.au-syllabus99-newhsc_assessment.pdf

22.3 Examination Techniques

Students should consider the following points:

- Before the exam students should work out exactly what time they should start and finish each question. It is advisable that students write on the examination paper the time they will finish each question so that they do not have to recalculate during the exam.
- Divide the time for the exam by the total marks to determine the number of minutes per mark (that is, 2.25 min/mark, for example).
- Students may like to use this guide which allows them 10 minutes to check their answers or complete questions:

Section I	10 marks	20 minutes
Section II	15 marks	30 minutes
Section III	15 marks	30 minutes
Checking		10 minutes
Total		**90 minutes**

- Students should not go over time on questions they feel they can answer particularly well. It is generally better to spend time starting a new question than running over time to finish the previous question.
- **Students should not leave the exam early.** Students will gain **extra marks** by checking the answers. Students should make sure they have answered **all** of the multiple choice questions.
- Students should make sure they allow plenty of time to get to the examination venue.
- Students should seek positive influences just before the exam. It is best for a student's frame of mind if they do not get involved with negative people or people who have priorities other than excelling.
- Practise these techniques throughout the course whenever you have a major test or exam.

Analysing the Exam

Section I

The instructions for multiple choice questions in Part A state 'select the alternative A, B, C or D that **best** answers the question'. A student may think there are two or more correct answers, but only one is the **best** answer.

Students should not panic if they make a mistake while doing the multiple choice questions. They should simply put a cross through the wrong answer. If they make a mistake twice, cross out the incorrect answers and, if it is unclear, draw an arrow pointing to the correct answer.

- Carefully read the whole question.
- Underline key terms.
- On the question paper, students should **cross out** the options that they know are **incorrect**.
- From the options left, students should select the one that is the most correct.

Section II

Lines are provided for the answers and are a guide to approximately how much information is required to fully answer the question.

- Students should be clear and specific in their answers — do not waffle or generalise.
- Students should not write in essay style. Point form is fine and sometimes flow charts or labelled diagrams are most appropriate.
- Do not rewrite the question or be repetitive.
- Underline key points, or indicate them by dots, dashes and so on.
- Answer the question in the manner in which it was set out. Clearly indicate the part being answered. Markers are keen to award marks, so make it as easy as possible for them to find where they can be awarded.
- Students should make sure they understand what the question is actually asking them.
- If there are two parts such as compare and contrast and students only compare (that is, show the similarities) then they can only expect to receive half marks even if their answer is correct.
- Students cannot 'blitz' this question by learning a prepared answer off by heart, but they can be very prepared.
- This question will test higher order thinking skills.
- In order to allow yourself plenty of scope to answer questions fully, make sure your case study reflects the syllabus (see Chapter 20 for more detail).
- Students should not make up the case study. They cannot answer the questions well with a fictitious case study or a case study they only know general details about.

Section III

- After carefully reading all three questions, students should choose the one that they think they can answer the best. Students need to understand exactly what the question requires them to do. Read the question carefully and underline key words. Identify exactly what is required before committing pen to paper.
- A student should cross out the two questions they **do not** intend to do to ensure that they do not get carried away. Students are not awarded any more marks if they answer more than one so that would be a waste of time.
- Students should formulate and write out a brief plan as it may help them gain a few extra marks if they run out of time.
- These questions are known as 'extended response' questions. They are not essay-style questions and should not be approached as such. Students are expected to communicate what they know and apply concepts and processes they have learnt to particular focus questions. Students can draw upon examples of designs and design processes they have studied in class, aspects of their Major Design Project and from private reading they have done.

Written Marking Procedure

- *The marking process is designed to be accurate and fair to all students. The markers are thoroughly briefed before beginning marking.*
- *The marking procedure aims to rank candidates from the best to the worst, with the best candidates on any question receiving full marks, and the worst receiving none. Full marks are awarded to the best answer under examination conditions.*
- *Write clearly. If sentences are totally illegible and cannot be interpreted by the examiners it is difficult for them to give marks. The examiners will give you credit for whatever they can. They will be looking to give you marks, not take them away. Be kind to yourself and the examiners.*

Extension

Team up with another Design and Technology student and mark each other's practice questions. Analyse the legibility of the responses and make suggestions on how you could both improve.

Summary

- **Knowledge** is the key.
- If you are well-organised you will be more **confident**.
- If you are confident, you will be **calmer** and **think clearly**.
- If you are thinking clearly you will perform more **efficiently**.
- Students who get full marks are armed with **knowledge, want to do well** and are willing to **make an effort**.

General Instructions

- Reading time — 5 minutes
- Working time — 1 $^1/_2$ hours
- Write using blue or black pen

Section I

- Total marks (10)
- Attempt questions 1–10
- Allow about 15 minutes for this section

Section II

- Total marks (15)
- Attempt Question 11
- Allow about 35 minutes for this section

Section III

- Total marks (15)
- Attempt ONE question from Questions 12–14
- Allow about 40 minutes for this section

Section I — Total marks 10

Attempt all questions

Select the alternative A, B, C or D that best answers the question

Allow about 15 minutes for this section

1. An architect is designing a beach house for a client. Which process should be ongoing throughout the project's development?
   (A) Adhering to a financial plan.
   (B) Building a model for the client to view.
   (C) Evaluating the project's progress in relation to meeting the client's needs.
   (D) Adhering to a strict time plan.
2. A designer would patent a plan to:
   (A) Ensure the company's profits.
   (B) Protect intellectual property.
   (C) Sell the design overseas.
   (D) Market the product.
3. The factor that will most contribute to the ongoing success of an innovation is:
   (A) Financial planning.
   (B) A quality product.
   (C) Marketing that coincides with product release.
   (D) The use of the design process.
4. A textile-dyeing company may best minimise the environmental impact on the community by:
   (A) Using an environmental impact statement.
   (B) Recycling all possible waste.
   (C) Including waste disposal in the budget.
   (D) Undertaking a life cycle analysis and modifying design decisions.
5. Built-in obsolescence is a tool used by designers and manufacturers to:
   (A) Create a limited working life for the product.
   (B) Continue to provide a resource for landfills.
   (C) Assist the renewal of worldwide natural resources.
   (D) Ensure the moral obligations of the company are met.
6. When designing a toy for young children, one of the most important factors to consider is that:
   (A) It abides by Australian safety regulations.
   (B) Children and their parents like the toy.
   (C) It fits the recent market trends.
   (D) It will increase profits.
7. The evaluation of a design should be carried out:
   (A) Constantly throughout the design process.
   (B) At the beginning of the design process.
   (C) At the end of the design process.
   (D) In the middle of the design process.
8. A design process should include all of the following components (in order):
   (A) Sketch, research, manufacture and evaluate.
   (B) Make, research and evaluate.
   (C) Investigate, create, evaluate and produce.
   (D) Define and solve the problem, manufacture and evaluate.
9. Why is the use of sustainable technology important to designers?
   (A) To ensure support from the 'greenies'.
   (B) To stop the drain on fossil fuels.
   (C) To ensure that most components are recycled.
   (D) To minimise the negative impact of products on society and the environment.
10. A designer of high moral/ethical fibre would:
   (A) Ensure their advertising campaigns are not offensive.
   (B) Be concerned with bias, community needs and the environment when designing.
   (C) Not usually steal others' intellectual property.
   (D) Adhere to all published Australian standards wherever possible.

Section II — Total marks 15

Attempt all of Question 11

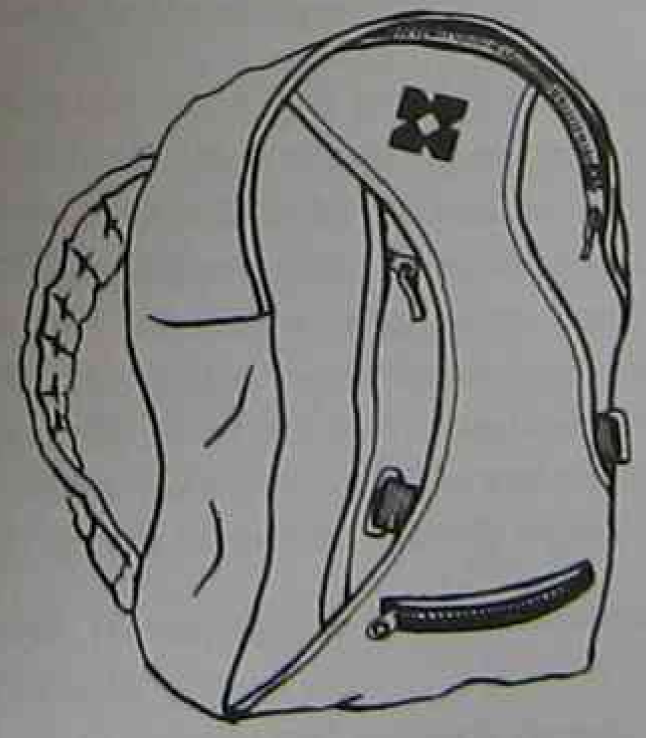
Allow 35 minutes for this section

Question 11

(a) What is meant by 'intellectual property' and why is it important to designers? (2 marks)

(b) Many students throughout Australia use backpacks. Analyse the design of a backpack in relation to function and aesthetics. (4 marks)

Note: In the exam you may be given an example of a design or be directed to choose from ones you have studied.



Function:

Aesthetics:

(c) 'The multicultural diversity of the Australian people has resulted in a diversification of Australian eating habits'. Explain what cultural diversity is and briefly describe one way that it has impacted on Australian design. (2 marks)

(d) Explain how a new and emerging technology has had an impact on an innovation that you have studied. (2 marks)

(e) Discuss the health and safety considerations addressed by the designer in your study of an innovation. (5 marks)

Section III — Total marks 15

Attempt ONE question from Questions 12–14

Allow 40 minutes for this section. Use a separate writing booklet.

Question 12

New and emerging technologies are impacting significantly on the development of new design innovations, which in turn impact on society.

(a) List any environmental considerations that have or have not been addressed in an innovation that you have studied. *(2 marks)*

(b) Describe the impacts on the individual of this innovation. *(3 marks)*

(c) Discuss the impacts of this innovation on society. *(4 marks)*

(d) Critically analyse the ethical considerations that have or have not been addressed in this innovation. *(6 marks)*

OR

Question 13

A company is investigating the development of a new digital mobile phone with Internet access. Note: You can refer to Chapter 18 for background information on mobile phones.

(a) List ***four*** *aesthetic factors to be considered in the design of the phone.* *(2 marks)*

(b) Describe ***three*** *functional criteria that would need to be considered in the development of the mobile unit.* *(3 marks)*

(c) Construct a timeline to demonstrate the historical development of this communications device. *(4 marks)*

(d) Critically analyse ***three*** *social considerations that may influence the development of this device.* *(6 marks)*

OR

Question 14

A company is designing a new range of toys for 4 to 6-year-old children.

(a) Name and justify **two** primary research methods to be used. (2 marks)

(b) Name and justify methods by which the data gathered might be graphically presented to the design team. (3 marks)

(c) Design a sample of **one** of the primary research methods. (4 marks)

(d) Discuss the specific importance of **two** ways this data might be communicated to the design team. (6 marks)

Suggested Answers

Section I page 214

Question number	Answer	Outcomes assessed	Marks
1.	C	H1.1	1
2.	B	H1.2	1
3.	B	H3.1	1
4.	D	H2.1, H2.2	1
5.	A	H4.2	1
6.	A	H1.1	1
7.	A	H1.2	1
8.	C	H1.1	1
9.	D	H2.1	1
10.	B	H2.2	1

Section II page 215

Question 11

(a) Criteria: Defines and clearly describes the importance of intellectual property to the designer. (2 marks)

Defines and states the importance of intellectual property to the designer. (1 mark)

Intellectual property is property of the mind. If a person has created something original, they are able to protect their intellectual property from theft, copying and so on by registering a patent, trademark, registered design, plant breed or trade secret. This means that if intellectual property is stolen, the owner can seek compensation through the courts. Note that copyright and circuit layout rights do not have to be formally registered.

(b) Criteria: Thoroughly analyses the functional and aesthetic factors. (3–4 marks)

Lists the functional and aesthetic factors. (1–2 marks)

Function:

- The backpack needs to hold heavy items such as books so the seams must be strong enough to withstand this pressure.
- The straps need to be wide and padded in order to be comfortable, and must also be strong enough to hold the weight of the carried objects.
- The bag should be durable enough to withstand abrasion from a variety of surfaces, being sat on or squashed, and being handled roughly. It should last a reasonable time.
- The bag must be large enough to hold all necessary items.

Aesthetics:

- The bag should be stain-resistant or a colour that does not show dirt readily. It needs to be borne in mind that the bag will probably be used regularly and often deposited on the ground.
- The bag should look attractive in terms of colour, texture (visual and tactile) and shape, otherwise it will not sell.
- The size and shape should suit the person using it. It should not be too large or small.
- A design feature such as a logo will give the owner a brand identity and hence a group identity. This should be distinctive but not overwhelming.

(c) Criteria: Describes cultural diversity, giving examples, and explains how cultural diversity has impacted on Australian design. (2 marks)

Defines cultural diversity and gives a simple example. (1 mark)

Cultural diversity is when a community is made up of people from different cultural backgrounds, such as Greek, German, Indonesian, Chinese, Anglo-Celtic and Australian Aboriginal. There are many examples of how cultural diversity may influence design. Students could choose examples from food products, clothing, home and garden design, buildings, the alcohol industry and so on.

The influence of cultural diversity on design can be seen in many Australian houses. Examples include North American (the Californian bungalow), Mediterranean (the use of fountains, statues and stucco wall finishes) and Asian (following spiritual concepts in relation to plans and placement of objects — feng shui) influences.

(d) *Criteria: Explains how an emerging technology has impacted on an innovation.* *(2 marks)*
Describes an emerging technology. *(1 mark)*

A new and emerging technology occurs when new or developing materials, tools or techniques are created. These technologies, if successful, often have an impact on new designs. For example, if you studied mobile phones as an innovation, you could look at the emerging WAP (Wireless Application Protocol) technology. This enables users to display weather reports and news, buy goods and access e-mail via their phone. It also has the potential to control home appliances. The impact of this technology includes:

- *Increased versatility of the mobile phone.*
- *Increased size and weight (though this will change over time).*
- *Increased cost.*
- *Students must be aware of the difference between an innovation and a new and emerging technology and, if they are not, this will be apparent in their answer.*

(e) Criteria: Relates the health and safety considerations to the innovation. (4–5 marks)
Discusses health and safety considerations and an innovation. (2–3 marks)
States general health and safety considerations. (1 mark)

Note: Health and safety issues may be addressed through the impact of design, production, use and disposal of the product.

The following relates again to mobile phones.

Safety:

- The use of phones while driving necessitated the addition of a hands-free kit to reduce the risk of car accidents.
- The size, shape and versatility of the mobile phone make it easy for most people to use, including adolescents and children. Many young people are encouraged to have a mobile phone for safety whilst travelling and for emergency contact.

Health:

- There are suggestions that the electromagnetic energy produced may affect human brain cells and cause headaches, dizziness and fatigue. The use of a hands-free set is believed to reduce this risk.

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Question 12

Outcomes assessed: H2.2, H3.1, and H6.2

Innovation: Black box flight recorder (Flight Data Recorder or FDR) is a device carried in an aircraft which automatically records flight information which can be retrieved after a crash.

(a) Criteria: Lists a number of relevant environmental considerations. (2 marks)
Lists one environmental consideration. (1 mark)

Note: The black box flight recorder is used as an example of an innovation for this answer. As listed below, environmental considerations were not paramount in its construction or use. However, the innovation that you choose for your case study is very likely to involve a number of environmental factors.

Environmental:

- Impact of design, production and disposal not addressed to a significant extent, as the safety issue was a greater priority.
- Sustainability not addressed as, as above, saving lives was the priority.

(b) Criteria: Describes possible impacts on the individual. (3 marks)
States possible impacts. (2 marks)
Names one impact. (1 mark)

Impact on individuals:

- Safer flights as improvements are made to aircraft based on crash details.
- Some peace of mind due to both the above and the fact that if a plane does crash, it may be possible to determine why.

(c) Criteria: Discusses two possible impacts on society. (3–4 marks)
States two possible impacts on society. (2 marks)
States one possible impact on society. (1 mark)

Impact on society:

- Improvements in air transportation systems due to feedback resulting in more efficient services. If the service is efficient, more people are likely to use it.
- Increase in use of air transport can improve relationships between people from different countries.
- Greater movement of goods and services around the world.

(d) Criteria: Critically analyses a few ethical considerations and any associated issues. (5–6 marks)
Analyses an ethical consideration and an associated issue. (3–4 marks)
Discusses a few ethical considerations or any associated issues. (2 marks)
Analyses an ethical consideration or an associated issue. (1 mark)

Ethical:

- Improves travel safety for individuals and people in the industry.
- Patent was taken out by the Aeronautical Research Laboratories. British firm later bought the rights. Intellectual property was protected.
- The safety implications address community needs and expectations.
- The FDR addresses the needs of people who fly aircraft irrespective of cultural, ethnic or socio-economic background.
- The FDR does not invade an individual's privacy, but it may expose some unsafe professional practices.
- The design aims to improve one facet of the modern world and it fits in with a basic consumer right — the right to safety.

Question 13

Outcomes assessed: H1.1, H1.2 and H2.2.

(a) Criteria: Lists four aesthetic factors. (2 marks)
Lists two or three aesthetic factors. (1 mark)
Lists one aesthetic factor. (0 marks)

Aesthetic factors may include:

- Unit lights up (also a functional factor).
- Numbers/letters/symbols are clear and easy to read (also functional).
- Comes with interchangeable covers to suit moods and fashions of user.
- Slimline, 'modern' look.
- Range of colours available.

(b) Criteria: Describes three functional criteria in detail. (3 marks)
Briefly describes three functional criteria. (2 marks)
Briefly describes one or two functional criteria. (1 mark)

Note: Examples of functional criteria could include size, shape, ease of use, appropriate weight, speed of access to the Internet, versatility, range and connection ability, strength and durability, safety and long-term effects of use, memory, battery life, ergonomics and so on.

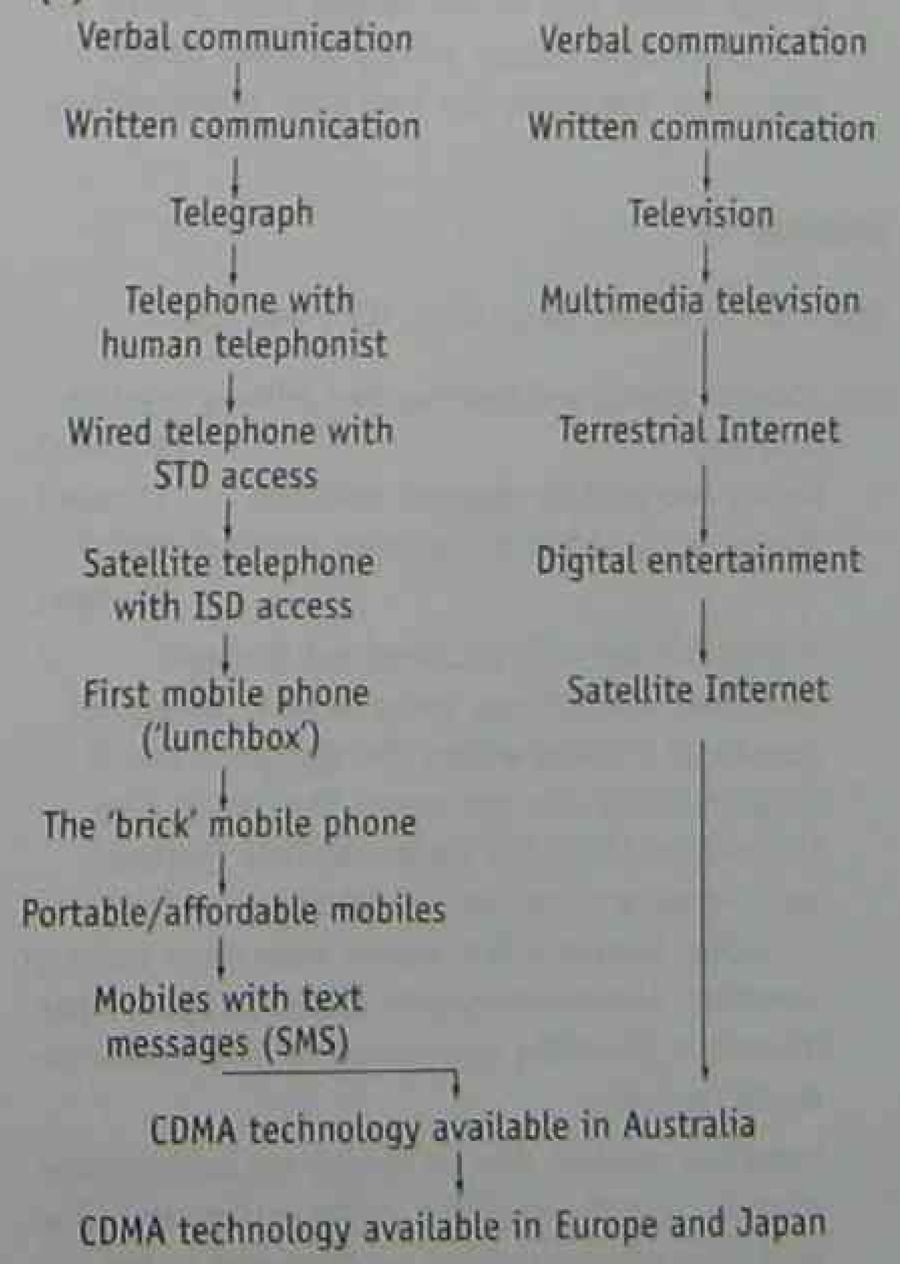
Size — the unit should be small enough to carry in a pocket and fit well in an average-sized hand. It should be large enough to display graphical and text images and the buttons should be of a size that minimises the risk of pushing two buttons at once or the wrong button.

Speed — the processing of information through the Internet needs to be relatively fast to reduce frustration on the part of the user. The key pad needs to be simple yet flexible to reduce wasted time and allow the use of menus within menus.

Battery — must be powerful enough to allow all processes and last a reasonable time. It must also be easy to recharge.

(c) Criteria: Lists three telephone and three media communication devices in correct order and merging into CDMA technology. (4 marks)
Lists one or two telephone and media communication devices in correct order and merging into CDMA technology. (3 marks)
States either telephone or media communications merging into CDMA technology. (2 marks)
Lists either telephone or media communications. (1 mark)

(d)



(d) Criteria: Critically analyses three social factors. (6 marks)

Analyses three social factors. (5 marks)
Critically analyses one or two social factors. (4 marks)
Analyses one or two social factors. (3 marks)
Describes three social factors. (2 marks)
Describes one social factor. (1 mark)

Note: Social factors include impact of the cost, safety implications, protocol, privacy (hacking), health implications and changing trends.

Cost — if it is marketed as an essential item and it is expensive, there may be implications for over-spending and encouraging people to have unmanageable debts as has happened with regular mobile phones.

Time used — the unit may encourage anti-social behaviour as people will not only be talking on their phones in public, but will also be checking e-mails, searching for information and buying goods and services. While these activities occur all the time, the ability to carry them out on a mobile phone will mean they are done much more in public.

Privacy — there may be a loss of privacy due to more people having access to a phone and thus private details may be less secure. Also, talking on a mobile phone reduces privacy as many people forget that the public can hear their conversations.

Question 14

Outcomes assessed: H1.1, H2.2, H3.1 and H5.2.

(a) Criteria: Names and justifies two primary research methods. (2 marks)
Names two primary research methods. (1 mark)
Names and justifies one primary research method. (1 mark)

Descriptive research is carried out through interviews and surveys, using random samples of parents of children within the age group and of children within the age group. This would give information about the target market's (parents') preferences and the user's (children's) preferences. A random sample is less biased than other forms of sampling. Interviews may be closed or open. Open interviews allow the respondent to give a more in-depth response.

Historical research may be carried out to determine what is currently available in the market and what sells well, which can then be compared to the proposed new range.

(b) Criteria: Names and provides high quality justification of two different presentation methods, for example, pie graphs and histograms. (3 marks)
Names and provides high quality justification of one presentation method. (2 marks)
Names and provides lower quality justification of two different presentation methods. (2 marks)
Names and provides lower quality justification of one presentation method. (1 mark)

Refer to Chapter 9, Research Methodology, for an examination of different ways of presenting research data.

(c) Criteria: Sample includes a number of appropriate and analysable questions. (3–4 marks)
Sample has appropriate layout. (1 mark)

Sample answer, to be completed by the interviewer:

1. Age:
☐ 4 years ☐ 5 years ☐ 6 years

2. Sex: Male/Female

3. What are your favourite toys?
____
____
____

4. Why are they your favourites?
____
____
____
____
____
____

5. How often do you play with these toys?
☐ Every day ☐ Once a week
☐ Once a month ☐ Not very often

6. Which of the following describes your most favourite toy?
☐ It moves ☐ It is cuddly
☐ It is colourful ☐ It makes a noise
☐ I can play with it outside ☐ It plays a tune
☐ I can play with it inside ☐ It does not break
☐ Other reason ______________________.

(d) Criteria: Discusses the specific importance of two ways data may be communicated. (6 marks)
Discusses the specific importance of one way data may be communicated. (4–5 marks)
Discusses in general terms how data is communicated. (3–4 marks)
Describes data collection. (1–2 marks)

Clear and effective communication is essential. The research data may be communicated through the use of:

- Multimedia packages showing images of children (to establish a mood).
- Graphs and charts to graphically depict the collected data.
- Verbal commentaries and computer-generated text and music.

This would allow the communicator time to check the information before it was presented to ensure accuracy and lack of bias. It would engage the audience and also allow for discussion forums after the presentation.

A hard copy report, including background information and charts and graphs representing the data collected and analysis of the findings, may be given to the design team for appraisal. A workshop for discussion and brainstorming activities could take place once the design team has had a chance to examine the information.

23 — Glossary

Chapter Overview

The following key words, terms and concepts include most of those you will encounter in your study of Design and Technology. It is important that you are familiar with them and their correct meanings, and that you use them appropriately in both your course work and the HSC examination.

aesthetic criteria	Refers to those aspects of a design related to how it looks.
aesthetics	Refers to the beauty of the design.
alcohol fuel	Fuel using alcohols such as ethanol and methanol.
anthropometric data	Data based on scientifically collected measurements from a wide variety of people of various age groups.
anthropometry	Study and technique of taking human measurements.
appropriate technology	Technology which in its creation and use meets human needs while considering the short- and long-term consequences for society and the environment.
architect	A person who designs buildings.
automation	Use of mechanical and electronic devices that take the place of human effort, observation and decisions.
batch production	Form of production that is used when only a limited number of the same product is wanted. Also known as job lot production.
biogas	Gas produced when animal waste or other organic material rots in the absence of oxygen. Methane is a major component.
biomass energy	Energy obtained from plant and animal waste material.
Bloom's taxonomy of thought	A hierarchical structure which suggests that as thought patterns develop they become gradually more complex. It helps people identify what level they are working at.
brainstorming	A technique in which a group of people meet in order to stimulate creative thinking, develop new ideas and solve problems.
built-in obsolescence	When a product is designed to last for a certain period of time.
CD burner	Slang term for a peripheral device that can record data on a compact disk. The correct term is 'compact disk rewriter'.
chindogu	Japanese word that literally means 'odd or distorted tool'. It has come to be known as 'the art of useless design'.
closed response	A type of research question that requires the respondent to choose an answer from a selection given.
cognitive organisers	Systems that may be used to help people clarify their thinking.
collaborative	Working together and sharing all aspects of work in order to achieve set goals.
communication	The process of sending and receiving messages. Effective communication will allow a student or a designer to clearly convey thoughts and ideas in portfolios to the examiners or the clients.
community needs	Those needs perceived by the whole community to be important.
compact disk rewriter (CD-rewriter)	Peripheral device that can record data on a compact disk. The slang term for this device is a CD burner.
computer-aided design (CAD)	Designs created using a computer and special graphics software.
computer-aided engineering (CAE)	Use of computers in drafting, design analysis, numeric control, tool and mould design, quality control and process planning.
computer-aided manufacture (CAM)	Use of computers to control production equipment.
computer drafting	Use of a computer to carry out manual drafting functions such as measuring, marking and reproducing.
computer-integrated manufacturing (CIM)	Total integration of the manufacturing process using computers.
computerisation	The use of computers to complete tasks.
constraints	Guidelines that the designer must adhere to. They may include information on cost, materials, techniques, size, weight, production, manufacturing and marketing.
copyright	Automatic protection of written material, artistic work, music, dramatic works, computer programs, compilations, films, sound recordings, broadcasts and published editions.
cradle to grave approach/analysis	Assessing the impact of a product from its conception to its disposal.

craftsperson	A person who specialises in a particular craft form such as jewellery, ceramics, glass, metal smithing, textiles, wood or leather work.
creativity	This involves originality of thought or expression.
cultural beliefs	Those beliefs that are formed by people living and interacting together.
cultural diversity	Variations in people's beliefs, traditions and values due to their ethnic background.
custom production	Where a special order is placed and one person or several people work on that project to completion. Also known as one-off production.
data	Information collected.
databases	Software that enables the user to store a large group of data that may be cross-referenced, retrieved and manipulated.
decision support systems	Computer programs that assist people to make decisions by providing information, models and analysis tools.
descriptive research	Research that explains or describes a current situation. It may be carried out through interviews, surveys and analysis of data.
design	May be defined as 'the plan on which an object is constructed and/or decorated', or 'the art of relating or unifying contrasting elements'.
design — good	Is functionally sound and aesthetically pleasing. It efficiently fulfils its purpose and presents a unified and harmonious appearance.
design — poor	Is a design that does not function and/or is visually displeasing. Beauty, like ugliness, is very subjective, but generally speaking a bad design is one that does not succeed commercially.
design brief	A clear statement describing a need that can be fulfilled by the development and manufacture of a product, system or environment.
design failure	A design that has not generated a commercial profit.
design success	A design that has generated a commercial profit.
designed for assembly	Where a product is designed to allow for easy assembly by the consumer.
designed for disassembly	Where a product is designed to allow it to be taken apart, that is, used or recycled by the consumer.
desktop publishing	Use of a combination of computer hardware and software to produce near typeset quality work using a variety of sizes, styles, fonts and graphics.
digital still camera	Camera that uses an electronic sensor array to capture the image and store it in electronic memory.
digital versatile disk (DVD)	Large capacity disk used to store sounds and pictures.
digital video camera	A camera which converts pictures and sound into digital signals and records them onto a tape or disk.
digital visual effects and animation	A growth area in television, multimedia and film production. Increasingly, much of the work for television commercials, station promotions and title graphics are being produced through the use of desktop computer software.
durability	The lasting ability of a design.
e-books	Electronic books that may be downloaded for reading offline.
ecological factors	Describes the relationship between living things and their environment.
economic factors	Financial considerations that may influence design.
economic issues	Issues that influence purchasing power and spending.
egalitarianism	A belief which asserts the equality of all people.
electronic mail (e-mail)	Communications system whereby messages are transmitted to, and received from, other computer users via a modem or some other communication device.
e-library	Specialised websites that provide information covering a wide range of educational areas.
emerging technology	Products that create a new need or satisfy an existing one in a totally new way are known as innovations. The new materials, tools or techniques that allow the design to work are known as emerging technologies.
energy	A source of power or capacity for doing work.

entrepreneurial activity	An organised business venture.
environmental factors	The physical conditions that affect the design.
environmental issues	Issues that affect the world around us.
equity	That which is fair or just.
ergonomics	The study of the relationship between people and their working environment.
ethical factors	A system of beliefs and rules guided by a sense of right or wrong that have an impact on design.
ethics	Moral principles by which people judge right or wrong, good or bad.
evaluation	Each step of a project is evaluated and questions are asked such as is the design working, are concerns being dealt with and so on?
experiment	A test or trial that is used to test a hypothesis.
experimental research	Research that occurs as a result of planned experiments.
expert systems	Computer programs that provide information and solve problems that would otherwise require a person experienced in the field.
fashion designer	Designer who works in the field of clothing and accessories.
financial management	Managing money.
fine artist	A Fine Arts degree is the first step towards a career in galleries, arts administration and emerging visual media.
flexible manufacturing systems (FMS)	This is where variations to the product design can be made at the manufacturing stage, depending on specific customer requirements.
formal interviews	Interviews that have set questions and structure are also known as structured interviews.
fossil fuels	Fuels such as coal, crude oil and natural gas, which were formed underground over millions of years from the remains of ancient organisms.
function	Pertaining to whether a design works.
functional criteria	Refers to what you want the product, system or environment to do.
furniture	Objects that function in a social, behavioural way by defining the nature of our living spaces.
geothermal energy	Energy obtained by harvesting the energy created by the Earth's molten centre.
global issues	Those issues that have worldwide significance.
global warming	When gasses in the atmosphere insulate the Earth, preventing some of the sun's heat from escaping into space and resulting in the warming of the Earth. Also known as the greenhouse effect.
goals	The desired ends towards which a person is willing to work.
graphic designer	A profession that crosses a range of design disciplines and a range of communication services including marketing, public relations, advertising and multimedia. Involves creating designs or pictures in a variety of media.
graphics (computer)	Production of pictures, patterns and diagrams by a computer.
greenhouse effect	Refer to **global warming**.
hedonism	Devotion to pleasure.
historical research	Research that is carried out to reconstruct events that have happened in the past from records, diaries, autobiographies and so on.
hydro energy	Energy created by the flow of water.
hypothesis	An idea or theory that researchers try to prove or disprove.
industrial designer	A person who designs the processes for manufacturing mass-produced products.
informal interviews	Interviews that allow flexibility in the response. They are usually based on an open-ended questionnaire and are also known as unstructured interviews.
information	Data processed and presented in a way that makes it useful and provides people with knowledge.
innovation	Products that create a new need or satisfy an existing one in a totally new way are known as innovations. It involves changes to existing designs or is when something new or different is introduced.
intellectual property	The product of a person's mind or intellect.

intelligent systems	Computer programs that receive data from the environment, react to that data and produce an intelligent response.
interior designer	A person who designs interior environments to suit the functional and aesthetic requirements of their clients.
Internet	Worldwide network of computers connecting millions of users via existing telecommunications infrastructure.
Internet relay chat (IRC)	Chat service that enables direct conversations between Internet users.
invention	An original concept or discovery.
job lot production	Form of production which is used when only a limited number of the same product is wanted. Also known as job batch production.
just in time (JIT)	A method of production whereby a company produces and distributes only what a customer needs as they demand it.
life cycle analysis	Analysis of a design at all stages from conception to disposal.
Likert scale	A scale that is commonly used in questionnaires, which allows the respondent to decide whether, and to what degree, the particular idea or element is desirable or undesirable.
limitations	Refer to **constraints.**
mailbot	E-mail server that automatically sends out response information via the e-mail.
mailing list	Virtual forum where e-mail messages are delivered to the people who subscribe to the list.
management	The planned use of resources to achieve goals.
manufacturing	Refers to the making of anything.
market distribution	Refers to the channels through which a product will reach its market at the right time, and the system for physically handling and transporting through the channels.
market research	The gathering of as much information as possible about a particular situation for analysis so that an effective marketing strategy can be developed.
market segmentation	The division of the whole market into groups so that marketing can be focused.
market variables	Refers to the variations within a market such as demographics, socio-economic status, geographic location, psychological influences and lifestyle variations.
marketing	Collective term that encompasses the planning, developing, pricing, promoting and distributing of goods and services to consumers.
marketing elements	The basic components of a marketing plan such as product, price, promotion and place.
marketing environment	This includes all factors that may influence the development of the product.
marketing mix	Refers to the ways in which the marketing elements are combined.
marketing plan	A series of activities leading to the setting of marketing objectives and the formulation of plans for achieving them.
marketing price	Monetary value placed on a product. It is determined by many factors.
marketing promotion	Refers to the method used to inform and persuade the market of the merits of the product.
mass market	A market which includes all groups.
mass production	Refers to producing goods in large quantities.
mean	The average.
mechanisation	Involves the use of machinery to aid the production process.
median	Statistical analysis term that refers to the halfway point in the data when it is set into an ordered arrangement.
metacognition	Thinking about how people think.
midrange	Statistical analysis term that refers to a quick estimate of mean made by averaging the extremes of the data collected.
millennium products	Products that are designed to minimise the impact of the design on society as a whole.
mode	Statistical analysis term that refers to the data point with the highest frequency.
multiculturalism	The belief that it is beneficial to a society to maintain more than one culture within its structure.

multimedia (computer)	Computers that give information in many forms such as words, still and moving pictures, sound effects and music.
multimedia and web designer	Designers who use multimedia software to create computer-generated designs.
needs	Something an individual must have in order to survive and grow.
networks (computer)	The linking of computers to other computers via a cable.
news groups	Online discussion groups.
niche market	Smaller market within a market segment that has particular characteristics that set it apart from other groups.
non-participant observation	Research method in which the researcher observes a group or a situation without taking part in any way.
non-renewable resource	Resources that cannot be replaced within a time span relevant to humans.
nuclear fission	The break-up of large atoms to produce energy.
nuclear fusion	Occurs when light atoms are fused together to form energy.
nuclear power	The creation of an energy source from the breaking-up or fusing together of atoms to produce power.
numerical control (NC)	Form of programmable automation in which numbers control a machine.
obsolescence	When a design is no longer usable.
off the job training	Training employees receive from external providers such as TAFEs, universities and through private training organisations.
on the job training	Training employees receive while working.
one-off production	Where a special order is placed and one person or several people work on that one project to completion. Also known as custom production.
open-ended questions	Questions that are designed to have an open response.
operational research	Research that involves evaluating the performance of an operating situation. For example, assessing the environmental impact of manufacturing meat pies.
ozone layer	A layer of gases above the Earth's surface which form a protective shield against ultra violet radiation.
parameters	Refer to **constraints.**
participant observation	Research method in which the researcher interacts with the respondents.
patent	A temporary monopoly granted to the patentee by the government on a new or improved product or process.
personal computer	Standard desktop computer, also known as PC or IBM-compatible.
photographer	Records information or art by capturing images.
plagiarism	When a person presents another person's ideas, thoughts, images or material as their own.
planned obsolescence	Refer to **built-in obsolescence.**
plant oils	Oils obtained from plants.
political issues	Issues that are influenced by laws, government bodies and pressure groups.
population	A term used in research that refers to the whole group about which conclusions are drawn.
precoded questions	Questions that are designed to have a limited range of responses. For example, questions that use scales or closed response questions.
primary data	Data that is collected first-hand.
product management	The management of a product to ensure its ongoing viability.
production	Making of goods by any action or operation.
production designer	Is responsible for designing every aspect of the visual environment in which a play, opera, dance, film or video takes place.
qualitative research	Examines people's feelings about some issue or event.
quality	A standard relative to the requirements of the design.

quality assurance	A term applied to all processes in the workplace that are capable of leading to continuous improvements in quality.
quantitative research	Research that can be expressed in statistical or numerical form, such as experiments.
questionnaire	A printed question and tally sheet all in one.
random sample	A sample chosen from the whole population that is picked in such a manner that every individual in the population has an equal chance of being chosen.
rating scale	A scale that is commonly used in questionnaires to allow respondents to rate their responses.
recyclability	The ability of an item to be broken down after use to serve as a raw material for a new product.
rendered sketches	A drawing technique that uses shading to give a 3-D feel to the sketch.
renewable resource	Resources that can be replaced within a time span relevant to humans.
research methods	Ways of conducting research such as descriptive, historical, experimental and operational research.
resource	Something we use to achieve our goals. There are two types — human and non-human. For example, knowledge, skills, raw materials and money.
resource — human	Attributes we can use to our advantage — skills, ideas, talents and so on.
resource — non-human	Items that we have at our disposal to use.
robotics	A machine that can copy the movements and processes of the human body.
sample	Research method that selects a number of people from the whole population.
scanner	A device that reads printed codes, characters or images and converts them into a form that can be processed by a computer.
search engine	Online database of websites.
secondary data	Data that is obtained from other people's research.
semantic differential	A scale that is commonly used in questionnaires to indicate a response to a question and degrees within the response.
simulations	A demonstration of how a design will work by using either models or computer graphics.
simulations (computer)	Artificial onscreen creation of some form of real life so it can be manipulated and studied more easily.
social class	Relatively permanent and ordered divisions within a society whose members share similar values, standards, interests, incomes and behaviours.
social conscience	Refers to a person's determination of what is right and wrong in respect of issues that influence society.
social issues	Issues that affect people and the way they relate to each other.
social trends	Changes in society.
solar energy	Energy created by harnessing energy from the sun.
spreadsheet	Software that enables the user to personalise reports by the use of extensive mathematical, financial, statistical and logical processing.
standards	A measure used to determine whether a goal has been achieved.
storyboards	A series of sketches or photographic evidence that tells the story of how the design solves the design problem.
strategic marketing	Refers to the process that analyses, implements and evaluates the marketing of activities that will assist in the achievement of goals.
structured interviews	Interviews that have set questions and structure. Also known as formal interviews.
survey	When a person collects sample opinions or statistics in order to draw conclusions about the overall situation.
sustainability	Meeting the resource needs of the present without compromising the ability of future generations to meet their own needs. Using resources at a rate no faster than they can be replaced.
sustainable development	Development that improves the quality of life in a way that maintains vital ecological processes.
sustainable resources	Resources that can be replaced within the lifetime of the average person.
sustainable technology	Technology that meets production requirements while still conserving natural resources.

target market	Refers to a group of people for whom the product is specifically intended.
technology	The knowledge and creative processes that assist people to use resources to solve problems.
telecommunications	The transmission and reception of messages using radio or microwaves, light or electricity.
test	A standardised procedure for obtaining a response.
thumbnail sketches	An initial sketch idea usually about 5 cm x 5 cm.
tidal energy	Energy created from harvesting the energy of the changing tides.
tools	Things that are used to assist people to work.
total quality management (TQM)	Approach to management that aims to continually improve the quality of performance in all aspects of the processes, products and services of an organisation.
trade secrets	Confidential information regarding an organisation.
trademark	A logo, picture, word, letter, phrase, shape, number, feature and so on that differentiates the goods or services of one organisation from another.
trends	Things that become popular for a short space of time.
tropical deforestation	Loss of tropical forests.
unstructured interviews	Interviews that allow flexibility in the response. They are usually based on an open-ended questionnaire and are also known as informal interviews.
validating information	Determining whether a source of information is reliable.
value added management	A variation of total quality management based on continuous improvement, identification and elimination of waste, and the complete creative involvement of all employees.
values	A belief about what is good and desirable. Those things we regard highly.
video conferencing	Form of teleconferencing whereby people from geographically distant locations can see and talk to each other using video cameras and monitors. It may be achieved through the Internet.
virtual reality (VR)	Computer-generated effects that create surrounds that seem real but only exist as electronic signals inside a computer. The effect is aided by the use of a head set, gloves, shoes and sometimes whole suits.
voice input	Software that allows the user to enter data and issue commands to the computer with spoken words.
wants	Something an individual desires but could live without.
wind energy	Energy created by harnessing energy from the wind.
word processing	Computer software that allows the user to create, edit, store, retrieve and print documents.
workplace teams	Structure within the working environment where workers in groups share common goals, communicate and problem-solve.

24 – Useful Internet Sites

Chapter Overview

The following is a review of useful Internet sites. As Internet sites and the information within them is changing daily, some of the details may vary and some sites may no longer exist or may be under another name. For students to keep up-to-date with current information they should access the sites fairly frequently.

ABC Online http://www.abc.net.au

Excellent up-to-date site with many relevant links. One part of the science section is devoted to innovations, and is well worth a visit. This site also provides transcripts of many ABC shows. An e-mail address is provided.

Australian Centre for Innovation and International Competitiveness (ACIIC) http://www.aciic.org.au

This site contains information of the role of the ACIIC, globalisation, innovation plus news articles. There are links to other sites.

Australian Competition and Consumer Commission (ACCC) http://www.accc.gov.au

This is an informative website with information on the role of the ACCC, media releases, resources, news items, consumer protection, small businesses, product safety and so on. The case studies are well worth reading. An e-mail address is provided.

Australian Consumers' Association
http://www.choice.com.au

This site provides current consumer reports and news items concerning a range of topics. It has a scam file, consumer alerts, details of campaigns, FAQ, and a four-year index. It is easy to use and very informative. The e-mail address is supplied.

Australian Copyright Council
http://www.copyright.org.au

This site contains publications, information sheets and news items. The information sheets are particularly good and should be read frequently as they contain current information. Individuals may subscribe for free updates. An e-mail address and links to other sites are provided.

Australian Institute of Computer Ethics (AICE)
http://www.aice.swin.edu.au

Provides information about AICE, links to other sites, resources and transcripts of event papers. An e-mail address is also supplied.

NSW Board of Studies
http://www.boardofstudies.nsw.edu.au

This site enables students to access past HSC papers, the syllabus, examiner comments, specimen papers and FAQ. The NSW Board of Studies website provides very useful resources and is constantly updated.

Consumer Affairs Division
http://www.treasury.gov.au/consumer

This site outlines the role of the Consumer Affairs Division and provides some useful links to information about product safety and recalls, e-commerce, consumers online and the *Trade Practices Act* 1974.

Critical Thinking
http://www.yorku.ca/admin/cdc/lsp/read/read4.htm

This site contains notes on critical thinking. Interesting reference materials.

Desert Designs
http://www.ctl.com.au/desert/desert.htm

A very basic site covering some information. The site is soon to be updated and linked to other sites.

http://waapa.cowan.edu.au/disc/sova/objpike.htm

This site describes the collaborative printmaking experience involving Jimmy Pike. There are samples of his work and some useful links.

Dick Smith's Genuine Australian Foods
http://www.dicksmithfoods.com.au

This is a very interesting and informative website. It examines current ethical issues, entrepreneurial activities, marketing concepts and globalisation. It also has historical information on Australian and foreign-owned companies. There is information about Dick Smith, food products, media, sponsorship, FAQ, ownership of foreign companies, promotions and financial information. It is a very interesting and user-friendly website. Students should be aware of the obvious bias. An e-mail address is supplied.

The Environmental Defender's Offices (EDONet)
http://www.edo.org.au

This site is very useful as it supplies links to other sites containing information about environmental concerns. There is a brief outline of the role of the organisation and an e-mail address is supplied.

IP Australia http://www.ipaustralia.gov.au

Extensive, informative and easy to navigate site which outlines intellectual property, services, role of IP Australia, patents, trademarks, designs, news and so on. It has excellent links to other sites and a very useful educational section. An e-mail address is supplied.

Moller International http://www.moller.com/

This site provides useful information on the Skycar and Rotapower engine. It is particularly useful for the study of an innovation and there are pictures of both innovations. The FAQ section is worth reading.

National Occupational Health and Safety Commission (NOHSC) http://www.nohsc.gov.au

A very detailed website covering the role of the NOHSC, OH&S legal obligations, OH&S solutions and practical guidance, small business initiatives, research, resources, statistics, chemicals, preferred terms relating to OH&S, and related sites. An e-mail address is supplied.

National Safety Council of Australia
http://www.safetynews.com

The official site for the National Safety Council of Australia contains very useful news articles on safety and OH&S. The articles provide good background information. An e-mail address is supplied.

NSW Department of Fair Trading
http://www.fairtrading.nsw.gov.au

This is an excellent website with a wealth of information. There are details on safe products, shopping, cars, bikes, boats, home building, renovating, home owning, renting, business matters, co-operatives, legislation, the Fair Trading Centre, the Fair Trading Tribunal and so on. An e-mail address is supplied.

NSW WorkCover Authority
http://www.workcover.nsw.gov.au

An informative website that covers information about WorkCover NSW, news items, FAQ, workplace injury management, OH&S, and links to other sites. An e-mail address is supplied.

Plant Breeder's Rights
http://www.dpie.gov.au/agfor/pbr/pbr.html

This site provides detailed information about plant breeder's rights.

Powerhouse Museum http://www.phm.gov.au

A detailed website that is constantly updated to provide information about the museum and support materials. Through the schools' section, users can access information about technologies and innovations. This is an extremely useful website and an e-mail address is supplied.

Small Business Institute of Australasia
http://www.sbi.com.au/

This site outlines the role of the Institute. The news articles often contain relevant and interesting information. An e-mail address is supplied.

Standards Australia International Limited
http://www.standards.com.au/

As well as providing information about Standards Australia, this website provides risk management case studies, outlines of current topics, allows a search for products, and gives detailed information about writing standards, certification, publishing and management. An e-mail address is supplied.

The Body Shop http://www.thebodyshop.com.au

This site gives details of The Body Shop's entrepreneurial activities. The history of the organisation is also outlined. It is particularly strong in areas of ethics covering issues such as reconciliation, animal protection, self-esteem, human rights and environmental concerns. An e-mail address is supplied.

Vegemite Rules http://www.vegemite.com.au

This is an easy to use interactive site that details the history of Vegemite, profiles of marketing strategies, the trademark and package details, plus lots of other information.

Whistleblowers Australia
http://www.whistleblowers.com.au

This is a basic site with information about Whistleblowers Australia and related laws. An e-mail address is supplied.

WorkSafe Western Australia
http://www.safetyline.wa.gov.au

A detailed website with lots of very useful information. There is information about laws (Acts, regulations, Codes of Practice), manual handling, chemicals, noise, falls, industries, statistics, resources and so on. There is an excellent educational section. This site provides links to other sites and an e-mail address is also supplied.

World Intellectual Property Organisation (WIPO)
http://wipo.org/eng/index.htm

Contains information on the international protection of industrial property in both industrialised and developing nations. Covers international conventions and treaties dealing with the issues of copyright, patents, and intellectual property.

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Please note that many of the sites listed in Chapter 24 were also used as a reference source.

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Notes

EXCEL HSC DESIGN & TECHNOLOGY PASS CARDS

Your Pass to Success!

This set of cards is designed for you to use as the final step in your revision programme. The author has carefully selected the most important facts of the course for you to focus on just before your exam or test. You can use your Excel HSC Pass Cards:

On the go — in the car, bus or train. If you are by yourself, read over each card again and again until you completely master its content. If you're with a friend, revise as a team by turning the bullet points into questions and quizzing each other on key points. Your answers will be there on the cards.

At home — at your desk. Read each card thoroughly and make sure you understand all the points. You should also know more detailed information on each topic — if you are not completely sure of a topic, look for the page reference at the bottom of the card and turn to this page in your Excel study guide.

Good luck!

Contents 2 *EXCEL* HSC Design & Technology Pass Cards

UNDERSTANDING DESIGN

Terms & Concepts

1

- The **design brief** is a clear statement describing a need that can be fulfilled by the development and manufacture of a product, system or environment. (PSE)
- Design is the **plan** on which a product, system or environment is manufactured and/or decorated.
- Good design is **functionally sound** and **aesthetically pleasing**. It efficiently fulfils its purpose and presents a unified and harmonious appearance.
- **Aesthetic design** refers to the aspects of the design that make it pleasing to look at.
- **Functional design** refers to the aspects of the design that make it work.
- **Design success** refers to a design that has made a commercial profit.
- **Design process** is a series of steps used by designers.

DESIGN & TECHNOLOGY

See *EXCEL* HSC Design & Technology p. 14

UNDERSTANDING DESIGN

The Elements of Design

3

The **elements of design** are factors to be considered when planning a design.

All visual design can be reduced to **seven elements**:

- Value
- Line
- Direction
- Colour
- Shape
- Texture
- Size.

The following sentence will assist you to remember these design elements. The first letter of each word relates to each of the seven elements:

Very **L**arge **D**ogs **C**an **S**tand **T**remendously **S**till.

DESIGN & TECHNOLOGY

See *EXCEL* HSC Design & Technology pp. 15–16

UNDERSTANDING DESIGN

The Design Process

5

Evaluate at every stage of the design process.

Step One: Define the Problem → E
Step Two: Initial Ideas → V
Step Three: Research — Secondary → A
Step Four: Refine Ideas → L
Step Five: Research — Primary → U
Step Six: Refine Ideas → A
Step Seven: Manufacturing → T
Step Eight: Evaluate → E

DESIGN & TECHNOLOGY

See *EXCEL* HSC Design & Technology pp. 18–19

UNDERSTANDING DESIGN

Case Study on Designers

7

In your **case study** on designers you must include information on the following:

- **Name and contact details**, if available.
- **Biography** of the designer's life.
- Designer's **training and work history**.
- **Accolades, scholarships and awards** received by the designer.
- **Timeline** of design successes.
- **Factors** contributing to the **designer's success**.
- Factors contributing to the **designer's difficulties/failures**.
- How the designer **overcame adversity**.

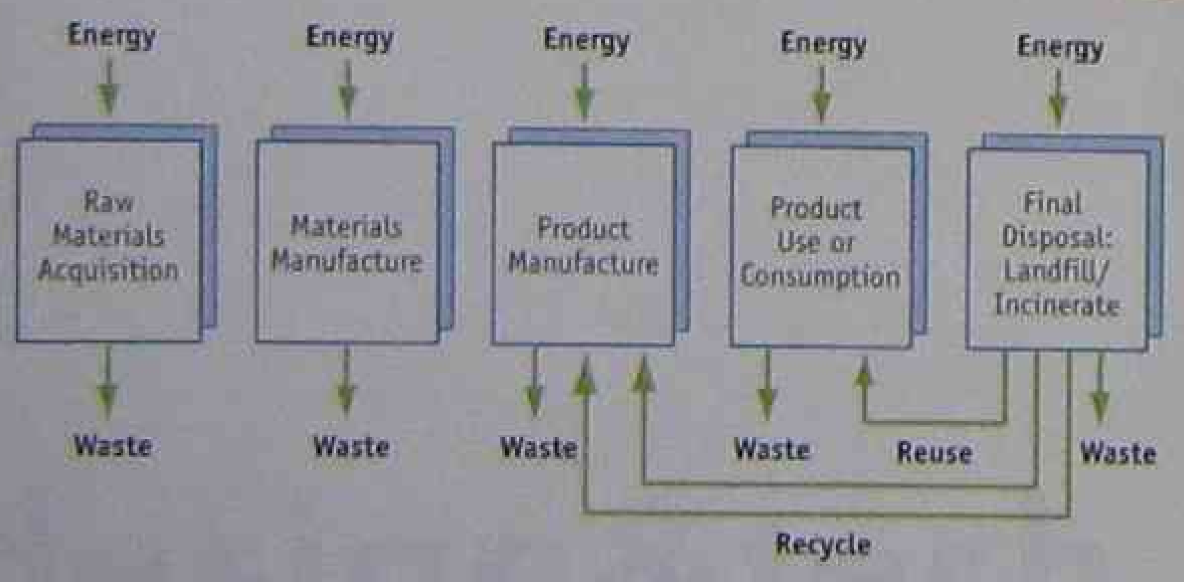
DESIGN & TECHNOLOGY

See *EXCEL* HSC Design & Technology pp. 23–27

FACTORS AFFECTING DESIGN

Cradle to Grave Analysis

9



DESIGN & TECHNOLOGY

See *EXCEL* HSC Design & Technology p. 38

DESIGN SUCCESS & FAILURE

Factors Contributing to Design Success

11

A **design's success or failure** can be measured by whether or not it has produced a commercial profit.

Factors that contribute to a product's success or failure include:

- Accurate **market research**.
- Whether the design **fulfils a 'real' need** or solves a problem.
- Efficient and effective use of **emerging technologies**.
- Thorough **research and testing** of ideas, tools, materials and manufacturing techniques.
- Ongoing **supply** of materials.
- Efficient manufacturing and use of **appropriate technology**.
- Consideration of the **environmental impact** — recycle, renew and reuse.
- Retail cost and **effective distribution**.
- Sound **marketing and advertising** strategies.
- The four P's: Product, Price, Promotion, Place.

DESIGN & TECHNOLOGY

See *EXCEL* HSC Design & Technology pp. 48–50

DESIGN SUCCESS & FAILURE

Design Failures

13

The success or failure of a design is generally determined by whether or not it returns a profit to the manufacturer. If a design does not return a profit it is a failure, no matter how good the original design or idea was. Failure can be caused by a number of factors. Some notable failures are:

- **The Dvorak keyboard**. Major reasons for failure included competition from QWERTY keyboard, economic climate (the Great Depression then Second World War), expensive to convert typewriters to this system.
- **The Leyland P76**. Reasons for failure include 1970's fuel crisis, competition from smaller imported cars, manufacturer's reliability questioned. Ironically, the P76 is now a collector's item.
- **The Ford Capri**. Reasons for failure include last minute re-design because of changes in American laws, 1990's recession, promoted to 'wrong' market.

DESIGN & TECHNOLOGY

See *EXCEL* HSC Design & Technology p. 50

Evaluating Design Solutions

20

- **Evaluation** should be ongoing and occur at every stage of the process.
- Include an evaluation of both the **functional** and **aesthetic** criteria.
- All **primary research** must be summarised and findings evaluated and applied to the design.
- All **secondary research** must have conclusions drawn. These will have impact on design decisions. Document which factors influenced these decisions and how they were made.
- Consider the impact of the design on **society**. How will it influence the people who use it? (ie a PMI).
- Explain the impact of the design on the environment.
- Discuss this in relation to Victor Papanek and his 'green' design approach.

See E.X.C.E.L. HSC Design & Technology pp. [illegible]

DESIGN & TECHNOLOGY

SOLUTIONS Design Solutions (2)

18

Other factors to be considered when visualising a solution include:

- **Materials** are important. Designers have an ethical responsibility to use **sustainable**, **renewable** resources.
- **Aesthetics** must be appropriate so design is marketable.
- An **appropriate design solution** must evolve and develop through processes of testing and experimentation with ideas, tools, techniques and materials.
- The processes used and the **manufacturing method** must be suitable, efficient and cost effective.
- The **finish** is important. A good design is of **high quality** and is **innovative**.
- The **ergonomics** must ensure the design is safe and comfortable.

See E.X.C.E.L. HSC Design & Technology pp. 73–75

DESIGN & TECHNOLOGY

HISTORICAL & CULTURAL INFLUENCES

Influences on Australian Design (2)

16

- **World War II and the post-war boom** (1940–1974) —post-war baby boom, new immigration policies.
- **Internationalisation and speculation** (1975–1989) — international and local competition, mid-1970's world recession, stock market crash of late 1980s, environmental issues taking a more significant role.
- **Recession and recovery** (1990–present) — recession of early 1990s, technology (in particular computer technology) used in most households, Goods and Services Tax (GST) introduced in 2000, environmental protection embraced by large sections of community, recreational designs even more popular.

See E.X.C.E.L. HSC Design & Technology pp. 55–56

DESIGN & TECHNOLOGY

MARKETING & MARKET RESEARCH

Marketing Plans

26

A **marketing plan** is a series of activities leading to the setting of marketing objectives and the formulation of plans for achieving them. A marketing plan may consist of the following stages:

1. **Mission statement** or corporate objectives
2. **Financial summary** or marketing audit
3. **Market overview**
4. **SWOT analysis** (Strengths, Weaknesses, Opportunities and Threats)
5. **Assumptions**
6. Marketing **objectives and strategies**
7. **Programs** (with forecasts and budgets)
8. Identifying alternative **plans and mixes**
9. **Programs and implementation**
10. **Evaluation**

See E.X.C.E.L. HSC Design & Technology p. 94

DESIGN & TECHNOLOGY

RESEARCH METHODOLOGY

Ethics

24

Some **ethical considerations** that influence researchers include:

- Invasion of **privacy**
- **Confidentiality**
- **Honesty**
- **Integrity**
- Not using **misleading information**
- Not **suppressing information**
- **Prejudice**
- **Validating information**
- **Intellectual property** and patents, trademarks, designs, copyright, circuit layout rights, plant breeder's rights, trade secrets
- **Plagiarism**
- **Tests on animals or people.**

See E.X.C.E.L. HSC Design & Technology pp. 66–90

DESIGN & TECHNOLOGY

RESEARCH METHODOLOGY

Sources of Data

22

Primary data is collected when the researcher conducts first-hand research. The data only exists because the researcher has collected it.

Secondary data is obtained from other people's research. This research may be obtained from:

- **Statistics** such as census data, health statistics, economic and tourism surveys and ergonomic statistics.
- **Mass media** such as newspapers, television, radio, films, videos and magazines.
- **Published material** such as textbooks, journals and other non-fiction sources.
- **Other sources** such as the Internet, diaries, historical documents and photographs.

Research may be also classified as either **quantitative** research, or as **qualitative** research.

Quantitative research is when research data can be expressed in statistical or numerical form.

See E.X.C.E.L. HSC Design & Technology pp. 79–80

DESIGN & TECHNOLOGY

COMMUNICATION

Communication (2)

32

One of the uses of communication in design is for **visualising solutions**. A range of types of sketches and drawings are part of the visualisation process.

- **Sketches and drawings** can include rough and developmental sketches, thumbnail sketches, technical drawings, exploded views, rendered and computer aided drawings.

Presentation techniques can include:

- **Prototypes and models** — these may or may not be working models.
- **Demonstrations** — to show that the design will work as intended.
- **Storyboards** — a series of sketches or photographs that show how the design solves the design problem.

See E.X.C.E.L. HSC Design & Technology pp. 105–106

DESIGN & TECHNOLOGY

MARKETING & MARKET RESEARCH

Market Research

30

Market research involves gathering as much information as possible about a particular situation for analysis so that an effective marketing strategy can be developed.

The **market research process** includes:

1. **Determining the objective.** The organisation must clearly state what it expects the research to answer. Setting objectives will give the research a clear direction.
2. **Determining data collection methods.** Given the objectives, the researcher has to determine the method that is best suited to collecting data about the problem.
3. **Analysing the data.** The data must be collated and interpreted to determine any significant trends.
4. **Preparing a report with recommendations.** The report should explain how the research was carried out, detail the findings, summarise the results and make recommendations.

See E.X.C.E.L. HSC Design & Technology pp. 96–97

DESIGN & TECHNOLOGY

MARKETING & MARKET RESEARCH

Market Groups

28

There are several terms to describe **market groups**, including:

- **Target market.** This refers to the group of people for whom the product is specifically intended.
- **Market segmentation.** In order to develop a product that is viable businesses need to clearly identify which group of consumers they are aiming for. This group represents a section of the market, not the whole market.
- **Niche market.** This is a smaller market within a market segment that has particular characteristics that sets it apart from other groups.
- **Mass market.** This market includes everyone, not just specific groups.

See E.X.C.E.L. HSC Design & Technology p. 90

DESIGN & TECHNOLOGY

DEVELOPING & PRODUCING DESIGN SOLUTIONS Evaluating Design Solutions

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See *EXCEL* HSC Design & Technology pp. 75–76, 144–145

DEVELOPING & PRODUCING DESIGN SOLUTIONS Design Solutions (2)

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See *EXCEL* HSC Design & Technology pp. 73–75

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See *EXCEL* HSC Design & Technology p. 94

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- **Prejudice**
- **Validating information**
- **Intellectual property** and patents, trademarks, designs, copyright, circuit layout rights, plant breeder's rights, trade secrets
- **Plagiarism**
- **Tests on animals or people**.

See *EXCEL* HSC Design & Technology pp. 86–90

RESEARCH METHODOLOGY
Sources of Data

Primary data is collected when the researcher conducts first-hand research. The data only exists because the researcher has collected it.

Secondary data is obtained from other people's research. This research may be obtained from:

- **Statistics** such as census data, health statistics, economic and tourism surveys and ergonomic statistics.
- **Mass media** such as newspapers, television, radio, films, videos and magazines.
- **Published material** such as textbooks, journals and other non-fiction sources.
- **Other sources** such as the Internet, diaries, historical documents and photographs.

Research may be also classified as either **quantitative** research, or as **qualitative** research.

Quantitative research is when research data can be expressed in statistical or numerical form.

See *EXCEL* HSC Design & Technology pp. 79–80

COMMUNICATION
Communication (2)

One of the uses of communication in design is for **visualising solutions**. A range of types of sketches and drawings are part of the visualisation process.

- **Sketches and drawings** can include rough and developmental sketches, thumbnail sketches, technical drawings, exploded views, rendered and computer-aided drawings.

Presentation techniques can include:

- **Prototypes and models** — these may or may not be working models.
- **Demonstrations** — to show that the design will work as intended.
- **Storyboards** — a series of sketches or photographs that show how the design solves the design problem.

See *EXCEL* HSC Design & Technology pp. 105–108

MARKETING & MARKET RESEARCH
Market Research

Market research involves gathering as much information as possible about a particular situation for analysis so that an effective marketing strategy can be developed.

The **market research process** includes:

1. **Determining the objective**. The organisation must clearly state what it expects the research to answer. Setting objectives will give the research a clear direction.
2. **Determining data collection methods**. Given the objectives, the researcher has to determine the method that is best suited to collecting data about the problem.
3. **Analysing the data**. The data must be collated and interpreted to determine any significant trends.
4. **Preparing a report with recommendations**. The report should explain how the research was carried out, detail the findings, summarise the results and make recommendations.

See *EXCEL* HSC Design & Technology pp. 96–97

MARKETING & MARKET RESEARCH
Market Groups

There are several terms to describe **market groups**, including:

- **Target market**. This refers to the group of people for whom the product is specifically intended.
- **Market segmentation**. In order to develop a product that is viable businesses need to clearly identify which group of consumers they are aiming for. This group represents a section of the market, not the whole market.
- **Niche market**. This is a smaller market within a market segment that has particular characteristics that sets it apart from other groups.
- **Mass market**. This market includes everyone, not just specific groups.

See *EXCEL* HSC Design & Technology p. 95

HISTORICAL & CULTURAL INFLUENCES
Influences on Australian Design (2)

DEVELOPING & PRODUCING DESIGN SOLUTIONS
Design Solutions (2)

18

DEVELOPING & PRODUCING DESIGN SOLUTIONS
Evaluating Design Solutions

20

- **Evaluation** should be ongoing and occur at every stage of the process.
- Include an evaluation of

COMPUTER-BASED TECHNOLOGIES
Modeling

33

Computers assist with design development by producing **accurate low cost** models that may be easily manipulated and accurately analysed. Computer modeling is advantageous because it may be used to:

- **Accurately depict the design's form** from a variety of angles on a computer screen, which may then be analysed by the designer.
- **Create computer-generated models** of products in operation. For example, showing the mechanical or electrical behaviours of the product. This type of model may also be viewed on the computer screen.
- **Create a functional prototype or model** by integrating the use of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) systems, which may be externally tested.

See *EXCEL* HSC Design & Technology p. 112

COMPUTER-BASED TECHNOLOGIES
Simulation & Graphics

35

Computer simulations and graphics **are used to model the real world or some set of real conditions** so that they can be manipulated and studied more easily. Examples of such systems include:

- **Computer-Aided Engineering** (CAE)
- **Computer drafting**
- **Computer decision support systems**
- **Intelligent systems**
- **Expert systems**
- **Virtual Reality** (VR)
- **Graphics**.

See *EXCEL* HSC Design & Technology pp. 113–114

COMPUTER-BASED TECHNOLOGIES
Presentation

37

Forms of presentation include:

- **Word processing** — Software allows people to create, edit, store, retrieve and print documents.
- **Desktop publishing** — A combination of hardware (PC, laser printer, scanner) and software that together provides near typeset quality output in a variety of sizes, styles and fonts. This technology can combine graphics and text to produce professional looking pages.
- **Multimedia** — Multimedia computers give information in many forms (or media), including words, still and moving pictures, sound effects and music. They are also interactive, which means that the user can take part in the program using a mouse, keyboard or joystick.

See *EXCEL* HSC Design & Technology pp. 115–116

MANAGEMENT
Factors Affecting Management

39

To **manage effectively** a person must be able to perform a variety of mental processes and then act on the decisions made. Management requires the following skills:

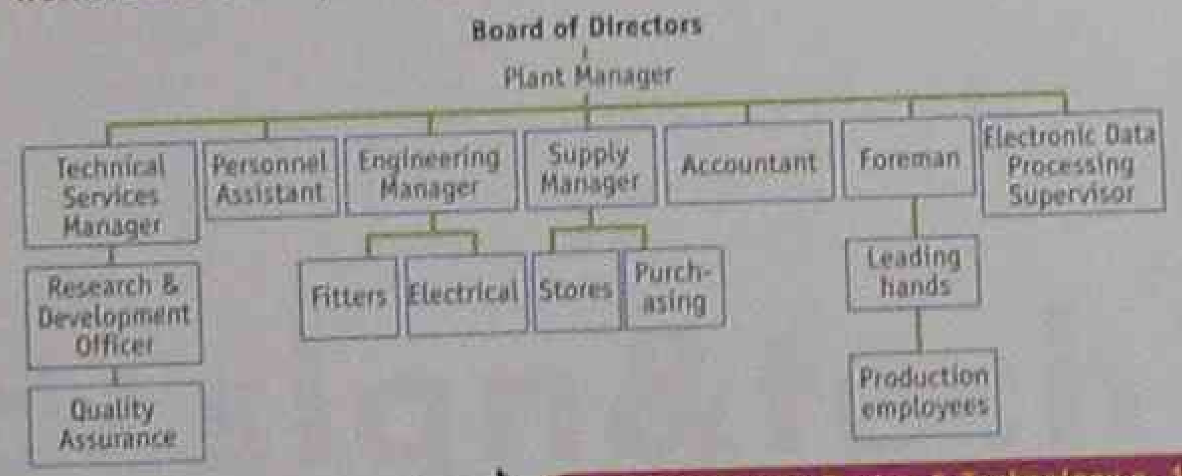
- **Setting priorities** for needs and wants
- **Identifying available resources**
- **Clarifying values**
- **Setting goals**
- **Setting standards**
- **Seeking possible alternatives**
- **Evaluating the costs and benefits** of each alternative
- **Making and implementing decisions**
- **Task descriptions and sequencing**
- **Evaluation throughout the process** and of the final result.
- **Documentation**.

See *EXCEL* HSC Design & Technology pp. 118–119

MANAGEMENT
Horizontal Management Structures

41

Horizontal structures have fewer levels, larger spans of control for managers, and tend to allow for greater horizontal communication. This model replaces the traditional model by a **flatter structure of management**. There are fewer layers of management between the workers and the top management.



See *EXCEL* HSC Design & Technology p. 122

MANAGEMENT
Applying the Management Process

43

See *EXCEL* HSC Design & Technology p. 124

MANAGEMENT
Management Theories (2)

45

- **Behavioural theories** involve management which understands the needs of people. Communication is very important.
- **Quantitative theories** involve the application of scientific methods to managerial problems.
- **Systems theories** appreciate the entire organisation and its component parts, including internal and external forces.
- **Contingency theories** emphasise that there is no approach to management that will work in all circumstances. The management style should therefore depend on the situation.
- **Management by objectives** involves setting goals for all people in an organisation and assisting them to achieve these goals.

See *EXCEL* HSC Design & Technology p. 125

MANAGEMENT
Responsibilities of Managers

47

Managers have **a responsibility** to a variety of stakeholders including: customers, employees, other organisations, creditors, owners, suppliers, government, society, the environment and future generations.

Managers have the responsibility to:

1. Manage **change**
2. Consider **social justice**
3. Consider **ecological sustainability**
4. Comply with the **law**
5. Follow **codes of practice**.

See *EXCEL* HSC Design & Technology p. 126

MANUFACTURING, PRODUCTION & TECHNOLOGY
Manufacturing & Production

49

Manufacturing refers to the making of anything. It may be large scale or one-off products. **Production** refers to making goods by any action or operation. The cost of tools and materials, availability of resources and market demand determines production techniques used.

Manufacturing involves
↓
Tools
Materials
Labour
Processes
↓
to produce **products**

See *EXCEL* HSC Design & Technology p. 130

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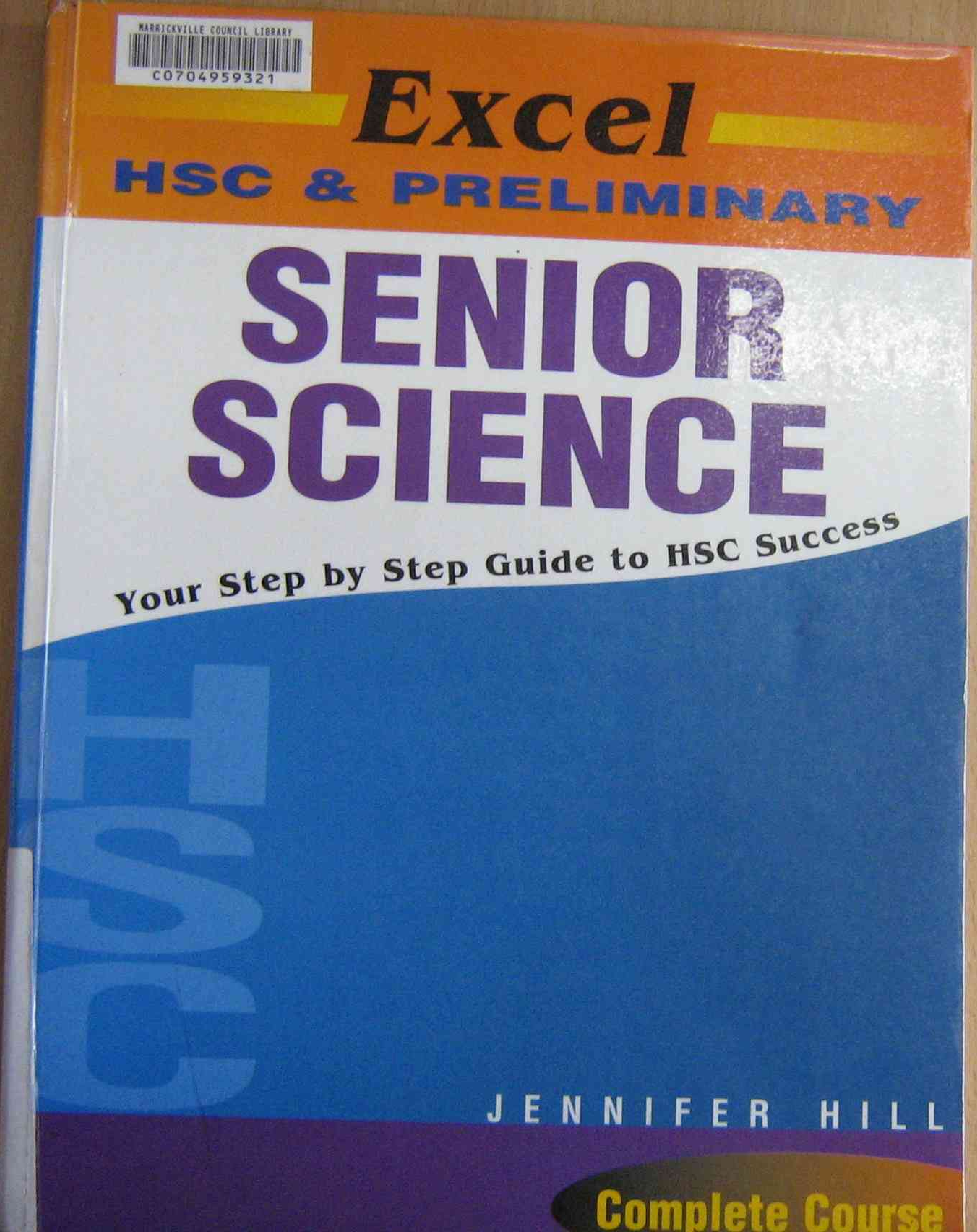

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Students:
All care has been taken in the preparation of this study guide, but please check with your teacher or the Board of Studies about the exact requirements of the course you are studying as they can change from year to year.

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Chapter 12
HSC Option – Space Science

Introduction and Course Outline

Introduction

Please spend 15 to 20 minutes reading the following information. (So often readers skip this part of a book!) There are no magical answers as to how each individual should study. Study is more effort-dependent than time-dependent. However, with so much to do, it makes sense to study in a way that makes effective use of your time. Anyone who has studied could list time wasters — the things that you do to put off the actual hard slog of revising notes and trying to make sense of the subject.

You are more likely to be successful if you:

- Understand the structure and ensure you meet all requirements of the 2 Unit Senior Science course.
- Develop and practise good study and work habits to achieve the outcomes of the Senior Science course. This is much easier when you enjoy the subject!
- Develop techniques to ensure you can demonstrate your knowledge and skills in exams and assessment tasks.

The structure and requirements of the 2 Unit Senior Science course

The Preliminary course — syllabus overview

The Preliminary course consists of core content that should be covered in 120 indicative hours.

The Preliminary course incorporates the study of:

- Water for Living (30 indicative hours)
- Plants (30 indicative hours)
- Humans at Work (30 indicative hours)
- The Local Environment (30 indicative hours).

The Preliminary course contains content that is considered assumed knowledge for the HSC course.

The HSC — syllabus overview

The new HSC is about developing independent lifelong learners. You will be rewarded for showing initiative to complete this course to the highest standard possible.

The HSC course builds upon the Preliminary course. You may also undertake the Senior Science HSC course after completing the Preliminary 2 Unit Biology, Chemistry, Physics or Earth and Environmental Science courses.

The HSC course incorporates the study of:

(a) The Core topics which constitute 90 indicative hours and include:
  - Lifestyle Chemistry (30 indicative hours)
  - Medical Technology — Bionics (30 indicative hours)
  - Information Systems (30 indicative hours)

(b) An option topic which constitutes 30 indicative hours and may comprise any ONE of the following:
  - Polymers
  - Preservatives and additives
  - Pharmaceuticals
  - Disasters
  - Space science

Note: Practical experiences are an essential part of your course work. You will complete 80 (indicative) hours of practical investigations and fieldwork during both the Preliminary and HSC courses with no less than 35 (indicative) hours of practical experiences in the HSC course.

Practical experiences include:

- Planning investigations
- Conducting investigations
- Communicating information and understanding
- Developing scientific thinking and problem-solving techniques
- Working individually and in teams.

HSC assessment

Your HSC Senior Science course result is based on:

- An (internal) assessment mark submitted by your school, and
- An (external) examination mark derived from the Board of Studies HSC Senior Science examination.

Assessment will be based on the course knowledge and skills outcomes.

Your HSC results

A course report containing a performance scale with bands describing standards of achievement will be given. Your indicated position on these bands will indicate your result.

Examination results are no longer obtained by students competing against each other to receive a ranked order. Students are now being measured against standards that reflect achievement of course outcomes. Students who perform to the same standard should get the same result, irrespective of which year they sit for the Senior Science HSC examination. Close analysis of the achievements of students in the examination and internal assessment will be used to construct the descriptions of student achievement that make up each performance level.

External examination

This will consist of one examination paper of three hours. It will have TWO sections:

Section I Core (75 marks)

Part A (15 marks)

- 15 multiple choice
- All questions will be compulsory
- All questions will be of equal value
- Questions will be based on the HSC core

Part B (60 marks)

- Short answer and extended response questions
- Marks for individual questions will be shown on the examination paper
- All questions will be compulsory
- Questions will be based on the HSC core

Section II Options (25 marks)

There will be five questions: one on each of the FIVE HSC options. Each question may consist of several parts.

- Marks for individual parts will be shown on the examination paper
- Candidates must attempt ONE question
- All questions will be of equal value

Care will be taken to ensure a consistent level of difficulty across each of the options in the examination.

Preparation for the exam involves trying to lengthen your concentration span. It is important not to waste time or daydream during the exam.

Internal assessment

Components, weightings and suggested tasks for the HSC course internal assessment are shown below. These are specified in the syllabus.

Component	**Weighting**
Lifestyle Chemistry	25
Medical Technology — Bionics	25
Information Systems	25
Option	25
Total Marks	**100**

Internal assessment tasks could include exams and topic tests, reports, assignments, open-ended investigations, model-making, research projects, practical tests, fieldwork studies and reports and oral reports. At least 30% must be allocated to students' first-hand investigations and the communication of information and understandings that result from them.

No more than 50% of the internal assessment can be derived from written topic tests or examinations.

Slight modifications of the syllabus may occur from time-to-time. Everyone can access the latest version of the syllabus through the Board of Studies website: http://www.boardofstudies/nsw/edu/au

Note: you may choose to download Adobe Acrobat Reader to be able to read the syllabus. This is available free on the website but it takes some time to download.

It is also worth accessing examination reports from previous exams from this site. These detail many of the common errors that students make.

Skills development

It is important that you are familiar with ALL the skills listed in the course. These activities should lead to and enhance your understanding of the main ideas in the course. You are expected to have employed all the skills at least once. You may be asked in an exam, for example, to explain how you have used an appropriate technology such as a data logger or sensor to gather first-hand information, or how you carried out a controlled experiment, listing the variables, as well as the factors that were kept constant.

Using the Internet — One of the skill areas that you may need to develop is your ability to use the Internet efficiently and effectively. While this guide gives you some addresses, it is essential that you develop expertise in using search engines. The use of + and — signs to help clarify search terms is often useful. Making the most of either searching by categories or browsing can also aid in information-gathering.

Resources — Make use of a range of resources and your teacher to ensure you are focused on essential course content. This study guide has been written so that it closely aligns with the syllabus.

The Board of Studies or Department of School Education has links to the new HSC On-Line website. This provides excellent advice in detail about study and exam techniques, as well as having useful links to information sites for most subjects.

Hints for developing good study and work techniques and habits

Below are some hints for developing good study techniques:

1. Establish an appropriate **place** to study — somewhere quiet, free from interruption, comfortable (but not too comfortable) and organised.
2. Practise **self-discipline** and **self-motivation**. This can be linked to establishing clear long-term and short-term goals. Establish a goal, for example 'to understand how improvements in technology have contributed to advances in bionics by the end of a study session'. It should be clear when you have achieved this goal so you can give yourself a small reward as well as having the satisfaction of achieving your goal.

   Your motivation to study will improve when you link studying to the confidence that you can achieve goals. If you are struggling with deciding a career path, try to focus on the long-term goal of success in the HSC and/or obtaining a good UAI. Even if you don't want to follow a career in science, doing well in this course will produce benefits that relate to many career paths and your life in general. You will develop skills in lifelong learning and become an informed citizen on important issues in today's society.
3. Prepare a **study timetable** — do not study one topic for too long, and try to revisit topics with a reasonable degree of frequency. You have to balance the demands of school assessment tasks with revision and preparation for the external examination. Your timetable should include preparation for the trial and other mandatory tasks such as the open-ended investigation.
4. Establish a **regular time** for study.
5. **Take care of yourself** — set aside time for mental relaxation, keep physically fit, eat regular meals, get plenty of sleep. Your state of mind is also important. If you are stressed, or don't believe you can learn, or can't see the point of what you are learning, you won't learn well.
6. Reflect on how you learn best and what is working for you. REMEMBER — we are all unique in the way we prefer to take in information and learn. There is no one right way. If you know how you best learn, you can make your study time more productive.
7. Show yourself or someone else that you understand what you've learned. Just reading through notes is not always the best way. Doing something with the information helps it stick in your memory. Developing your own bank of questions and answers works well for some people. To make sense of information you need to:
   - **Read it** — see it
   - **Hear it** — say it aloud
   - **Write it** — do something with the information.
8. Memorise one or two key facts so the rest of what you've learned comes flooding back. Put the key points down in your own words. Put the key ideas into tables or draw diagrams. Some people use associations such as in acronyms to help remember. You might write key words on cards or post-it notes, or draw a learning map of all the key concepts. The important thing is that effective learning occurs when you combine **seeing, hearing, and doing**.

Use the information in this book as a guide to organising your own notes and, if you feel you need to, preparing your own summary. Use the answers/explanations to modify your notes or resummarise your summarised notes.

How to use this study and revision guide

The purpose of this book is to:

1. Provide you with a course outline that will help you study and make sense of the subject. The outline includes a variety of features including: key points, summary tables, written notes, diagrams and a glossary.
2. Give suggestions of the ways you can approach many of the mandatory practical and information-skills activities in which you will need to be able to demonstrate competence in the course
3. Provide you with practice questions and a sample trial exam. (The more you can do the better, and try doing some of the questions under exam conditions.)

Each chapter has:

1. **A list of outcomes**
2. **A checkpoint** — to check assumed knowledge before you begin the review of the main points of each module
3. **An extended outline** covering all the important concepts and facts from the course syllabus. These are covered in the order in which they appear in the syllabus. To help you with quick pre-exam revision, the main ideas for each topic are highlighted in boxes, tables, or diagrams, or printed in bold print or capital letters.
4. The **mandatory skills** that you need to be able to demonstrate are highlighted using the following two icons, one for first-hand investigations, the other for research using secondary sources:

   As part of meeting the requirements of the course, you are expected to have performed a first-hand investigation to ...

   As part of meeting the requirements of the course, you are expected to have gathered information from secondary sources to ...
5. At the end of each chapter there is a **checklist** of key terms for revision, and a set of **practice questions** — multiple choice questions with answers and explanations, and short answer and longer response questions with answers and explanations.

Also included:

- A **practice trial exam** in Chapter 13 with answers and comprehensive explanations
- A **glossary of key terms** for the HSC Core Modules at the end of the book

Note: The HSC Senior Science course introduces you to many new words. It is a fairly 'wordy' course. Words that you do not understand, may be scientific words (for example, biodiversity, emulsifier or optical fibre) or everyday words that also have a special scientific meaning (for example, solution, frequency, transmission). You need to list these words and satisfy yourself that you understand what they mean before going too far with the rest of your revision.

Hints for answering exam questions

1. **Read all parts of each question before you begin.** Work out how many parts need to be answered. Also check the mark value of each question. Some questions may be worth eight marks but consist of only one part. At first these 'mini essay' type questions may seem difficult, but it is essential that you attempt them, even if you do not feel confident. Not attempting questions is just throwing away marks.

2. **Answer all 'parts' and answer in the correct space.** Underline key words such as verbs in the question that tell you what is being asked. For example, a question might ask you to 'assess the contribution of two advances in science on the development of technology'. The key words here are **assess**, **two advances** and **how each** of these advances **contributed** to the development of technology. You would need to name the advances and make a judgment about ('assess') how each contributed to a specific technological development.

3. **Be familiar with the language of exams and the language of the syllabus.**

(a) Questions containing the following instructions require short answers of only a few words or one or two sentences:

- Give one reason, define, describe, identify, outline, recall, recount, summarise, list, name, state
- What part is represented by ...
- List THREE factors; name TWO functions; what are FOUR features; give TWO examples and so on.

(b) Answers to questions containing the following terms usually require slightly longer answers:

- assess, critically analyse, justify, evaluate, classify, compare, contrast, deduce, demonstrate, discuss, examine, explain, extract, extrapolate, interpret, investigate, predict

At times you may have to bring together ideas from throughout a module for your answer. Remember, your answer should be **comprehensive but concise**.

4. **Decide how best to organise your answer**
    - Full sentences may not be necessary and are often a waste of space. This is not like an English essay.
    - Organise your thoughts logically — use tables, flowcharts, and accurately labelled diagrams.
    - Do not answer in excessive length in relation to the space provided.
    - Do not rewrite the question.

5. **Answer only the question asked.** This involves taking the time to read the question carefully and determining exactly what it means. HSC examinations are set on a criterion or standards-referenced approach. This means that there will be a full range in the degree of difficulty of questions. Generally within sections or multiple-part questions, the easier questions will come first.

6. **Do not expect the examiner** (the person marking your answer) **to read your mind.** Don't say to yourself 'They will know what I mean' and don't expect examiners to fill in the gaps in your answer. State all relevant facts and give complete explanations where appropriate.

7. **Answer the question as a person** who has **studied the subject** (not from general knowledge). Don't use 'slang'. Remember, the question is testing specific knowledge of the course; if you think you can answer it using general knowledge, you are probably missing the point of the question.

8. **Plan your time and approach to the exam ahead of time.** You have 180 minutes to achieve a maximum of 100 marks. That means approximately 20–30 minutes to complete the multiple-choice section and 45 minutes to complete the questions on your option. Consider answering multiple-choice questions last to avoid wasting time.

9. **Do not panic if you think you are running out of time**; simply jot down the essential points on the answer booklet and come back later if time permits. This is especially important for the questions that are worth up to eight marks.

10. **Read over your answers to all sections** after you **have finished.**

Preliminary Core Study Module 1

1 — Water for Living

Introduction

In this chapter you will review how water is a precious resource and an important ingredient in the maintenance of the Australian environment. You will also review how ground water, river systems, wetlands, estuaries and marine environments have been disturbed by human activities such as run-off from mining, agricultural and urban systems, damming and re-routing. Finally you will review some possible strategies to reduce the impact of these activities.

As a result of working through this chapter you will be able to:

— Assess the impact of particular technological advances on our understanding of pollution and strategies to reduce pollution

— Identify uses of pesticides and herbicides that affect society and the environment

— Identify how investigations, such as a study of the effects of pollutants on the growth of plants, can be improved.

☑ Checkpoint

Before you begin your review, you need to check your understanding of the following:

- Living things are made of cells. All cells contain water.
- Water is important in the body as a solvent. Water dissolves more substances than any other liquid. Water dissolves substances so that they can react chemically. One of the main functions of water in the body, therefore, is to provide a medium for chemical reactions in cells.
- The importance of water as a solvent in the bloodstream. Blood plasma is made up of 90% water. Substances such as carbon dioxide (in the form of bicarbonate ions), lipids and other products of digestion are carried in blood plasma in solution or as a suspension.
- The importance of water as a solvent in the transpiration stream. Water carries dissolved mineral nutrients, such as nitrogen, from the soil to the leaves of plants.
- Aqueous mixtures can be defined in terms of the solute, solvent and solution. Solute refers to the particles of substances dissolved in the aqueous mixture, for example, salt. The solvent is the substance in which the solute is dissolved, for example, water. The solution refers to the mixture, for example, salt water.
- The water cycle.

Water and the health of humans and other living things

Water exists on Earth in liquid form as surface and ground water. Water is also in the atmosphere as the main gas that reabsorbs radiation from the Earth to assist in stabilising the Earth's surface temperature and climatic conditions. Usable (fresh) water covers less than 1% of the Earth's surface, yet all living things depend on water for survival. Aquatic habitats are hugely diverse and complex, and increasingly under threat from human activity.

Australia is the driest continent on Earth. Australia is also the second highest user of water per capita in the world. Each Australian consumes 1 million litres of fresh water each year. Water scarcity and water quality are major concerns in Australia.

Living things cannot survive without water. Every living cell has water in it. To survive, living things must have ways to maximise the uptake of water, minimise water loss and maintain a balance of salts and water in their cells and tissues.

As part of meeting the requirements of the course, you are expected to have carried out experiments to identify the range of substances that will dissolve in water and be able to name the solute and solvent in each case.

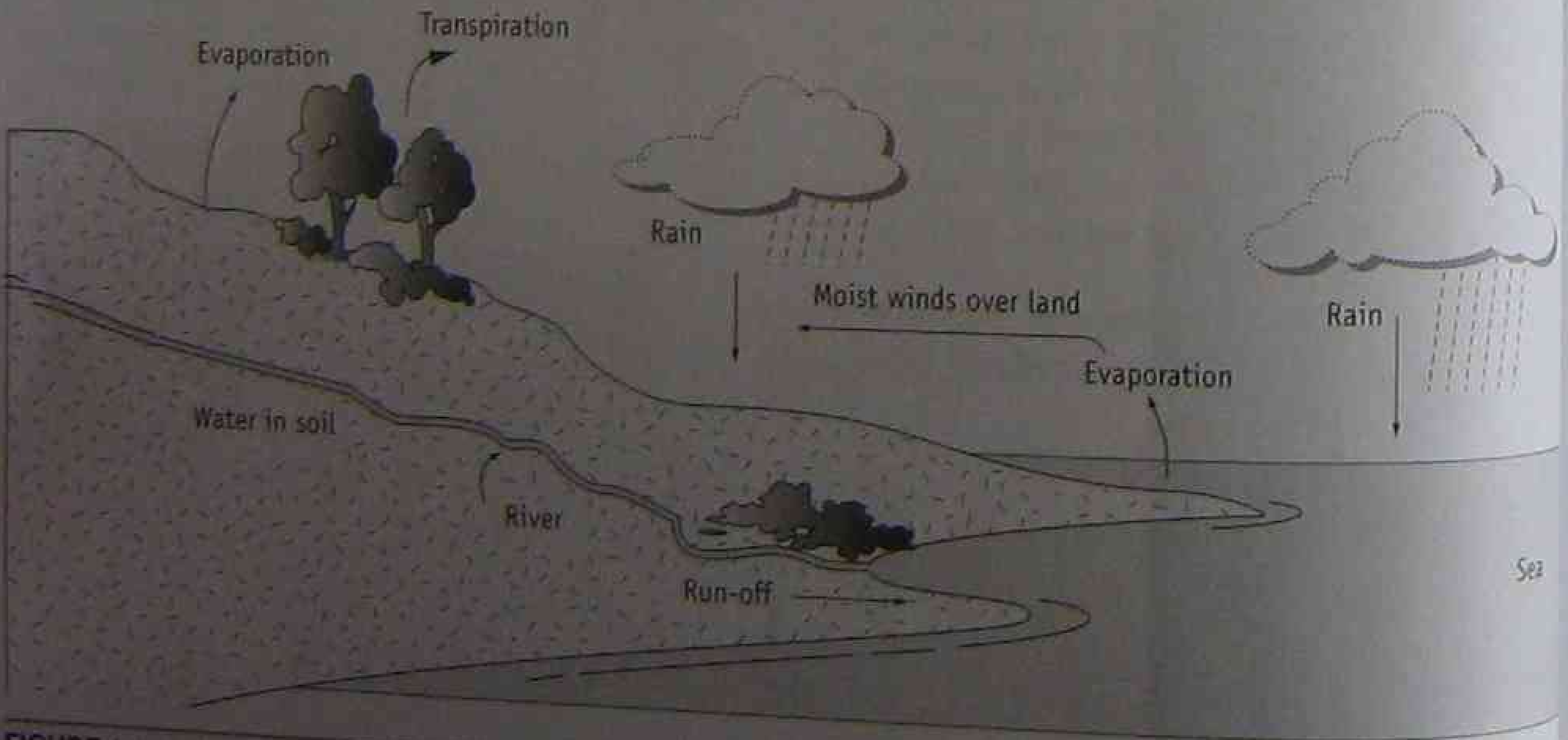


FIGURE 1.1 A simplified diagram of the water cycle

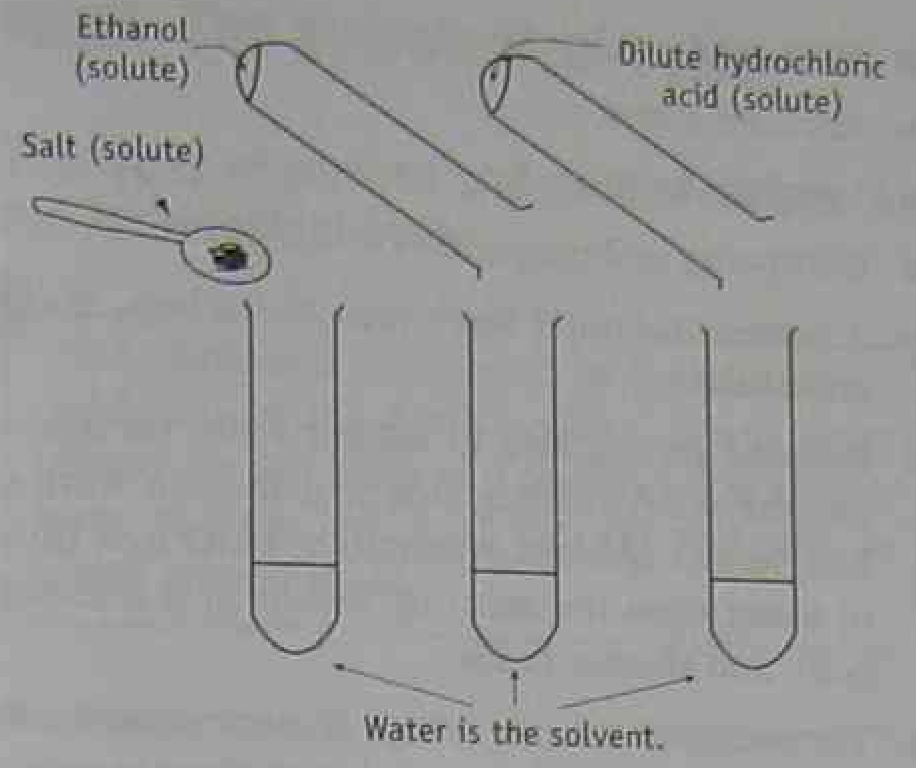


FIGURE 1.2 Testing a range of substances that will dissolve in water and identifying the solute and solvent. Some substances are more soluble in water than others. Ethanol, for example, is very soluble.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to determine the amount of water in a variety of fruits and vegetables.

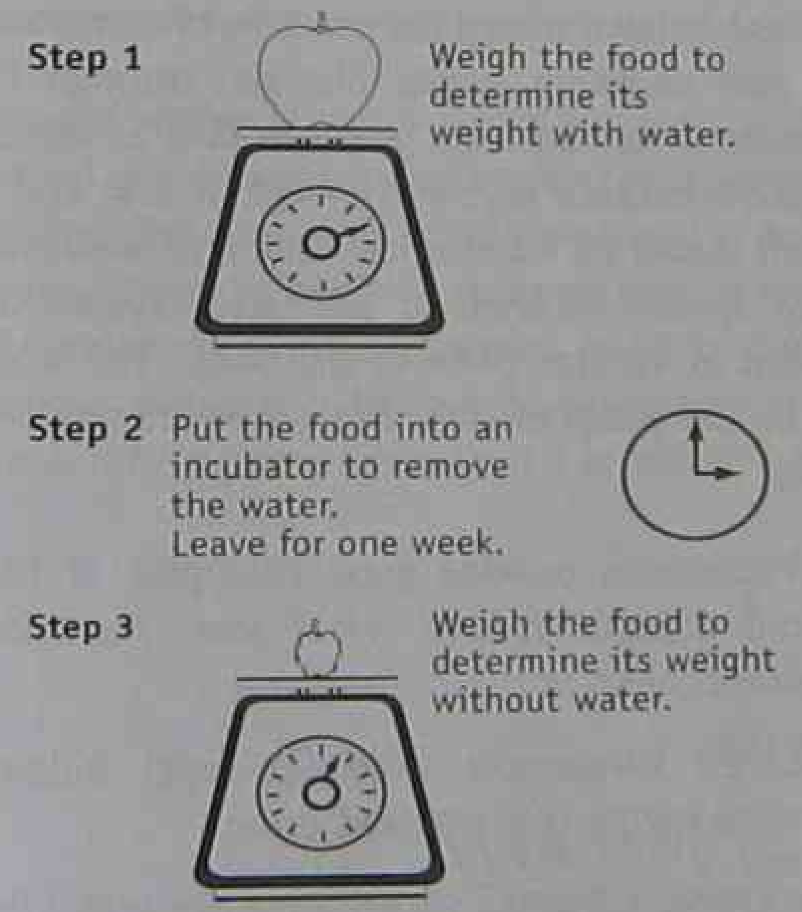


FIGURE 1.3 Steps in determining the amount of water in a variety of fruits and vegetables

Ways that plants optimise water uptake

In general terms, plants have thousands of root hairs that increase the surface area for water absorption. Root hairs ensure close contact with soil to increase the rate of water uptake. Examples of the ways in which some plants optimise water uptake include:

- The development of large, deep penetrating root systems
- Plants grow sparsely to reduce competition for water in areas where water is scarce
- Leaves slope steeply upward to catch rain and direct the rain to a dense shallow root system close to the trunk (for example, Mulga trees)
- Swollen stems to store large quantities of water.

Ways that plants reduce water loss

Plants lose water through special openings in their leaves called stomates. The rate of water loss increases in higher temperatures and high wind conditions. Water loss decreases as humidity increases. Water loss tends to increase as the surface area of the leaf increases and the number of stomates per leaf increases.

Australian land plants have a range of adaptations that assist in minimising water loss while, at the same time, allowing for gas exchange. These include:

- A thick outer coating or cuticle on leaves — this reduces evaporative water loss
- A reduced number of leaves, or leaves reduced to spikes
- Dropping leaves in times of drought
- Reduced number of stomates, located on the under surface of the leaf
- Hairs on the leaf, or the ability for the leaf to curl. This increases the humidity around the leaf.
- Some plants only open their stomates at night when temperatures are cooler.

As part of meeting the requirements of the course, you are expected to have examined a range of plants to identify features that assist in reducing water loss.

This investigation may have included observations of structures such as waxy leaf cuticles, hairy leaves, sunken stomata, few stomates on leaves, leaves rolled inward (such as spinifex grass), leaves reduced to spikes (such as cacti). Investigations may also have included microscopic observations.

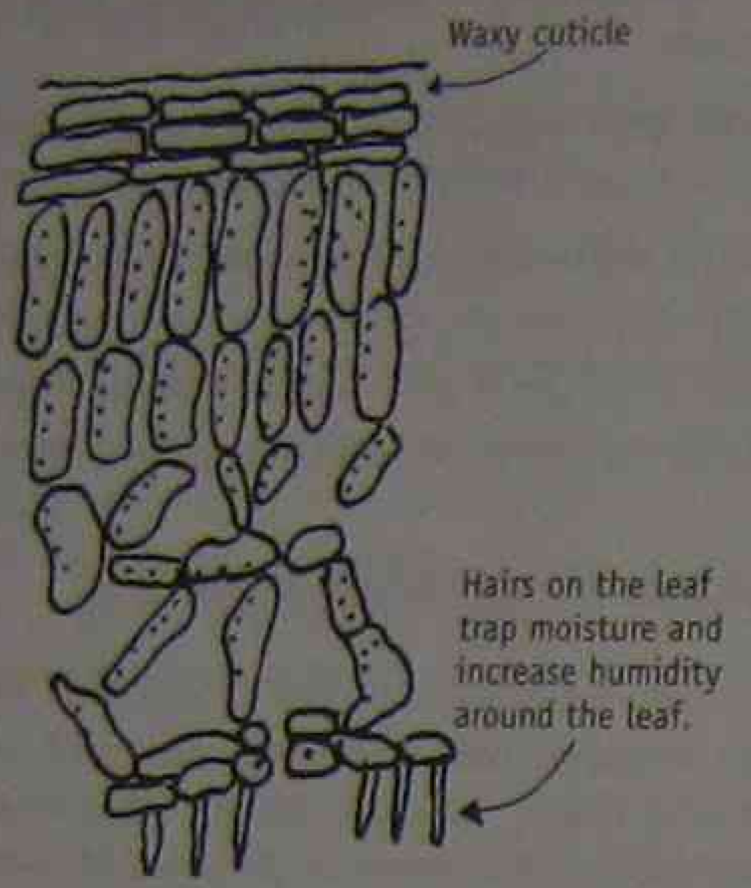


FIGURE 1.4 A cross-section of a leaf showing a waxy cuticle and hairs on the undersurface which assist in reducing water loss

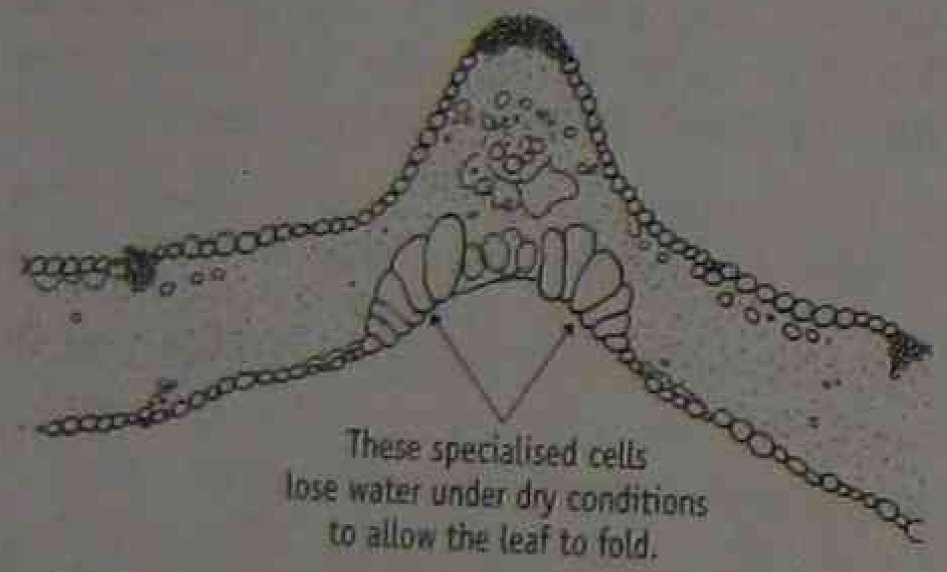


FIGURE 1.5 Drawing of a microscopic view of a leaf of maram grass

Ways that animals reduce water loss

Hot, dry habitats are the most common in Australia. Animals that live on land face the problem of conserving water and at the same time removing nitrogenous wastes in a form which is concentrated and not toxic. It is difficult for them to spare the water that is normally needed to dilute toxic ammonium ions from excess nitrogen.

Some of the ways that animals reduce water loss include:

- Excreting uric acid instead of urea. Uric acid is insoluble. Birds, for example, excrete a paste of insoluble uric acid to conserve water.
- Excretion of highly concentrated urine
- Nocturnal behaviour
- Reduced activity
- Lying in the shade
- Burrowing underground
- A waterproof outer layer such as feathers, sh and scales
- Reduced surface area to volume ratio. For ex ple, the water-holding frog that lives in Aus lian deserts reduces evaporative water loss (l of water from the skin) by means of a round body and shorter limbs.
- The ability to tolerate a high level of urea sto in the body which is only excreted when water available.

As part of meeting the requirements of t course, you are expected to have used secon ary sources to research the ways in which range of terrestrial animals reduce water loss

Some examples are provided below. They may n be the same as the ones you have researched.

Many insects have solved the problem of conservi water and excreting excess nitrogen through th conversion of nitrogenous products into an almo insoluble substance called uric acid. If uric acid i excreted, almost no water is lost. Uric acid is excret through special tubules, or uric acid crystals a deposited in various parts of the body. The whi scales on the wings of some butterflies are uric ac deposits.

Desert mammals provide good examples of ho terrestrial animals reduce water loss. Australia examples include:

- The red kangaroo's (*Megalia rufa*) kidney produce highly concentrated urine.
- The mulgara, a small carnivorous marsupial tha inhabits sandhill deserts in central Australia does not drink. Moisture is absorbed from foo and the large amounts of urea produced by carnivorous diet are excreted in highly concen trated urine.
- The murid hopping mouse lives on dry seeds with no drinking water and has a great ability t concentrate urine.

The hydrological cycle

The types of surface and ground waters in the hydrological cycle

The hydrological cycle refers to the continuous circulation of the Earth's water. When water falls on the soil some of it washes off as surface water and the rest sinks into the soil and becomes ground water.

Surface water is found above the ground. The types of surface waters include:

- Rivers
- Lakes
- Wetlands such as billabongs, swamps, salt marshes, mud flats and mangroves.

Dams and reservoirs store water and therefore delay and restrict the flow of surface water. Wells and bores take water from the ground and affect the amount of water that is needed to keep underground water sources in balance.

Ground water is water which is found under the ground. It contains varying amounts of dissolved salts and supplies about 15% of all water used in Australia. Sixty per cent of Australia relies on ground water for all uses except drinking water, such as irrigation. Ground water is a limited resource and in many areas, is being used faster than it is replenished. The ground water from some bores is very old, for example, the bore water from the Great Artesian Basin (Australia's largest ground water system) may be up to two million years old. In many areas, the uncontrolled flow of water from bores has resulted in large-scale waste of ground water reserves.

The types of ground waters include water that flows and water that is contained.

Artesian water — ground water flows through aquifers. Aquifers are areas of permeable rock that are saturated with water. If an aquifer is surrounded by impermeable rock, the water is unable to escape. This water is called artesian water.

The water table — the upper boundary of the saturated zone is called the water table. The level of the water table varies from time to time. It is higher in wet weather. When wells are drilled they are driven down below the water table. Water from wells is called bore water.

Any disturbance to the hydrological cycle is a threat to living things. Human activity interferes with natural fluctuations of water which occur with seasonal changes. Polluted air can change the water quality of precipitation. Destruction of plant life reduces the amount of transpiration in the cycle. The removal of vegetation such as trees also increases surface run-off and soil erosion. The water table is affected by changes to drainage, irrigation and removal of trees. Polluted ground water reduces the amount of usable water.

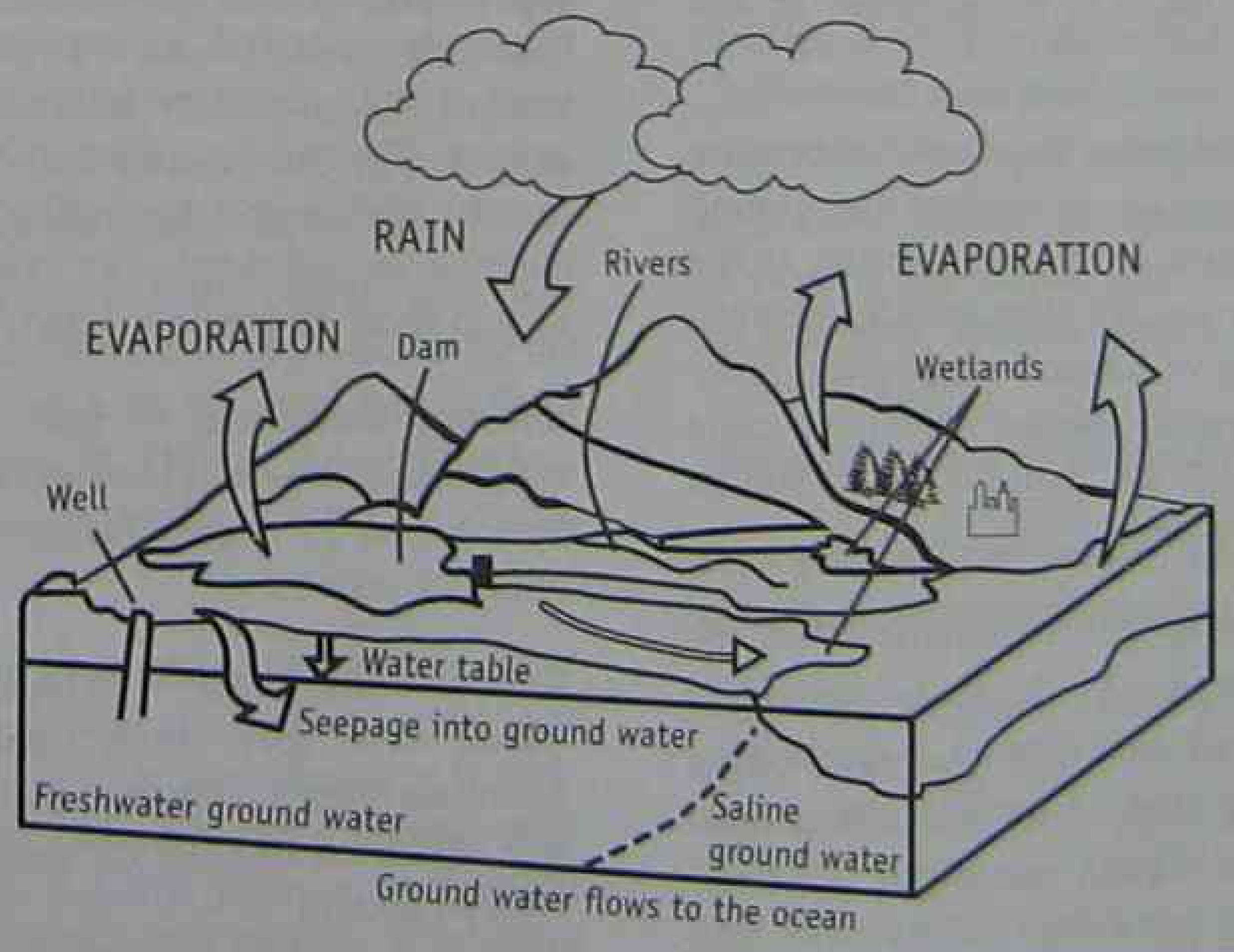


FIGURE 1.6 (a) The hydrological cycle

FIGURE 1.6 (b) Water in cave environments is a type of ground water.

The impact of the continued use of surface and ground waters

The availability and quality of surface water and ground water determines whether natural and human communities survive. In natural environments the numbers of living things tend to increase around water sources. Almost all rural cities and towns are built on water sources and coastal cities and towns are expanding. Each human activity and development impacts on the water quality of the area and therefore on the health of natural ecosystems. The health of the system, in turn, impacts on the number and range of living things in and around the area.

The expansion of irrigation has been a primary factor in the increasing use of surface and ground water. The development of the rice industry in the 1970s along the Murray and Murrumbidgee Rivers, and the development of the cotton industry in the 1980s and 1990s along the Darling River have made a significant impact on natural and human communities in these areas.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research and draw a map showing the location and type of surface and ground water in the local area.

A topographic map of the local area will show the location of some surface water such as c and rivers. Sydney Catchment Authority h formation on drainage and ground water for Sy Illawarra and the Blue Mountains. The Depar of Land and Water Conservation is responsib mapping ground water. Your local council may be a good source for this information. The co may provide local drainage system maps inclu stormwater drains, the drains under the streets carry away rainwater. When it rains, anything w ed into gutters and drains (oil, grease, l detergents, dog faeces, suspended solids, and off from roads) flows untreated into the waterw

> As part of meeting the requirements of course, you are expected to have used seco ary sources to research and describe the r tionships between rainfall, water supply a different types of ecosystems.

A summary of relationships between rainfall, wa supply and types of ecosystems in NSW.

Rainforests — plants need to be well watered a well protected; rainforests need high humidity a fertile moist soil. When water supply is reduced soils become well-drained (such as sandstone so rainforest gives way to wet sclerophyll forests.

Wet sclerophyll — moist but well-drained a protected from dry winds; they are therefore coo and wetter than dry sclerophyll forests.

Dry sclerophyll — sclerophyll means hard-leave Plants are adapted to dry conditions and we drained soils, therefore water requirements are n as great. The main examples in Australia are eucaly forests. With a greater likelihood of drought and decrease in soil depth, dry sclerophyll forest gi way to shrubby low woodland.

Shrubby woodland — low, open woodland o sandstone plateaus. Plants grow sparsely to redu competition for water. Plants usually grow to le than two metres.

Coastal community — adapted to severe salt-lade winds and very poor, rapidly draining so Therefore they have low water requirements. The is a restricted number of species and plants hav stunted growth.

Water pollution, salt water intrusion, ground salinity and sulfur compounds

> Pollution is contamination of the environment by a range of substances and processes including human activity. It can occur when humans deliberately or accidentally release substances into the environment in quantities that adversely affect health and/or harm natural resources.

Pollutants can directly harm organisms or they can accumulate in the body tissue of organisms, causing damage over time.

Water pollution — freshwater pollution is caused by the disposal of industrial and household waste (detergents, sewage and so on) and run-off from contaminated soil. Pollution of the ocean is the result of run-off from land (nutrients from pesticides and fertilisers, sewage effluent, storm water discharge from urban areas), oil spills, the dumping of sewage and garbage from ships and industrial waste. Ground water pollution comes from soil contamination. Water leaches through the soil bringing pollutants to aquifers.

Examples of water pollution in Australian environments:

- Bottlenose dolphins in the Gulf St Vincent, South Australia, have been recorded with the highest levels of mercury in the world in dolphins and with dangerous levels of a now banned but long-lived chemical called PCB. Researchers believe that the pollutants came from stormwater. Reference: Prideaux M. & Bossley M. (2000) 'Lethal waters: the assault on our marine mammals', *Habitat Australia*, April, pp. 13–20.
- Rising nutrient levels in run-off from sugar cane and cattle farms are said to be responsible for the death of inshore corals on the Great Barrier Reef. Reference: Prideaux M. (1999) 'Presiding over a world heritage graveyard?', *Habitat Australia*, April, pp.16–18.

Salt water intrusion and ground salinity — after more than 200 years of land clearing and removal of topsoil and with increasing developments in irrigation, salinisation is now a major environmental problem in Australia. Salinity prevents agricultural crops from growing, affects the quality of drinking water, has a serious direct or indirect impact on native plants and animals which are not adapted to high salinity levels, corrodes pipes, and damages roads and buildings. Salt affects plants before it kills them. Plants affected by salinity grow slower, are stunted and have smaller leaves.

> The clearing of vegetation reduces 'pumping' from aquifers. This clearing combined with increased surface evaporation draws the water table closer to the surface. The water table brings with it millions of years of naturally accumulated salt. As a consequence, intrusion of salt water can occur in both irrigated and dryland soils.

Ground salinity — not all salt brought to the surface through ground water rise goes into rivers. Excessive tree clearing and intensive farm practices have drastically raised the amount of salt in arid and semi-arid areas. The salt accumulates to form dryland or ground salinity.

Salt water intrusion — where irrigation occurs, the impact from salinity can be more severe. Irrigation (and lack of vegetation from land clearing) further increases the amount of water seeping into the ground, therefore increasing the level of the salt-water table. The salt intrudes into river systems and wetland areas, drastically changing the salt concentration of the water.

Increasing salinity levels within streams may also influence other aspects of water quality, for example:

- High salinity levels within streams can lead to increased algal growth because of increased light penetration through the water.
- Salinity directly affects the level of dissolved oxygen: the higher the salinity, the lower the dissolved oxygen levels at a given water temperature.

This is illustrated on the next page.

Examples of salt water intrusion and ground salinity in Australian environments:

Salt water intrusion is an increasing problem in many areas such as the Murray-Darling Basin. The Murray-Darling river system is the largest in Australia and drains about 14% of the continent. The environment within the Murray-Darling Basin has been affected by alterations in both the flow regimes of rivers and salinity levels. Three thousand tonnes of salt travel down the Murray River each day. Studies estimate that $700 million per year is lost because once usable land is destroyed by salination, and that by 2100 there will be 10 million tonnes of salt moving in the Murray-Darling Basin. Salinity in a catchment area will also impact on the 'end-of-system' rivers and wetlands such as swamps.

On 22 October 1999, the Murray-Darling Basin Commission (MDBC) released a Salinity Audit which compiled information on the current extent of salinity in the Murray-Darling Basin and predicted the likely extent of salinity in the future. The Salinity Audit covers the entire area of the Murray Darling Basin — more than one million square kilometres, extending over three-quarters of NSW, more than half of Victoria, significant portions of Queensland and South Australia, and the whole of the ACT. The Basin includes the NSW catchments of Lachlan, Macquarie, Murray, Murrumbidgee, Castlereagh, Namoi, Gwydir and Barwon-Darling Rivers. Studies are also being conducted in the basin's 'end-of-system' wetlands — the Macquarie Marshes, Gwydir Wetlands and the Great Cumbung Wetlands Swamp to determine the impacts of flow regimes and salinity.

See: http:// www.dlwc.nsw.gov.au/care/salinity/execsummary/index.html — for the Department of Land and Water Conservation's summary of findings of the MDBC salinity audit.

http:// www.acfonline.org.au — Australian Conservation Foundation Salinity Appeal.

Luntz S. (2000) 'Audit predicts grim salinity futu *Australasian Science*, Jan/Feb, pp. 23–24.

Charman P.E.V & Murphy B.W (eds) (1994) *Soils their properties and management — a soil conser ation handbook for NSW*, Sydney University Press

Sulfur compounds: Sulfur compounds in wat change the pH of the water — acidity increases Sulfur compounds come from a number of sources These include:

(a) Sulfur dioxide emissions from the burning of oi natural gas and coal. Sulfur dioxide acidifies rain lakes and other bodies of water. Acidified water moving through soil leaches heavy metals into surface and ground water systems; and

(b) Soils. Some soils are naturally sulfide soils When these soils are disturbed and exposed to air and water by mining, urban development the removal of vegetation or overgrazing, they release sulfuric acid. The acid leaches into sur face and ground water systems. Non-acid soils can also become acidified by the overuse of fertilisers.

Examples of sulfur in Australian environments

Acid-sulfate soils along Queensland's coast are being disturbed by sulfuric acid released through mining and urban development. The acid released from oil shale mining is threatening wetlands and estuarine ecosystems and inshore reefs along the North Queensland coast. There are proposals to expand the oil shale mining industry into the World Heritage Areas of the Great Barrier Reef.

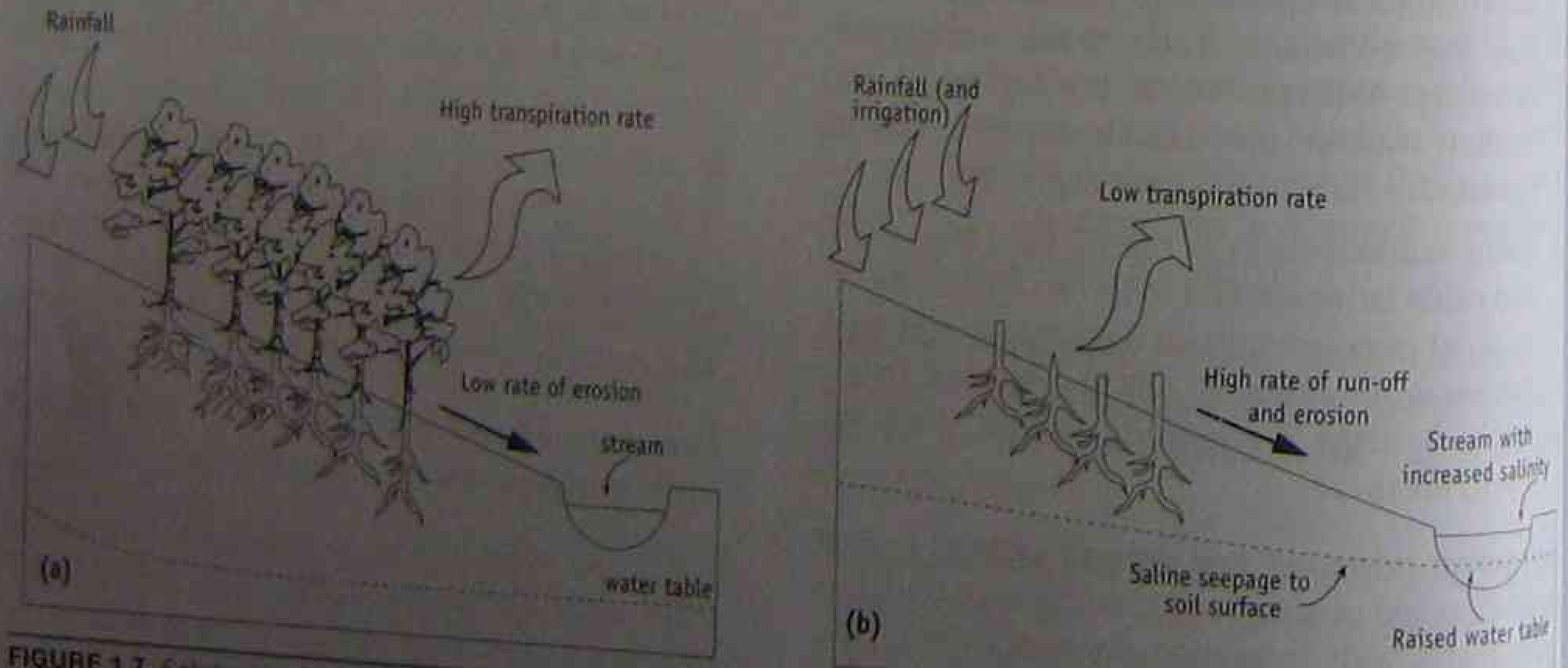


FIGURE 1.7 Salinisation occurs when the balance between surface water and ground water is disrupted. When trees are removed less water is pumped from the ground water system. Irrigation increases the rate of seepage. This results in more water entering the ground water system.

See: Prideaux M. (1999) 'Presiding over a world heritage graveyard?', *Habitat Australia*, April, pp. 16–18.

http://www.abc.net.au/science/news — ABC news January 2001 and proposed oil exploration in an area 50 km off the Great Barrier Reef.

As part of meeting the requirements of the course, you are expected to have used secondary sources to:

(a) Research and assess the impact of human activity on an aquatic ecosystem or water source in Australia; and

(b) Identify the consequences of this impact and some possible ways to rehabilitate the area. Some ideas are provided below.

- **The Snowy River** — 99% of the Snowy's flow was diverted with the development of the hydro-electric scheme. The water flows inland to the Murray and Murrumbidgee irrigation areas. Low flows and siltation from upper catchment erosion are killing the river. Sediment build-up is filling in previously deep river channels and destroying fish habitats. Siltation makes the river more susceptible to invasive weeds.

  Possible rehabilitation strategies have caused debate and controversy. Environmentalists and local communities have called for a return of some of the flow to the river. This has caused arguments between different interest groups because it would mean diverting some water from the Murray River.

  See: Fisher T. (2000) 'Water Torture: Will the Snowy ever get a drink?', *Habitat Australia*, April, pp. 8–10.

  http://www.acfoline.org.au — Australian Conservation Foundation.

  http://www.abc.net.au/landline — *Landline* program on the Snowy River.

- **Wetland areas such as swamps and mangroves** are often destroyed by urban development. In many areas they have been drained and filled with garbage to provide land for housing, industry, roads and playing fields. The impact of human activity also includes:
  - The introduction of pollutants such as fertilisers, organic wastes (sewage), toxic substances (pesticides, cyanides and herbicides) and suspended or floating particles (silt, grease, and plastic) that reduce light penetration in the water
  - Changes to freshwater inflow or levee construction that change the direction of water flow or tidal movements
  - The introduction of bacteria, viruses and fungi from garbage and sewage
  - The introduction of pest species, such as European carp and gambusia, and water weeds, such as salvinia, alligator weed and water rushes
  - Oil spills, which also pose a major threat to saltwater and estuarine environments.

  See: 'Liquid gold: Australia's wetland wealth', *Habitat Australia*, October 1997.

  See also: Yu P. & Yu S. (1999) 'Living Water', *Habitat Australia*, June, pp. 24–27 — for a case study on the West Canning ground water basin and proposals to extensively tap the ground water basin for cotton irrigation.

  Environment NSW, Nature Conservation Council of NSW Inc., September 1999 — for articles on damming of the Clarence River system and the use of ground water in the Namoi catchment.

Possible solutions to environmental problems caused by the overuse of ground water

Little is currently known about the long-term consequences of overuse of ground water, particularly in wetlands and plant communities that are dependent on ground water. Further research is needed in this area.

Water reform in NSW includes stronger policing powers by the EPA, water allocation procedures, bore capping, limits on irrigation licences, and measures to return river flows to sustainable levels. (See page 10 for further details.)

Reference: Newton G. & Hack B (1997) 'To flow or not to flow?', *Australasian Science*, Vol. 18, No. 4, pp. 21–24.

Possible solutions to environmental problems caused by the overuse of ground water include:

- The rehabilitation of farmland, for example replanting of native vegetation to reduce salinity problems.
- Changing farm managment practices to improve the quality of farm water systems, such as different cropping systems, crop rotation and excluding stock from waterways.
- Traditional methods of farming have been water intensive; therefore, more sustainable farm practices are needed to reduce demands for water.
- A high percentage of irrigation water is wasted due to leaking irrigation channels, poor irrigation practices and evaporative water loss. Solutions include fixing and improving irrigation systems, better water metering and reducing evaporative loss from irrigation channels.
- Reallocations of quotas to irrigators to ensure environmentally sustainable water use and controlled flows. Water extraction in NSW is regulated through a licensing system. Water users are currently licensed to extract approximately 7.2 million megalitres of water a year from regulated rivers (rivers which are dammed and therefore have the flow released and regulated). 7 million megalitres of which is for irrigation. Land users with property on unregulated rivers must have a licence to use the water. Licences specify a maximum pump size and a maximum area which can be irrigated.

The water campaign section of the Nature Conservation Council of NSW is monitoring these proposed changes.

See: http://www.nccnsw.org.au/water — for the Nature Conservation Council of NSW's water policy.

http://www.csiro.au/page.asp?type=mediaRelease &id=Prricetrees — for news about combatting salinity in the Murray Irrigation Area.

Environment NSW, Nature Conservation Council of NSW Inc., Dec. 1999 — for information on water reform legislation, flows, caps and dams.

State and Federal Government policies designed to address water supply problems in NSW

Governments have responded to problems relating to water supplies with research, legislation and policies, such as Total Catchment Management.

State legislation focuses on regulating issues su the discharges to the sewers and waterways of ardous chemicals, radioactive substances and wastes. There are now limits regulating the disc of wastes into river systems and ocean outfalls.

In NSW, the key Acts of Parliament include the

- *Water Management Bill 2000* (due to be pa in 2001)
- *Protection of the Environment Operations 1997*
- *Native Vegetation Conservation Act 1997*
- *Protection of the Environment Administration 1991.*

See: http://www.austlii.edu.au/ — for the Aus asian Legal Information Institute and updates government legislation.

Some other relevant NSW Acts include the:

- *Pesticides Act 1999* (fully commenced 1 July 20
- *Environmentally Hazardous Chemicals* Act 19
- *Coastal Protection Act 1979*
- *Marine Pollution Act 1987*
- *Waste Minimisation and Management* Act 19
- *The Environmental Offences and Penalties 1989* — this Act introduced fines and jail se tences for offences against it and other Acts.

These Acts are administered by several governme departments and local councils. Government depa ments include:

The Environment Protection Authority (EPA) – the leading NSW public sector organisation respo sible for environmental protection and water qua objectives. See: http://www.epa.nsw.gov.au a http://www.epa.nsw.gov.au/legal/ for updates legislation.

The Department of Land and Water Conser ation — the principal NSW government agen responsible for the management of the Sta natural resources (soil, water, ground water, ve tation and coastline). This is the NSW governme agency with the lead role in Total Catchme Management.

Sydney Catchment Authority — responsible f the water supply in the Sydney, Illawarra and Bl Mountains areas. See: http://www.sca.nsw.gov.au

Sydney Water — responsible for the sewerage system in the Sydney, Illawarra and Blue Mountains areas. In 2000, Sydney Water proposed a strategy to reduce the amount of effluent discharged into Sydney's waterways by recycling, intercepting and preventing discharge. See: http://www.sydneywater.com.au. See also: http://www.nccnsw.org.au/ parliament — The Nature Conservation Council of NSW.

At federal level, Acts of Parliament are not directly related to water quality but do include protection and conservation such as the *Environmental Protection and Biodiversity Conservation Act 1999*, administered by the Department of the Environment and Heritage. In November 2000, the Federal Government launched a $1.4 billion program to combat salinity over the next seven years.
See: http://www.environment. gov.au/epg.

Other legislation and policy includes:

- *The Local Government (Approvals) Amendment (Sewage Management) Regulation (1998)* which requires all on-site wastewater treatment systems in NSW to be licensed by councils. The installation of any new system in NSW now requires council approval.
- Many local councils have adopted erosion and sediment control policies and codes of practice to minimise erosion and accumulation of sediment.
- Discharge systems, for example for polluted water from sediment or tailings ponds, must meet strict standards in order to be licensed by the EPA.
- It is necessary to get a special government permit to build or develop near watercourses and there are regulations for developments within catchment areas (see zoning, page 81).

Community-based groups include:

- **Landcare** is a network of people who care for natural resources — soil, water, vegetation and fauna — repair and prevent land and water degradation, and care for the local environment. Landcare is uniquely Australian and is led by members of the community, working together with Commonwealth, State and Local governments, universities, the corporate sector and other organisations such as Greening Australia and the NSW Farmers' Association.
- **The Rivercare program** targets the riverine corridors (river channel, river bed and adjacent riparian lands) in NSW which are in need of management and, in some cases, rehabilitation.
- **Streamwatch** is an environmental action network supported by the Department of Land and Water Conservation and regional catchment management trusts. Schools and communities work together to carry out water quality monitoring and programs of action. See: http://www.waterwatch.org.au/broch_1.htm.
- **Waterwatch Australia** is a national community-based network which collects data from waterways and coastal areas throughout Australia. The Waterwatch data is collected to assist the community to assess the health of their own catchments. See: http://www.environment.gov.au/bg/environm/wetlands/waterwatch/index.html

Chemicals used in human activity which may impact on water systems

Fertilisers, herbicides and pesticides

Some chemicals, including fertilisers such as compost and cow manure are natural (organic); others such as synthetic fertilisers, herbicides and pesticides, are manufactured. Manufactured fertilisers include sulfate of ammonia. Herbicides and pesticides are poisonous. The first synthetic pesticides were manufactured about 50 years ago. Before that time, synthetic pesticides were not known on a global scale and were not available for everyday use. The increased use of manufactured fertilisers, herbicides and pesticides has significantly altered soil structures and waterways.

Fertilisers provide elements such as nitrogen, carbon, phosphorous and potassium that are needed for plant growth. Fertilisers are used in horticulture, agriculture and domestic gardens to improve crop yields.

Herbicides are weed killers. Examples include commonly used herbicides such as Glyphosate.

Pesticides include insecticides (insect killers), fungicides, and pest poisons such as rat poison. Pesticides are used in the horticultural and agricultural industries, and for pest control in and around homes, offices and factories. For example, endosulfan is used in the cotton industry in Australia, although its use is currently under review.

Organochlorines used in pesticides are fat soluble rather than water soluble and very stable. They can contaminate soil and water for long periods of time and accumulate in the tissues of living things. Organochlorines are now banned for sale in Australia. The organochlorines, diedlrin and aldrin, were used under concrete slab constructions (under houses) and on crops in Australia, such as tobacco, until 1981 when their use was prohibited. In 1987 cattle from properties that once grew tobacco were found to have higher than the maximum acceptable residual levels of dieldrin and aldrin in their meat. It is estimated that 87,000 tonnes of soil in NSW and several million tonnes Australia-wide may have been contaminated through the use of organochlorine pesticides on crops.

Chemicals are now subject to regulation under the *NSW Pesticides Act 1999*, administered by the Environment Protection Authority.

See: http://www.epa.nsw.org.au/chemicals/

http://www.agric.nsw.org.au — Department of Agriculture in NSW for information on pesticides, new endosulfan regulations for horticultural crops, preventing endosulfan residues in stock and fodder, and management of organochlorine-related residues.

http://www.dpi.qld.gov.au — the Department of Primary Industries in Queensland.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to determine the effect of different concentrations of fertiliser on algal growth.

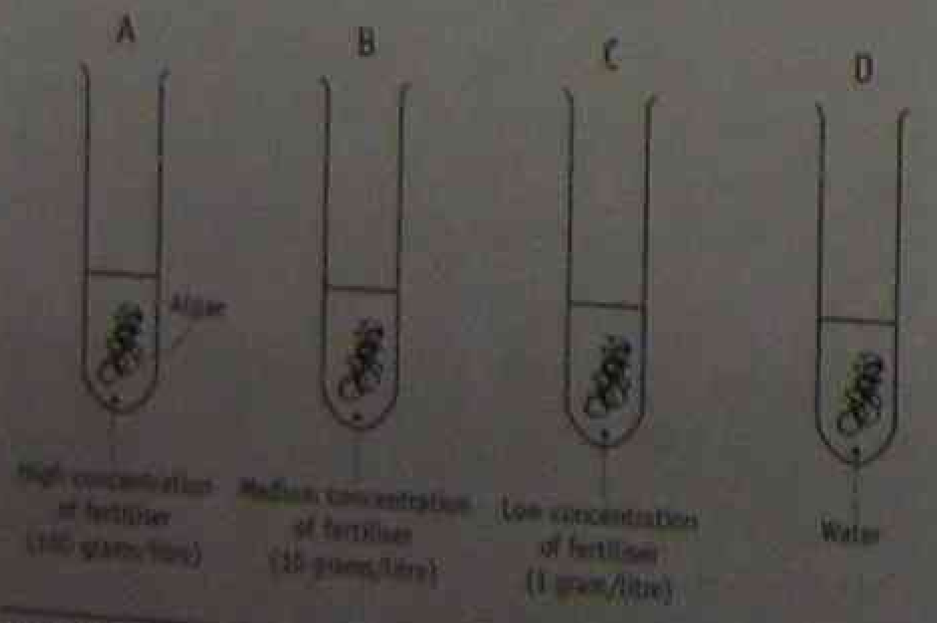


FIGURE 1.8 Investigation to determine the effect of different concentrations of fertiliser on algal growth

Use different concentrations of fertiliser such as *Aquasol* or blood and bone. Note that all factors are kept the same except for the variable that you are testing. In this case, the variable is the concentration of fertiliser. Record your results using:

- Labelled diagrams or graphs; and/or
- A data logger to measure the amount of light that comes through the algal population. The lower the light intensity the greater the algal growth.

A NOTE ON CONTROLLED EXPERIMENTS AND RECORDING DATA

Controlled experiments — a controlled experiment has a part of its experimental method lacking the factor being tested. The control is used to make comparisons and test the effect of the variable. A simple controlled experiment is divided into two identical procedures, except that one of the procedures lacks the feature being tested, or may have an additional feature. For example, in an experiment which aims to test if a plant disease is caused by magnesium deficiency, you could use a number of healthy plants of the same species and age and grow them in identical conditions except for one plant which lacks magnesium. The magnesium, or lack of it, is the variable or factor being tested. More often, a series of controlled expermiments is used. For example, testing the effect of temperature on a range of synthetic fabrics will require a range of fabrics and a range of temperatures. Temperature and fabric type are the variables. The factors which will be controlled (kept constant) include time and the surface area and thickness of each fabric sample.

Recording your results — results can be recorded in a number of ways, for example, as labelled diagrams, in tables or in graphs, or in a data base. Make sure each table or graph has a heading and you include units of measurement.

Producing a graph — producing a graph from a table of data is often done as a line graph.

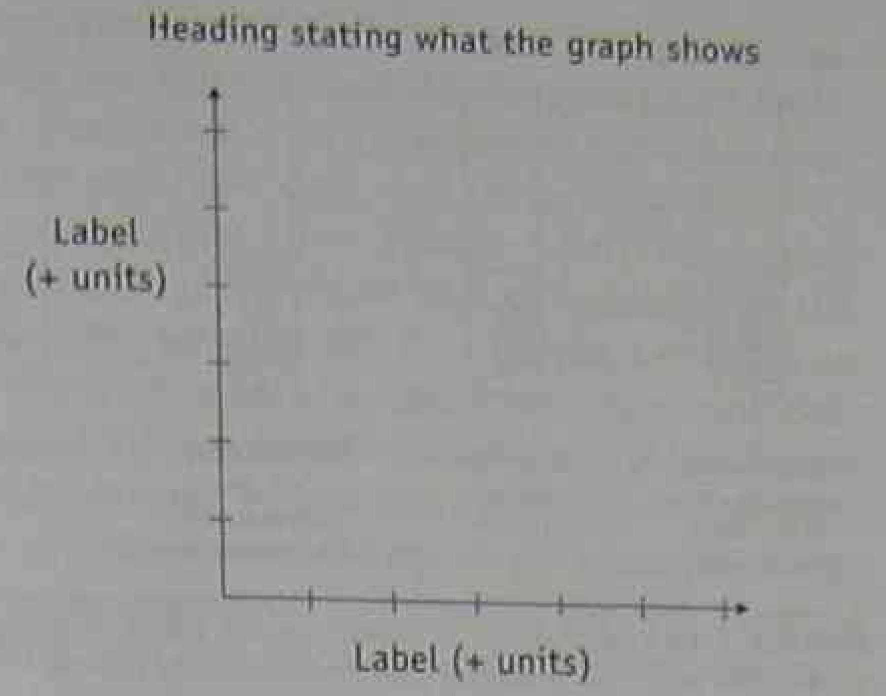


FIGURE 1.9 Axes

The size of one of the quantities will often depend on the size of the other quantity. For example, the growth of algae or a seedling (height, length, number of leaves) depends on a number of other factors (nutrients, amount of light, amount of water, its age — the time it has had to grow). Therefore factors such as time are called the independent variables. These are placed on the horizontal axis. Growth/height are placed on the vertical axis. Make sure that graphs have a descriptive heading and each axis is labelled with units of measurement also shown.

How fertilisers and pesticides are carried into water systems

When fertiliser is used in excess of the crop needs, a significant build up of phosphorous, nitrogen, metals (such as copper, iron, zinc and magnesium) and salt occur in the soil. The fertilisers may be leached from the soil into water courses and are also carried into water systems in run-off, stormwater and sewage. Pesticides are transported into water systems by wind and water (run-off). Pesticides may directly kill or damage non-target organisms or become concentrated in the food chain (see page 78). Land clearing and grazing increase erosion and run-off, and therefore the levels of fertilisers and pesticides entering waterways.

Household waste products and water pollution

Household wastes include:

Oil — a major source of oil pollution. This is caused by tipping oil down the sink, cleaning down oily/greasy surfaces or washing oil into stormwater drains. Oil is a major pollutant because it floats on the surface of water and therefore can cover a lot of water as a thin film. The oily layer stops oxygen getting into the water and the water becomes stagnant. Oils may also contain toxic substances. If the feathers of waterbirds become covered in oil, the feather structure and water-proofing quality is destroyed. The feathers stick together and the bird gets wet and dies. In soils and wetland areas, oil decreases the biological activity of organisms. This affects soil biota and nutrient uptake by plants.

Detergents, bleaches and toilet cleaners — can contain high levels of chemicals such as nitrates and phosphates that are mostly non-biodegradable and can contribute to the formation of algal blooms. Chemicals in these products can also be toxic to aquatic organisms and birds. Most detergents contain wetting agents which assist transport of chemicals deeper into soils.

Insoluble materials — include solids like food scraps and insoluble materials like oils, greases and paints, solvents (mineral turps) and preservatives. When materials such as food scraps get into waterways and start to decompose, they use up the oxygen in the water (see page 17).

Sewage — can contain high levels of nutrients, human-borne diseases, toxic chemicals and antibiotics. Sewage is treated in a number of ways:

(a) Effluent undergoes treatment at sewage treatment plants (STPs) and most of the treated effluent is released back into the environment (rivers or ocean). Despite treatment, effluents may still contain nutrients, such as phosphates and nitrates and may contain pathogens such as cryptosporidium and giardia. Cryptosporidium and giardia are found in the gut of infected animals. They may be introduced into the water supply through faeces. In 1998 there was widespread panic when it was reported that Sydney's water supply was contaminated by cryptosporidium and giardia.

(b) In areas where homes are not connected to a sewerage system, sewage is treated on-site using septic tanks, sullage trenches or aerated wastewater treatment systems. When systems are not properly designed or installed, untreated sewage including nutrients and pathogens can enter surface and ground water.

Pet faeces — pet faeces that is not picked up and disposed of, usually ends up in stormwater channels. This is a source of pollution because of the potential for excess phosphorous, nitrates and salts and organic pollution from undesirable micro-organisms and pathogens (disease-causing organisms).

Heavy metals, phosphates, nitrates and radioactive material

Heavy metals — such as zinc, iron, arsenic, mercury and lead from industry and mining are absorbed by the body but are not easily excreted and therefore build up in the body tissue of aquatic organisms. Heavy metals also become concentrated up the food chain (see page 78).

Phosphates and nitrates — increased quantities of phosphorous and nitrogen from sources such as farming, promote algal growth (see page 17).

Radioactive materials — uranium contains mutagenic chemicals (cancer-causing chemicals that change the DNA of cells). Radioactive wastes have a long half-life and therefore stay in the environment for a very long time. Uranium mining releases radioactive waste from mine tailings where it may contaminate surface and ground water.

See: Sweeney D. (1999) 'Australia at the nuclear crossroads', *Habitat Australia*, February, pp. 13–20 for information on *in-situ* leach uranium mining. This process uses a solution of sulfuric acid that is pumped underground to dissolve and transfer the uranium from the ore body into the ground water so that it can be brought to the surface.

> As part of meeting the requirements of the course, you are expected to have carried out an experiment to determine the effect of waste water from your home on the growth of algae or plants.

See Figure 1.10.

Record your results as:

- Diagrams or graphs; and/or
- Data from a data logger which measures the amount of light that comes through the algal population and therefore provides an estimate of algal growth.

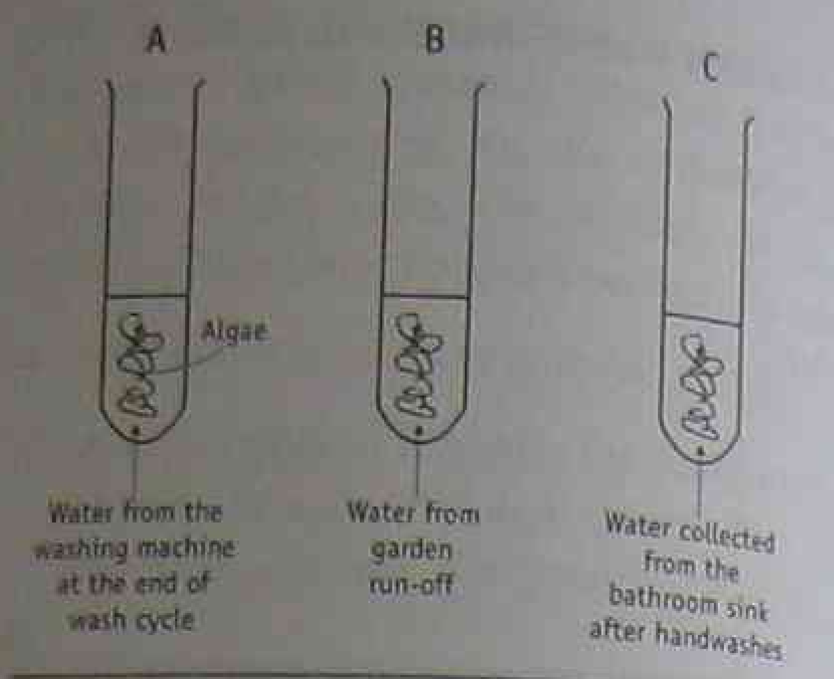


FIGURE 1.10 Investigation to determine the effect of w water from your home on the growth of algae or plants

Accumulated sediment, leaching from ti and bioaccumulation

Accumulated sediment — erosion adds sedi nutrients (such as phosphorous and nitrogen), other chemicals to waterways. Accumulated s ments fill in wetlands, cover and degrade na vegetation, reduce water flow and become suspe in water, therefore increasing the turbidity of w and decreasing the amount of light available. Se ment can block urban drainage, stormwater dr and watercourses. Added run-off washes the sedi further downstream. Nutrient-rich sediments courage the growth of algae and weed species. A hi sediment load also causes physical damage aquatic organisms, for example, the gills of fish become blocked with fine sediment.

Leaching from tips — more than 90% of the wo domestic and hazardous wastes are disposed of landfills. Leachate is the liquid that drains fro waste dump or tip when water percolates throug The water picks up pollutants with the result th the leachate may contain toxins, such as ammo pathogens and heavy metals. The water may be r water or surface water from a stream. Poor land management can produce huge volumes of leacha that can leach into and pollute surface water a eventually, ground water. If the landfill waste is hi in organic matter (such as food scraps), the leach in general is more acidic and contains more nu ents and contaminants. The leachate may cause o gen depletion of the surface waters it contamina

Bioaccumulation — occurs when large or sm quantities of material which cannot easily move i cycles of matter are released into some part of th environment and accumulate. For example, excess phosphates (from household detergents and fertilisers, that are not used up by plants) move into river systems and cause toxic algal blooms (see page 17). Bioaccumulation also occurs when substances accumulate in body tissue and are passed along the food chain (see page 78). For example, research into the death of whales, dolphins and porpoises indicate that the accumulation of toxic pollutants causes cancer, damage to nervous systems and reproductive disorders. In addition, large amounts of the toxins are transferred to calves in the first weeks of feeding. Whales, dolphins and porpoises are high-order predators and often eat fish that is heavily polluted.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research methods of bioassay to assess water purity.

An assay is an analysis. Bioassay is short for biological assay which involves comparing an unknown, such as the number of faecal coliforms, or total chlorine content, in a water sample with a standard, such as the maximum number of faecal coliforms, or maximum amount of chlorine permitted in a water sample as a measure of water purity and health risk. Bioassay aims to minimise variation and avoid errors resulting from variation.

To protect public health during recreation, specific recreational water-quality guidelines (Australian Drinking Water Guidelines) and standards have been developed in accordance with National Guidelines. They include:

- Counts of faecal coliforms and enterococci used to assess microbiological quality
- Numbers of blue-green algae
- Measurement of pH
- Measurement of water temperature
- Assessment of visual clarity
- Visual assessment of surface films.

See pages 22 and 76.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research the impact of the release of ballast or bilge water on aquatic ecosystems and discuss the difficulties of imposing quarantine regulations.

Ballast — ships are designed to float and maintain stability with a certain weight in them. After a ship has delivered its cargo to a port, it must take up water (called ballast) to maintain the same weight as the cargo and ensure the ship is stable. This ballast water is then released when the ship arrives in another port to load new cargo.

The impact of the release of ballast:

(a) Pest species can be introduced into Australian waterways from ballast water. At least 170 known species of foreign plants and animals (seaweed, starfish, fish) have been introduced to Australian coastal waters and most of these have probably arrived in ballast water or on the hulls of ships. Introduced species endanger or cause the extinction of native species through competition.

(b) Contamination may occur from ballast water. For example, if ballast is taken up in an area where a toxic algal bloom is occurring, the algae may be released with the ballast water into the waters of another area or country.

Bilge water is water found at the bottom of a ship. It contains engine oil, grease and other insoluble pollutants which are released into the ocean when bilge water is pumped out.

The Australian Quarantine Inspection Service (AQIS) imposes mandatory ballast water regulations including:

- All vessels arriving at their first Australian port of call are required to provide an AQIS ballast water pre-arrival report form. Verification tests are applied to ensure accurate reporting. There are penalties of $10,000 or five years' imprisonment, or both, for false reporting.
- A ship must have a safe on-board ballast water and/or ballast sediment sampling point and assistance must be provided to Australian quarantine inspectors in removing ballast tank covers.
- Sediment resulting from tank and/or hold cleaning must be disposed of in an AQIS approved manner on land.

Ships' masters are requested to comply and adopt precautionary practices such as avoiding taking ballast up in shallow water, or where there is a known outbreak of cholera, or where dredging is occurring.

These requirements and requests are difficult to impose and police nationally and internationally. Australia's coastline extends for 25,000 kilometres. The oceans are vast areas and what happens at sea and along the coastline is difficult to monitor.

See: www.epa.nsw.gov.au — Environment Protection Authority

www.aqis.gov/au/shipping/index/htm — Australian Quarantine Inspection Services

Strategies for reducing water pollution

Every day we do things that affect water systems. If we throw oil, milk or coffee grains down the sink, they may end up in our waterways. Fertilisers and pesticides may do the same.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research and outline ways of reducing water pollution.

Personal initiatives include:

- Household strategies to reduce water pollution (see below)
- Reporting spills and stormwater leaks to authorities
- Starting a community group to monitor and care for the local waterways or becoming involved in local initiatives and community action groups
- Educating others.

Some of the strategies that households can use to reduce water pollution include:

- Reducing the amount of waste from households
- Not putting oils and greasy or insoluble substances down the sink or into the sewerage system
- Not installing 'insinkerators' for food scraps
- Composting
- Recycling engine oil
- Minimising the use of detergents and other cleansers and only using those that are biodegradable
- Picking up pet faeces to ensure they don't get washed into stormwater drains
- Keeping chemicals out of gutters and dra
- Ensuring downpipes and stormwater ar connected to the sewer
- Installing a silt tap where water leaves the
- Controlling run-off from the block
- Removing and controlling weeds.

(See also page 17 for ways water pollution agriculture can be reduced.)

> As part of meeting the requirements of the co you are expected to have measured the amo of water used by your household for a rang activities and identified ways to reduce water

Your investigation may have included activities as measuring:

- Water used per toilet flush: 11–13 litres per f
- Water use per shower: 10 litres per mi (water used by a bath: 50–120 litres per fill)
- Water use by dishwasher: 40–90 litres per w (dishwashing by hand: 8 litres per wash)
- Water use by washing machine: 150 litres load
- Water used washing hands: 2 litres per wash
- Water used cleaning teeth: 1 litre per clean
- Water used in the garden: up to 25 litres minute
- Water used washing car: 100–300 litres per w

Ways in which water use can be reduced include

- Fit an AAA rated showerhead to cut wa delivery by half.
- Do one wash-up per day.
- Put plugs in the sink when washing hands.
- Put the plug in the sink when rinsing clothes dishes.
- Half flush the toilet.
- Only wash with a full load in the wash machine or dishwasher.
- Fix dripping taps.
- Use a 'sud-saver' on your washing machine.
- Sweep paths and driveways instead of hos them.
- Bucket wash the car (on the lawn) instead using the hose.
- Mulch the garden.

See: http://www.sydneywater.nsw.gov.au — Sydney Water

http://www.seda.nsw.gov.au — the Energy Smart Information Centre

Habitat Australia, Vol 30, No 3, June 2002, pp. 11–18

Water pollution and algal blooms

Water systems such as rivers and lakes naturally contain single-celled plants such as green algae and blue-green algae. The numbers of these species are normally kept in balance by the lack of available nutrients. Conditions which promote the growth of these plants to produce algal blooms include:

(a) High nutrient loads of phosphates and nitrates from effluent, stormwater run-off and run-off from farms; and

(b) Dry periods and therefore low river flow.

The impact of algal blooms in rivers

The impacts are both direct and indirect.

Direct impacts — blue-green algae are toxic to many plants and animals, including humans.

Indirect impacts — algal blooms can cover large areas of the surface of rivers and reduce the amount of light available to other aquatic organisms. The growth of algal blooms uses up oxygen in the water and reduces the amount of oxygen available to other aquatic organisms.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research the causes of algal blooms and their impact on waterways in NSW.

Algal blooms can kill aquatic organisms, as well as birds and domestic animals. Algal blooms also impact on the recreational and commercial value of water. Some blue-green algaes can cause dermatitis and influenza-type symptoms in humans as well as gastrointestinal problems if the water is swallowed. Oysters, prawns and fish farmed in areas affected by algal blooms can contain high concentrations of algal toxins.

Quality monitoring (bioassay) is used to assess the health of river systems. Public health algae warnings are used to alert people to the risks of using the water or swimming in affected areas.

See: http://www.dlwc.nsw.gov.au — Department of Land and Water Conservation, for information on algal blooms.

http://www.hncmt.nsw.gov.au — the Hawkesbury-Nepean Catchment Management Trust.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to develop an action plan for the sustainable use of water locally and globally.

See page 16.

See also: Yencken D. & Wilkinson D. (2000) 'Resetting the compass: Australia's journey towards sustainability', *Habitat Australia*, June, pp. 13–20 or

www.acfoline.org.au — for the Australian Conservation Foundation.

Strategies for reducing water pollution in agriculture

Alternative agricultural practices include:

- Changing farm management practices, for example, replacing monoculture and intensive farming (which require large amounts of toxic pesticides) with diverse systems and biological pest controls.
- Nutrient cycling by using ponds to hold and 'digest' manures and fertilisers before reapplying them to pastures.

State legislation and industry sewage treatment

Industries can use the sewer to dispose of waste under trade waste agreements. Industries must pay to dispose of toxic and other intractable waste. Illegal dumping of substances into sewers (as well as landfill and water systems) can occur, but if detected leads to heavy penalties. The contamination of sewage by industry affects the potential for reuse of treated effluent.

State legislation regarding the treatment of waste before it can be discharged, has become more stringent. Industries must now analyse and monitor process-samples and wastewater and comply with regulations before discharging these substances into the sewer. Treatment of oils, dyes and wool-scouring wastes, for example, must now occur on-site (at the factory) before treated substances can be released into the sewer. There are now high penalties for industrial spills and leaks. (See page 10 for further details on State legislation.)

See: http://www.epa.nsw.gov.au/licensing/

How technology can be used to reduce water pollution

As part of meeting the requirements of the course, you are expected to have used secondary sources to present information on some of the latest technologies being used to purify and treat water.

An example of technology used to reduce water pollution is the development of reed-bed systems to treat toxins such as cyanide, PCBs, wastes from the manufacture of plastics, dioxins and bitumen, and coal pollutants. The reed-bed system uses bacteria in soils to break down the pollutants in water. These are contained in a shallow area sealed off from ground water by a protective liner.

Possible long-term effects of this technology — reed-beds may cut the construction cost of sewage treatment by half, and running costs by up to 90%. Reed-beds use natural ecosystems to filter polluted water and leachate. (Wetland systems are also being designed and created to do this.) The system requires land — one hectare of reed-bed is needed to process the sewage produced by 3000 people. Reference: *Engineers Australia*, June 1999, pp. 32–34.

Technological advances and our understanding of pollution and pollution control

While developments in computer technology and material and chemical sciences have created new sources of pollution, they have also enabled improvements in pollution monitoring systems, data collection and analysis, and filtration, waste water and other pollution treatment processes. For example, developments in tip design, such as the use of impermeable liners of clay or synthetic material and the collection of leachate, can minimise the impact of pollutants on ground and surface water. Improved monitoring and site management at tips a ensure that only the wastes for which the si been designed are accepted.

Other examples of technological advances inclu

- A flocculation process which uses mag material to produce a positive charge. The ch attracts wastes such as suspended solids, grease, bacteria and phosphates which ten float and cannot be easily treated with tradit methods of purification.
- Polymer membranes which filter oil eff from metal processing and oil and fat emuls found in the food industry.
- A process called AAA — alternating aerobic a anaerobic treatment. In secondary sewage tre ment, raw sewage is mixed with bacteria und aerobic conditions. Research has shown tha the air supply is interrupted, bacteria continue grow and then when the oxygen is returned, t bacteria multiply rapidly and break down t sewage faster.
- The development of a process called an activa primary tank which is able to remove pho phorous from effluent without the need to a chemicals.

Reference: *Waste Management and the Environment*, Vol. 5, No. 12, October 1994.

See: http://www.sydneywater.com.au/

Local water pollution and its impact on global water

The well-being of all humans and other livi things, locally and globally, depends on the quali of the environment, its soil, water and air. There ar no boundaries to the world's water and ai Australia's water cycle is really the world's wat cycle. Air pollution activities in Australia tha contribute to global warming and the production o greenhouse gases are global issues affecting al other countries. The pollution of Australian wat systems becomes pollution of the world's oceans.

Indicator organisms

Vertebrate organisms such as frogs, sea turtles an some dolphins can be indicators of unpollute water. Invertebrate organisms are used as indicators of water quality. Safe water supplies contain a diversity of organisms including some organisms that are very sensitive to pollution such as stonefly nymphs, mayfly nymphs and yabbies. If these organisms are present we can conclude that the water is not polluted.

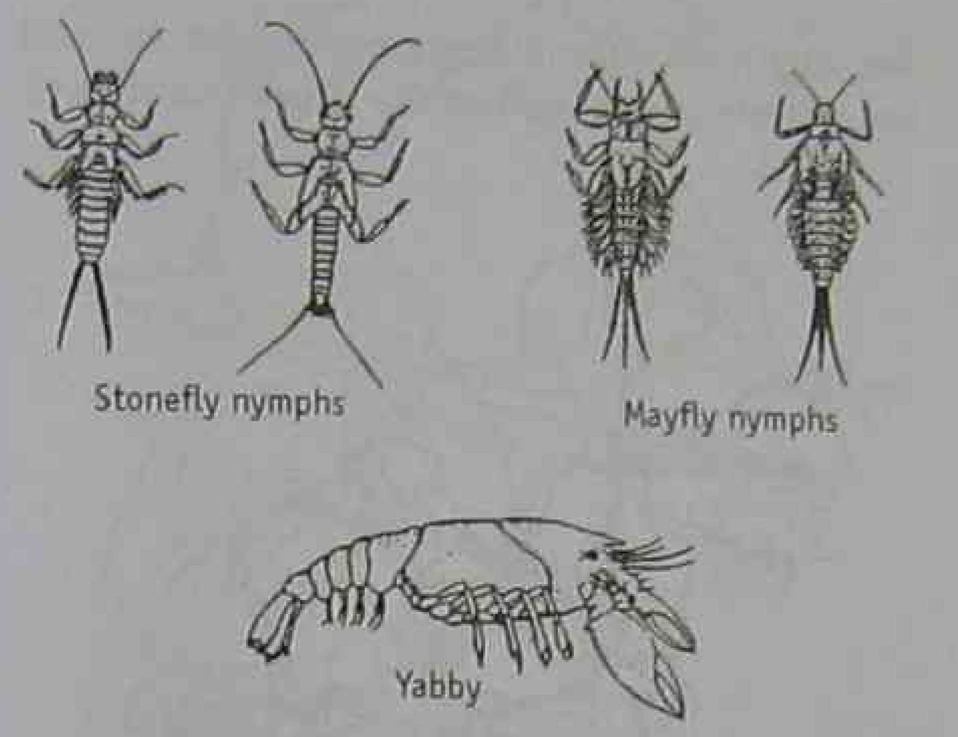


FIGURE 1.11 Examples of organisms which indicate non-polluted water

Polluted water has less diversity and the organisms that survive are pollution-tolerant, for example, mosquitoes and mosquito larvae, bloodworm larvae and midge fly larvae. Tubificid worms are usually abundant in water heavily polluted by organic materials.

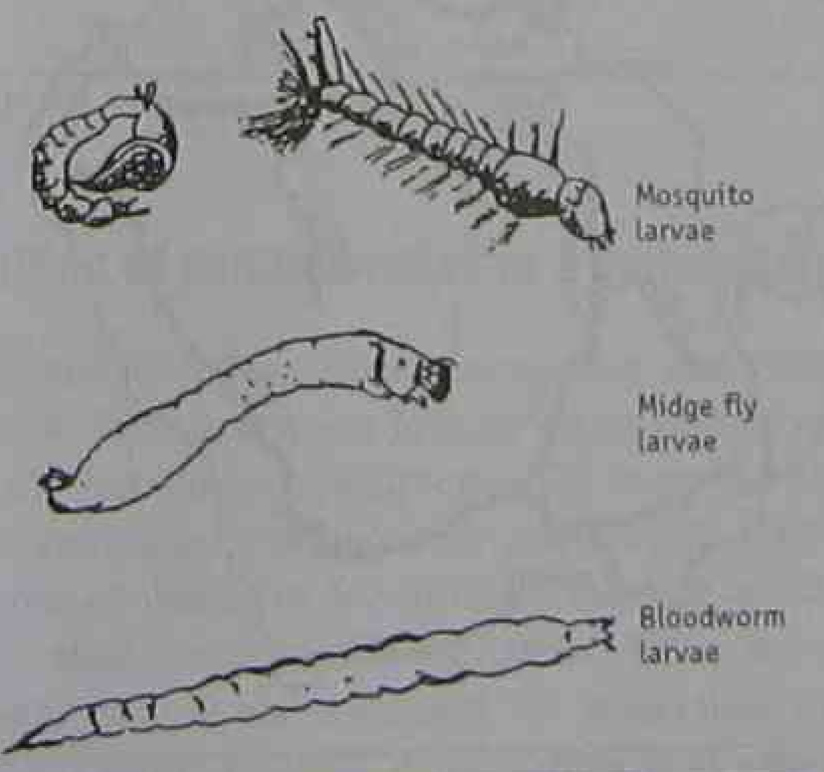


FIGURE 1.12 Examples of organisms which are pollution-tolerant

Micro-organisms such as bacteria are also used as indicator organisms for polluted water. Faecal coliforms (*Escherichia coli*) and enterococci are used as indicators of contamination. *E. coli* occurs naturally in the gut of mammals and is introduced into water through faeces. (See also page 15.)

The presence of blooms of green algae and blue-green algae also indicates pollution. (See also page 17.)

Catchments

A catchment is an area made up of natural physical boundaries that catch rainfall. The surface water is directed into streams by hills and ridges. The rainfall flows to a common watercourse or water body. Catchments are the source of water for an area. They can also be the source of pollutants. Within a catchment there are many smaller sub-catchments consisting of creeks and streams.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to show the links between the movement of materials between bodies of water and the atmosphere.

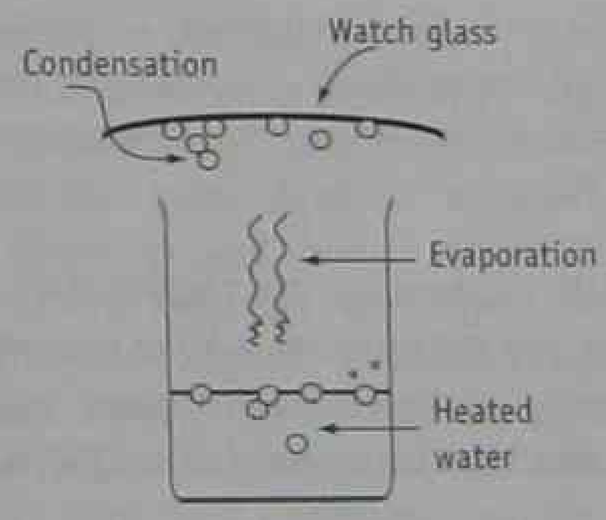


FIGURE 1.13 A simple demonstration of evaporation and condensation: the movement of materials between bodies of water and the atmosphere

Local catchment area(s) and water sources

Catchment areas in NSW are listed below:

Barwon-Darling and Far Western, Bega River, Bellinger River and Coffs Harbour, Brunswick River, Camden, Haven and Hastings River, Castlereagh River, Clyde River and Jervis Bay, Cooks River, Georges River, Gosford and Northern Beaches Lagoons, Gwydir River, Hacking River, Hawkesbury-Nepean, Hunter River, Illawarra Karuah River and Great Lakes, Lachlan River, Lake Macquarie and

Tuggerah Lakes, Macleay River, Macquarie-Bogan River, Manning River, Moruya River, Murray River, Murrumbidgee River and Lake George, Nambucca River, Namoi River, Richmond River, Sydney Harbour and Parramatta River, Towamba and Genoa River, Tuross River, Tweed River.

See: http://www.epa.nsw.gov.au/ies — for more details and to obtain a statewide map to select your local catchment area.

http://www.sca.nsw.gov.au — the Sydney Catchment Authority, established as a result of the Sydney Water Inquiry which investigated contamination of Sydney's water between July and September 1998. The authority manages water supply, protects catchments, supplies bulk water, and regulates activities within the upper catchment areas of the Hawkesbury-Nepean River System to improve water quality, and protect public health and the environment.

In May 2000, the Department of Land and Water Conservation established 18 new catchment management boards in NSW to replace the existing catchment management committees.

See: http://www.duap.nsw.gov.au — the NSW Department of Urban Affairs and Planning for a copy of the report *Sustaining the Catchments Draft Regional Plan.*

As part of meeting the requirements of the course, you are expected to have researched the source(s) of water feeding into your local catchment area using maps or field trips.

Your local council is one source of information.

See also: http://www.sca.nsw.gov.au — Sydney Catchment Authority.

http://www.dlwc.nsw.gov.au — for information about your local catchment management organisations.

Hawksbury-Nepean Catchment: a case study — more than 800,000 people live in the Hawkesbury-Nepean catchment. The area covers 22,000 square kilometres. The Hawkesbury-Nepean catchment is the second most productive catchment in NSW and produces 10% of NSW's food. Large areas of alluvial flats are used to grow turf for landscaping, and lucerne and hay crops. Other land uses include urban development, extractive industries and recreation. Over the 20 year period from 1973, an esti 1100 square kilometres of land have been lo production. Sub-catchments include the C Macdonald, Mangrove and Blue Mountains. Th are largely rugged natural bushland protected national parks, nature reserves, protected w catchments and proposed wilderness areas.

See: http://www.hncmt.nsw.gov.au — for an ex lent website on the Hawkesbury-Nepean Catchme

FIGURE 1.14 (a) Cox's River Catchment

The Cumberland Plain woodland, largely contained within the South Creek and Middle Hawkesbury-Nepean sub-catchments, has been mostly cleared of natural bushland. Many species are threatened with extinction if development is not managed properly.

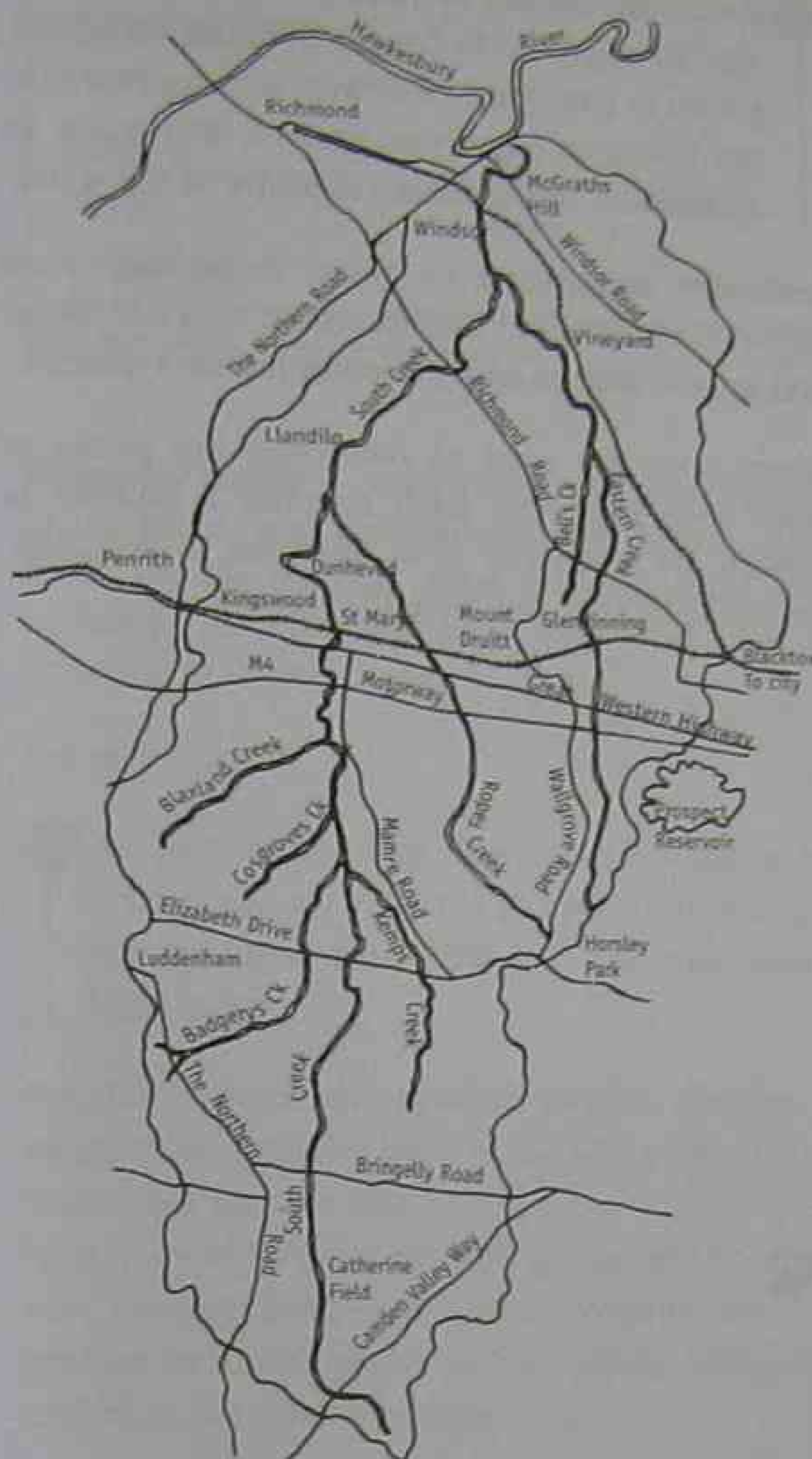


FIGURE 1.14 (b) South Creek Catchment

Sources of contamination in a catchment

Contamination may come from point and diffuse sources. Diffuse sources include uncontrolled water run-off that picks up pollutants such as eroded soils, salts, fertilisers, pesticides, oil and rubbish. Diffuse sources of pollution are difficult to locate because they often come from large areas. Point sources include the direct discharge of pollutants from specific sources such as industries and sewage treatment plants.

In general, sources of contamination include land use practices such as land clearing, mining, forestry and urbanisation, and agricultural practices such as irrigation, intensive farm practices and overuse of pesticides, herbicides and fertilisers.

Industry — developments in technology have increased our ability to exploit the Earth's resources and the amount and types of by-products we now have to dispose of as wastes. These by-products include acids, alkalis, toxic chemicals (such as ammonia and chlorine), radioactive waste and heavy metals. For example, extractive industries such as mining, produce large piles of waste. Water trickles through this waste for many years even after mining has ceased. Drainage waters from some mines can be acidic and/or saline and carry sediments. Mining along a river for gravel and sand widens the river channel and causes sedimentation, bank erosion and bed deepening.

Land clearing — removal of plants for housing, agriculture and forestry increases the rate of erosion and contributes to sedimentation and salinisation.

Agricultural practices — animal wastes from intensive farm practices such as chicken feed lots, piggeries and dairies can enter waterways; cattle near or in waterways cause contamination of water; run-off from farms can contain high levels of nutrients and toxic pesticides.

Urbanisation — the concentration of pollutants in run-off from urban areas is generally higher than rural or forested areas. Pollutants such as nutrients and pesticides, grass clippings, eroded soils and animal droppings and heavy metals from road surfaces flow or seep into waterways. Undeveloped areas have greater capacity to absorb large amounts of rainfall before run-off occurs. Urbanisation increases the area of impervious surfaces such as roads and roofs in a catchment, and rainfall that previously infiltrated the soil or flowed off catchments at a slow rate, flows off quickly and at greater volumes. The water is collected in stormwater drains. Stormwater empties into local water systems such as rivers and beaches.

Tests to monitor and assess local water quality

Everything that happens in a catchment area is reflected in the quality of the surface water and ground water.

Tests for water quality include:

- The presence of faecal-related pathogens such as coliform bacteria

- Turbidity — a measure of suspended material in the water
- Colour — water should be colourless
- The presence of aluminium, iron, manganese and chloride ions
- The presence of algal blooms
- Gross pollutants such as litter
- The presence of nutrients such as phosphates and nitrates
- The presence and diversity of invertebrates such as water 'bugs'.

See pages 15 and 19.

See: http://www.sydneywater.com.au

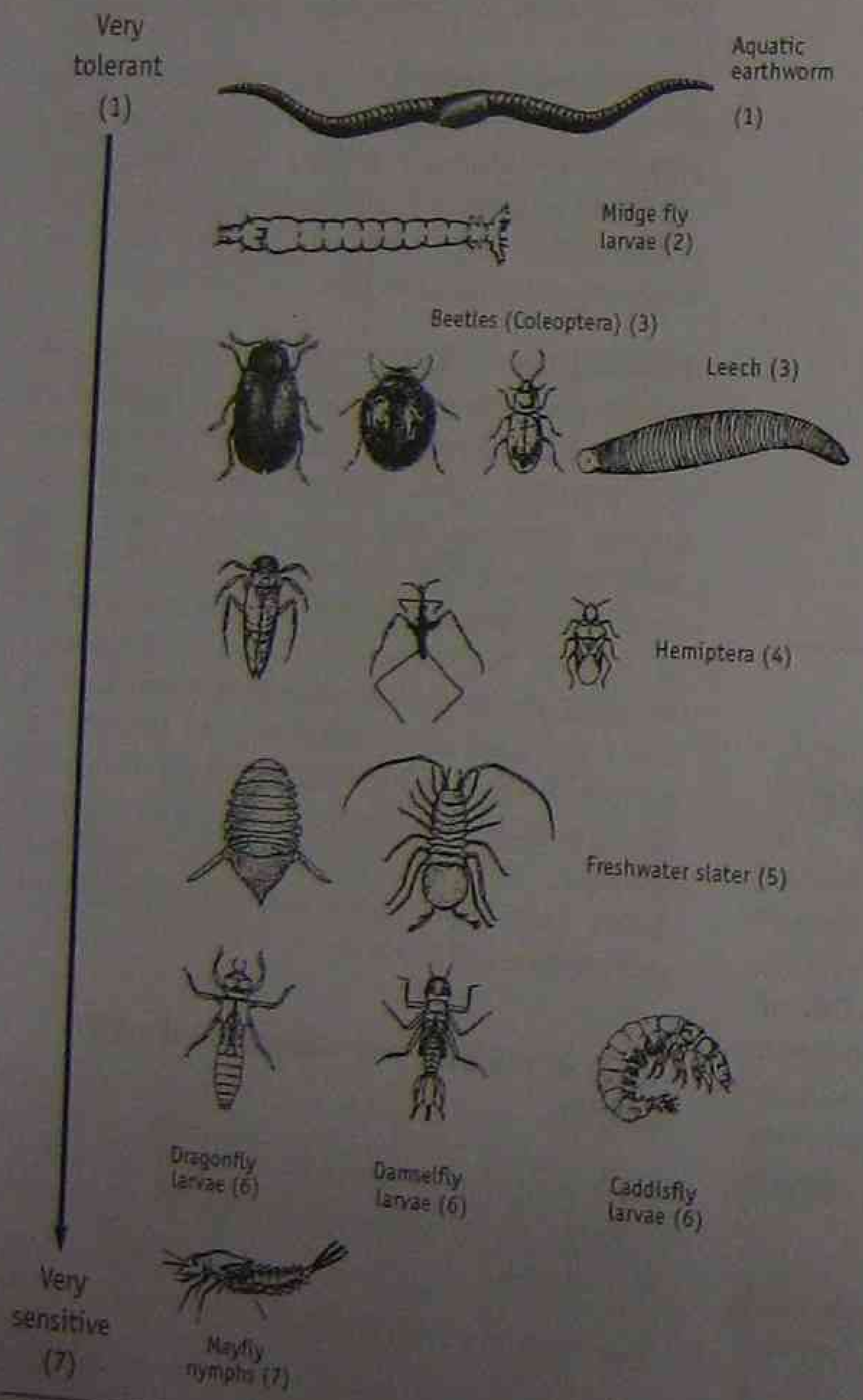


FIGURE 1.15 A range of indicator organisms

As part of meeting the requirements of the
you are expected to have carried out an
gation in your local catchment area to deter
the indicator organisms present, and ma
assessment of the chemical purity of the

Indicator organisms — your study may
included observation and recording of water
and the calculation of a pollution index.

Water bugs are used to determine the puri
water (see page 19). Each bug has a numbe
indicate its sensitivity to or tolerance of poll
See the diagrams and table that follow.

Pollution Index (total water bug number)	Water Quality Rating
20 or less	Poor
21–35	Fair
36–50	Good
51 or more	Excellent

FIGURE 1.16 A sample index of pollution and water quality

Chemical purity — your study may have included observations and measurements of colour, smell, litter, surface oil film, algal growth, water froth, turbidity, dissolved oxygen, water pH and the presence of chloride ions.

See also page 76.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the use and treatment of local water.

See: http://www.sydneywater.com.au/environment/cycle_frameset.html — for what happens to water that we use; and http://www.sydneywater.nsw.gov.au/environment/sew_frameset.html — to find information on sewage treatment plants in the Sydney, Illawarra and Blue Mountains regions.

See also http://www.uprct.nsw.gov — for information on the Upper Parramatta River Stormwater Source Control Project.

Heat pollution

Heat pollution occurs when heat is added to a body of water. Power generation plants and many industries require large amounts of water for cooling. If the water is not allowed to cool before being returned to rivers and lakes, it causes heat pollution.

In addition, global warming is bringing about an increase in ocean temperatures.

Heat pollution and water quality

Heat pollution can directly kill many organisms. Species intolerant of warm conditions may disappear. Other species not normally found in the unheated water may thrive. The solubility of gases such as oxygen, decreases as temperature increases. If a body of water is heated sufficiently, the oxygen level decreases and fish suffocate. This is particularly serious in deep lakes because the warm layer tends to stay at the top and prevents oxygen from reaching deep water. Heat pollution may also increase bacterial action which reduces the level of oxygen. (The bacteria use up available oxygen.)

How water quality in one area can affect the water quality in other areas

What occurs upstream in the catchment area will impact on everything downstream including water quality in the estuarine and marine environments and water quality in ground water through leaching and seepage.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research and present information identifying some major disasters involving water or the water cycle over the last 50 years. Some ideas are provided below.

- Acid rain
- The Exxon Valdez disaster in Alaska — In 1989 the tanker Exxon Valdez hit a reef. Forty five million litres of oil were spilt into the ocean, contaminating breeding grounds of seals, sea lions and birds. (Chemicals used for dispersing the oil from an oil spill can also cause problems to the water environment.)
- Cyanide spill in Romania — In 1999, 95 tonnes of cyanide accidentally spilt from the tailing ponds of an Australian-owned gold mine contaminating water supplies and rivers in Romania, Hungary and Serbia.
- BHP and Ok Tedi — BHP's open-cut copper mine in Papua New Guinea discharged 80,000 tonnes of tailings per day into the Ok Tedi-Fly River systems. The increased sedimentation and heavy metal contamination resulted in the loss of

species, raised river beds, increased flooding and loss of livelihood by communities along the rivers. The river was declared biologically dead for 70 kilometres. In 1996, BHP settled out of court with Ok Tedi landholders, agreeing to compensate them and to cease pumping tailings into the river system.

Reference: 'Papua New Guinea's race against time', *Habitat Australia*, 1996.

Checklist — Key terms for revision

- hydrological cycle
- surface water
- ground water
- water pollution
- salt water intrusion
- ground salinity
- sulfur
- fertiliser
- herbicide
- pesticide
- sewage
- heavy metals
- phosphates and nitrates
- accumulated sediment
- leaching
- bioaccumulation
- algal growth/algal bloom
- sewage treatment
- indicator organisms
- catchment
- heat pollution
- Total Catchment Management

Test — Water for Living

Multiple choice questions

1. Measurements were made under controlled conditions of the amount of water lost from leaves of different kinds of plants.

Plant	*Volume of water (mL) lost per minute per unit leaf area*
I	0.04
II	1.00
III	0.20
IV	1.35

The plant most likely to have small leaves with a thick waxy cuticle would be:

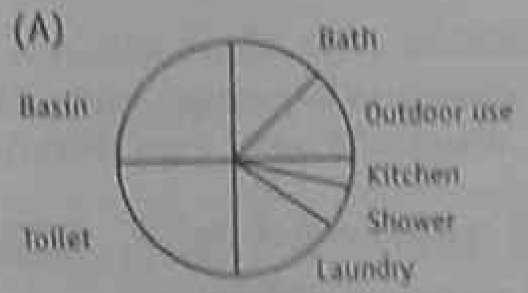
(A) I (B) II
(C) III (D) IV

2. The following statements explain data for the amount of domestic water used in Sydney.

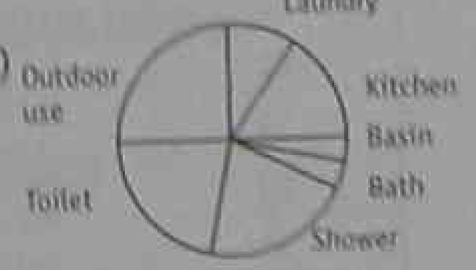
Most water used in Sydney for domestic purposes is used outdoors (25%), closely followed by showers and toilets. The laundry activities use 16%, kitchens 10% and baths and basins 3% each.

Which pie graph below best represents the statements?

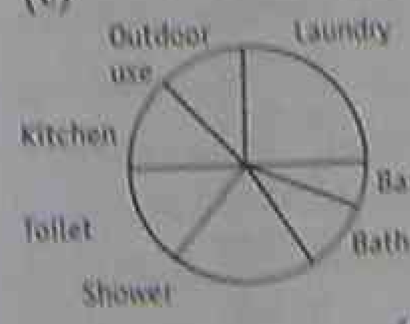
(A)



(B)



(C)



(D)

Questions 3 and 4 refer to the table below.

The table shows water quality assessment for suitability for swimming and water skiing at three different sites along the Hawkesbury-Nepean River in 1998 and 1999.

Site description	No. of Results		FC		ENT		ALG		pH	
	1998	1999	'98	'99	'98	'99	'98	'99	'98	'99
Eastern Creek at Nurragingy Reserve	5	5	■	■	■	■	▨	▨	▨	▨
Plumpton Park Reservoir, Blacktown	5	5	■	▒	■	▒	▨	▨	▨	▨
Cattai Creek at Fred Caterson Recreation Reserve	5	5	■	■	■	■	▨	▨	▨	▨

FC — Faecal coliforms
ENT — Enterococci
ALG — Algae
pH — Level of acidity

░ Fair ▒ Poor □ No data
▨ Good ■ Very poor

3. Which of the following statements most accurately represents the information in the table?

(A) Bacteriological indicators in all areas are fair and pose no risk to swimmers or water skiers.

(B) Algal counts at Cattai Creek are a cause for concern.

(C) It is not possible to compare water quality at the three sites as the number of results taken for 1998 and 1999 are different.

(D) Bacteriological indicators improved marginally at Plumpton Park Reserve between 1998 and 1999.

4. If you were developing a local action plan to improve the water quality at the Cattai Creek Reserve, what is the *first action* you would be most likely to suggest?

(A) A public education program for residents in the area to improve on-site sewage treatment processes and reduce faecal coliforms and enterococci entering the creek.

(B) A public education program for residents in the area to monitor run-off and stormwater flow into the creek.

(C) Determine the sources of faecal coliforms and enterococci .

(D) Contact the local catchment management trust.

5. In a study of a local catchment area, a student observed the following water bugs and made an estimate of the number of each present. Each water bug can be used as an indicator of water quality and is given a number from 1 to 7 according to its tolerance of pollution. 1 is very tolerant. 7 is very sensitive.

From these observations the student might conclude that:

(A) The water quality is very good, but other tests are needed to confirm findings.
(B) The water quality is poor, but other tests are needed to confirm findings.
(C) The water quality is very polluted.
(D) The water quality is good.

Short answer and longer response questions

1. A government study of the Murrumbidgee River catchment area in NSW produced the following key findings:
   - 17% of the Murrumbidgee Irrigation Area and 4% of Coleambally I irrigation area are salt affected.
   - Crops can no longer be grown on one-third of those areas.
   - 15% of river banks have eroded between Hay and Berembed Weir.

   (Source: *SMH*, August 30 1995)

   List three possible solutions to the problems in the catchment area. (3 marks)

2. Using diagrams, explain each of the following statements. (4 marks)
   (i) Excessive deforestation has led to an increase in accumulated sediment in rivers and lakes.
   (ii) Plant fertilisers are not considered as poi
   yet they may contribute to the death of a
   or stream.

3. (4 m

   The increase in the salinity levels of many riv
   will have a significant impact on the biota. Th
   would be either directly through the individu
   species' salinity tolerance or indirectly throug
   impacts on breeding/nesting areas or food sou
   (a) What is salinity? How does it come about?
   (2 ma
   (b) Name two specific impacts of salinity on th
   environment.
   (2 ma

4. Describe the impact of one technological adva
   on our understanding of pollution and strategie
   to reduce pollution.
   (2 ma

5. Using an example for each, identify how the applications of pesticides and herbicides affect society and the environment.
   (4 ma

6. (3 ma

   The table below shows the amount of gas that
   dissolve in water at different temperatures.
   (a) What happens to the solubility of oxygen a
   temperature increases?
   (1 m
   (b) What is heat pollution?
   (1 m
   (c) How does heat pollution impact on water systems?
   (1 m

Temperature °C	Amount of oxygen gas that will dissolve in water (gm/100ml)
0	0.0069
10	0.0054
20	0.0043
30	0.0036
40	0.0031
50	0.0027
60	0.0023
70	0.0019
80	0.0014
90	0.0008
100	0.0000

Test answers

Multiple choice questions

Answers

1. A 2. B 3. D 4. D 5. B

Explanations

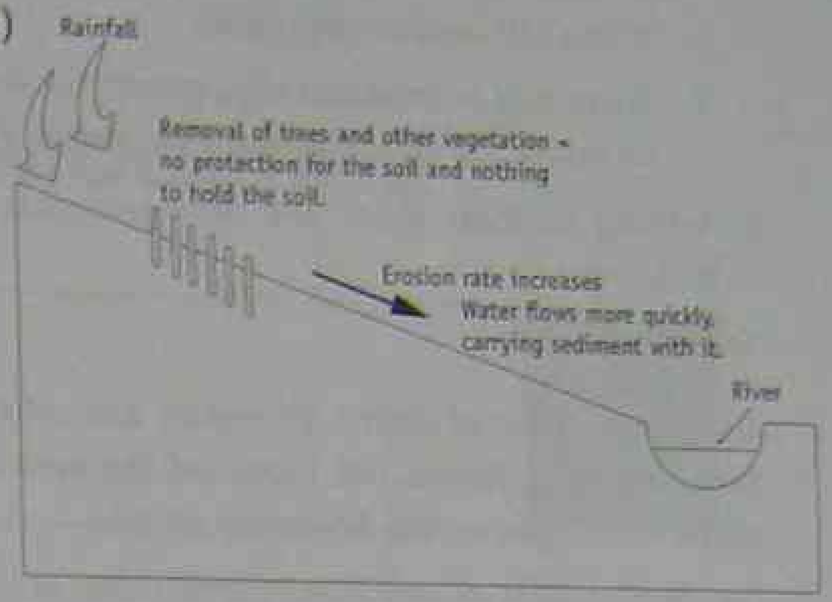
1. A thick waxy cuticle is one type of adaptation used by plants to minimise water loss. For other examples of ways that plants reduce water loss, see page 3.
2. As part of meeting the requirements of this course, you are expected to be able to read and interpret data represented in different forms, such as graphs and tables.
3. Again, this question is designed to test your ability to read and interpret data. Alternatives A, B, and C are incorrect statements.
4. All alternatives are good suggestions, but in this case contacting the local catchment management committee would probably be your first step. You can find out what actions are already being taken in order to develop a local action plan which may include A, B and C.
5. See page 22 for more information on indicator organisms and tests for water quality.

Short answer and longer response questions

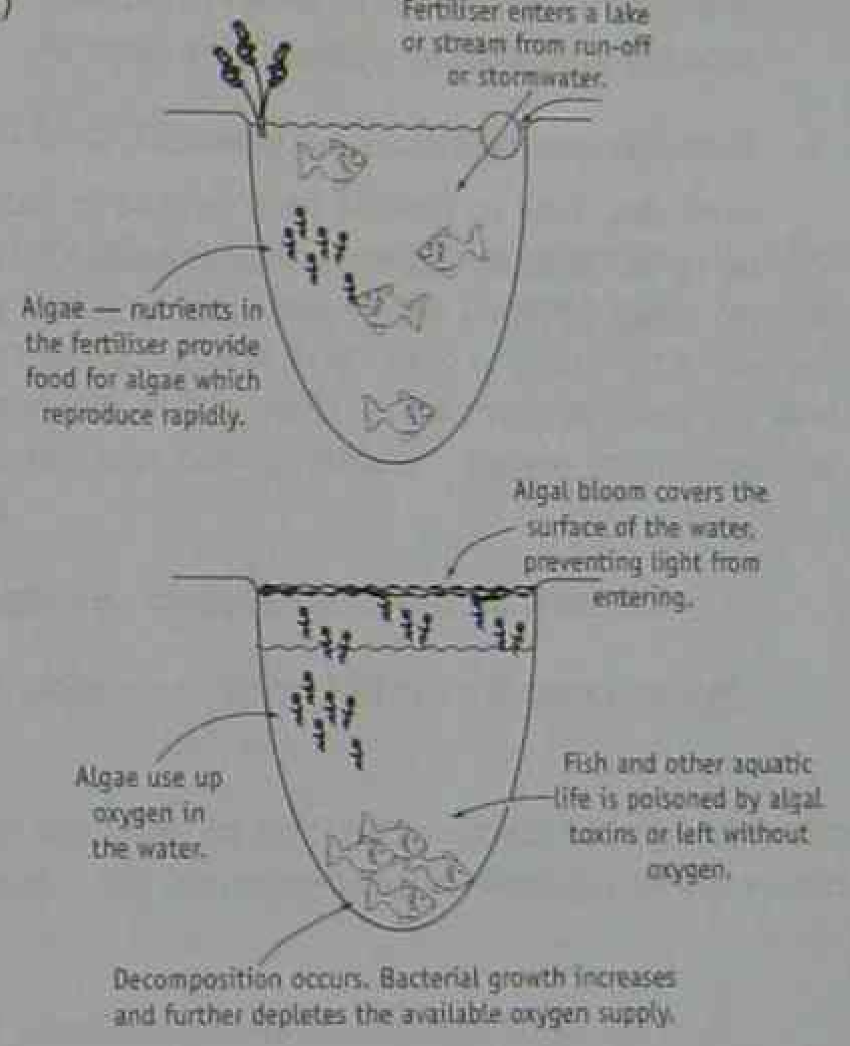
Answers and explanations

1. Possible solutions include:
   - Replanting of indigenous (native) vegetation such as the spotted gum on farmland and along river banks to lower the water table and hold the soil to prevent further erosion
   - Legislation to limit the amount of water that can be used by irrigation systems
   - Improvements in irrigation practices such as up-dating equipment and removing or repairing leaking irrigation channels, to minimise water loss and improve efficiency of systems.

2. (a)



2. (b)



3. (a) Salinity refers to environmental problems associated with the accumulation of salt in rivers, lakes and wetland areas (salt water intrusion) and on the ground, particularly in arid and semi arid areas (ground salinity). It has come about as a result of intensive land clearing and farm practices, the over-use of groundwater and intensive irrigation which raises the water table, therefore bringing salt to the surface.
   (b) High concentrations of salt in environments which don't normally experience salinity is a form of pollution.

Impacts:

- Salinity affects the drinkability and other aspects of water quality:
  - it can kill aquatic organisms
  - it can lead to increased algal growth because of increased light penetration through the water.
- Salinity corrodes pipes and damages roads and buildings.

See page 7.

4. The development of digital pH meters and other data collecting devices has increased the ease with which water quality can be tested on-site.

   The development of membranes which line tip sites and other landfill areas to prevent leachate entering ground water systems. See page 18.

5. Pesticides and herbicides are poisons.

   Pesticides, such as Dieldrin (now banned in Australia), can directly kill organisms or accumulate in the tissue of living things and accumulate up the food chain. Pesticides can remain in the envi ment for a long time and pollute soil, surfac water and ground water systems. See page 1

   Herbicides, such as Roundup, can be leached soil into water systems and kill aquatic orga Over-use of herbicides can lead to the develop of weed species which are resistant to poison

6. (a) The amount of oxygen decreases.

   (b) Heat, or thermal pollution, is a form of wa pollution which results from heat being ad to water systems from, for example, indus

   (c) Heat pollution:
   - directly kills those organisms which intolerant of warm conditions
   - other species not normally found in the heated water may thrive
   - as temperature increases, the solubility gases such as oxygen decreases.

Preliminary Core Study Module 2

2 — Plants

Introduction

In this chapter you will review how an increase in our understanding of plant germination and growth is being used to apply technologies to the propagation and care of native plants and the Australian environment. You will also review the increased awareness of the need to maintain biodiversity and to preserve and maintain plants, and how Australian native plants can be used for a variety of purposes.

As a result of working through this chapter you will be able to:

- Outline the historical development of van Helmont's conclusions regarding plant growth
- Apply the processes that are used to test and validate models, theories and laws of science to first-hand investigations in seed germination and plant growth
- Identify areas of current scientific research in plant cloning
- Explain relationships between plants and other organisms in the environment
- Identify and implement improvements to investigation plans.

☑ Checkpoint

Before you begin your review you need to check your understanding of the following:

- Tissues, organs and organ systems in multicellular organisms consist of different types of cells.
- Multicellular organisms require specialised organs and systems to supply the needs of the cell. This is because multicellular organisms, such as flowering plants, have a small surface area to volume ratio (a large volume compared with a small surface area). As a result, many cells are a 'long way' from the external environment. There needs to be specialised systems such as roots, stems and leaves to meet the cells' requirements.

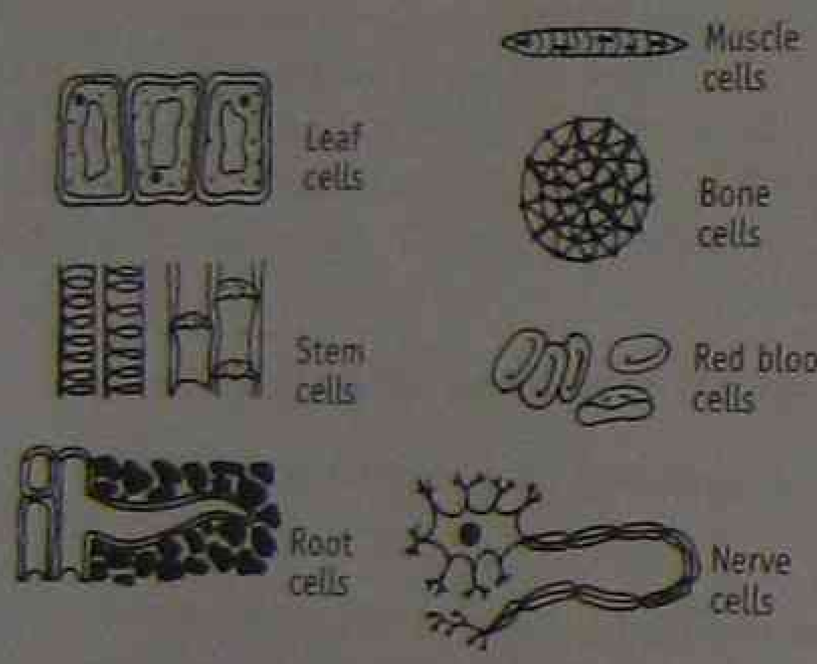


FIGURE 2.1 Examples of cells from multicellular organisms

- The role of the root, stem and leaf in maintaining flowering plants as functioning organisms.

  Roots — absorb water and dissolved minerals from the soil, and provide anchorage and support to the plant.

  Stems — transport substances such as water, minerals and the products of photosynthesis throughout the plant.

  Leaves — carry out photosynthesis, gas exchange and transpiration of water from the plant.
- Controlled experiments — see page 12.

How plants grow

All life on Earth depends on the food produ green plants. Plants are autotrophic orga Autotrophic organisms can make organic ma from water, carbon dioxide and inorganic subs using the energy from sunlight. This proc called photosynthesis.

$$\text{Carbon dioxide} + \text{water} \xrightarrow[\text{absorbed by chlorophyll}]{\text{using light energy}} \text{glucose} + \text{oxygen} +$$

FIGURE 2.2 A simplified equation for photosynthesis

As part of meeting the requirements of the course, you are expected to have used seco sources to research and model van Helmont' experiment and discuss the validity of his conclusions.

Prior to the seventeenth century, it was belie that plants took their needs from the earth th grew in. Van Helmont observed that soil was primarily responsible for a plant's change in mass it grew. Van Helmont weighed dried soil, placed i a large pot and then planted a weighed willow sh in the soil. Over five years, he only added water the soil. Then he weighed the willow tree and t soil. The weight of the soil had only slightly chang The weight of the willow had increased by mo than 160 pounds. Van Helmont concluded that t increase in weight had come from the water. Fr our modern understanding of photosynthesis, va Helmont's conclusions were not valid. He did n realise, for example, that carbon dioxide ha contributed to the gain in weight.

Fruits and vegetables

Fruit is a specific term associated with the flower o a plant. The flower is where sexual reproductio takes place. The seed that results from sexual reproduction is often enclosed in a fruit. Examples of edible fruits include tomatoes, oranges, apples and pears.

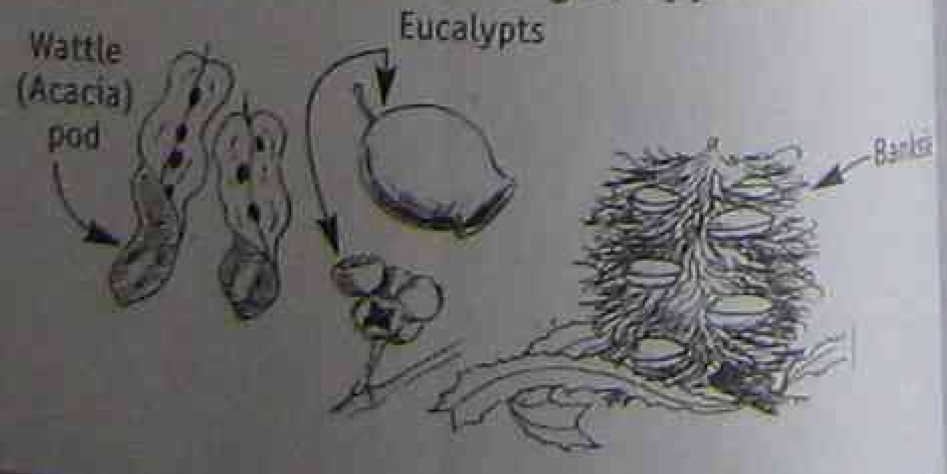


FIGURE 2.3 Examples of fruits from some Australian plants

Vegetable is a general term that can be used to refer to the fruit (for example, a tomato), stem (for example, celery), leaves (for example, lettuce) or root (for example, carrot) of the plant.

Mineral nutrients required by plants

Plants require the following mineral nutrients:

Trace elements — mineral elements that are needed in small quantities only. They are essential for plant health and include iron, manganese, copper, zinc and boron.

Macrominerals — nutrients that are needed in large quantities. Macrominerals include nitrogen, phosphorous, potassium, calcium, magnesium and sulfur.

The majority of Australian soils are infertile — they lack many nutrients, especially nitrogen and phosphorous. Australian native plants are adapted to these kinds of soil. If we add fertiliser to these soils, we can potentially change or destroy natural habitats.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to identify elements by their colour in a flame and used the results to identify some of the elements in fertiliser.

Heat a little of the fertiliser sample on a platinum wire in a bunsen burner flame. Test a sample of a salt known to contain the element that you are testing for, such as potassium nitrate and calcium nitrate. Compare the results.

* Identify safe practices such as the use of a fume cupboard. Do not look directly at burning magnesium. The gas sulfur dioxide is poisonous.

Some of the elements in fertiliser	Flame test
Potassium	Burns in air with a violet flame.
Calcium	Burns in air with a red flame.
Magnesium	Burns with a brilliant white flame.*
Copper	Becomes coated with a black powder when heated.
Sulfur	Burns in air with a purple flame.*
Zinc	Becomes coated with a yellow powder which turns white on cooling.

FIGURE 2.4 Some flame tests

As part of meeting the requirements of the course, you are expected to have carried out an experiment to determine the effect of mineral deficiency on plant growth.

Using hydroponics, water the seedlings in different pots with tap water, distilled water and solutions of magnesium sulfate, calcium nitrate, potassium phosphate and a full nutrient solution. Keep all other factors the same. Record the resulting differences in growth rate.

For a note on controlled experiments, see page 12.

The germination of seeds

The role of temperature, moisture and oxygen concentration in seed germination

Germination refers to the development of the young plant, the seedling, from the seed. During this development, the stored food in the seed provides energy and some of the raw materials for growth.

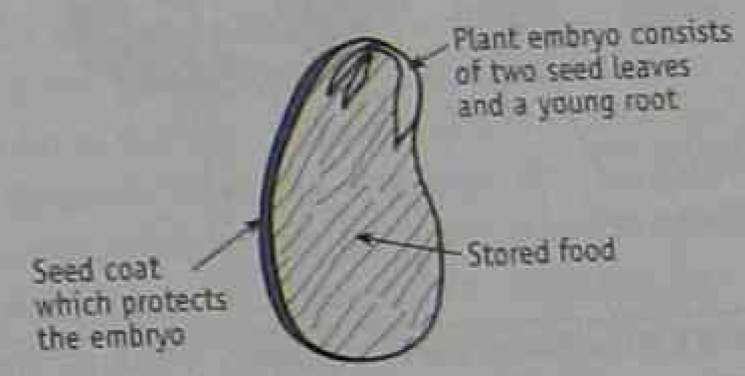


FIGURE 2.5 A vertical section of a bean seed. The seed is surrounded by a protective seed coat.

In order to germinate, seeds require:

Water — the seedling must not dry out.

Oxygen — oxygen is necessary for respiration in the germinating seed.

The correct temperature — the temperature varies from species to species. Seeds of most Australian plants require temperatures of 26°C to 35°C. Some seeds (such as alpine species) will not germinate, even with the right amount of moisture, unless they are exposed to low temperatures (0–5°C) for a period of time. Other seeds (such as some desert species) need high temperatures to germinate.

Too great a depth of planting may inhibit germination. Most seeds don't need light for germination, but do need light once seed leaves appear. Nutrients are not required until a plant starts to grow the first pair of true leaves.

As part of meeting the requirements of the course, you are expected to have:

- Researched, designed and performed a series of controlled experiments to investigate the effect of a range of temperatures, moisture levels or oxygen on the germination rate of a seed
- Used data loggers or probes attached to data loggers to monitor temperature, humidity or oxygen levels in experimental conditions
- Used data analysis software to graph the changing temperature, water or oxygen levels
- Used a database package to store and retrieve data as it is collected on the rate of growth of seedlings in varied conditions.

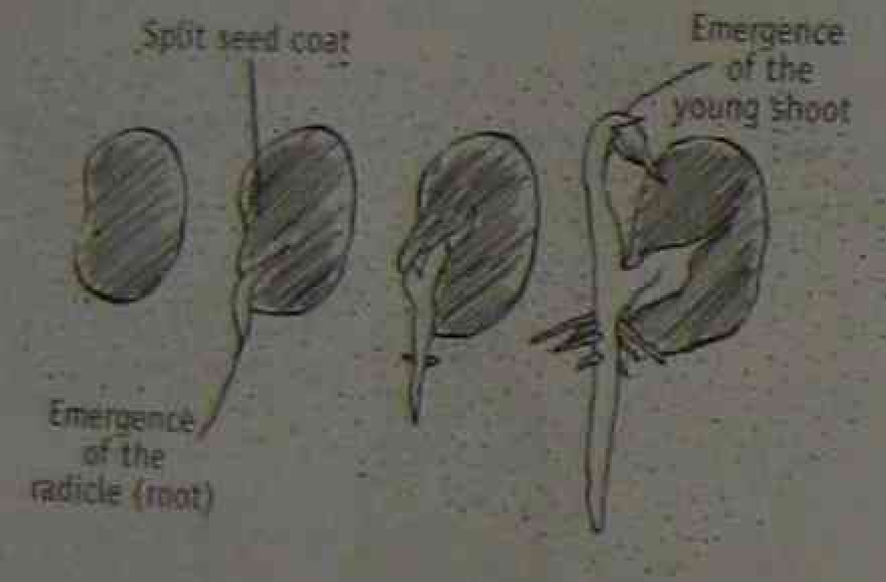


FIGURE 2.6 Growth of a bean seedling

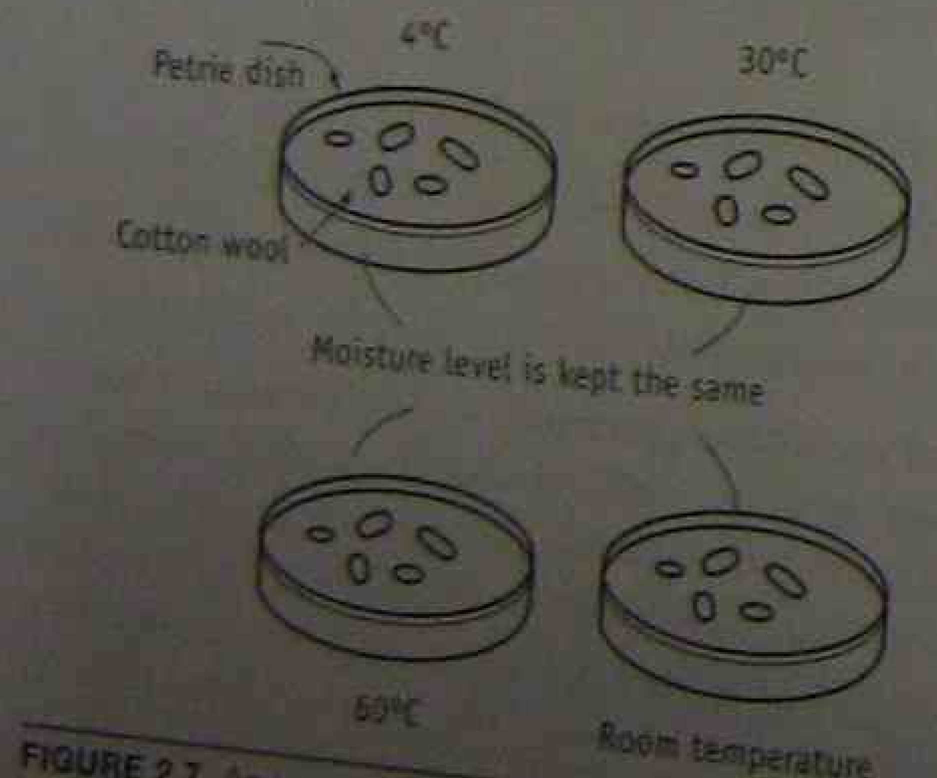


FIGURE 2.7 An investigation into the effect of a range of temperatures on the germination rate of a seed

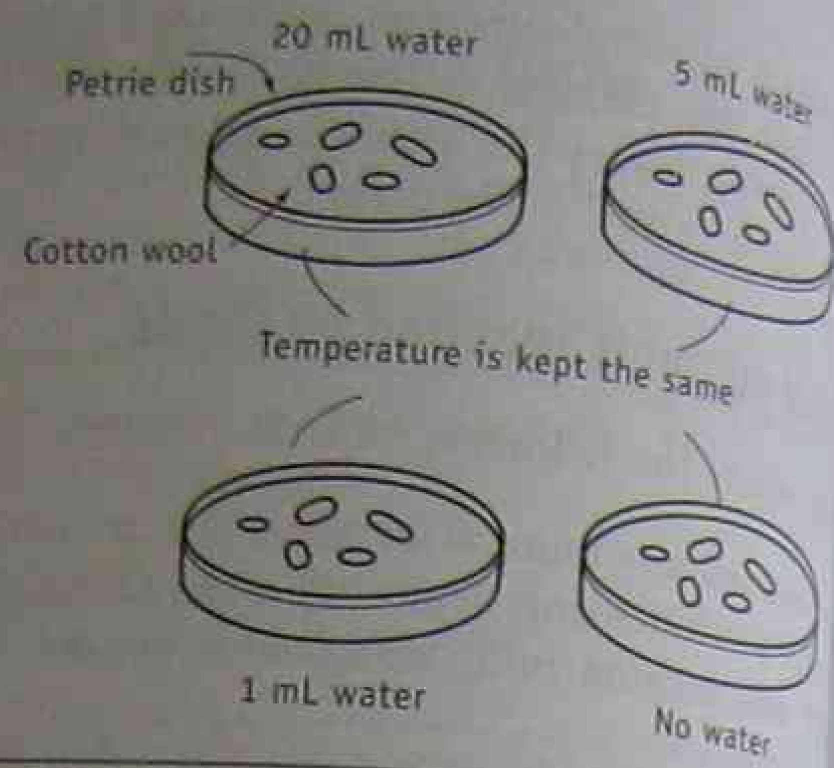


FIGURE 2.8 An investigation into the effect of moisture levels on the germination rate of a seed

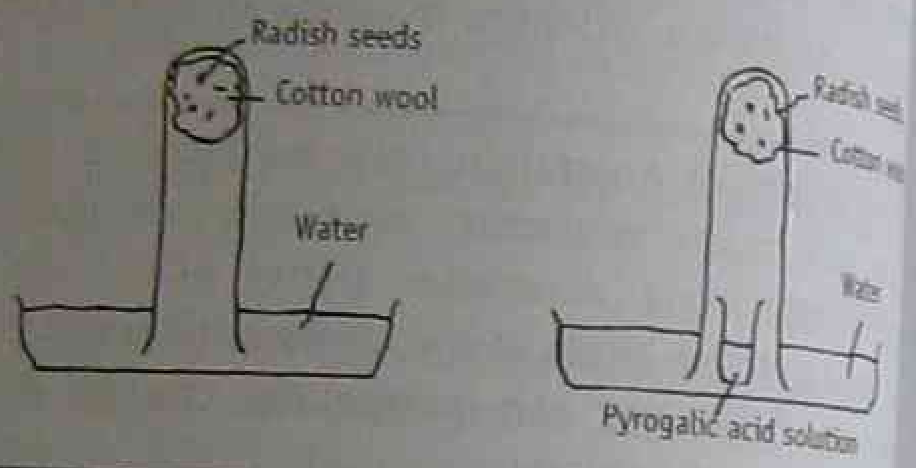


FIGURE 2.9 An investigation into the effect of oxygen su on the germination rate of a seed. Note: Pyrogalic acid solu absorbs oxygen.

Inhibiting germination

Humans have developed techniques for collec and storing seeds until they are needed for pr gation. Seeds are living parts of plants. In orde keep the seed from germinating until requ techniques are used to lower metabolism (li processes) and inhibit germination. These inclu

Cold storage — seeds are stored at temperat which are too low for most seeds to germinate

Vacuum packing — oxygen is prevented from rea ing the seed. Oxygen is removed from packaging high powered pump creates the vacuum.

Desiccation/dehydration — water is taken ou the seed and prevented from re-entering the seed

Promoting germination

Techniques are used to promote seed germina when required for propagation. These include:

Heat beds — used to provide a warmer tempera for seeds stored in cold storage.

Lime pelleting

fixing and to help germination in highly acidic soils. (Legumes have the ability to absorb, or 'fix' atmospheric nitrogen. This is done in the nodules of legume roots by rhizobia bacteria.)

Misting — rehydrates seeds that have been dehydrated and provides the moisture needed for germination.

Pre-germination requirements of some Australian plants

Some Australian seeds exhibit physical and chemical dormancy and must be pretreated before they will germinate. They may require pre-germination treatment such as abrasion, scarification, heat, smoke and leaching.

For example, the seeds of acacias (wattles) and papilionaceae (pea flowers) are hard coated which makes the seeds impervious to moisture. The hard coat must be broken for moisture to enter. In nature this may happen as a result of repeated wetting and drying or bushfire. Some seeds have temperature requirements, such as a cold period followed by a warm period, before they will germinate. Chemical dormancy is the result of germination inhibitors present in the seed. The germination inhibitors must therefore be washed or leached out of the seed before it will germinate.

Examples of Australian plants that **do not** require pre-germination treatment are eucalyptus, callistemon, casuarina, kunzea, viola, melaleuca.

Examples of Australian plants that **do** require pre-germination treatment — acacias, pultanaea, fabaceae, kennedia, hardenbergia, grevillea, cassia, chorizema, hovea.

As part of meeting the requirements of the course, you are expected to have researched some Australian native seeds that are germinated by pre-treatments such as abrasion, scarification, heat, smoke and leaching.

Pre-treatments include:

Abrasion and scarification — involves rubbing the seed between two sheets of coarse sandpaper or tumbling the seed in a mechanical scarifier until the seed coat is thin. Some careful scratching or nicking of the seed coat to allow moisture into the seed without damaging the embryo may also be needed.

Heat — involves soaking the seeds in boiling water to soften the seed coat. Grevillea is sometimes difficult to germinate and requires soaking (and nicking).

Smoke — seeds of plants from fire-prone vegetation (such as flannel flowers and some eastern Australian grevilleas) often show dormancy and germinate in response to fire-related clues such as smoke. Seeds are treated with heat and smoke in a smoke chamber or smoke water is used. Smoke water is used as a spray or as a solution in which seeds are soaked.

Leaching — involves washing seeds under running water to leach out germination inhibitors. Eriostemon, boronia and crowea seeds undergo leaching pretreament. In some cases the seed must also be abraded to expose the embryo.

Bulbs, corms and flowering

Bulbs are large buds with a small stem at the lower end surrounded by many fleshy leaves. Corms are storage stems that resemble bulbs. An example of an Australian plant that produces bulbs is the terrestrial orchid, pterostylis. Bulbs and corms require certain temperatures — such as cold conditions — to initiate flowering. In horticulture, many bulbs and corms such as tulips are removed after the plant has finished flowering and kept dry and stored in very cold conditions in order to initiate flowering the following year. This process simulates the conditions found in their natural environment: for example, tulips naturally require very cold temperatures in winter to initiate flowering in spring.

Environmental conditions and germinating seedlings

Different plants have different requirements for growth

Different plants are adapted to different environmental conditions including:

- Rainfall (how much water and at what time of year)
- Temperature variations
- Winds
- Soil (depth, type of rock underneath, acid or alkaline, amount and type of nutrients). Many Australian plants, such as grevillea species,

- Drainage. Banksia seedlings, for example, are particularly sensitive to poor drainage and excessive amounts of phosphorous in the soil.
- Pollination (by wind, insects, birds, water).

Overcrowding and seedling growth

Overcrowding does not allow sufficient air movement around seedlings. Lack of air flow encourages fungal growth (damping off) which can cause seedlings to rot. Growth is also inhibited if there is not enough room for individual development of seedlings.

Wavelength, light intensity and seedling growth

Normal (white) light is a mixture of light of varying wavelengths represented by red, orange, yellow, green, blue and violet light. Plants do not use all wavelengths of light for growth. As most plants appear green, it seems clear that green light is reflected and not absorbed by plants for photosynthesis. The wavelengths of the action spectrum that are used most for growth are blue and red.

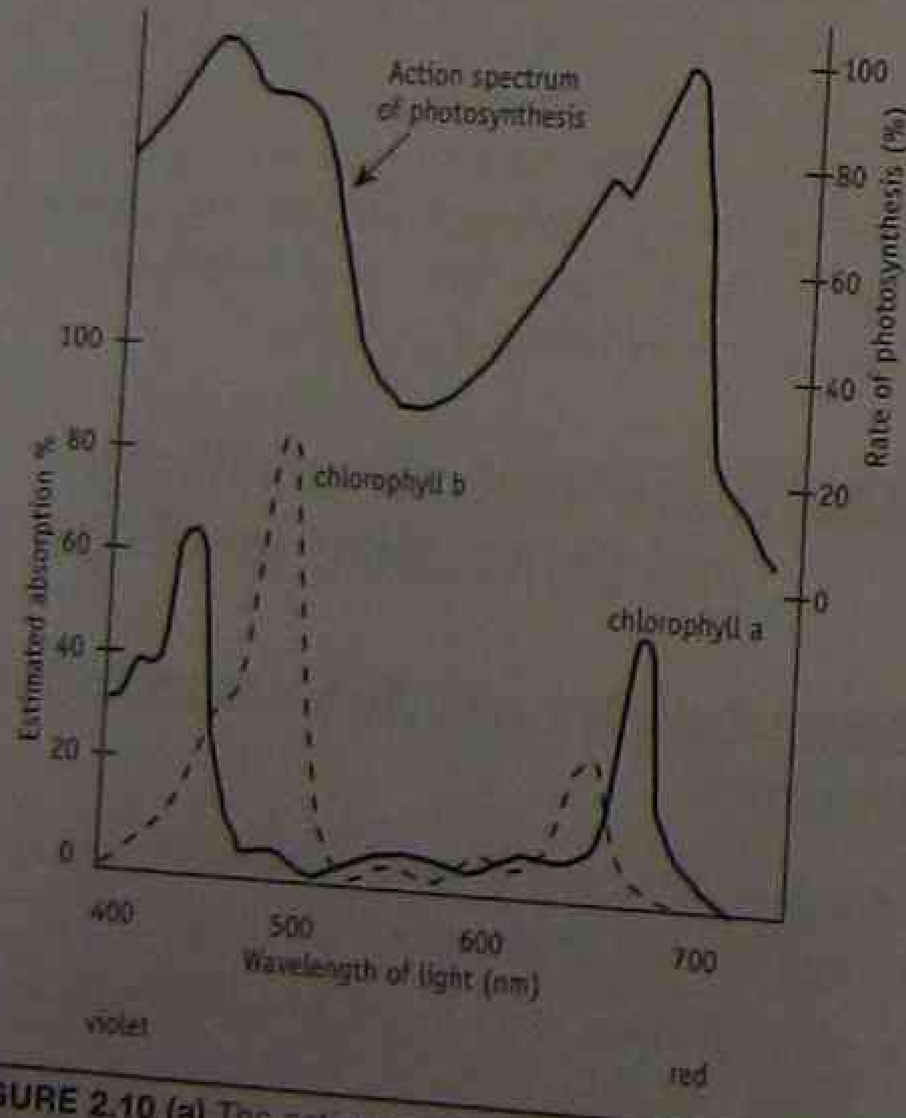


FIGURE 2.10 (a) The action spectrum of photosynthesis

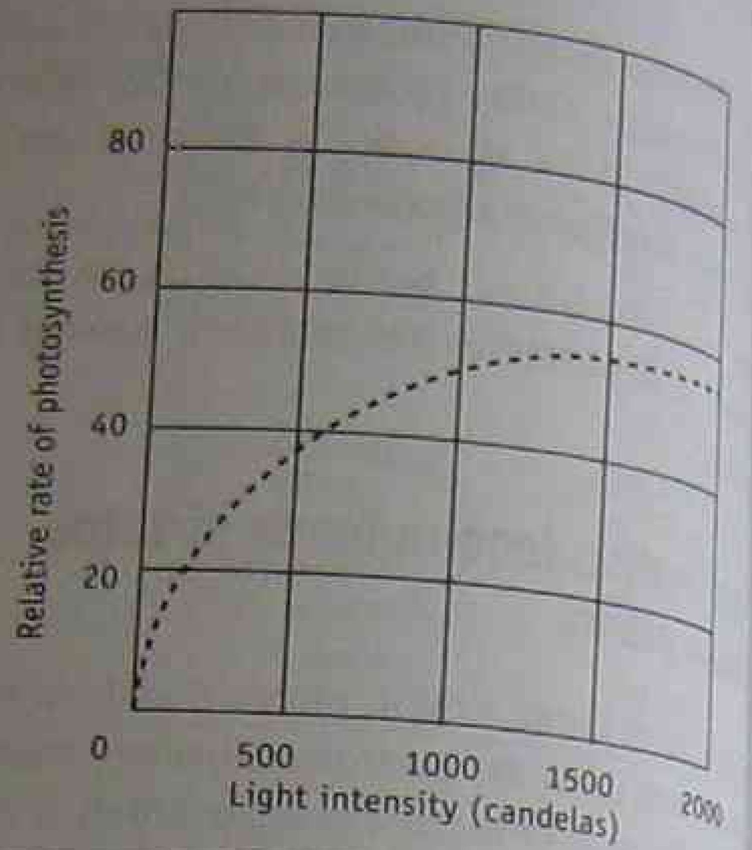


FIGURE 2.10 (b) In bright light photosynthetic rate incr with an increase in temperature up to about 45°C. In di increase in temperature only produces a slight increase in t of photosynthesis. The rate of photosynthesis increases a intensity increases, until saturation occurs when the rate o synthesis, and therefore gas production, will remain cons

As part of meeting the requirements o course, you are expected to have carri experiments (and presented your fin to analyse the effect of **one** of the follo variables on germination or plant grow

Temperature — grow seedlings of the same ty plant at different temperatures. Keep all factors the same. Use data loggers to measur temperatures and to maintain the temperatu each seedling at a constant rate.

Moisture — grow seedlings of the same typ plant with different amounts of moisture. Kee other factors the same. Use probes attached to loggers to measure the moisture content of the and ensure the different levels of moisture maintained at a constant rate for each seedling

Light — expose seedlings to different wavelen of light: ultraviolet, blue light and red light expose seedlings to different light intensities. Use loggers to determine and measure light intensity each seedling. Keep all other factors, such as te erature, moisture level and water quality the sa

Water quality — see Figure 1.10, page 14.

Crowding of seedlings — grow seedlings conditions which simulate different amounts crowding.

You are expected to have used a data analysis s ware package to graph and compare the importa of variables on seedling growth. Therefore, you have worked in different teams to analyse different factors and then compared your results. If this was the case, you would need to have ensured that experimental methods and data collection processes were consistent.

As part of meeting the requirements of the course, you are expected to have carried out experiments to compare the growth rate of different seedlings and different plant parts.

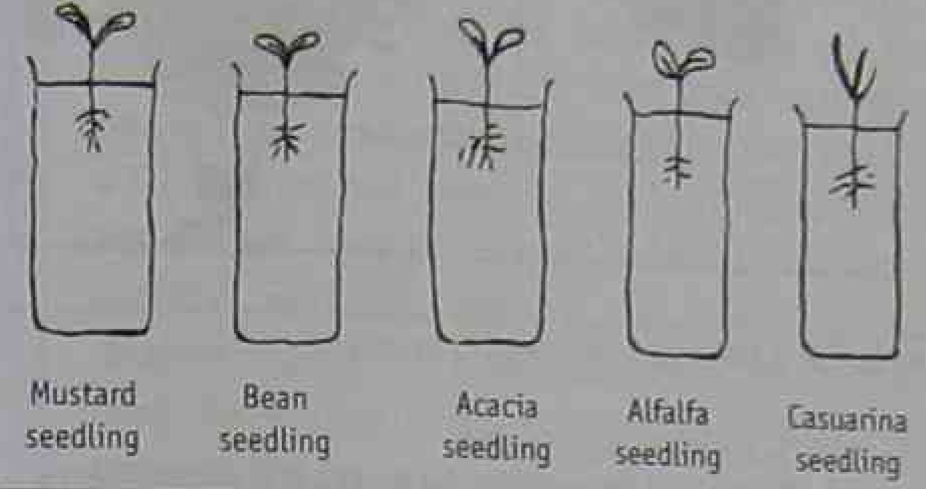


FIGURE 2.11 An investigation to compare the growth rate of different seedlings. Keep all other factors the same.

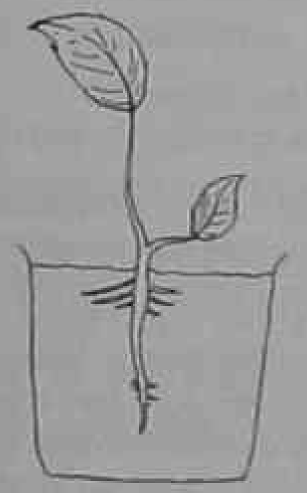


FIGURE 2.12 An investigation to compare the growth rate of different plant parts — root, stem and leaves

Different types of plants have different water requirements

All plants need water to survive. Some plants however, require large amounts of water and can only survive small losses of water. Other plants called **xerophytes** can survive in very dry conditions.

The adaptations of xerophytes — xerophytes can survive dry conditions by reducing water loss, gaining water or waiting out the dry season as a seed, rhizome, bulb or corm. Adaptations for reducing water loss include:

- A thick outer coating or cuticle on leaves
- The presence of waxes and oils on the leaf surfaces
- Reduced number of leaves, or leaves reduced to spikes (such as cacti)
- Leaves that have a long spiky shape (such as porcupine grass)
- Dropping leaves in times of drought
- Delaying flowering until a more favourable season
- Hairy or shiny leaves (such as saltbush) help reflect heat and reduce evaporative water loss
- Reduced number of stomates, located on the under surface of the leaf
- Hairs on the leaf or the ability for the leaf to curl. This increases the humidity around the leaf and reduces evaporative water loss.
- Channeling water such as dew and directing it onto the roots
- The ability to orientate leaves at right angles to the sun reduces the surface area exposed to the sun and reduces evaporative water loss.

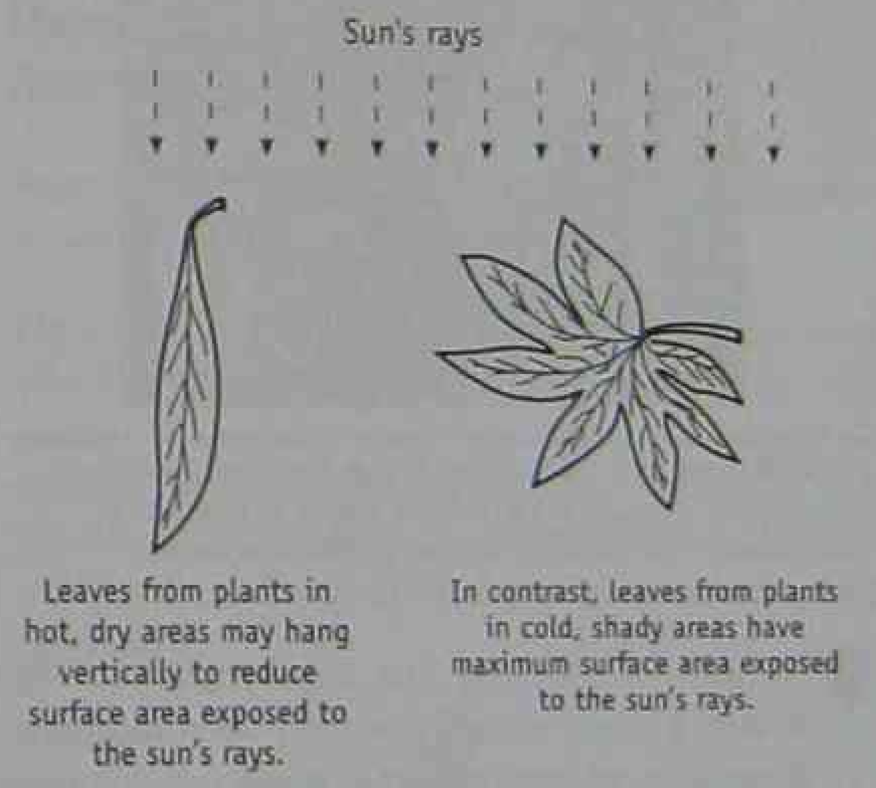


FIGURE 2.13 Plant adaptation

The adaptations of mangroves — mangroves are plants that are adapted to survive in ever-changing tidal conditions near seashores and in estuaries. An estuary is at the tidal mouth of a river where freshwater mixes with salt water. Mangroves can withstand higher concentrations of salt than other plants. Different species of mangrove show different degrees of salt tolerance.

Adaptations to cope with saline environments include:

- The leaves of some mangroves secrete excess salt through special glands.
- Some mangroves store excess salt in their cells.

Mangroves grow in waterlogged soil. Adaptations to this include:

- A network of stilt roots
- Vertical aerial roots.

Adaptations of epiphytes — epiphytes grow on the branches or trunks of trees and use the tree as a base for attachment and support. Epiphytes do not 'feed' off the tree. Epiphytes are similar to Australian xerophytes in that they are adapted to scarce water supply. Epiphytic orchids, for example, have roots which attach to the tree and have a spongy structure which absorbs moisture and nutrients from the air.

FIGURE 2.14 *Bromeliad epiphyte* has thick leaf cuticles, a spongy root mass and cupped leaf bases to trap water. Spiny leaves help protect the plant against herbivores.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research different water requirements of Australian native plants found in different climatic areas of the country.

Water supply and temperature determine the distribution of plant communities and vegetative growth patterns. For example, some plants such as kangaroo paw grow best in zones with dry summers and need a period of summer dormancy (when vegetative growth is slow). In Australia, eucalypt forests dominate temperate, wetter zones. Rainforests which were once extensive have now contracted to a few small patches in tropical and sub-tropical zones. Acacias, mallees (a type of eucalypt) and grasses are found in semi-arid and arid zones. Ironbark woodlands are found in zones which have cold winters with frosts. See also page 6.

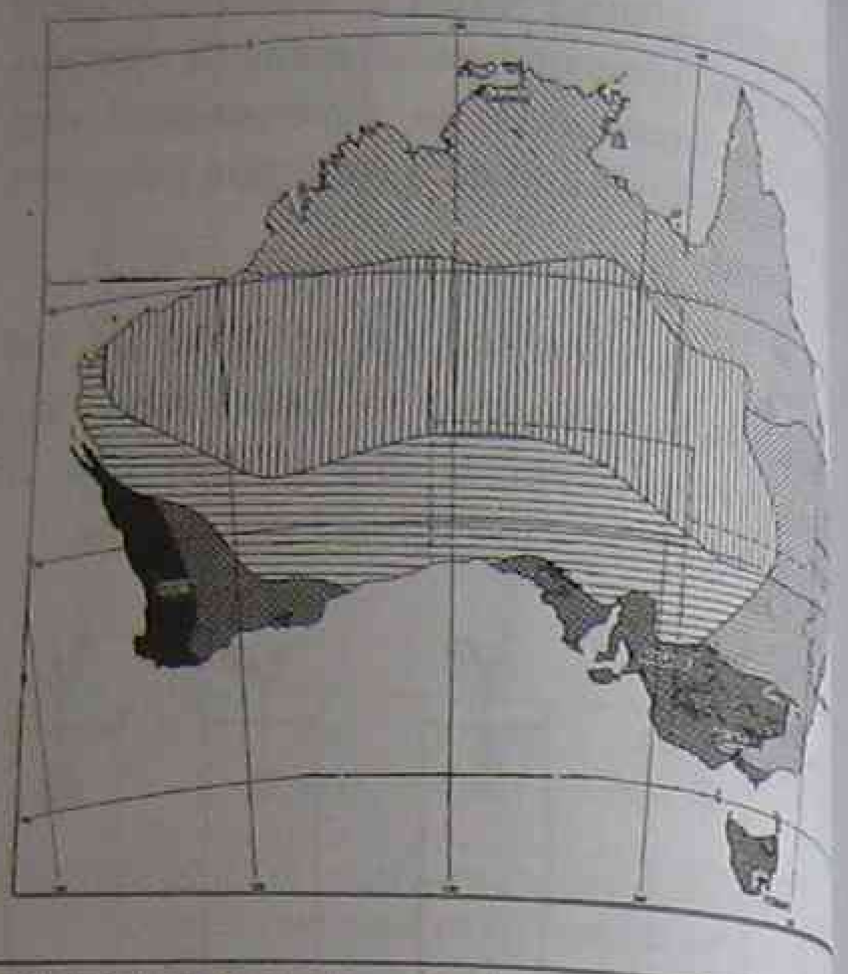


FIGURE 2.15 Australian climatic zones

▨	Summer rainfall: tropical Plants require summer rain and high humidity, dry winters.
▨	Summer rainfall: sub-tropical Plants require summer rain and high humidity winters with some rain.
░	Uniform rainfall: temperate Plants require summer rain and cold winters wit
■	Winter rainfall (heavy): temperate Plants require light rain in summer; warm, hot summers, cool winters with rain.
▒	Winter rainfall (moderate): temperate Plants require very light rain in summer; warm summers, cold winters (frosts) with moderate
▥	Arid: sub-tropical Some summer rain; hot to extreme and very mild to warm dry winters.
▤	Arid: warm temperate Irregular rain in summer; hot to extreme and ve dry; cool to mild to dry winters.

Too much water can be harmful to plants

Excessive watering changes the osmotic balan the soil, causes leaching of nutrients and encou the growth of fungi. Water-logged soils do not sufficient oxygen for most seeds to germinate.

Some technological developments in horticulture and agriculture

Horticulture involves the cultivation of flowers, vegetables and ornamental plants. Horticultural agricultural practices attempt to provide plants the essential requirements for maximum gro

Technological developments, such as advances in computer technology, have increased the capacity of growers to manipulate the plant environment and provide more precise amounts of nutrients, light and water. Horticultural and agricultural systems are becoming more automated. Variables such as nutrient levels, pH, air circulation, temperature, light intensity and water supply (such as irrigation systems) are controlled and monitored using electronic sensors, and the information fed into computers.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research and identify the use of watering control systems in horticulture and agriculture, looking in particular at computer-assisted watering systems and discussing the relative merits of these systems. You should then have used your research to predict the sensors and/or programs that would be needed to control such a system.

Sensors monitor variables such as nutrient levels, pH, air circulation, temperature, light intensity and water supply.

Watering control systems must take into account:

- The differing needs of different plants species. A generalised watering system can lead to underwatering or overwatering of some plants. Separate lines and shut-off valves are used to regulate water flow to different plants.
- Ways of maintaining moisture and at the same time minimising growth of moulds and fungi.
- Methods of capturing and recycling waste water and nutrient solutions.
- The benefits and problems associated with different watering methods such as micro-sprays and drippers. Microsprays provide a spray or mist. They help maintain high humidity and can deliver water to plant foliage and soil over large areas (depending on the coverage needed). The problems associated with microsprays include water wastage as a result of evaporation and the spray being blown away with the wind. The high humidity creates favourable conditions for moulds and fungal growth. Drippers deliver water over an extended period of time slowly and evenly to the root zone of plants.The use of water is more efficient as there is less wastage.

Asexual reproduction and genetic cloning of plants

Many plants reproduce by asexual means, for example runners, rhizoids and tubers. The distinguishing feature of asexual reproduction is that it occurs without fertilisation. The offspring produced are identical to the parents — that is, they are genetic **clones**. Common horticultural practices have used this fact to propagate desirable or rare varieties of plants, and plant cloning has been practised for a long time. Plant breeders have traditionally used asexual reproductive methods such as grafting and taking cuttings. Technological advances in micropropagation techniques allow horticulturalists to grow plants in tissue cultures. It is now routinely possible to produce completely fertile plants from single cells or small plant parts grown under sterile conditions on culture media in test tubes and other glassware, without contamination from other organisms.

Means of asexual reproduction in Australian plants

Vegetative propagation or asexual reproduction techniques include:

Lignotubers — large woody swellings of the stem which occur at and below the surface of the soil. Almost all eucalypt seedlings have lignotubers. In mallees the lignotuber develops into the mallee root. *Banksia oblongifolia* and *Lambertia formosa* (mountain devil) and waratahs can also propagate from lignotubers.

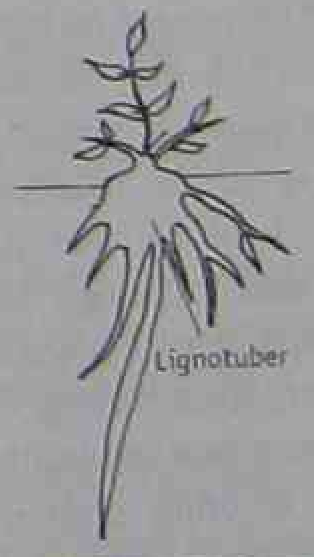


FIGURE 2.16 A lignotuber

Epicormic buds — special dormant vegetative structures which occur as swellings or buds along the trunk or branches. Shoots develop asexually from the bud, usually after bushfires.

Runners — *Scaevola striata* (fan flowers) and a number of other dune plants, *Commelina cyanea* (which is often confused with the weed species tradescantia), pratia and basket grass are examples of Australian plants that propagate from runners.

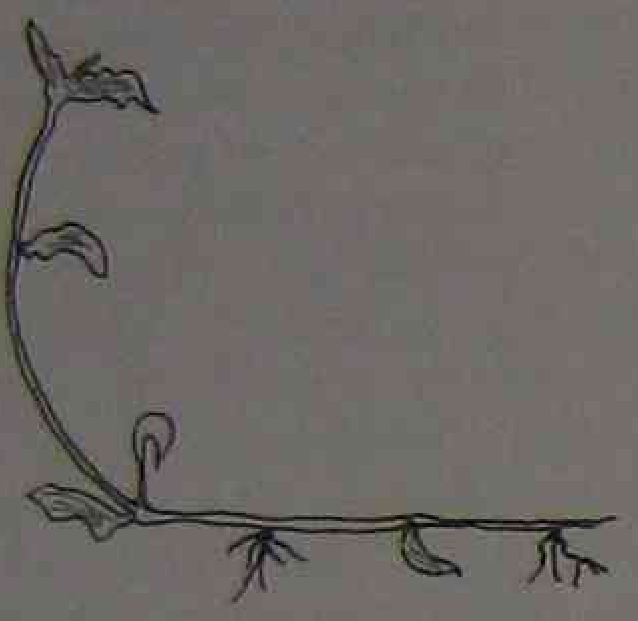


FIGURE 2.17 Commelina

Many heathland plants such as *Banksia ericifolia* and *Casuarina nana* use vegetative propagation techniques such as lignotubers, rhizome tubers and bulbs which allow regeneration of the plant after the above-ground part has died. Many eucalypt species can regenerate after fire from epicormic buds or lignotubers at the base of the trunk.

Issues associated with different propagation methods

Issues to be considered when choosing the most appropriate propogation method include:

- The length of time to achieve a viable plant. Some plants do not produce viable seeds, or seeds may not mature or be present on a plant when propagation is desired. It may therefore be necessary to choose a propagation method other than propagation from seed. For example, acacias (with scarification), banksias and hakeas are easily grown from seed (although heat is needed to promote germination), whereas waratahs are often best grown from cuttings. Seed germination rate for kangaroo paw is usually low. Therefore, root division is often chosen as the easiest propagation method.
- Care of plants before they are ready to be transplanted. Plant parts may be planted in a rooting medium and then transferred to pots or directly into the soil if they are an easily rooted species. Plantings must be at the right soil depth. The potting medium needs to be well-drain free of diseases and weed seeds. As the become better established with full roo shoot systems, they may be gradually intro into the conditions they will encounter outdoors, a process called hardening. The of cuttings taken from eremophila (emu b myoporums must be kept dry and care when transplanting, as the root system is fragile. Other factors include whether to fe and if so, which fertliser to use. Banksia sensitive to high levels of nitrogen and p phorous.
- The balance between the need for water overwatering. Air temperature and humidity be controlled in a variety of ways, ranging high-tech greenhouses to shading plants plastic sheeting. Initially humidity levels are high to reduce water loss from new leaves or cut surfaces of the plants. The main con here is to avoid interfering with photosynth while avoiding diseases that prefer mois Some species of kangaroo paw are very sens to high humidity and develop a disease ca ink spot if the surrounding air is too moist.
- The balance between the need for light and ov heating. Seedlings and cuttings need morn sun but should be protected from the full hea the day, particularly in summer. Small pebb are used to provide cool root run.
- Availability of parent stock. Some pla hybridise easily and pure characteristics beco cross-bred with other characteristics that m not be desirable.

The benefits of cloning techniques in plant

Cloning, using both tissue culture and vegeta propagation techniques, makes it possible to:

- Breed plants from plant tissue when seeds a unavailable, when seeds are difficult to germina and when plants are rare and specimens a difficult to obtain and propagate from seeds laboratory conditions.
- Rapidly propagate large numbers of plants wi desired characteristics.
- Select plants with desired or 'superior' here tary characteristics and maintain the characteris without cross-breeding occurring.

Genetic engineering techniques have also enabled plant breeders to select, isolate, purify, clone and directly insert a desired gene into a plant species. Plant breeders can now obtain disease-free plants that can be propagated rapidly and delivered to breeders all over the world.

Genetic advantages and disadvantages of cloning

Advantages:

- Tissue for culture is easy to obtain.
- Species that have proven difficult to propagate from seed can be bred.
- Cloning does not require fertilisation. Cloning therefore produces populations of organisms that are identical to each other. The advantage of this is that the characteristics can be precisely controlled and organisms can be produced in short periods of time (without the testing needed in traditional selective breeding).

Disadvantages:

- Sexual reproduction provides a mechanism for bringing about diversity within a species. The plant population resulting from cloning is genetically identical (there is no diversity). Therefore, the ability of the population to adapt to environmental change is reduced.
- If an environmental change includes the introduction of a new strain of disease-producing virus, for example, the chances of the plants being resistant to the disease is greatly reduced. The whole population could be wiped out.

There are also ethical issues associated with genetic engineering and cloning of plants and animals. Some of these issues include:

- Concerns about pollution of gene pools, for example, cross-pollination from a genetically modified crop to a non-engineered crop
- Health risks associated with eating genetically modified foods such as soya beans which have been modified to be resistant to the herbicide Roundup. There is growing consumer opposition to genetically modified foods. There is also growing concern from consumers that products be clearly labelled to show what they contain.

Using tissue culture

Cloning plants from plant tissue involves the propagation of a new plant from a small piece of another plant. Most parts of the parent plant may be used for tissue culturing, but shoot tips and embryo tissue generally give the best results. The tissue is grown on a culture medium in a petrie dish or test tube. Desirable tissues are isolated using sterile (aseptic) procedures designed to eliminate bacteria and other disease organisms. For example, ultraviolet light and/or steam heat may be used to sterilise work chambers, instruments, glassware, and media.

Plant propagation became more feasible with the development of growth media that contain the required macronutrients and micronutrients for the developing tissues. Growth media typically consists of precisely measured quantities of distilled water, inorganic salts (minerals), and combinations of sugars, hormones, vitamins, and yeast extracts. Tissue cultures are maintained in a tightly controlled environment and may be manipulated in a variety of ways (such as genetic engineering) to develop the desired trait.

Tissue culturing is used to produce large numbers of plants in a short period of time and with the desired characteristics. For example, cloning and genetic manipulation are used to produce corn, potato and cotton that contain a gene that produces a toxin to control chewing insect pests. The gene is spliced into the plant cells from the bacteria *Bacillus thuringiensis* (Bt) which naturally creates a toxin that kills insect larvae.

See: http://www.isr.gov.au/ba — Biotechnology Australia

http://www.anbg.gov.au/anbg/ — Australian Botanic Gardens

http://www.accessexcellence.org/AE/AEPC/WWC/1993/culturing.html — for information on culturing plants from embryonic plant tissue.

As part of meeting the requirements of the course, you are expected to have used secondary sources to investigate Australian research into cloning and the use of tissue cultures in plant breeding, and the benefits of this research, using an example such as the Wollemi pine.

Two patches of Wollemi pine were discovered in a rainforest canyon in the Wollemi National Park in

1994. The population discovered in 1994 was down to 16 seedlings and 23 adults. The pine is a previously unknown genus from the age of dinosaurs and is a very rare species. It has remained virtually unchanged for tens of millions of years. Staff from the Royal Botanic Gardens and the National Parks and Wildlife Service freeze-dried and vacuum-sealed tissue from the pine for analysis. Seeds and tissue were also collected to cultivate the pine. The pines produced from tissue cultures are clones — they have no genetic variability from the original trees.

Analysis of the pine's tissue to date has revealed the pine's potential medicinal value. Two new strains of fungi associated with the pine have been tested and produced known anti-cancer chemicals. Four new penicilliums (the moulds that are used in antibiotics) have also been discovered.

Diversity in plants and the genetic health of the planet

Biodiversity is a shortened term for biological diversity. It refers to:

(a) Species diversity — the millions of different life forms on Earth, their ecological roles and the interrelatedness of living things

(b) The diversity of genes that occur in a given area, and

(c) Ecosystem diversity.

Monocultural crop development and urban development drastically reduce biodiversity.

Why species need genetic diversity

The survival of species in changing environments depends on a diversity of genes within the population. Genetic diversity:

- Enables species to adapt to changes in the environment.
- Provides a genetic buffer against disease-causing organisms. If, for example, a new disease appears in a population with reduced genetic variation, genes that are more naturally resistant to the disease may no longer exist within the population.

Why Australian plants become endangered

There are about 3329 rare or threatened plant species in Australia. Ninety-seven plant species have become extinct within the last 200 years. Many plant species in Australia are naturally rare. Eighty five per cent of Australia's flowering plants are endemic — that is, they are found nowhere else in the world.

Reasons why Australian plants become endangered include:

- Land clearing. Increasing demands for land, water, minerals and forest products have increased land clearing practices since European settlement more than 200 years ago. The 1996 *Australian State of the Environment Report* found that 40% of forests and 35% of woodlands have been lost or thinned due to land clearing. Land clearing destroys and fragments habitats. It has a major impact on biodiversity, through removal of native vegetation (trees, shrubs and grasslands), the removal of habitats, and drainage of natural wetlands. Dryland salinity is now also seen as a threat to biodiversity.
- The introduction of foreign animals and plants which increases competition. Some 1800 plant species have been introduced since European settlement.

References:

Spessa, A. & Newton, G. (1997) 'Biodiversity or bust', *Australasian Science*, Vol. 18, No.4.

'Falling down: Land clearing in Australia', *Habitat*, Feb. (1998), pp. 13–21.

'Native vegetation clearance, habitat loss and biodiversity decline', *Biodiversity Series*, Paper No. 6, Department of Environment, Sport and Territories, Commonwealth of Australia, 1995.

Beattie, A.J. (1995) *Australian Biodiversity*, Reed Books, Sydney.

See:

http://farrer.riv.csu.edu.au — an excellent website for information on Australian plants at risk.

http://www.nccnsw.org.au/member/tsn/ — the Threatened Species Network.

http://www.abc.net.au/science/news — salinity and threatened extinctions in Western Australia, September 2000.

Conservation strategies used for rare Australian species

Some conservation strategies include:

- Habitat conservation and regeneration through the development of National Parks and reserves and education programs to encourage habitat conservation on privately owned land — conserving biodiversity must take place *in-situ*, the site where organisms occur in nature. The Greater Blue Mountains area was listed on the World Heritage Register in November 2000 and joins the other World Heritage areas in NSW: Lord Howe Island, Lake Mungo and the East Coast rainforests.
- Research and development by organisations such as CSIRO and the Australian Botanic Gardens.
- Cultivation by organisations such as botanic gardens, government sponsored community-based organisations and universities.
- Government legislation such as the *Threatened Species Conservation Act* and government involvement such as the National Parks and Wildlife species recovery plans.

For example, in Australia there is growing concern that with extensive clearing of forests and woodlands, we have and will continue to reduce the gene pool of eucalyptus species. As genetic variation is reduced, the risk of extinction increases. Tree breeding programs, careful management of threatened areas, legislation to prevent land clearing, biological surveys of biodiverse areas and the setting aside of conservation areas help, to some extent, to maintain biodiversity.

See: http://www.anbg.gov.au/anbg/ — Australian Botanic Gardens.

Why conserve Australian species of plants?

Some reasons include:

- The health of natural ecosystems, such as the cycling of nutrients, relies on biodiversity.
- Soil biodiversity maintains soil fertility — sustainable agricultural practices require biodiversity.
- Future research into biological resources such as foods and medicines requires conservation of plant species. The discovery of the Wollemi pine, for example, suggests that there are other significant discoveries waiting to be made.
- The biodiversity of native plant species maintains a natural ecosystem's ability to respond to changes such as flood, fire and drought.

Australian native plants are naturally adapted to Australian environmental conditions. These adaptations mean that growing Australian plants is less disruptive to the natural environmental conditions. Less alteration of the soil and generally less water is needed for their growth.

Reasons for changing attitudes about the need to conserve diversity in organisms

Increasingly people are realising that human activities such as intensive farming and land clearing are unsustainable and have led to the loss of biodiversity and long-term environmental degradation which impacts on all living things and the quality of air, water and soil. Early settlers in Australia saw the Australian environment as something to be tamed and developed at all cost. There was little understanding of the short and long-term consequences of the loss of biodiversity.

Now the consequences are more obvious. Increasingly we are understanding that the loss of a species is an indicator of the poor health of the entire ecosystem. Major environmental problems which were once largely ignored are now given attention because of their economic costs. For example, it is estimated that $700 million per year of usable land is lost in the Murray-Darling Basin due to salination.

See: 'Biodiversity or bust', *Australasian Science*, Summer Issue, Vol. 18, No. 4 1997, pp. 10–12 — for information on biodiversity in Australia and the National Strategy for the Conservation of Australia's Biological Diversity.

The importance of seed, gamete and zygote banks

Seed, gamete, zygote and gene banks monitor and preserve genetic variability to help ensure that gene pools are not lost forever, and to maintain what biodiversity is left on Earth. Survival of species such as the Wollemi pine depends on both maintaining its environment and cultivating it — developing a bank of Wollemi seeds, tissues and zygotes.

Asexual reproduction diminishes genetic variability, as does the reliance on monoculture. Selective breeing has also led to the loss of original (wild) parent stock. One of the ways to avoid the loss of potentially useful gene combinations is to maintain storage sites — seed banks, zygote and gamete banks, and gene banks. For example, seeds, cuttings, and roots of wild and cultivated species are preserved, by freezing them to temperatures of -196°C (cryopreservation) to stop their metabolic activities.

As part of meeting the requirements of the course, you are expected to have used secondary sources to summarise the strategies used to protect a number of different Australian species.

Some ideas are provided below.

- Florabank — improves the availability and quality of native seed available for conservation and revegetation in Australia. It also provides information on the collection, storage, and use of native seed. See: http://www.florabank.org.au
- Government legislation
- National Parks and Wildlife — conservation of wildlife habitats
- Bushcare and bush regeneration
- Landcare — see page 11
- Wormwatch and Frogwatch — see the Nature Conservation Council of NSW, at http://www.nccnsw.org.au

See also the threatened species network of the Nature Conservation Council of NSW at http://www.nccnsw.org.au/member/tsn/support/index.html

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the technology involved to ensure biodiversity of crops and native flora including the development and use of seed banks.

See:

http://www.ento.csiro.au/biolink/home.htm — for information on the CSIRO biodiversity data base.

http://www.diggers.com.au — The Diggers (Seed Savers) Club.

Checklist Key terms for revision

autotrophic organisms	epiphyte
fruit	horticulture
vegetable	agriculture
mineral requirements	vegetative propagation
germination	cloning technology of plants
pre-germination requirements	tissue culture
van Helmont	genetic diversity/biodiversity
requirements for growth	conservation
xerophyte	seed, gamete and zygote banks
mangrove	

Test Plants

Multiple choice questions

1. This question refers to the information below. The rate of germination of saltbush seeds is affected by temperature. Below 10°C, the seeds survive but germination is extremely slow. Above 10°C, the rate of germination rises up to a maximum of 25°C. Above 25°C, the germination rate slows and ceases all together at 30°C.

Which table below is the best representation of this information for a total of ten seeds?

(A)

Temperature °C	No. of Seeds Germinated
8	0
15	5
25	5
27	10
30	10

(B)

Temperature °C	No. of Seeds Germinated
8	5
15	5
25	10
27	5
30	5

(C)

Temperature °C	No. of Seeds Germinated
8	0
15	5
25	10
27	5
30	0

(D)

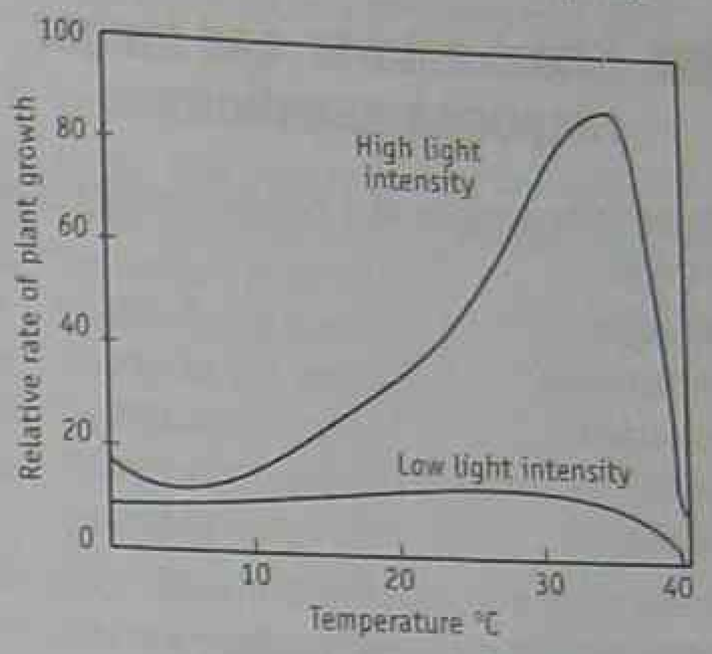
Temperature °C	No. of Seeds Germinated
8	0
15	0
25	10
27	10
30	5

2. In the seventeenth century, the botanist van Helmont grew a willow tree in a pot containing a pre-weighed amount of soil. After five years growth, the tree had gained 2.3 kg in weight and the soil had lost 0.1 kg in weight other than the water absorbed by the plant.

A reasonable conclusion from this investigation in the light of present knowledge would be that:

(A) The mineral matter absorbed by willow trees from the soil is not significant in their growth.
(B) Willow trees produce most of their food from soil water.
(C) Carbon dioxide from the air is a nutrient of major importance in willow trees.
(D) Willow trees absorb mineral matter from the soil.

3. The graphs below show the relationship between temperature and the rate of plant growth at two levels of light intensity for the same plant.



The data led to the conclusion that:

(A) The rate of growth varies directly in relation to the intensity of light.
(B) At temperatures below 25°C, there is no significant difference in growth rate between low and high light intensities.
(C) An environment at about 33°C and high light intensity provides optimal growth conditions for this species of plant.
(D) Growth rate is greatest at temperatures above 30°C.

4. Measurements were made of the amount of water lost from leaves of several kinds of plants from different climatic areas. The measurements were made under the same controlled conditions. The results are shown below.

Plant	Volume of water lost per minute per unit leaf area (mL)
I	0.04
II	1.35
III	0.08
IV	0.20

Using only these data, the plant most likely to have come from a tropical rainforest is:

(A) I
(B) II
(C) III
(D) IV

5. Which of the following techniques inhibits germination?
   - (A) Scarification
   - (B) Vacuum packing
   - (C) Lime pelleting
   - (D) Heat beds

Short answer and longer response questions

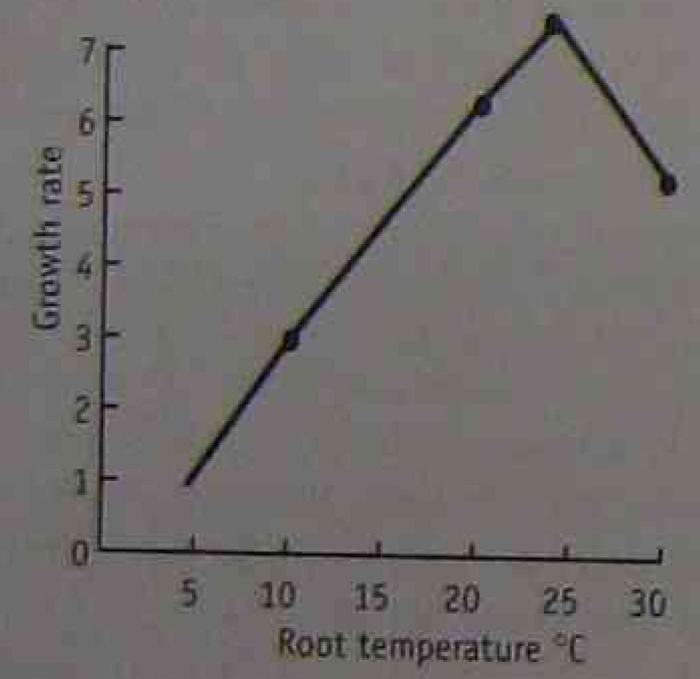
1. Below is an analysis of a common fertiliser used in gardens.

Nitrogen	7.25%
Phosphorous	5.49%
Potassium	4.98%
Sulfur	11.75%
Calcium	10.82%

Briefly outline an experiment that you could carry out to confirm the presence of some of the elements in the fertiliser. (2 marks)

2. (6 marks)

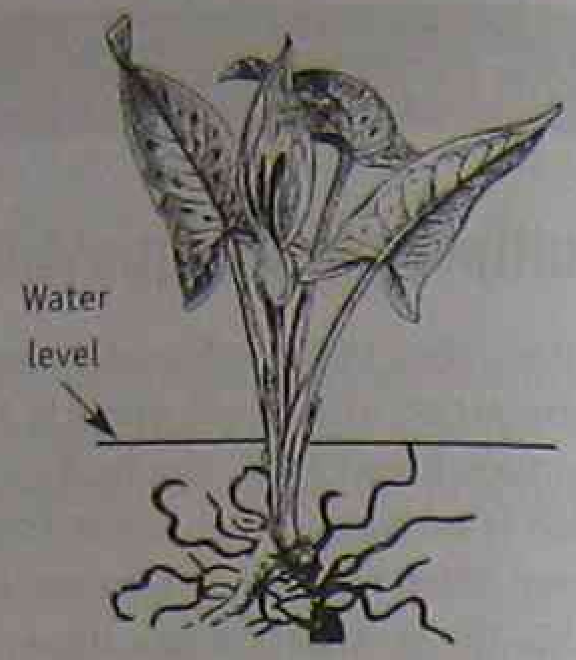
The graph below shows the effects of temperature on the rate of development of some roots.



(a) Write a statement that represents a conclusion you could draw from the shape of the graph. (1 mark)

(b) Outline a controlled experiment you could do to verify this data. In your answer include an aim, and describe the variable and the factors that you would control (keep constant). Indicate how you would measure and record your results. (5 marks)

3. The following diagram shows a plant that is adapted to being partly submerged.



Describe two leaf adaptations of this plant that would contrast strongly with the leaves of a xerophyte. (2 marks)

4. (5 marks)

Following the discovery in 1993 that smoke plays an important role in the germination of South African plants, scientists in Australia have conducted studies into the effect of smoke on the germination of many Australian plant species.

(a) Describe pre-germination requirements of three named Australian plants. (3 marks)

(b) If you were designing and performing a controlled experiment to study the effects of smoke on the germination of Grevillea seeds, what are two factors you would need to keep constant? (2 marks)

5. Describe two technological developments used to supply adequate water to seeds and plants in horticulture or agriculture. (2 marks)

Test answers

Multiple choice questions

Answers

1. C 2. D 3. C 4. B 5. B

Explanations

1. This question is designed to test your ability to interpret information or data represented as a table.
2. If there is loss of soil weight other than the water that is absorbed, the willow tree must absorb something from the soil. In the light of your knowledge, the something else is mineral matter.
3. This question is designed to test your ability to read information from a table and draw concluions.
4. Plant II lost the most water per unit leaf area per minute. A plant in a tropical rainforest lives in an environment of high humidity and rainfall and would be unlikely to have adaptations to minimise water loss. Plants I, III and IV lost little water and therefore are more likely to have adaptations which help minimise water loss — therefore are more likely to be found in environments other than rainforests.
5. Vacuum packing prevents oxygen from reaching the seed. A, C and D are techniques for promoting seed germination.

Short answer and longer response questions

Answers and explanations

1. Heat a little of the fertiliser sample on a platinum wire in a bunsen burner flame. Test a sample of a salt known to contain the element that you are testing for, such as potassium nitrate and calcium nitrate, or test a sample of the element in a flame. Potassium burns with a violet flame, sulfur with a purple flame and calcium with a red flame.

   Compare the results.

   Identify safe practices for flame tests, such as the use of a fume cupboard.

2. (a) An increase in temperature results in faster growth up to about 22°C.

   (b) Aim: to test the hypothesis that an increase in temperature up to a temperature of 22°C increases the growth of a plant species.

   The variable is the temperature.

   The factors that need to be kept the same (controlled) for each part of the experiment are:
   - The amount of water
   - The species of plant
   - The age of the plants
   - The amount of light
   - The type of medium in which each plant is grown
   - The time.

   Measure the growth of the stem and roots, the number of leaves and size of leaves over a given period of time.

   Record the data in a table, data base and/or in graph form.

3. A xerophyte is a plant that is adapted to survive in very dry conditions. The adaptations of xerophytes include a thick outer coating or cuticle on leaves, reduced number of leaves, or leaves reduced to spikes. The plant in the diagram would have adaptations in contrast to this — a large number of leaves, leaves without a waxy cuticle, leaves with a large surface area exposed to the sun.

4. (a) Acacias and pea-flowering plants require scarification — the seed coat is rubbed or abraded to expose the embryo, see page 33. Grevilleas require heat (and nicking) — soak the seeds in boiling water to soften the seed coat. Eriostemon, boronia and crowea seeds require leaching pre-treament — wash the seed under running water to leach out germination inhibitors.

   (b) The species used, the age of the seeds, the amount of smoke given and the method used (for example, as smoke water or in a smoke chamber), the time over which the experiment was conducted as well as the time of year.

5. Computer-assisted watering systems and sensors which monitor environmental variables such as nutrient levels, soil pH, air circulation, temperature, light intensity and water supply.

Preliminary Core Study Module 3

3 — Humans at Work

Introduction

The human body is structurally well adapted to the tasks required of it. The human body can also have demands placed on it which can result in injury. In this chapter you will revise the structures of the human body that enable it to deal with the everyday demands placed on it. You will also revise the safety measures that need to be considered and technologies that have been developed to protect the body from the hazards that are part of the modern environment. You will then revise the legislation and safe practices associated with occupational health and safety.

As a result of working through this chapter you will be able to:

— Assess the impact of some technological advances on our understanding of occupational health and safety

— Identify applications of science, such as the development of protective eye, ear and head equipment, that have reduced injuries at home and work

— Describe the structure of body organs and systems and relate the structure to our understanding of safe work practices

— Describe the effect of energy transfers and transformations when a hard hat or helmet protects the head.

☑ Checkpoint

Before you begin your review, you need to check your understanding of the following:

- Situations or phenomena where different forms of energy are evident. There are many forms of energy: light, sound, mechanical, electrical, heat, kinetic (the energy of movement), potential (stored energy), nuclear potential energy, chemical potential energy and electromagnetic energy. Electromagnetic (EM) radiation is around us all the time. EM radiation is waves of energy which are caused by the varying motions (speeding up and slowing down) of charged particles.

  The electromagnetic spectrum shows the range of different types of electromagnetic radiation or waves — radio waves, microwaves, light, ultraviolet light (UV light), X-rays, gamma rays. Only some of these forms of energy are detectable by the human senses. Our eyes can detect a particular frequency of EM radiation — we call this light. Even though we cannot detect some forms of energy, they still have the potential to harm us and other living things.

- The role of the digestive, circulatory, excretory, skeletal and respiratory systems in maintaining humans as functioning organisms:

  The role of the digestive system — the digestive system breaks down complex foods into simpler substances that can be absorbed through the wall of the small intestine into the blood.

  The role of the circulatory system — the circulatory system is responsible for the transport of digested foods and oxygen to all cells and the transport of metabolic waste products (carbon dioxide, nitrogenous wastes and water) away from cells.

  The role of the excretory system — the excretory system is responsible for the removal of the waste products of metabolism from the body and helps regulate the composition of the blood. For example, the excretory system helps maintain the concentration of body fluids such as water.

  The role of the skeletal system — the skeletal system provides protection and support for the organs and allows for movement.

  The role of the respiratory system — the respiratory system is responsible for the intake of oxygen, necessary for cellular respiration, and the removal of carbon dioxide, which is toxic in high concentrations. In humans the respiratory system consists of the lungs, diaphragm, trachea, bronchi, bronchioles and alveoli.

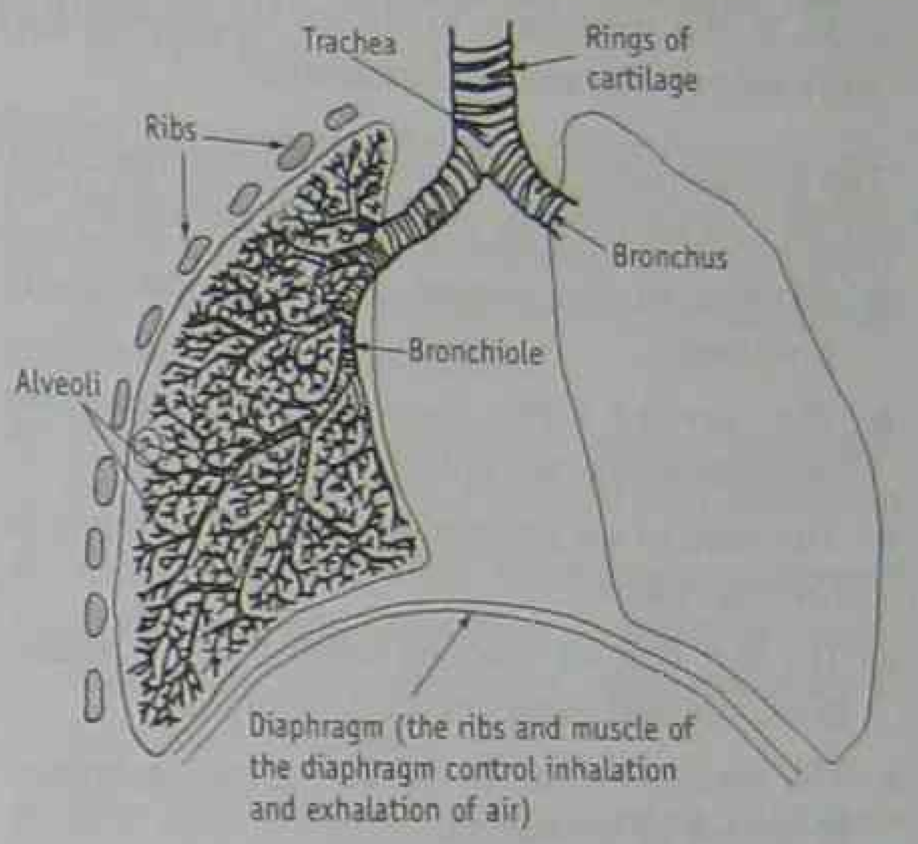


Figure 3.1 The human respiratory system

- Pollution is contamination of the environment. It may come about when humans deliberately or accidentally release substances into the environment in quantities that adversely affect health, and harm natural resources. Pollutants can directly harm organisms or they can accumulate in the body tissue of organisms to cause long-term damage to health.

- Toxic means poisonous.

The human body and injury

A **hazard** in the workplace is anything with the potential to harm life, physical and mental health, or property.

Our understanding of the damaging nature of noise, sunlight, certain chemicals, exposure to dust and fumes, and strain and impact injuries has developed over time. As a result, the need for adequate ear, eye, skin, lung and skeletal/muscular protection has been recognised and technologies developed.

The Occupational Health and Safety Act 1983

In the past, safety in the workplace often focused on the ability to deal with immediate injury in particular situations. Occupational health and safety (OH&S) now looks at the broader, longer-term issues such as identifying, assessing and controlling risks in the workplace to reduce the incidence of work-related illnesses and accidents.

The *Occupational Health and Safety Act* was introduced as a result of an increased awareness of:

- Dangers in the workplace not previously appreciated
- The use of new chemicals and processes presenting new workplace hazards
- The need to set a minimum standard of safety in the workplace
- The fact that all workers needed safety regulations, not just those on the factory floor
- The need to be able to enforce safety regulations by means of legislation.

The *Occupational Health and Safety Act* enforces safety regulations by means of legislation and covers **all** workplaces. The Act emphasises:

- Workplace participation and consultation by all employers and employees and sets out details in associated regulations, codes of practice and Australian standards, and
- The prevention of injury and illness being of paramount importance in every workplace.

The main features of the Act are:

- All employers, self-employed people and persons in control of premises are required to accept a duty of care for the health and safety of all people in the workplace. This includes employees and non-employees (such as visitors and contractors).
- The implementation of the duty of care requires everyone in the workplace to be aware of potential hazards and take steps to prevent work[illegible]ce accidents, injuries and illnesses.
- [illegible]ere is a general obligation on manufacturers and suppliers to ensure that their products are not a risk to health and safety when properly used, and to provide information on the correct use and potential hazards associated with the use of products in the workplace.

A number of regulations have been added to the *Occupational Health and Safety Act 1983* to cover a variety of working conditions and the use of a number of substances. These include the:

- *Occupational Health and Safety Act (Asbestos Dust) Regulation 1984*
- *Occupational Health and Safety Act (Confined Spaces) Regulation 1990*
- *Occupational Health and Safety Act (Manual Handling) Regulation 1991*
- *Occupational Health and Safety Act (First-Aid) Regulation 1989.*

In NSW, the Australian OH&S legislation is administered by **WorkCover NSW** which manages the State's workplace safety, injury management and workers' compensation systems. WorkCover is responsible for ensuring compliance with workers' compensation and occupational health and safety legislation. WorkCover administers the:

- *Occupational Health and Safety Act 1983*
- *Workplace Injury Management and Workers Compensation Act 1998*
- *Dangerous Goods Act 1975*
- *Construction Safety Act 1912*
- *Factories, Shops and Industries Act 1962*
- *Workers Compensation (Bush Fire, Emergency & Rescue Services) Act 1987.*

See:

http://www.workcover.nsw.gov.au

http://www.austlii.edu.au/ — for the Australasian Legal Information Institute and updates on OH&S legislation.

> As part of meeting the requirements of the course, you are expected to have carried out an occupational health and safety style audit of your school and home environment with reference to key aspects of Australian legislation on occupational health and safety.

Your investigation may have included:

- Identification of potential hazards
- For each hazard identified, the type of cause — physical, chemical or biological
- For each hazard identified, the people most likely to be at risk — due to age, skill, experience, physical capability

- Safety procedures, such as evacuation procedures, manuals on safe handling and hazardous chemicals, safety signs and equipment and its location, such as smoke alarms, fume cupboards, fire extinguishers and fire escape routes and exits.
- OH&S management and procedures such as emergency procedures and an OH&S committee.

See:
www.workcover.nsw.gov.au
www.worksafe.gov.au

Potential sources of risk

> Potential sources of risk can be assessed in terms of causes — physical, chemical and biological.

Physical causes include noise, vibrations, glare, dust, slipping, cuts, abrasions, injury to limbs, sprains and strains to parts of the body, allergens (such as pollen and dust), exposure to electromagnetic radiation such as ultraviolet (UV) light and ionising radiation (from radioactive substances), high voltages of electricity and static electricity. Static electricity is considered a risk because sparks can cause a fire or explosion.

Chemical causes include fire and explosions of highly flammable substances (such as paint thinners) and dusts such as coal dust and wheat dust which are explosive; corrosive substances (substances that 'eat' away skin); toxic chemicals; carcinogenic (cancer-causing) materials such as asbestos, glass fibres, tar products and benzene; mutagenic chemicals (carcinogenic chemicals that change the DNA of cells); asphyxiants (substances that exclude oxygen from the air, such as carbon monoxide — these are a high risk in confined spaces); heavy metals such as zinc, iron, arsenic, mercury and lead (these are absorbed by the body but are not easily excreted and therefore build up in the body over time); compounds such as chloroform, chlorinated solvents (for example, trichloethylene and PVC plastic) and neoprene rubber; aromatic compounds (that have strong odours) such as moth balls (napthalene), coal tar and bitumen.

See: http://www.haz-map.com/ — for information about toxic chemicals and hazardous jobs.

Biological causes include exposure to contagious diseases, contaminated tissue, undesirable organisms such as dust mites and pathogens (disease-causing organisms) such as bacteria. The risk is higher in industries that treat biological wastes, such as the health industry and sewerage treatment.

Factors in the workplace that increase the risk of injury

Factors that increase the risk of injury (hazards) are the main identifiable causes of occupational health and safety problems. They therefore provide a good starting place for examining ways to reduce injury and illness. The factors include:

- The workplace environment — such as poor lighting, noise levels, stress levels and poor ventilation
- The use of equipment (machinery, computers and so on) and substances — such as unsafe manipulation of machinery and exposure to hazardous chemicals
- Poor work design — such as unsafe equipment design, incorrect handling, lack of ergonomic furniture, fatigue or boredom as a result of long work hours, shift work or repetitive tasks
- Poor management systems and procedures — such as lack of supervision, lack of information and consultation, no avenues for complaints, no clear understanding of responsibilities, lack of safe clean-up procedures, lack of emergency procedures, poor monitoring, assessment and reporting procedures for risk identification and management
- Human behaviour — due to factors such as lack of training and skill development that include inadequate induction to the job and on-going workplace training, lack of training in hazard identification, lack of concern and care for others, fatigue, boredom and stress.

Potential for injury

> An individual's potential for injury is related to their age, experience, skill level and physical capabilities or weaknesses.

For example, the risks associated with manual handling may depend on a person's physical size and strength. A frail person may be at risk handling heavy loads or equipment. Similarly, people who are allergic to certain chemicals and air-borne particles would be at risk in some workplaces. Operating a fixed right-hand operated machine may pose a higher risk to a left-handed person.

The increased awareness of safety in the workplace and the home

The increased awareness of safety in the workplace and the home is related to an increased understanding of the structure and function of the human body. For example, understanding the muscular/skeletal system and how it works, particularly the spine and the mechanics of joints and muscles, helps people to lift and carry heavy objects with more safety and less risk of injury.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research and report on how our increased knowledge about the human body and workplace materials has affected safety practices. See Figure 3.2 below.

Risks to the respiratory system

Exposure to dust and chemicals in the workplace are safety hazards. Chemicals can be a risk if they enter or contact the body. Chemicals can enter the body through:

- Ingestion — they are swallowed accidentally
- Inhalation — the substances are breathed in. Inhaled substances can either directly affect the lungs or move from the lungs into the bloodstream. (See page 47 for information on the respiratory system.)

Protective measures include:

- Designing better equipment to eliminate the hazard
- Removing the hazard by using a less hazardous substance
- Adopting safer processes for working with the substance, such as protective equipment, enclosing or isolating the hazard, and providing effective ventilation.

Understanding of organ structure	Workplace materials	Safety practices
Eyes — understanding of effects of glare and radiation on eyes, eye damage and disease.	Developments in lenses which can filter harmful rays and impact-resistant, lightweight plastics.	Goggles, safety glasses, welding shields; regulations in workplaces which require eye protection to be worn.
Ears — understanding of the causes of hearing loss including industrial deafness; noise damages hearing and interferes with concentration.	Design and development of materials with high noise-absorption capacity such as polyurethane foam.	Earmuffs and earplugs and sound insulation; strict regulations require noise reduction in and around workplaces; limits on noise levels and time of exposure to noise.
Lungs — understanding that exposure to solid and liquid particles causes lung cancer and other serious diseases such as asbestosis.	Materials which filter harmful solid and liquid particles and toxic gases.	Regulations require wearing of masks, breathing apparatus, fans, filters, ventilation and extractors in workplaces.
Skull and brain — understanding the impact of head injuries on the brain tissue; damage to brain tissue is permanent.	Lightweight materials which can absorb shock and reduce impact.	Laws require cyclists to wear helmets. Strict regulations in workplaces which require hard hats to be worn; a range of helmets available for many different sports and other activities.
Skeletal/musculature system — understanding of the causes of back injury and the impacts of repetitive tasks on the musculature system.	Design and development of ergonomic furniture.	Safe-lifting practices; strengthening exercises; limits on what can be lifted safely in the workplace.

Figure 3.2 A summary of how increases in understanding about the structure of the eye, ear, lungs, skull/brain and skeletal/musculature system and workplace materials, such as lenses, plastics, silicones and filters have affected safety practices

The success of preventative methods such as dust masks, goggles, ear protection and special clothing depends on the constant cooperation of individual workers. The most successful ways of managing hazards involve reducing or eliminating the source of risk.

The function of the moist lining of the lungs

The moist lining of the lungs is required for the dissolved oxygen to diffuse through to the blood. For gas exchange to occur at a rate that ensures a constant supply of oxygen, the surface of the lungs must be kept moist, must have a large surface area and must have an extensive supply of blood. The lungs also have features (cilia) that help protect against disease-causing organisms (such as bacteria) and harmful substances.

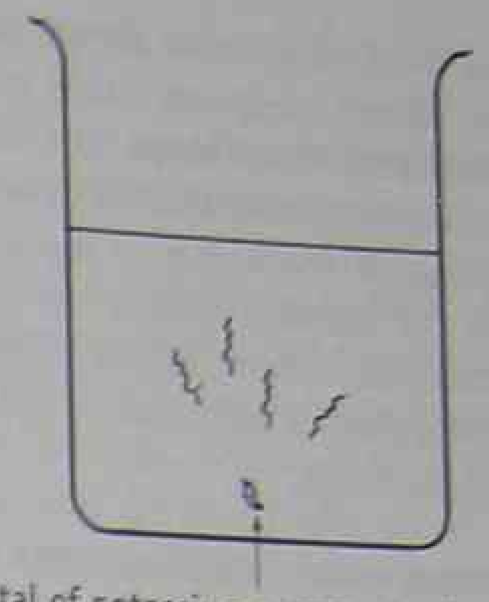
The purpose of mucous production — mucous on the lining of the lungs helps keep the lung surface moist so oxygen can diffuse into the blood at an efficient rate; protects the lung tissue; traps large inhaled particles; and helps remove pathogens and harmful substances such as pollutants and gases.

The role of cilia on epithelial tissue in the lungs — cilia are tiny hair-like structures that move back and forth on the lining of the lungs and help trap pathogens and harmful substances.

The role of the white blood cells in protection — white blood cells help fight disease and dispose of dead cells. There are different types of white blood cells. Some are phagocytes that engulf foreign bodies; some are lymphocytes (T cells and B cells which are responsible for the immune response in the human body).

As part of meeting the requirements of the course, you are expected to have carried out an experiment to observe diffusion.

Diffusion is a general term that refers to the spreading out of particles. Particles of gas, for example, diffuse easily and move freely to arrange themselves within the limits of the space they occupy. Particles tend to move from where there are many particles (high concentration) to where there are fewer particles (lower concentration). For example, if the lid is removed from a strong smelling substance in one part of a room, the particles will eventually spread (diffuse) throughout the room.



A crystal of potassium permanganate in water will diffuse throughout the water and dissolve to form a solution.

Figure 3.3 An experiment to demonstrate the process of diffusion

The inflammation reaction and how it produces allergic responses

Allergies are the body's hypersensitive response (over-reaction) to usually 'harmless' substances (such as pollen, grass seeds and dust) that stimulate an inflammation reaction. An **inflammation reaction** by the body is the result of complex reactions that are coordinated to:

(a) Isolate and destroy harmful substances and pathogens, and

(b) Prepare the body's tissue for healing and regeneration.

An inflammation reaction includes:

- The release of substances, such as histamine, by injured tissue to dilate the blood vessels, increase the permeability of blood vessels and stimulate white blood cells. The dilation of small blood vessels allows more blood flow to the injured tissue. This causes the tissue to become hot and red.
- The accumulation of fluid in the tissue. This fluid contains protein and special cells (white blood cells) that help the body to destroy foreign substances and foreign organisms. The build up of fluid causes swelling and pain.

In an allergic response, the body's immune system over-reacts and produces the inflammation reaction. The reaction causes swelling and redness (as in hives and spots on the skin) and an increase in fluid production (as in hay fever and sinus problems).

Histamine is involved in some allergic reactions. In asthma, the allergic response takes place in the mucous membranes of the lungs. The inflammation response can cause smooth muscle to contract. This causes swelling of the lining of the airways, the tightening of the muscles around the airways and the production of excess mucus. The result is narrower airways and a reduction of the flow of air in and out of the lungs.

See: http://www.asthma.org.au/asthma.htm — for the website of Asthma Victoria and information about asthma, its cause, effects, symptoms, prevention, and current directions in research.

The effect of chronic exposure to inhaled solids on lung tissue

The degree of risk of injury or illness is often related to the level of exposure to a hazard. The hazard posed by exposure to a solvent such as paint thinners, for example, increases with frequency (the number of times it is used) and duration (the length of time over which a person is exposed). Exposure to a large amount of a hazardous substance in a short time also significantly increases the risk.

> Chronic exposure to some inhaled solids such as asbestos, fine particles of silica and coal dust may increase the risk of serious lung diseases such as silicosis, asbestosis and lung cancer (see below).

> As part of meeting the requirements of the course, you are expected to have used secondary sources and available evidence to research and discuss the effect of smoking on lungs in terms of exposure to solids and liquid particles.

Cigarette smoking is the cause of serious respiratory diseases such as emphysema and lung cancer.

Emphysema is a disease in which the alveoli do not function properly. The development of lung cancer is complex. Exposure to solid and liquid particles in cigarette smoke causes inflammation of the cells lining the airways into the lungs. This causes the loss of the hair-like cells, cilia, that help trap pathogens and harmful substances and keep the lungs clear of secretions. The airways and lungs become clogged with particles. The normal plump lining cells change to flatter cells and abnormal cells begin to appear. (These abnormal cells are found in over 90% of active smokers.) A small cancer begins to develop. (These small cancers are found in the lungs of one in 20 heavy smokers.) The small cancer turns into an invasive cancer. The cancer can block the air passages and spread to other parts of the body.

> As part of meeting the requirements of the course, you are expected to have researched one respiratory condition caused by environmental factors including:
>
> - Cause
> - Effect on respiratory system
> - Symptoms
> - Prevention
> - Current directions in research to reduce the problem.

A number of ideas are provided below. They may not be the same as the respiratory condition you have chosen to study.

Repeated inhalation of cigarette smoke, asbestos, dust containing silica, coal dust and various toxic substances can cause irreversible damage to breathing passages and lead to lung cancer and other serious diseases, such as asbestosis, silicosis and mesothelioma (a relatively rare cancer of the thin membranes that line the chest and abdomen).

Lung cancer

Studies have shown that people who develop lung cancer are much more likely to have smoked or to be a smoker than those who do not. Eighty-three per cent of lung cancers are associated with and probably caused by smoking. There is also a correlation between the number of cigarettes smoked per day and the earlier age at which smoking was started and the risk of getting lung cancer. Passive smoking has also been linked to 3000 people per year getting lung cancer. In addition, high levels of pollution, radiation and asbestos exposure have been linked to the incidence of lung cancer. Early detection for lung cancer sufferers increases survival rates. If the lung cancer has not spread and is surgically removed, the survival rates are between 35% to 40% over five years. Otherwise survival rates are less than 10%. Lung cancer is currently the leading cause of death of both men and women, with the peak incidence occurring between 55 and 65 years of age. It occurs in one in every thousand people and death rates are increasing. Extensive public education programs and warnings on labels are used to alert people to the dangers of smoking (both passive and non-passive). In NSW legislation has been enacted to further ban smoking from a greater number of public places including smoking in cafes and restaurants.

See: http://health.yahoo.com/health/Diseases_and_Conditions/Disease_Feed_Data/Primary_lung_cancer/#Definition

Silicosis

Silicosis is a disease of the lungs caused by breathing dust containing crystalline silica (quartz) particles. Crystalline silica is a natural compound found in sand and granite. The dust can cause fibrosis or scar tissue formations in the lungs that reduce the lungs' ability to extract oxygen from the air. Employees in industries involving sandblasting are more likely to be exposed to crystalline silica. There is no cure for this disease, therefore prevention is the only answer.

See: http://www.osha-slc.gov/OshDoc/Factdatabaseof_data/FSNO96-54-html — for information about silicosis, its cause, effects, symptoms, prevention and current directions in research.

Asbestosis

Asbestosis is a chronic lung ailment that can produce shortness of breath and permanent lung damage and increase the risk of dangerous lung infections. Asbestosis is caused by exposure to asbestos, a naturally occurring fibre that has been extensively used in many industries including the building and construction industries.

See:
http://www.graylab.ac.uk/cancernet/600321.html — for information about asbestos and asbestosis, its cause, effects, symptoms, prevention and current directions in research. See also WorkCover NSW for regulations dealing with exposure to asbestos.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research the historical development of our understanding of one respiratory disease.

Tuberculosis

Tuberculosis is a deadly disease caused by the bacterium, *Mycobacterium tuberculosis*.

Evidence of the disease dates back to 4000 BC. Between the seventeenth and nineteenth centuries, a tuberculosis (TB) epidemic swept through England, Europe and America. No cause for the disease was determined until the late 1800s when Robert Koch (see page 168) isolated a rod-shaped bacterium which he called tubercle bacillus. Even with this knowledge, medical experts could not control TB. The disease was often more prevalent in poor or minority groups. Education and routine screening campaigns were instituted requiring children and adults to be tested for TB.

In 1943, streptomycin was found to be effective against TB but only temporarily. In 1952, a combination of drugs including streptomycin was found to be effective in treating TB. Death rates plummeted and the disease became controllable. Since 1985, the incidence of TB has resurfaced and is increasing.

Safety procedures in the school and workplace

Safety procedures to reduce inhalation of harmful substances include:

- Fume cupboards to enclose and isolate potentially hazardous fumes. Unfortunately, the fumes from many fume cupboards go straight into the air outside.
- Filtering masks as protective devices. (See details on page 54.) Different masks are made for dusts, fumes and gases. A dust mask will not protect against fumes and gases. Different cartridges in masks filter different substances. Cartridge masks have a limited shelf life. Once past their shelf life, the cartridge does not protect the wearer.
- Filters which can be separate or attached to masks and extractors.
- Dust extractors/fans, such as general exhaust fans or air extractors, which are designed to extract and enclose fumes or dust that is then disposed of safely.
- Adequate ventilation to ensure adequate space and air flow.

Figure 3.4 Filtering masks

As part of meeting the requirements of the course, you are expected to have researched different methods employed in various occupations to prevent inhalation of substances. Some examples are given below.

- Spray painting — single filter respirators, such as an A AUs P1 gas and particulate filter (P1 protection provides protection against mechanically generated toxic dusts and mists).
- Sand blasting — particulate filter masks or dusk masks for non-toxic dusts.
- Mining — particulate filter masks or dusk masks for non-toxic dusts.
- Carpentry — particulate filter masks and a gas filter where glues are used.

Generally, particulate filters are used to filter solid and liquid particles (dust, smoke, metal particles, mist) and are used in sawmills, quarries, cement works and sanding (carpentry). Gas filters are used to filter organic vapours in concentrations below 0.1% by volume, caused by chemicals such as solvents, adhesives, glues, degreasers, dyes and paints.

Combined gas and particulate filter masks are used to filter organic vapours in concentrations below 0.1% by volume as well as solid and liquid particles. They are used in spray painting, floor sanding and when using pesticides.

More information may be obtained by contacting the manufacturers such as Cigweld or BEAR Safety Products for details.

Eye protection

Eyes are very sensitive and easily damaged. Eyes can be damaged by grit, smoke, fumes, some vapours and gases, electromagnetic radiation such as ultraviolet light, and physical injury.

The function and structure of the eye

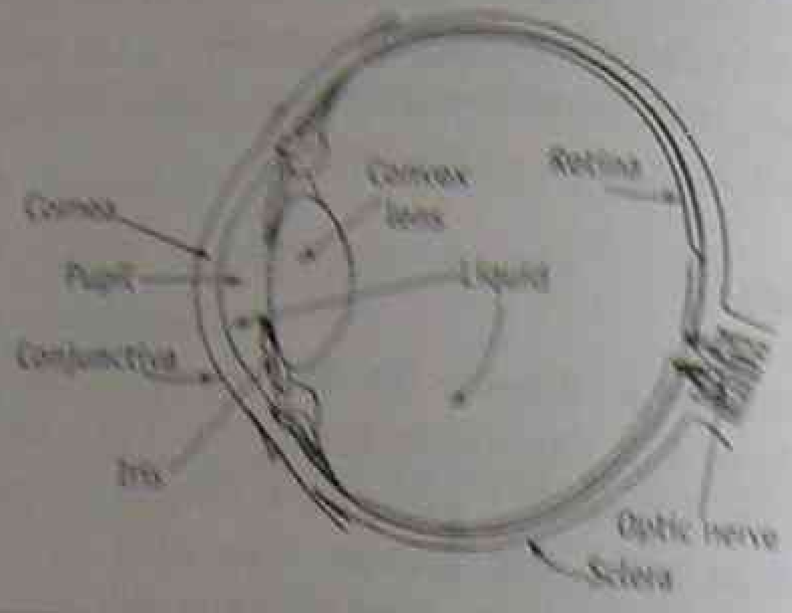


Figure 3.5 The eye — muscles move the eyeballs

Conjunctiva — a fine transparent membrane which covers and protects the surface of the cornea.

Cornea — transparent front window through which light enters the eyeball. The cornea performs much of the initial focusing of the image.

Sclera — the white of the eye; the tough outer layer that protects the eyeball.

Retina including rods and cones — a complex structure of photoreceptors (rods and cones) on the back of the eye. Photoreceptors (rods and cones) allow us to see shape, movement and colour; retinal nerve cells convert incoming light into nerve impulses. Rods are specialised for night vision. There are three types of cones, each containing a separate pigment sensitive to either blue, red or green light.

Tear ducts — ducts at the corner of the eye produce tears as a protective mechanism for the eye.

Eyelids — provide physical protection to the front of the eye.

Iris — the coloured part of the eye, the iris is a ring of muscle with a hole in the middle (the pupil). The iris controls the amount of light entering the eye: in dim light, the iris relaxes and the pupil dilates to let more light in; in bright light, the iris tightens and the pupil contracts.

Convex lens — behind the iris is the lens. The lens is a convex lens which focuses the light onto light-sensitive (photoreceptor) cells. The lens is focused with a circular, muscular ring called the ciliary body.

Optic nerve — contains one million nerve fibres; conducts the nerve impulses to the vision centres in the brain.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to model the effect of a curved surface on the path of light rays and relate this to visual acuity.

When light passes through a denser medium (such as water), its speed is slowed down. The denser the medium, the more it decreases its speed and the greater the refractive index of the medium as compared to air. If light waves hit the new medium at an angle to the medium, the light waves are bent or refracted.

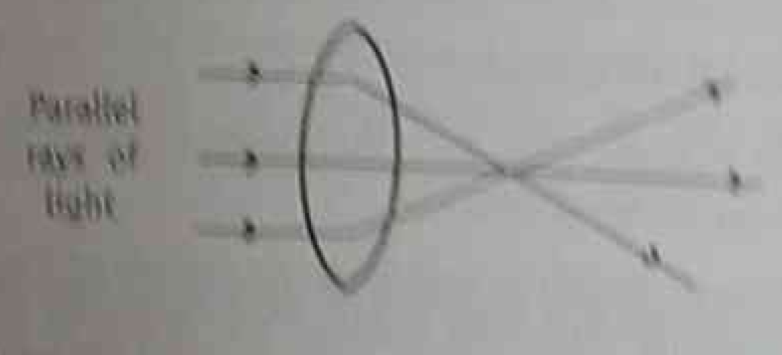


Figure 3.6 The effect of a curved surface on the path of light rays. **Visual acuity** refers to the sharpness of vision. The cornea and lens of the eye are curved surfaces that refract and focus light rays to produce a sharp image on the retina.

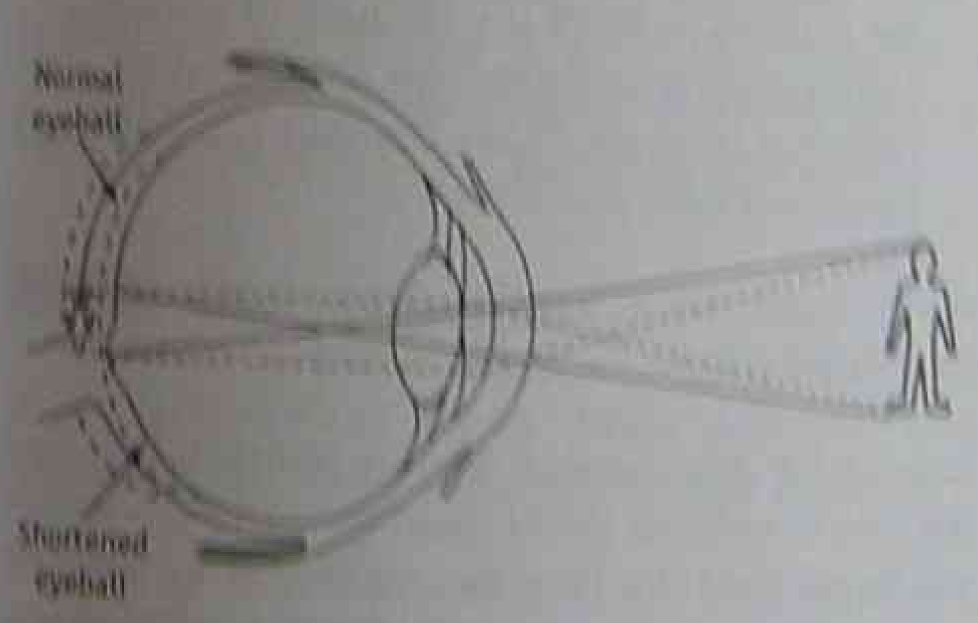


Figure 3.7 Long sightedness — when the distance between the lens and the retina is too short or the power of the lens is too weak, light rays coming into the eye from a near object will be focused on an imaginary spot behind the retina, so the retina receives only a blurred image.

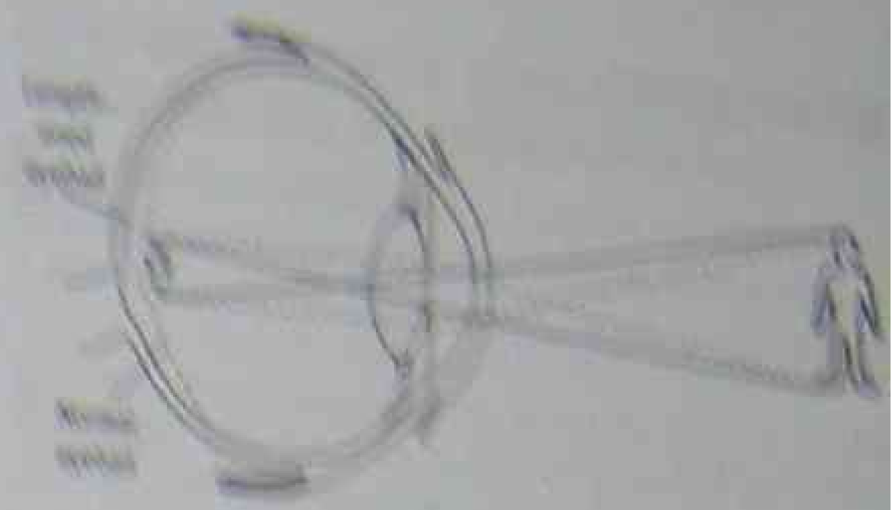


Figure 3.8 Short sightedness — when the distance between the lens and the retina is too great or the lens is too strong, the image will be focused in front of the retina. The image is blurred.

Avoiding damage to eyes in work situations

Many work situations such as computer work, factory work and building and construction, involve tasks which increase the risk of eye damage or create eye strain. Exercises, such as rolling the eyes gently right and then left, can be used to avoid eye strain.

As part of meeting the requirements of the course, you are expected to have conducted your own research to demonstrate first aid procedures when substances are splashed into the eye.

First aid procedures include irrigating the eye immediately and copiously with water for at least 20 minutes when substances are splashed into the eye. See first aid manuals for details.

As part of meeting the requirements of the course, you are expected to have researched how vision is affected by damage to the surface of the eye, including as a result of sports injuries.

All eye injuries are potentially serious. In work situations and sports, the eye can be cut or bruised by direct blows (for example, from a squash ball or hockey stick) or by glass from spectacles. A blow to the eye may result in a detached retina and loss of vision. A blow to the face around the eye may fracture the eye socket and cause loss of vision. Grazes on the cornea can scar the cornea or cause infection or possible deterioration of sight.

As part of meeting the requirements of the course, you are expected to have conducted research to compare the composition of tears with that of a commercial eye wash or contact lens solution.

pH is measured using pH indicators such as litmus paper, pH meters or universal indicator. Tears have a pH of 7.4. A deviation as small as 0.1 units from this 'normal' pH causes irritation of the eyes, therefore a commercial eye wash or contact lens solution has a pH close to 7.4.

When light can be dangerous

In the ultraviolet, visible and infra-red regions, radiation is mostly absorbed in the surface layer of the body — the skin, cornea of the eye and retina of the eye.

The eye is very sensitive to damage because it focuses beams of light onto a small area of the retina.

Light from a solar eclipse, welding light, laser light and high-intensity white light are causes for concern because in these examples, the energy is highly concentrated and focused.

Looking directly at the sun at any time can also damage the eyes. Usually it is too painful to look into the sun. However, during a solar eclipse the overall intensity of light is less and therefore it is less painful to look at the sun. The danger is that the energy is still the same and therefore the risk of damage is the same. This is why people are told not to look directly at the sun during a solar eclipse.

Glare is unwanted light. Sunglasses should be worn whenever there is a risk of exposing the eyes to glare.

Beams of light in the ultraviolet (UV) range can cause injury to the cornea and lens. Sunglasses are designed with UV protection which reduces the amount of ultraviolet radiation from sunlight entering our eyes. Welding light is also in the ultraviolet range.

Lasers are instruments that produce a highly concentrated beam of light. The energy is localised, narrow and carefully focused. The wavelength of lasers vary from infra-red to UV to visible light. Infra-red and UV are high energy radiations and therefore potentially damaging to the eyes.

Specialised protective glasses

Specialised protective glasses that are designed to protect the eye and sight include welding goggles (gas welding goggles and electric-arc welding full-face helmets), polarised sunglasses, safety goggles in the laboratory and glasses that protect against UV light (such as sunglasses).

Specialised glasses are made up of specialised lenses. The type and composition of the lens is related to the type of protection required.

Lenses can be designed to:

(a) Be shatter-proof and therefore protect the eye from physical damage

(b) Absorb or reflect certain frequencies of light and therefore filter and reduce the amount of light that enters the eye. Lenses that absorb light are composed of colourised additives to absorb different wavelengths. For example, yellow absorbs violet, blue and some UV light. The amount of the additive controls the strength of absorption. Lenses that reflect light are composed of anti-reflective coatings. These coatings can reflect all colours of light and UV rays.

When there is a hazard from flying objects, specialised glasses must also have side protection.

Goggles are wrap-around devices which fully cover the eyes in order to shield them from impact, splash and vapor hazards. They can be vented for air flow or non-vented. Non-vented goggles offer more protection from splashes and dust but need an anti-fog coating to keep them from steaming up when they are being used.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research how advances in scientific understanding have led to developments in protective eye-wear such as:

- Welding goggles
- Polarised sunglasses
- Safety goggles in the laboratory
- Glasses that protect against UV light.

Developments in our scientific understanding of chemical properties and material sciences have made it possible to produce a range of devices and lenses with specific tailor-made properties. For example, most lenses in protective eyewear are made from anti-glare coatings and polycarbonate, a lightweight, highly impact-resistant plastic, which absorbs 99% of UV light and can therefore be used in welding shields. Glass lenses are also used in protective eyewear. Glass is highly resistant to chemicals and solvents used for cleaning, but has much less impact resistance than polycarbonate lenses.

Polarised sunglasses are composed of lenses that absorb glare from snow, shiny metal surfaces and roadways. The development of polarised lenses was made possible by developments in our understanding of the polarisation of light waves.

Safety regulations involving maintenance of safety glasses

Safety glasses must be maintained in a sanitary (clean) and reliable condition. They must be used and maintained according to Australian OH&S regulations and marked to show their compliance standards. In addition, workers are more likely to use eye protection if it is clean and comfortable.

Ear protection

Noise is unwanted sound. Noise pollution is an increasing problem particularly in large cities.

Volume, or amplitude, refer to the loudness of the sound. The loudness of sounds is measured in decibels (dB). Frequency, or pitch, refer to how high or low a sound is. High-pitched (high frequency) noises are more damaging than low-pitched noises. Loud noises are more damaging than soft noises.

Humans cannot hear sounds of every frequency. The hearing range in humans is from 20 to 20,000 Hertz (Hz) or cycles per second (cps), with the greatest sensitivity around 1000 cps.

How earmuffs and ear plugs reduce sound energy reaching the auditory canal

Ear protection prevents excessive sound energy from entering the external ear canal.

Ear plugs are made of foam, plastic or glass-wool and fit inside the external ear canal. They are inserted in the external ear canal and can remain in position without support. Different shapes and dimensions of the canal in different people, sometimes makes fitting ear plugs difficult. Disposable one-use ear plugs can be moulded to shape the individual's ear canal. Ear plugs give better protection at lower frequencies.

Earmuffs are designed to fit over the pinna and cover the ear canal. Hemispheric cups are made up of light alloys or plastics filled with fibrous or porous sound absorbents. Sealing rims ensure a tight fit around the ear. A head band is needed to keep the earmuffs in place. Earmuffs give better protection at higher frequencies. Earmuffs should reduce noise levels to well below 80 decibels.

Figure 3.9 The structure of earmuffs showing how the sound waves are stopped from reaching the inner ear

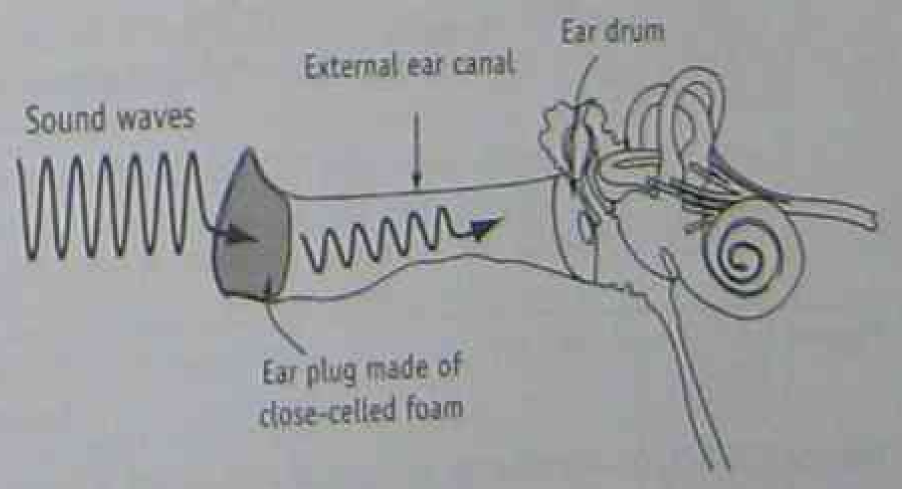


Figure 3.10 The structure of ear plugs showing how the sound waves are stopped from reaching the inner ear

As part of meeting the requirements of the course, you are expected to have carried out experiments to determine the material properties of a range of substances that could be used in earmuffs or ear plugs or to reduce sound in the environment.

Your investigations may have involved testing a range of substances (foam, glass wool, rubber, cotton wool, cardboard, lead) to determine which ones are best able to stop sounds of different loudness and pitch from reaching the inner ear.

When sound hits any surface, some sound energy goes through the surface, some dissipates within the surface (is absorbed), and some reflects back off the surface. The absorption coefficient of materials is the amount of sound absorbed by the material at frequencies from 125 Hz to 4KHz. Different materials absorb different frequencies of sound. Noise is reduced by reducing the vibration of the material. When a material absorbs sound, the kinetic energy of the air particles is converted into heat energy. Dense materials (such as lead), fibrous materials or dissimilar materials (such as layers of lead and foam with an air gap) are used to absorb sound. Foams include polyurethane foam with small pore size.

The function and structure of the ear

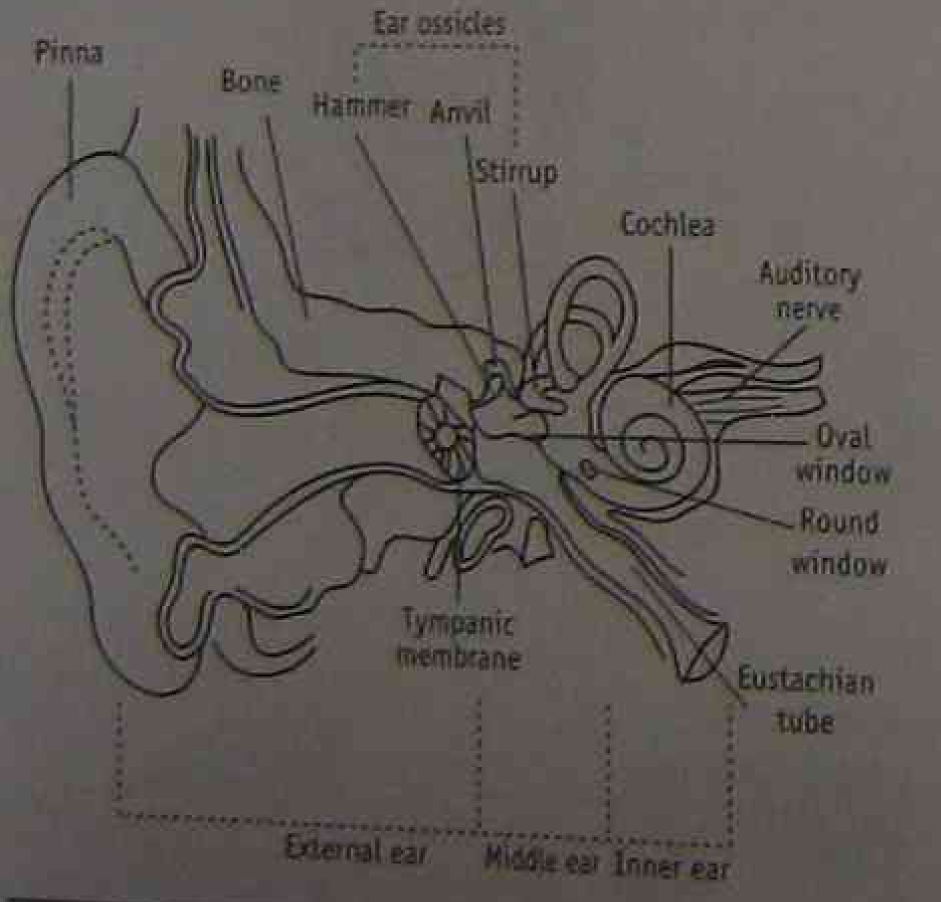


Figure 3.11 The human ear

Pinna (or flap) — collects sound waves from a wide area and funnels the sound into the external ear passage.

Tympanic membrane (or ear drum) — is stre across the end of the auditory canal and sepa the outer ear from the middle ear. Sound wa cause the tympanic membrane to vibrate. Th vibrations are then conveyed from the tympa membrane to the oval window by three tiny bo called the ear ossicles.

Ear ossicles — three intricately formed bones, t hammer, the anvil and the stirrup, transmit t sound waves to the inner ear.

Oval window and round window — two t membranes in the inner ear.

Cochlea — snail-like coiled tube, in the inner ea

Organ of Corti — contains the auditory recep cells.

Auditory nerve — transmits the sound vibrations t the brain.

The pathway of sound through the external, midd and inner ear:

External ear (ear canal and ear drum) → midd ear (vibrations are transmitted by the ear ossicles - the hammer, anvil and stirrup) → sound reaches th inner ear at the oval window (vibrations are tra mitted through the oval window to the rou window to the spiral cochlea containing fluid a nerve endings) → impulse to auditory nerve → auditory area of the brain.

The causes of 'industrial deafness'

Industrial deafness is noise-induced hearing loss. Once hearing loss occurs, it cannot be reversed.

Repeated exposure over a period of years to lou noises (sound waves with a high amplitude) ca damage the organ of Corti in the cochlea and ca irreversible hearing damage. High-frequency soun are known to have a destructive effect on th working of the delicate hair cells in the cochl Unlike other cells they are not replaced. The dama can also come from a single exposure to loud sou (such as an explosion) or from repeated exposure lower levels of sound (such as in many workplaces When damage to hearing occurs in the workplace is known as industrial deafness.

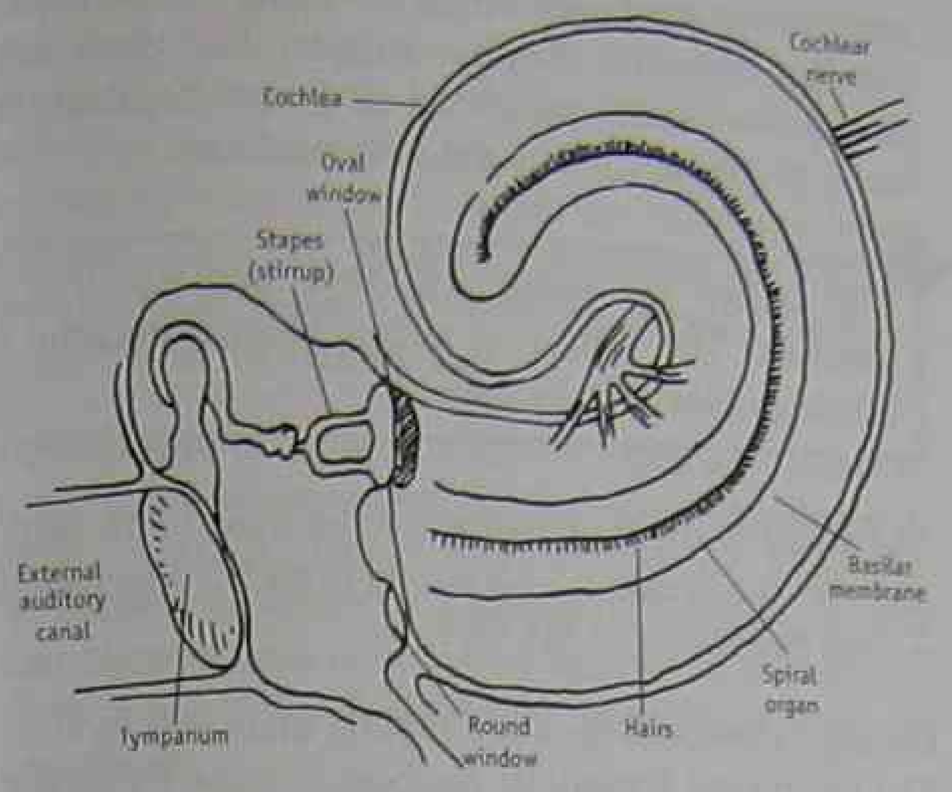


Figure 3.12 Simplified diagram of the cochlea and other parts of the ear showing which parts are damaged by long-term noise, sudden high decibel noise and the ageing process. High frequency sounds are sensed only by the specialised hair cells in the first part of the cochlea. Medium and low tones are sensed farther along. Exposure to loud sounds can damage the organ of Corti. High frequency vibrations cause the tiny, delicate hair cells to stiffen and die.

See: http://www.nidcd.nih.gov/ — website of the American National Institute on Deafness and other Communication Disorders, for more information on noise-induced hearing loss.

Sensory fatigue

Continued exposure to noise will often cause sensory fatigue (tiredness). This is because the need to concentrate hard to overcome the distracting noise requires energy. Very low-pitched noise will also sometimes cause nausea. For example, some machine noises are too low to hear but they cause vibrations which can cause nausea.

As part of meeting the requirements of the course, you are expected to have performed a first-hand investigation to examine the problems associated with hearing and learning in a noisy environment.

Your investigations may have involved a series of tasks that were done in both quiet and noisy conditions to compare the accuracy of results and levels of difficulty experienced.

Potential causes of hearing impairment

Most people suffer some hearing impairment as they get older. However, being in a noisy environment while ageing can make the hearing loss greater. Tinnitus (ringing in the ears) is a condition which can occur as a result of exposure to noise.

Noise level	Loudness on decibel scale (dB)	Type of noise	
Threshold of hearing	0–10	Rustling leaves. Light breathing.	
Faint	10–25	Whisper at two metres. Quiet office. Quiet neighbourhood at night.	
Moderate	25–50	Suburban playground. Restaurant. People talking quietly.	
Loud	50–70	Three metres from a dishwasher (50 dB). Three metres from a cicada (60 dB). City playground. Vacuum cleaner. Noisy office. Average traffic.	
Very loud	70–90	Three metres from a travelling car (75 dB). Portable sander. Food blender. Noisy party. Lawn mower. City traffic. Garbage disposal.	
Deafening	90–115	Seven metres from a truck under full power (90 dB). Three metres in front of a rock band (110 dB). Loud motorcycle. Car horn at one metre. One metre from a jackhammer (100 dB).	
Painful to ears	115–130	Thunderclap. Distant rocket. Siren at two metres. Jet engine revving for take-off.	
Physical damage to ears	130 or more	Jet plane taking off. Rocket engine at close range. Explosions. Large weapons (cannons, machine guns, etc.)	

Figure 3.13 Noise levels

Noise above 50 decibels has been shown to reduce the comfort and efficiency of people at work and at home. Higher levels are thought to partly contribute to high blood pressure, nervousness and mental illness. Chronic exposure to sounds of 90 decibels or more can cause long-term, permanent hearing loss.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to identify the relationship between age and the ability of individuals to hear a range of frequencies.

In young people the hearing range is approximately 20–20,000 Hz per second (with the middle range being the most sensitive: 500–4000 Hz). As a person gets older, their hearing becomes less acute in the higher frequencies.

Your investigations may have involved the use of a cathode ray oscilloscope and audio oscillator to produce sounds of known frequency to test the hearing range of individuals of different ages, and a number of different individuals of the same age.

For a note on controlled experiments, see page 12.

Protecting the soft tissue of the brain

The brain is surrounded by the hard bones of the skull which normally provide a lot of protection. However, in situations where a person is:

(a) Moving and then forced to a sudden stop (as in a car accident), or

(b) Not moving but hit on the head by a moving object (such as in many industrial accidents), the protection provided by the skull is not sufficient and head injuries can occur. A head injury can result in injury to the brain and/or to the skull where the skull is actually broken or perforated.

The changes in bones of the skull from birth to old age

Bones consist of living and non-living parts. The non-living part is made up of calcium which keeps the bones hard and rigid. The living part includes strands of protein, called collagen, which gives bones flexibility. The amount of calcium affects the strength of bones. Most of the skeleton of a baby consists of cartilage which is softer than bo Cartilage provides flexible support but does provide the same protection as bone. Cartilage found in places such as the nose and ears.

The bones of young children contain les calcium. The bones in older people become brittle as they lose protein.

The **skull** is the framework for the head. The sk includes the cranium — a strong protective coveri — and the bones of the face.

During babyhood, the skull rapidly increases in si The brain case (cranium) doubles in capacity in t first year. On every baby's head there are soft pla where the bones of the skull are incomplete a where soft cartilage covers the brain. The bones a soft to enable rapid growth of the skull as the bra grows. By 12 to 18 months old, the soft parts a closed and the brain is protected by bone. Th cranium reaches full size by about six years of ag The bones that make up the face grow more slow and reach maturity in the teen years.

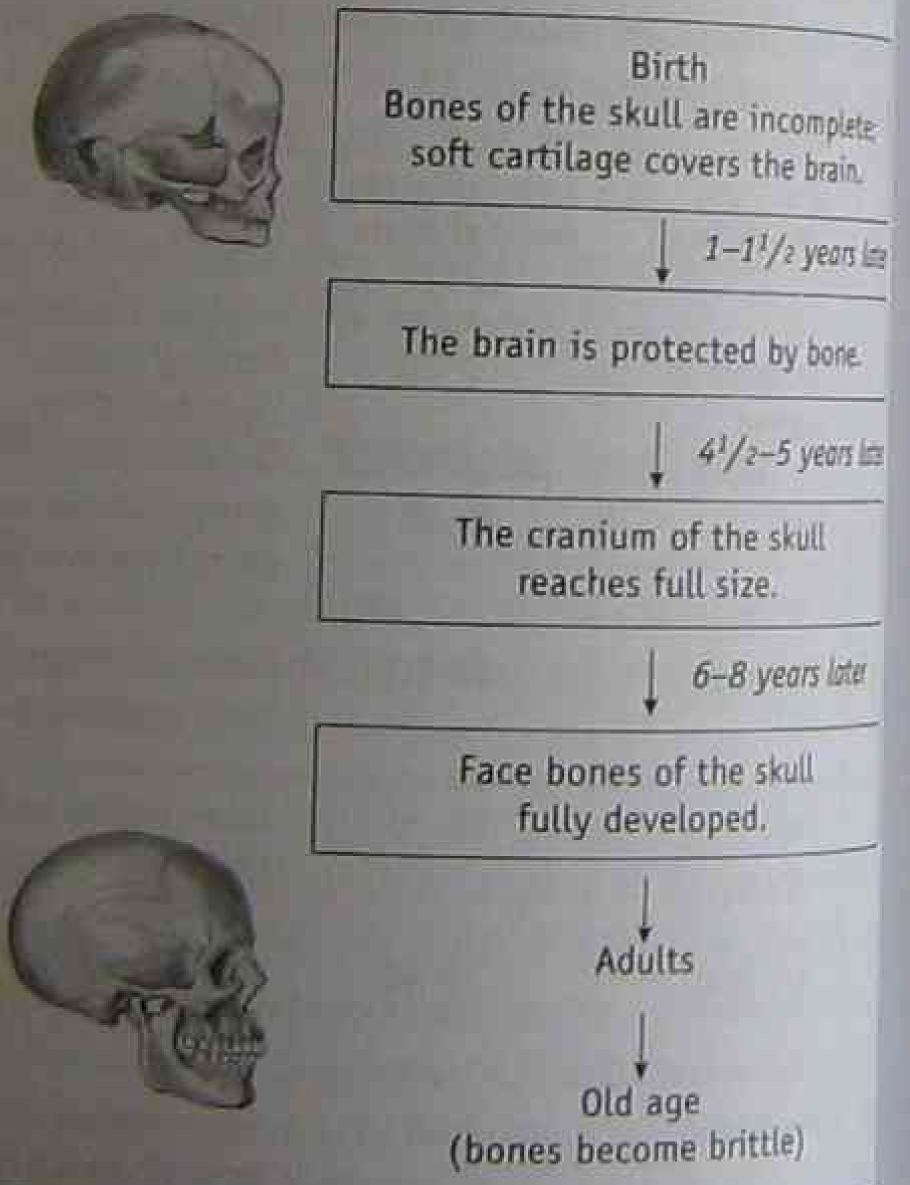


Figure 3.14 A simplified flow diagram showing the development of the bones of the skull from birth to old age

Damage to brain tissue and blood vessels

The brain fills the cranial cavity. The brain consis of a soft tissue that is easily compressed, torn, crushed. If a person is moving and stops suddenly, the brain will keep moving until it hits its own protective barrier (the skull), or it may be displaced sideways or bounce back. The energy in these movements shakes and bruises the brain and blood vessels. This can lead to concussion as well as severe head injury. If bleeding occurs, blood is spilled into the brain tissue.

Concussion is caused by severe shaking or blows to the brain. The symptoms of concussion include headache, blurred vision and altered or abnormal responses to touch or commands. Usually, people can recover from concussion without brain damage. Once brain tissue is damaged, however, it does not regenerate.

As part of meeting the requirements of the course, you are expected to have examined a model human skull to measure the thickness and inferred strength of the bone.

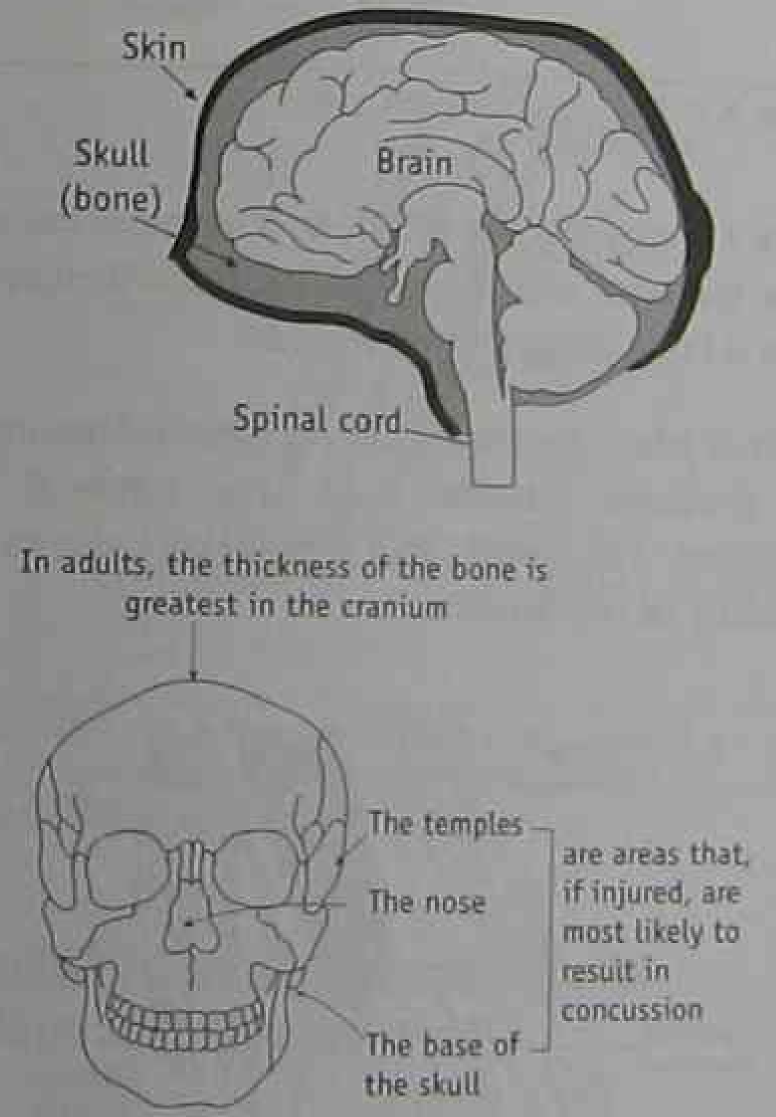


Figure 3.15 A human skull showing the thickness of the bone and the areas that are most likely to result in concussion if injured

How a hard hat or helmet protects the head from injury

All safety helmets must be able to reduce the destructive effect of shocks to the head. The hat or helmet reduces the destructive effects by absorbing the shock energy. The best way to absorb energy is by deformation (like the crumple zone on the front of a car). The helmet or hard hat absorbs the shock energy before the energy reaches the skull. The absorbed energy is converted to heat and sound energy.

Many occupations (such as the building industry), sports (motor racing, cycling, football, cricket and softball) and recreational activities require protection against head injury.

Both hard hats and safety helmets must protect the head by:

(a) Limiting the pressure on the skull by spreading the force of the impact over as great a surface area as possible

(b) Dissipating the energy in such a way that the energy is not passed to the head or neck.

Hard hats used in building construction also help deflect falling objects by having a smooth round shape. Safety helmets used in sport often need to be more aerodynamic and light weight than industrial hard hats. In many cases they also have to look 'good'.

As part of meeting the requirements of the course, you are expected to have researched laws and regulations governing the use of safety helmets and hard hats and used available evidence to discuss how the design of the protective headgear is related to the activity in one of the following:

- Football headgear
- Softball helmets
- Hard hats
- Cricket helmets
- Bike helmets.

A bike helmet must be a good fit, have openings for ventilation, and have a thick energy-absorbing foam to slow the head gradually. The energy of impact is absorbed by the foam. The helmet must also be lightweight, bright in colour and therefore easily seen, and allow the wearer to see and hear normally.

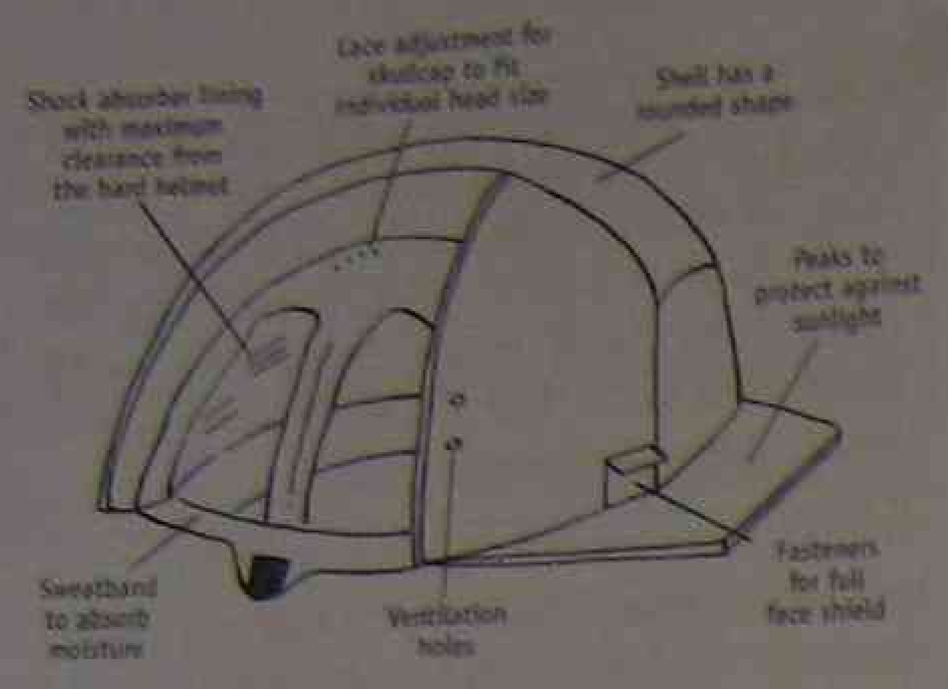


Figure 3.16 How the design of the hard hat is related to activity in the construction industry

Performance tests for helmets and hard hats are mandatory and must conform to Australian Standards. Helmets are tested for shock-absorbing capacity, resistance to perforation and resistance to flame.

Safety helmets are designed to absorb energy. Once they have been 'deformed' in an accident they will not offer the same level of protection again and should be discarded.

Safe work practices and the skeletal/muscular system

The skeletal system is made up of 206 bones and, along with the nervous system, is responsible for reflexes that protect soft tissue and prevent injury. The skeletal system and muscular and nervous systems enable movement. Bones are composed of both protein and calcium salts, which provide them with flexibility and rigidity.

The components of the axial skeleton

The **axial skeleton** is made up of the skull, backbone (vertebral column), breastbone (sternum) and ribs that form the axis (central part) of the body. The rest of the human skeleton is made up of the bones of the limbs and the bones that help attach the limbs to the axial skeleton.

The **vertebral column** supports the body. It is made up of 33 discs or vertebrae, 26 of which are separated by discs. Between each disc is a joint. **Joints** occur where the bones of the body come together. The joints in the vertebral column allow flexibility of movement — bending and twisting of the body and movement of the head.

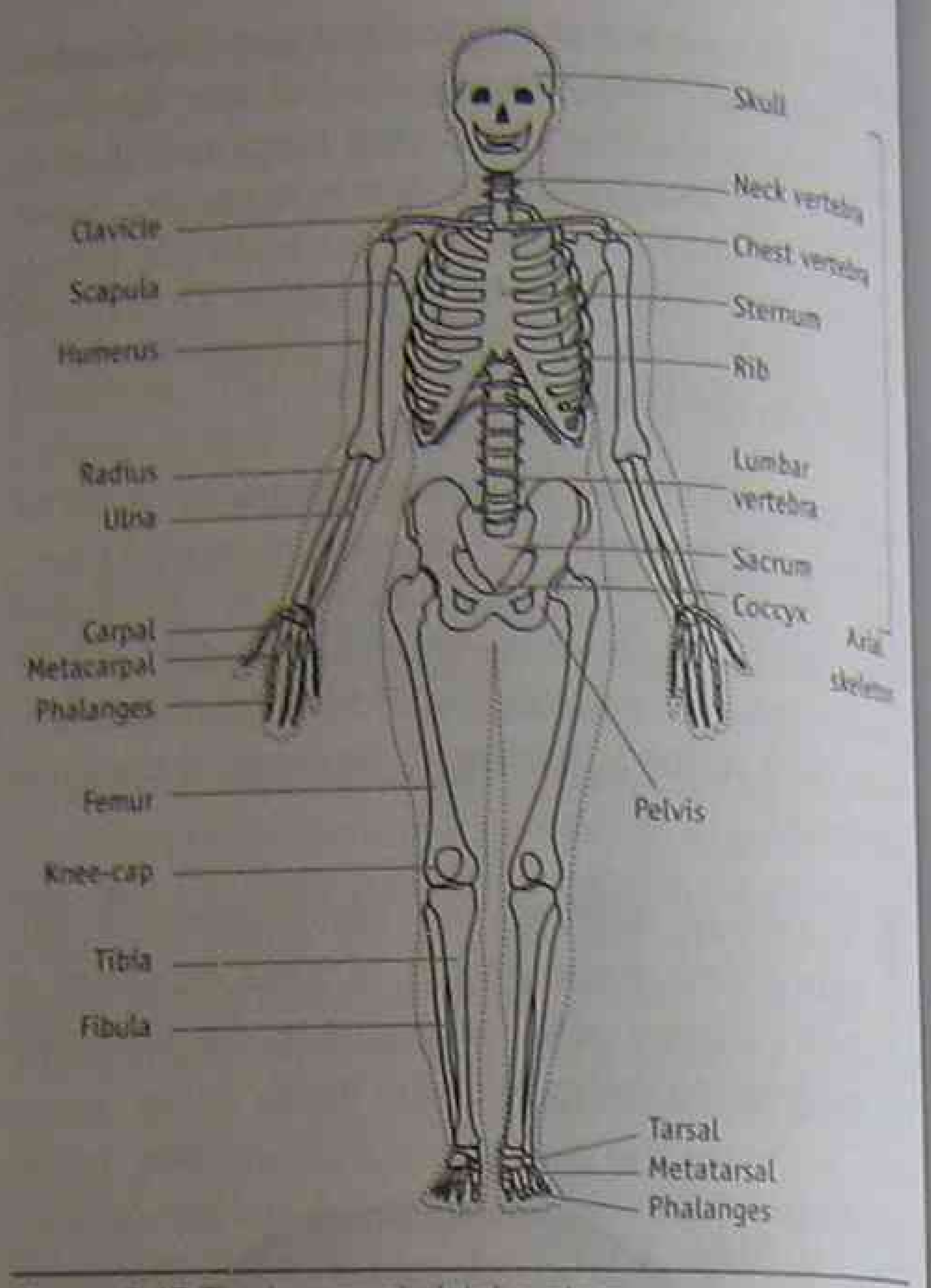


Figure 3.17 The human skeletal system

There are many types of joints. The most common is the **synovial joint**. Synovial joints are designed to allow a large range of movements.

Synovial joints are enclosed by a synovial membrane that produces synovial fluid. The synovial fluid lubricates the joint and therefore allows for flexibility of movement.

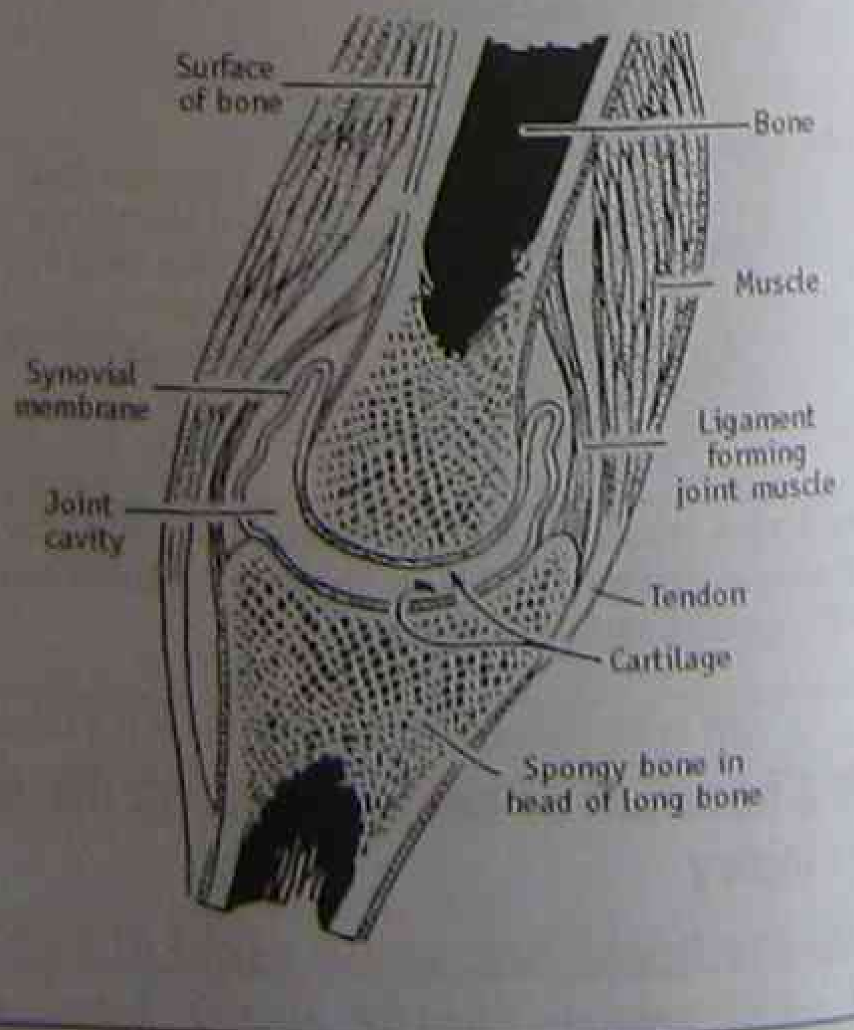


Figure 3.18 A moveable joint showing the synovial membrane

Different parts of the skeletal system differ in musculature and strength depending on the functions they perform. The vertebral column has a high degree of strength and musculature structure. The sternum protects the blood vessels that go to and from the heart and therefore must be strong. The ribs are light in comparison and are designed for the support and protection of the heart, lungs, stomach, liver and kidneys, rather than movement. Ribs also play an important role in breathing.

Muscles and movement — the skeletal or voluntary muscles are attached to bones and allow for movement. Where the movement occurs (at a joint), the muscles are attached to two bones and act in pairs. One muscle in the pair reduces the angle between the bones at a joint (bends or flexes the limb). The other muscle extends or straightens the limb, increasing the angle between the bones.

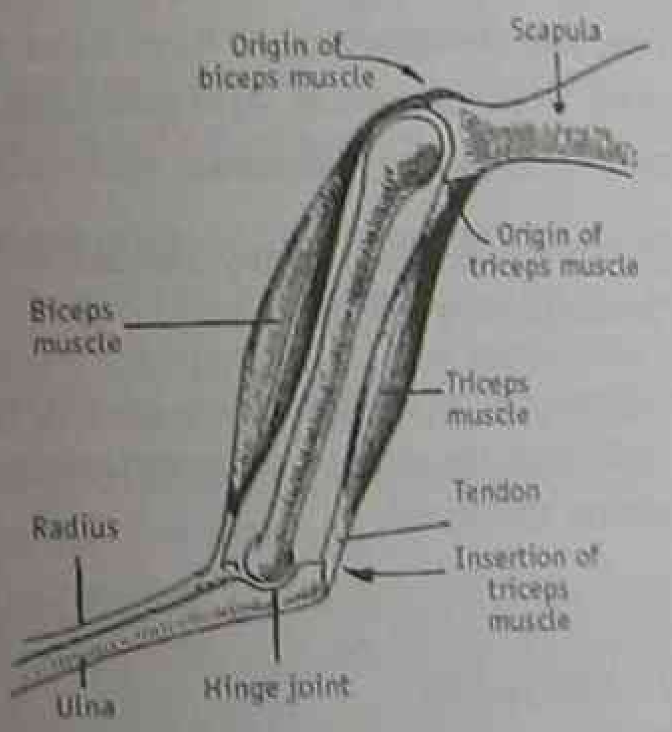


Figure 3.19 Muscles in the arm. The biceps muscle and the triceps muscle produce opposite effects. One of them must relax while the other contracts.

The role of ligaments, tendons and cartilage in joint movement

All movable joints have cartilage that reduces friction and acts as a shock absorber in those joints with extensive movement such as the backbone. Cartilage is made up of a tough elastic substance. The bones at a joint are bound together by strong, flexible fibres called ligaments. Ligaments allow movement but also ensure that the joint does not move too far. Therefore strong ligaments help prevent dislocation, sprain or injury to the joint. The role of the tendons is to attach the muscle to the bone. The Achilles tendon, for example, joins the calf muscle to the heel bone.

See Figure X, Chapter 6, for a moveable joint showing the ligament, tendon and cartilage.

As part of meeting the requirements of the course, you are expected to have carried out a first-hand investigation to examine the relationship between tendons, ligaments and cartilage in animal limbs.

Your investigation may have involved observation and description of a range of animal limbs such as chicken wings and sheep or cow joints.

Repetitive strain injury

Voluntary muscle is capable of strong contraction, but also tires more easily than other types of muscle (such as cardiac muscle in the heart). **Repetitive strain injury** (RSI) refers to injury that comes about when muscles become tired or fatigued — for example, if a person lifts or carries something heavy for an extended period of time, or repeatedly flexes a wrist or fingers as in typing. If the excessive repetitive pain continues, it can lead to injury of the tendons and ligaments associated with the muscle.

Carpal tunnel syndrome is an injury that is increasingly associated with computer keyboard use. Computer keyboards allow for continuous and rapid typing for long periods without breaks. In carpal tunnel syndrome, the nerve that passes through a 'tunnel' of bones and ligaments in the hand is compressed when the bones and ligaments become inflamed through repetitive use or strain.

Preventative measures include stopping the activity that causes the injury, such as taking frequent breaks from a repetitive task, and regular exercises that strengthen the at-risk area.

As part of meeting the requirements of the course, you are expected to have used secondary sources to identify ways in which repetitive actions in the workplace may contribute to injury.

Repetitive actions in the workplace which can contribute to injury include typing and the use of a computer keyboard and mouse; tasks in building and construction such as bricklaying; tasks associated with assembly line and factory work; checkout work in retail; and professional sports such as tennis and cricket.

Safe lifting practices

In industrial accident statistics, occurrences of back injury (followed by eye and hand injury) rate very high. There is probably no safe way to lift very heavy objects without the help of some mechanical means. OH&S legislation specifies maximum safe lifting loads for males and females.

When done properly, lifting these safe weights should be stress-free. Muscles in the legs and arms are used rather than muscles in the back. The strength of a healthy back is determined by muscles in the abdomen and the muscles and ligaments that run along the spinal column.

Steps to safe lifting:

1. Think ahead before lifting. Plan the lift by estimating the load and knowing exactly where it is to be placed.
2. Stand with feet apart with one foot in front of the other for good balance.
3. Turn the leading foot in the direction of the movement. This avoids twisting or rotation on the back or knees.
4. Bend the knees to keep the back straight - in alignment with shoulders and pelvis and not necessarily vertical.
5. Keep the arms as close to the body as possible.
6. Hold the head straight. Keep the head and chin tucked in and the back straight.
7. Grip the load securely. Wear gloves when anything with jagged edges or that could lacerations.
8. Straighten the hips and knees and lift jerking.

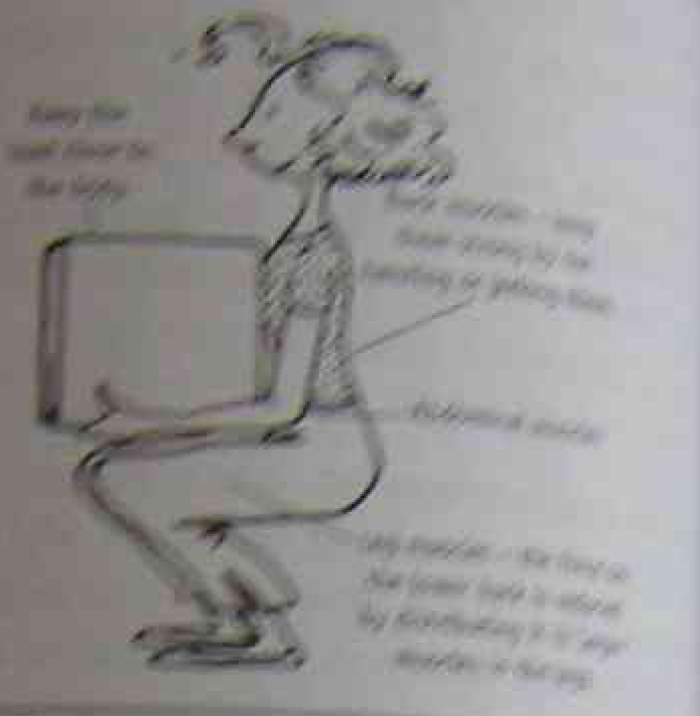


Figure 3.20 Safe lifting practice and the muscles used minimise injury

As part of meeting the requirements of course, you are expected to have used sources to demonstrate strengthening employed in a range of sports and occupa

See: http://www.physiotherapy.asn.au — the tralian Physiotherapy Association.

A physiotherapist, sport's trainer or PD/Heal teacher will also be able to demonstrate a strengthening exercises.

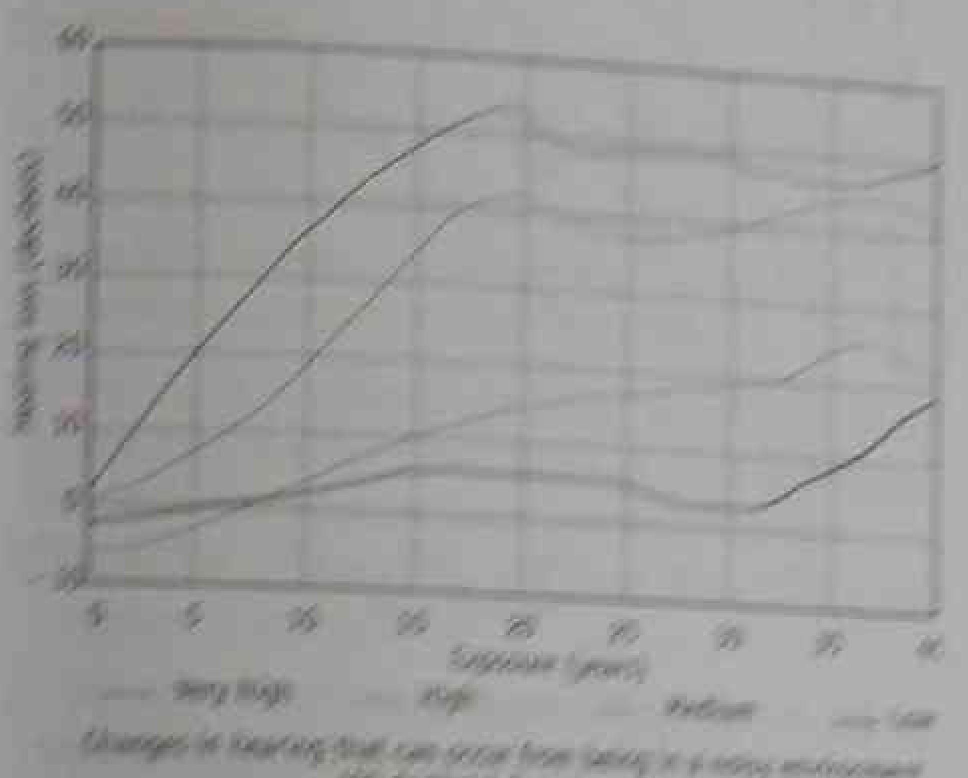
Checklist

Key terms for revision

Occupational Health and Safety Act	eyeball muscles
workplace hazard	protective eye wear
potential sources of risk	earmuffs/ear plugs
safety practices	auditory canal
mucous production in the respiratory system	industrial deafness
cilia on epithelial tissue in the lungs	hearing impairment
white blood cells	human skull
inflammation reaction	concussion
inhalation of harmful substances	head protection
diffusion	axial skeleton
respiratory disease	vertebral column
conjunctiva	synovial joints and discs
cornea	musculature and strength
ciliary	ligaments
retina	tendons
tear ducts	cartilage
eyelid	repetitive strain injury
convex lens	safe lifting practices

Multiple choice questions

1. The graphs below show changes in hearing that can occur from being in a noisy environment for a long time. Which statement below is NOT a correct interpretation of the graphs.



Changes in hearing that can occur from being in a noisy environment (95 decibels) for a long time.

(A) Hearing loss is temporary. Once hearing loss occurs it can be recovered.
(B) Very high hearing loss can occur after 15 years of exposure to noise.
(C) Some hearing loss will definitely occur after 30 years of exposure.
(D) Hearing loss in decibels can range from approximately 2 to 37 after 10 years of exposure.

2. Which of the following flow diagrams most accurately represents the energy transfers and transformations involved when a hard hat or helmet protects the head from injury?
(A) Kinetic energy → heat and sound energy
(B) Potential energy → heat and sound energy
(C) Potential energy → kinetic energy → heat and sound energy
(D) Sound energy → heat energy → kinetic energy

3. Which of the following bones would you expect to have a higher degree of strength than musculature features?
(A) Vertebrae
(B) Sternum
(C) Femur (upper leg bone)
(D) Finger bone

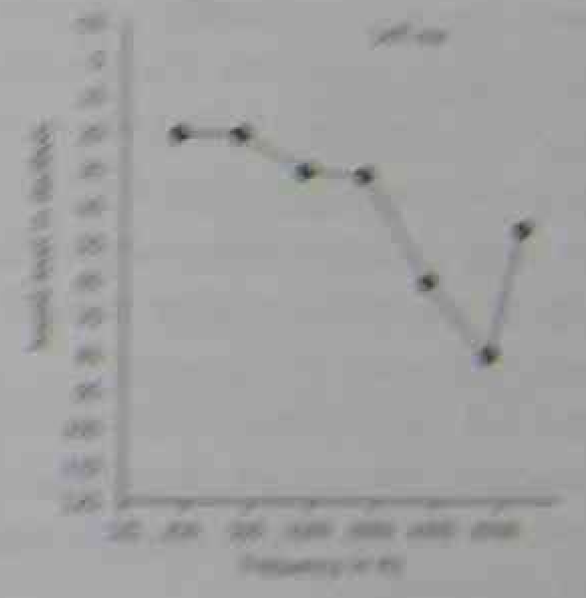
4. Which hazard below is a biological source of risk?
(A) Exposure to pathogens
(B) Exposure to noise
(C) Exposure to corrosive substances
(D) Glare

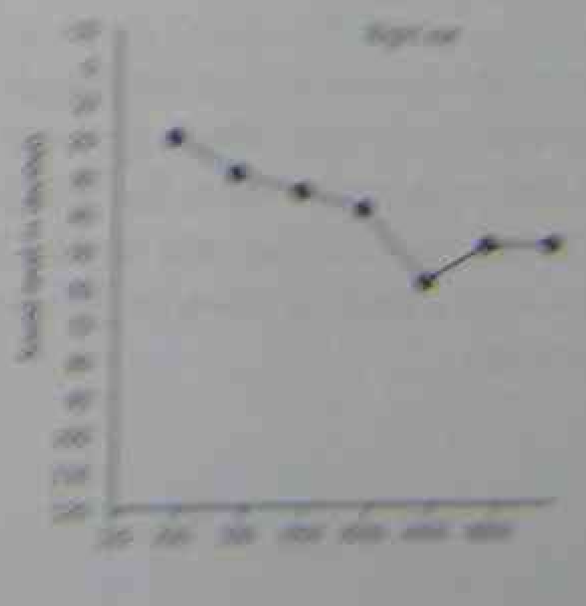
5. A student conducted an investigation to compare the pH of tears with that of a commercial eye wash. The student would expect that the pH of the commercial eye wash was closest to:
(A) 3.4
(B) 6
(C) 9
(D) 7.4

Short answer and longer response questions

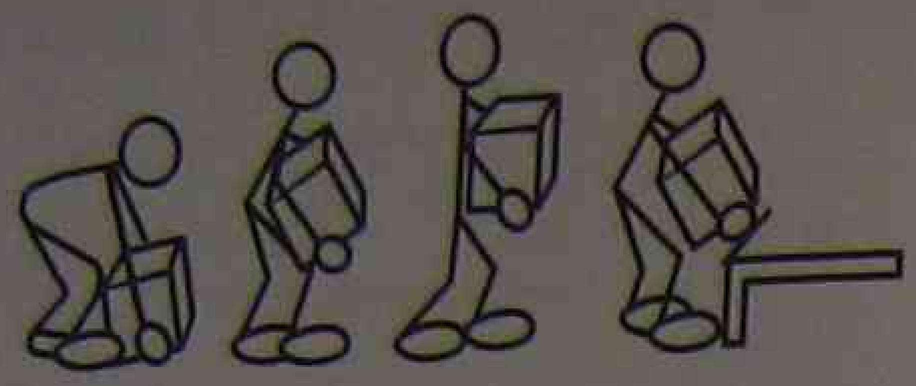
1. The audio graph below shows typical noise-induced hearing loss.

An audio graph shows a curve of attainable hearing. A young person who has healthy hearing and has never been exposed to noise will be able to hear all frequencies at zero or above zero. Most older people do not detect sound until the volume has been increased to 10 or 20 decibels. A flat audio graph indicates normal hearing. Write a statement that summarises the information shown on the audiograph. How else might you represent this information? (3 marks)





2. The diagram below shows safe lifting technique.



Analyse each step and briefly outline the step relative to the muscles used to minimise injury. (3 marks)

3. (6 marks)

The information below is health hazard information from a material safety data sheet for sulfuric acid.

Read the information and answer the questions (a) to (e) that follow.

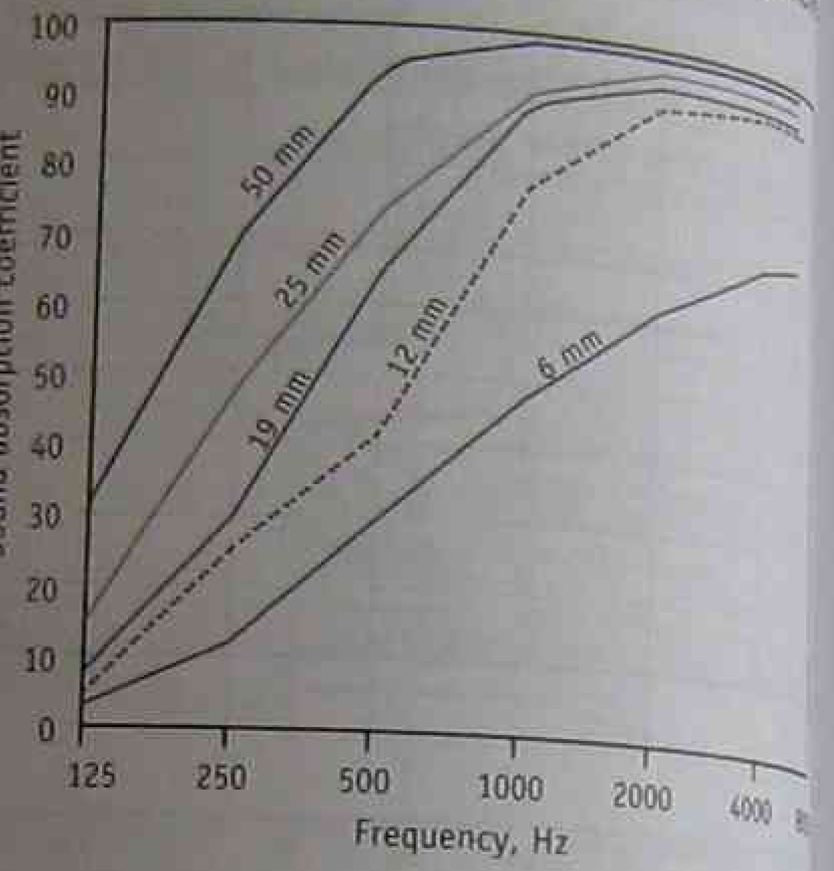
Acute effects
Eye: Corrosive to eyes; contact can cause corneal burns.
Permanent eye damage, including loss of sight may occur.
Skin: Highly corrosive to skin.
Causes severe burns.
Inhaled: Harmful by inhalation.
Possible harmful corrosive effects.
High concentration of vapour can cause severe irritation of the respiratory tract.
Swallowed: Can kill if swallowed.

(a) What is inhalation? (1 mark)
(b) What is the cornea? (1 mark)
(c) What is the respiratory tract? (1 mark)
(d) If a small amount of this substance was splashed into the eyes, what first aid procedures would you carry out? (1 mark)
(e) Name two occupational health and safety procedures that you would recommend to prevent accidents and eye or skin contact with this substance. (2 marks)

4. As part of this course, you carried out an occupational health and safety style audit of your school and home environment. List four potential hazards that you identified, and for each hazard, describe it as a physical, chemical or biological source of risk. (8 marks)

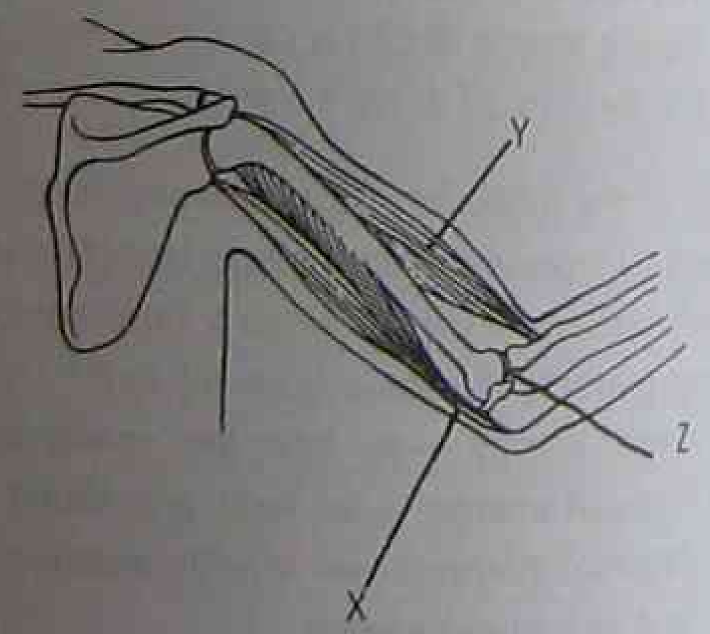
5. (4 m

(a) The graph below shows the absorption coefficients for different thicknesses of a f used for noise control in tractor cabs. Wr two statements that represent some of the information shown on the graph. (2 m



(b) As part of this module, you carried out an investigation to determine the material pro erties of a range of substances that could b used in earmuffs or ear plugs to reduce sou List two factors in your experimental desig that needed to be kept constant. (2 mar

6. Look at the diagram below.



Name the parts labelled X, Y and Z and for each part, describe its role in the movement of the body. (6 mar

Test answers

Multiple choice questions

Answers

1. A 2. C 3. B 4. A 5. D

Explanations

1. Once hearing loss occurs, it cannot be recovered.
2. See page 61 for details on energy transfers and transformations involved when a hard hat or helmet protects the head from injury.
3. The sternum protects the blood vessels that go to and from the heart and therefore must be strong. A, C and D are examples of bones which are involved in movement. Therefore, they have a high degree of muscularity.
4. Pathogens are disease-causing organisms, such as some bacteria.
5. The pH of tears is 7.4. A commercial eye wash must have a pH similar to the pH of tears in order to prevent eye irritations.

Short answer and longer response questions

Answers and explanations

1. Noise induced hearing loss has a curve showing a loss at about 4 KHz. The hearing seems to be retained in the higher frequencies. This information could be represented in a table or as a series of diagrams.
2. Stand with feet apart for balance, and turn the feet and body in the direction of the movement. Bend the knees and keep a straight back. Keep the arms close to the body. Muscles in the arms and legs are used to minimise injury. Keep the head straight and straighten the body without jerking. Muscles in the abdomen and muscles that run along the spinal column are used to minimise injury.
3. (a) Breathing in (see page 50).
   (b) The transparent covering on the front of the eye.
   (c) The parts of the body responsible for breathing in oxygen and breathing out carbon dioxide.
   (d) Irrigate the eye immediately and copiously with water for at least 20 minutes and call an ambulance immediately.
   (e) A number of answers are provided. You only need to provide two.
   - Clear labels to warn of hazards
   - Safe handling manuals and clear procedures for cleaning up spills
   - Evidence of thorough training
   - Rubber gloves made from substances resistant to acids (synthetic rubber)
   - Full protective clothing
   - Goggles with side protection and face mask attachments
   - Ventilation and fume extractors.
4. Make sure you answer each part of this question. See page 49.
5. (a) There are a number of statements that represent information on the graph. A sample answer is:
   - The thicker the foam material, the better it absorbs sound.
   - Material with a thickness of 50 mm has a maximum absorption coefficient at about 750 Hz.

   (b) Factors to be kept constant include the thickness of each sample material and the distance each is placed from the ear.
6. X: tendon — attaches muscle to bone.

   Y: muscle (bicep) — contracts to allow movement of the arm (bending).

   Z: joint (hinge joint) — allows movement in one direction.

Preliminary Core Study Module 4

4 — Local Environment

Introduction

In this chapter you will review your understanding of ecology and ecosyste and the field study of your local environment — its unique physical, chemic geological and biological features, the interaction of these features, the type of ecosystem that is present and the type and number of flora and fauna t ecosystem is able to sustain. You will also review your assessment of t human impact on the environment and realistic solutions to the proble caused by this impact.

As a result of working through this chapter you will be able to:

— Apply the processes that are used to test and validate ecological models

— Identify applications of technology that affect society and the environment, such as technology that causes pollution

— Identify trophic and other kinds of relationships between organisms i an ecosystem

— Conduct a field study to gather data and assess its validity and reliabi

— Use appropriate terminology and reporting styles to communicate information gathered from a field study.

☑ Checkpoint

Before you begin your review, you need to check your understanding of the following:

- How living things adapt to factors in their environment. Organisms live where they do because they survive there. To survive and reproduce in a particular environment, organisms have features — adaptations — that suit them to that environment. Adaptations can be:
  - (a) Structural — for example, the forelegs of the red kangaroo have a dense network of blood vessels close to the surface of the skin.
  - (b) Physiological — this refers to function. The network of blood vessels in the kangaroo's forelegs allow increased blood flow to that area during heat stress and therefore increases the amount of heat lost by radiation.
  - (c) Behavioural — the kangaroo licks the foreleg to cool down.
- How producers, consumers and decomposers in Australian ecosystems are related, using food chains and food webs.

> ✓ Energy flows through an ecosystem one way from producers to consumers. Decomposers return organic matter to the ecosystem.

The cycling of matter is driven by the sun.

Producers are organisms that make their own food (autotrophs) using energy from the sun; plants are producers.

Consumers are organisms that feed on other living things. Animals are consumers. In food chains and food webs, consumers are referred to as first-order consumers (or herbivores), second-order consumers (omnivores or carnivores), and higher-order or third-order consumers (carnivores).

Decomposers are organisms that absorb nutrients from dead tissue or waste products of organisms.

Bacteria and fungi are the main decomposers in an ecosystem.

Food chains are a simple way to show feeding relationships and energy flows in an ecosystem. Feeding relationships are called **trophic** relationships.

Food webs are used to show the complicated feeding relationships that are more likely to occur in an ecosystem.

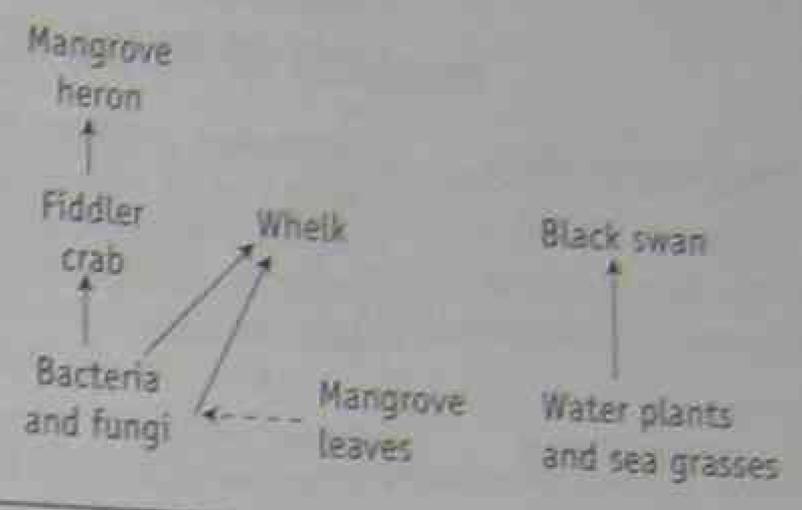


Figure 4.2 A food web. NOTE: The arrow → means 'is eaten by'. The 'dotted' arrow ⇢ means 'is decomposed by'.

- The roles of photosynthesis and respiration in ecosystems — photosynthesis and respiration are the basis of the carbon/oxygen cycle. Photosynthesis releases oxygen to the air. Respiration releases carbon dioxide to the air. Energy is needed for all life processes. Photosynthesis changes light energy from the sun into glucose. Respiration changes glucose into chemical energy.

Biotic and abiotic factors of ecosystems

The differences between abiotic and biotic features of the environment

Biotic factors are all of the living components or biological features of the environment — members of the same species and members of different species, for example, competitors and predators.

Abiotic factors are the non-living features of the environment, such as physical and chemical soil factors, temperature and rainfall.

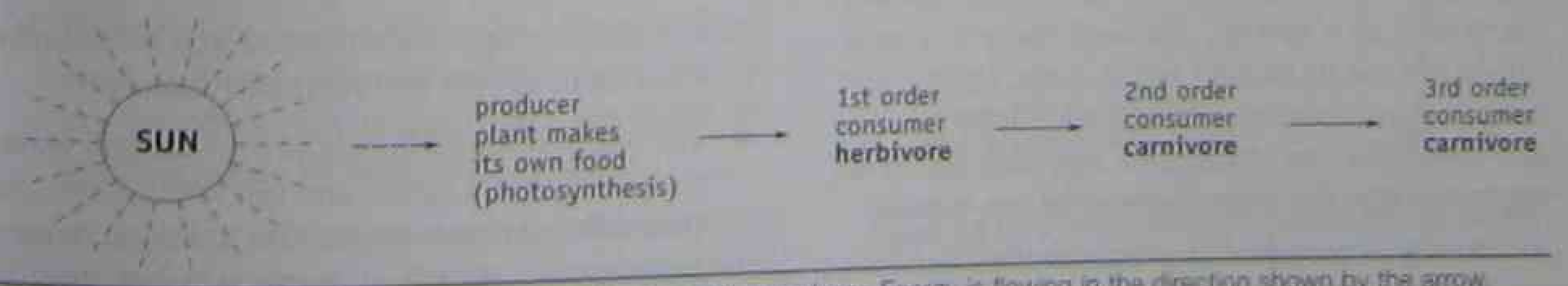


Figure 4.1 A food chain. Note: Every food chain begins with a producer. Energy is flowing in the direction shown by the arrow. Some energy is lost at each step in the food chain. The arrow → means 'is eaten by'.

The abiotic characteristics of aquatic and terrestrial environments

Abiotic characteristics	Aquatic environments	Terrestrial environments
Viscosity — the stickiness of a fluid and its power to resist movement.	Water is more viscous than air.	Air is less viscous than water.
Buoyancy	Organisms that live in water experience an upward force or upthrust; water is dense; water provides some support to organisms.	Organisms that live in air do not experie an upthrust; organisms that live in air must have structures for support.
Temperature variation	Temperature variations are much less in water than on land; they are most stable in seawater; temperatures vary most in small ponds; temperature in water decreases as depth increases.	Temperature variation is extreme on land air temperature in the desert, for example may reach 40°C during the day and 2°C a night.
Availability of gases	Oxygen availability is lower in water than in air; the solubility of oxygen is 0.5% (5 cubic centimetres per litre of air) in sea-water and slightly higher in freshwater; diffusion of oxygen is slower in water; carbon dioxide availability is higher than oxygen; carbon dioxide dissolves in water to form bicarbonate ions.	The concentration of oxygen in air is highe than in water — 21% (210 cubic cm per litre of air); diffusion of oxygen is 300,00 times faster in air than in water.
Availability of water and ions	Organisms that live in water are surrounded by water in which ions are dissolved; salt content is lower in freshwater than in seawater.	Water availability varies greatly on land; i deserts, rainfall is low (less than 245 mm per year on average); ions are not as readi available; ions are dissolved in soil water
Light penetration	Light penetration decreases as depth increases in water.	Light intensity is high on land.
Pressure variation	Water pressure increases as depth increases.	Air pressure decreases as height increases

The distribution and abundance of species

Distribution refers to the places where a species is found — its range.

Abundance of a species refers to how many individuals there are at a specific time in a specific area.

A combination of factors affect the abundance and distribution of a species. Although there is a great variety of habitats on land and in water, aquatic and terrestrial environments have basic characteristics that determine the abundance and distribution of organisms that live there. General factors include:

- Climate — temperature, wind, rainfall, humidity and light intensity
- Availability of food
- Shelter
- Other resources such as living space, nes material and soil
- The interaction of organisms with other org isms. The distribution and abundance of pl affects the distribution and abundance of ani and vice versa. Human activity in an area imp on the abundance and distribution of organis

Factors determining the distribution and abund of a species in aquatic environments include:

- The rate of water flow — tidal regions, still wa such as lakes and ponds, and fast flowing str have different characteristics. For example, oxy availability is greater in moving water tha still water.
- The availability of light — plants need light for photosynthesis. Water absorbs light, therefore the distribution of plants and animals is largely restricted to depths where light can penetrate.

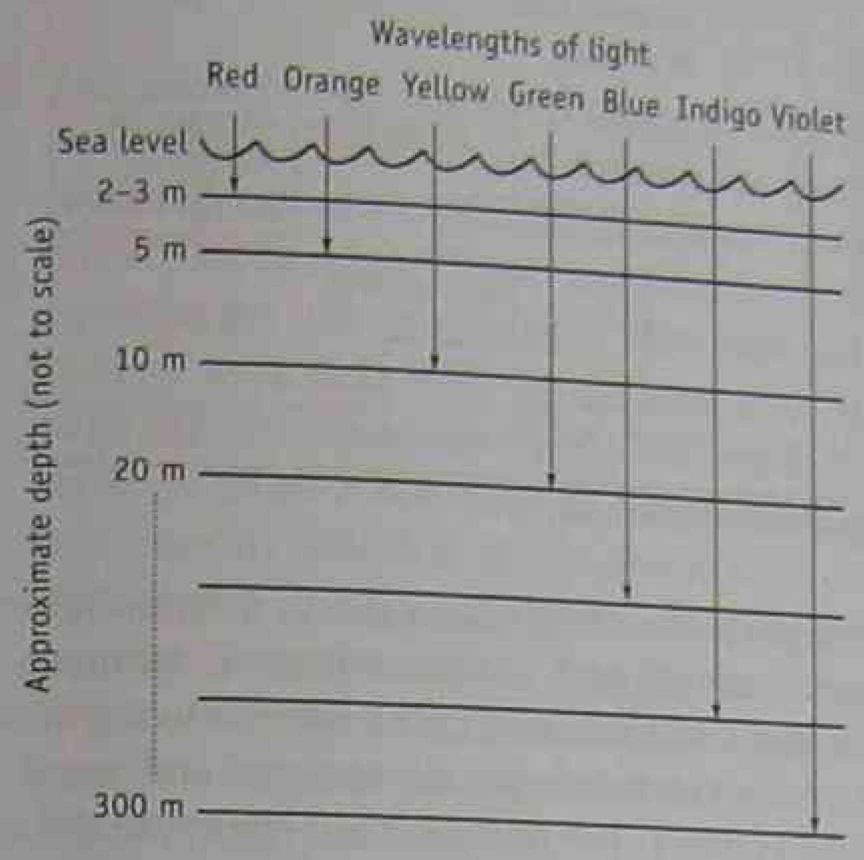


Figure 4.3 The vertical distribution of plants in water is related to the ability of different wavelengths of light to penetrate water to different depths.

Factors determining the distribution and abundance of a species in terrestrial environments include:

- Topography — aspect and slope. Aspect is the direction that the slope faces. North facing aspects are more exposed to light than south facing aspects and will therefore have a greater abundance of plants that can survive higher light intensity. Slope affects wind speed and water speed. The steeper the slope, the faster the wind moves uphill and the faster water moves downhill.
- Exposure to wind and availability of shelter.
- Soil type — the water-holding capacity of soils and the amount of organic matter in the soil. For example, sandy soils have a lower water-holding capacity than clay soils. Many Australian soils are low in mineral nutrients such as nitrogen and phosphorous. This reduces the abundance of plants that need high levels of nitrogen and phosphorous.
- Temperature — temperatures vary greatly on land. In deserts where temperatures are extreme, the distribution of animals and some plants will be determined by availability of shade.
- Availability of water — any wet surface exposed to air loses water to the air. Water evaporates faster in dry air than in humid air and when air temperatures rise. High rainfall environments such as rainforests support a greater abundance of organisms than low rainfall environments. In deserts plants are usually spread out thinly to reduce competition for limited water. Animals will tend to cluster around waterholes. Mobile species such as parrots and cockatoos can escape times of low water availability by flying to other areas.

Competition for resources

Competition occurs when members of the same or different species need the same limited resources of shelter, food, water, space, sunlight and nesting places. Competition occurs between those organisms that are most alike.

In the short-term, competition leads to a decrease in the availability of resources such as food, and amount of space.

The long-term consequences include:

- Degradation of the environment: resources become depleted.
- The diversity of organisms present may be reduced.
- Extinction: one species may cause another species (or a number of other species) to become extinct. The 'survivor' will be the species that can reproduce and survive best under these conditions.
- Evolution: under different environmental conditions the results may be different. The two competing species may minimise competition by evolving under strong selection pressures to occupy different niches.

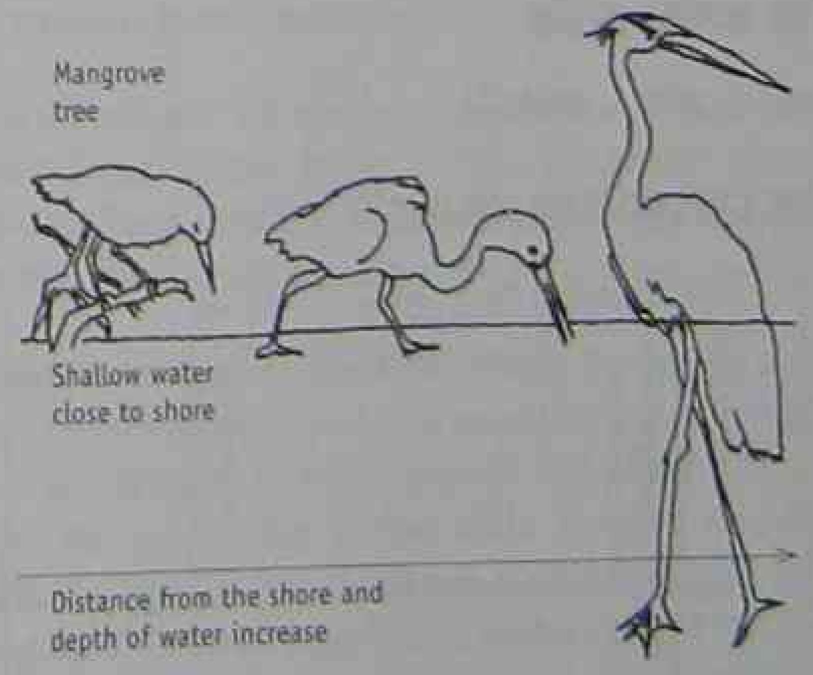


Figure 4.4 Herons have evolved to occupy different niches in order to minimise competition. The herons live in the same habitat, shallow brackish water, and like the same food.

Sampling techniques and population estimates

Sampling techniques, such as quadrats, are used to make population estimates of abundance when total counts cannot be made. Total counts are difficult to make when there are too many organisms, when the organisms are very mobile, or when they are scattered over too big an area. (See page 73 for details).

The flow of energy and matter in an ecosystem

The importance of the cycling of materials in ecosystems

The amount of matter on Earth is fixed. It cycles through living and non-living materials. The Earth does not receive a continuous supply of chemical nutrients. This matter is passed from one organism to the next in closed cycles. Increasingly, humans are interfering in the natural process of cycling of materials in nature.

The flow of matter through a natural ecosystem

Matter is recycled through a natural ecosystem. Dead matter and waste materials from living things are broken down by decomposers and returned to the soil. Nitrogen, carbon, oxygen and water are examples of non-living matter that is recycled through natural ecosystems.

The water cycle

See Chapter 1, page 2.

The carbon/oxygen cycle

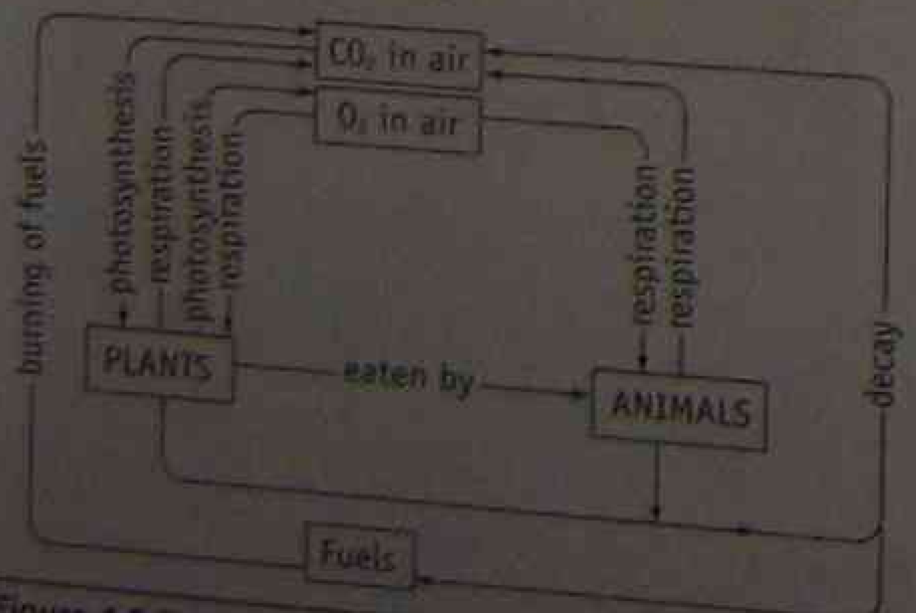


Figure 4.5 The carbon/oxygen cycle

The nitrogen cycle

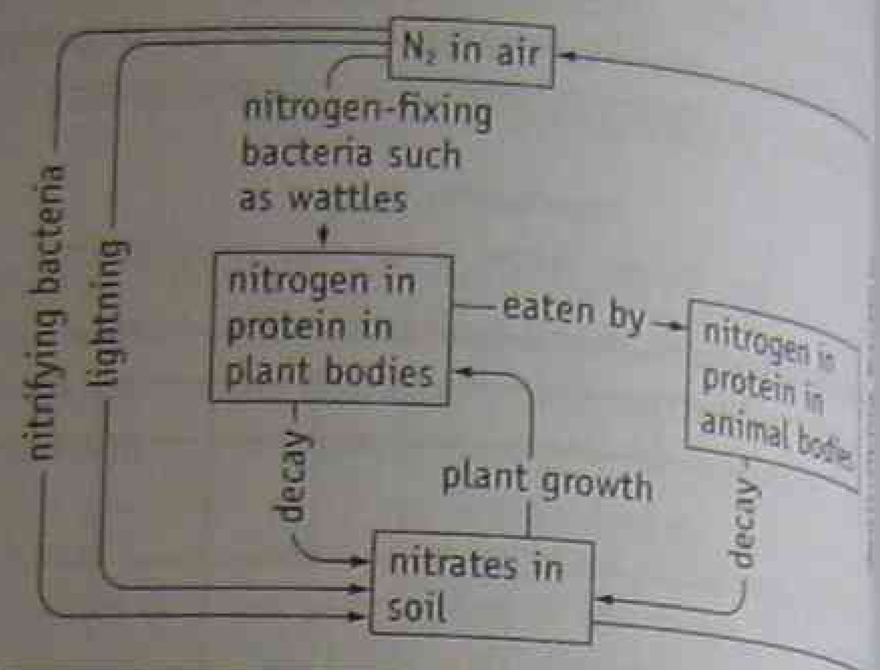


Figure 4.6 The nitrogen cycle

Nitrogen is one of the main gases in the atmosphe Plants use nitrogen to make protein. Nitrogen changed into a soluble form by bacteria living in or water. Plants take up the nitrogen and use make proteins. The nitrogen then returns to the when the plant dies and decays. Animals obtain rogen by eating plants or other animals and relea nitrogen in urine or when they die. Nitrogen is turned to the atmosphere by the action of bacteri

The uses of energy in organisms

Light energy is used by plants for photosynthesis - process that converts energy from the sun into che ical energy that is stored in high energy compou

Respiration converts high energy compounds lower energy compounds through a series of chemical reactions.

The energy is used in organisms for:

- Growth and repair
- Movement
- Biochemical reactions
- Maintaining the functioning of organs and tissues
- Movement of substances in and out of the organism
- Making compounds.

The flow of energy through a natural ecosystem

Energy flows through an ecosystem in one directio There needs to be a continual input of energy from the sun for all life on Earth to continue (see page

Each local aquatic or terrestrial ecosystem is unique

Field study

As a result of studying this module, you are expected to have drawn on your existing knowledge of your local area to expand your understanding of the impact of biotic and abiotic factors operating in the environment. You will have undertaken a field study in the local area (see page 74) and prepared a report. Your report will have included: a statement of purpose; a clear and detailed definition of the area studied; any background material collected on the area; appropriate presentation of data collected; analysis of data; discussion of the relationships that exist in the area; and an assessment of the human impact on the area.

As part of meeting the requirements of the course, you are expected to have used transect, random quadrat, capture-recapture and tagging/marking methods to make estimates of real or simulated populations of organisms in a local ecosystem and used your observations to discuss the advantages and disadvantages of these different methods.

Transect — a transect represents a line through a study site. Select a line through the study area to include most of the plant groups. Anchor your string at one end, then spread it along the selected line to form a transect. Draw a profile of the selected transect on graph paper using a scale without too much vertical exaggeration. The changing levels along the transect are easily determined using a line level and two rods of suitable length.

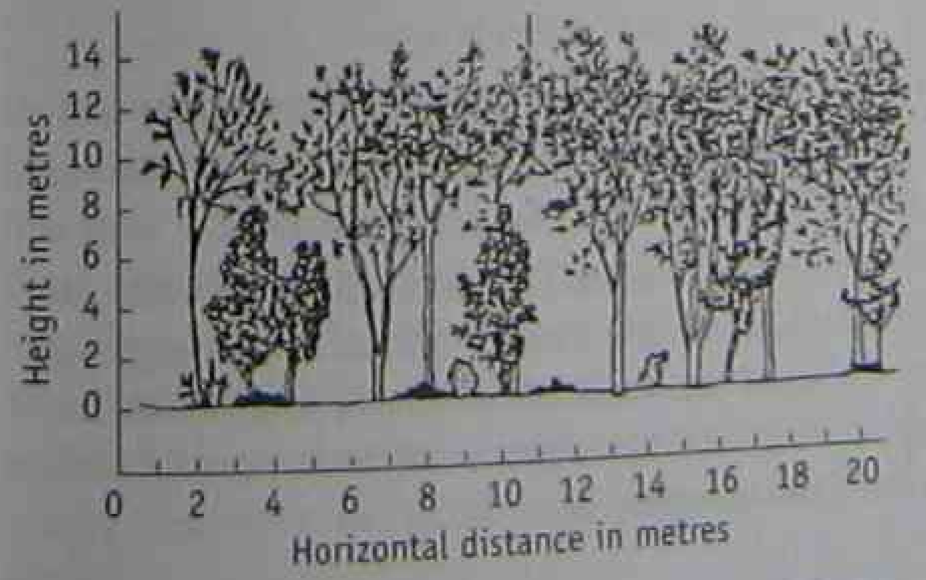


Figure 4.7 A profile along a transect of 20 metres

Advantages of a transect — transects are useful for measuring distribution when the area is too large to do a direct observation.

Disadvantages of a transect — you only record organisms found across the transect. One transect may not be an accurate representation of the study site. Therefore you may need to do a number of transects and compare your findings.

Random quadrats — a quadrat represents an area (or areas) within the study site. A quadrat is a randomly chosen area within this study area. Quadrats can be measured and pegged out with string or a 1 m x 1 m frame is used.

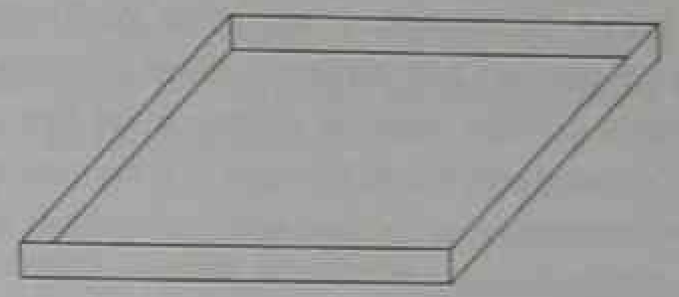


Figure 4.8 A quadrat

Using the frame, make random selections of the study area. Count the number of organisms in each quadrat. Calculate the average number and multiply this by the total area of the study site to give the estimated abundance. The formula below is used to estimate the number of organisms in the sample area using the quadrat count:

$$\frac{\text{Number in the quadrat}}{\text{Area of the quadrat}} = \frac{\text{Number in total area}}{\text{Total area}}$$

Advantages of random quadrats — it is a more specific way to estimate types and numbers of organisms than a transect.

Disadvantages of random quadrats — you only record organisms found in the randomly chosen areas. These may not be an accurate representation of the entire study site.

Capture-recapture method — this is used in ecology to estimate the size of a population. Individuals are captured, marked or tagged and released back into the population giving them time to disperse before a sample population is recaptured. The proportion of marked individuals in the sample enables calculation of the population size, and study of distribution.

Estimated population =

Total of tagging 1 x $\frac{\text{Total of tagging 2}}{\text{Total recaptured}}$

$$EP = \frac{T1 \times T2}{TR}$$

Advantages of the capture-recapture method — this method avoids the need to count every single member of a population, a task which is often impossible particularly if the population is constantly moving.

Disadvantages of capture-recapture — you have to know something about the biology of the organisms in the study and have some idea about their range and mobility. Daily and seasonal changes in the distribution of the population will affect your measurements. If you are not aware of these changes, you may carry out the study at a time when the population has migrated out of the area. Capture-recapture can be destructive or damaging to individuals or impact on them indirectly.

Tagging/marking methods — are used with capture-recapture for populations such as migrating birds and sea turtles.

Advantages of tagging/marking — these methods can be used along with technologies such as satellite beacons and radio transmitters to track populations, as well as computer probes to study not only the range and distribution but also individual characteristics such as weight, age, size and feeding habits.

Disadvantages of tagging/marking — the methods can be expensive and labour intensive, requiring ongoing monitoring and central data collection. They can also be destructive or damaging to fauna or impact on them indirectly.

Simulations — a simulation is a way of studying ecosystems second-hand. It allows you to study situations and/or make predictions that may not be possible in the field study. In a simulated population, you study an imaginary population using the same methods as you would in a first-hand field study.

For some examples of ecosystem simulations see:
http://www.ecobeaker.com/ — EcoBeaker
http://www.immll.uow.edu.au/IMMLL/iluka.htm — Lake Iluka
http://www.immll.uow.edu.au/IMMLL/Nardoo/nardoo.htm — human impact on ecosystems along the Nardoo River.

As part of meeting the requirements of the module, you are expected to have conducted a field study of a local terrestrial or aquatic system. In carrying out the field study you have:

- Identified occupational health and safety issues to identify potential sources of physical, chemical and biological risk before undertaking an investigation (see page 75)
- Measured abiotic variables, such as temperature (see page 75), compared your measurements with records such as weather reports and related measurements to the distribution of organisms
- Estimated the size of a plant and an animal population in the ecosystem using transects and/or random quadrats and/or capture-recapture and tagging/marking techniques
- Gathered data on the distribution of the plant and animal species
- Described the distribution and abundance of two plant and animal species found in the area
- Observed and described trophic relationships of two plant and animal species found in the area
- Tabulated data collected in the field and graphed changes over time
- Determined the indicator organisms present in, and the chemical purity of, water in the local environment being studied (see page 76)
- Prepared a report on your field study – the report should include an introduction describing your purpose, a description of your methods used, the results shown graphically and a discussion of your results using available evidence
- Surveyed local residents on their concerns about the impact of people and technology on the local area
- Constructed food chains and food webs to illustrate the flow of matter and energy, and used the available evidence to discuss the relationships between different organisms in the ecosystem.

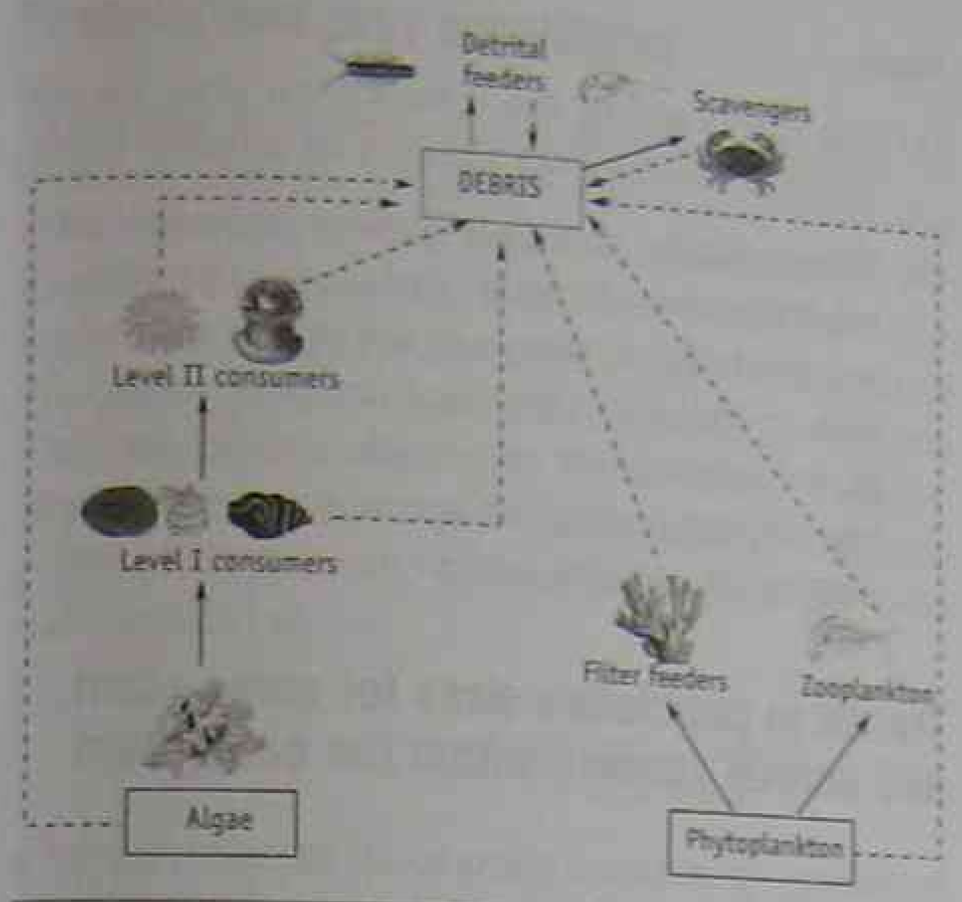


Figure 4.9 A sample food web on a rock platform

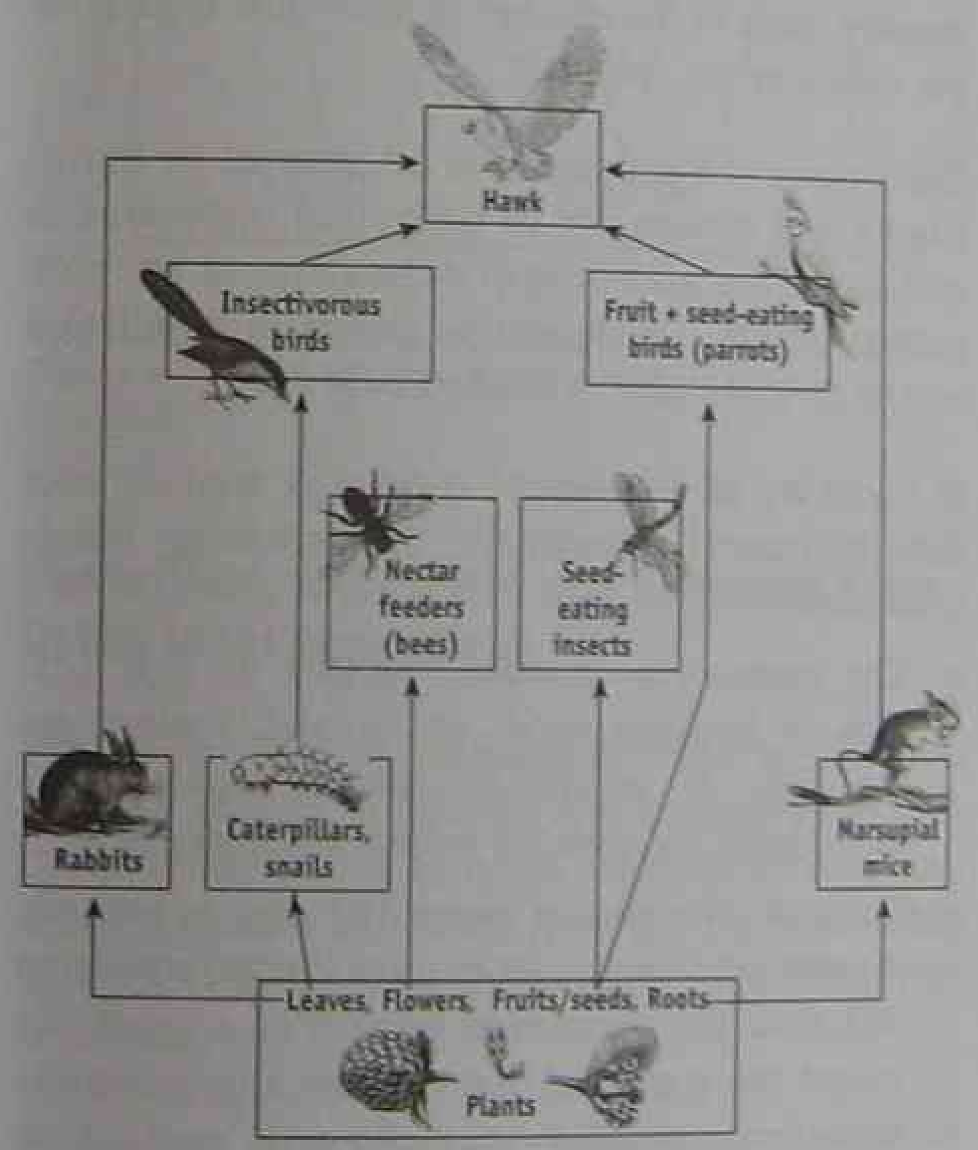


Figure 4.10 A sample food web in a grassland ecosystem

Occupational health and safety (OH&S) issues

(See also Chapter 3.) Potential sources of physical risk may include skin irritation, glare, dust, slipping, cuts, abrasions, injury to limbs, sprains and strains to parts of the body, bites from insects, snakes and other animals, and exposure to allergens, such as pollen and grass seeds. Equipment should include sturdy footwear or gumboots, a hat and sturdy gloves.

Potential sources of chemical risk may include exposure to pollutants such as pesticides and heavy metals. Potential sources of biological risk may include exposure to disease-causing organisms such as bacteria and blue-green algae.

Care should be taken:

- When using chemicals in the field
- When collecting, storing and transporting samples for testing
- When disposing of samples and chemicals used for testing
- To observe warning signs and avoid direct contact with contaminated water or soil. Before undertaking an investigation, you may need to check with the local council or the Department of Land and Water Conservation for public health warnings in the study area.

Measuring abiotic variables

- Light intensity — use a light meter or probe on a data logger.
- Moisture — use moisture meters, a probe on a data logger or cobalt chloride paper. Cobalt chloride paper is blue when dry and pink or white when moist. The time it takes for the paper to dry is a measure of the dryness of the environment.
- Temperature — use a thermometer or the temperature probe on a data logger.
- Exposure to wind — use a qualitative scale such as + for very sheltered to + + + + + for very exposed (windy), or a wind meter or anemometer. Observe and describe the aspect and slope of the area.
- Height and depth — use a metre rule or marked stick.
- Rate of flow — measure the time taken for an object to float a measured distance.
- Turbidity — use a qualitative scale such as + for clear to + + + + + for almost opaque (turbid); or put a metre rule into the water to as far as you can still see the bottom of the ruler and measure this distance to the surface (the smaller the distance, the more turbid the water); or use a Secchi disc or turbidity tube.
- Soil — soil can be sorted to assess the percentage of leaf litter and soil grains. A soil profile can be made. Observe and describe the most common rock types in the area.

- Percentage cover — this indirectly affects light intensity, moisture levels and so on; it is an estimate of the percentage of an area covered by water, algae, herbs (small plants), trees, shrubs and leaf litter.

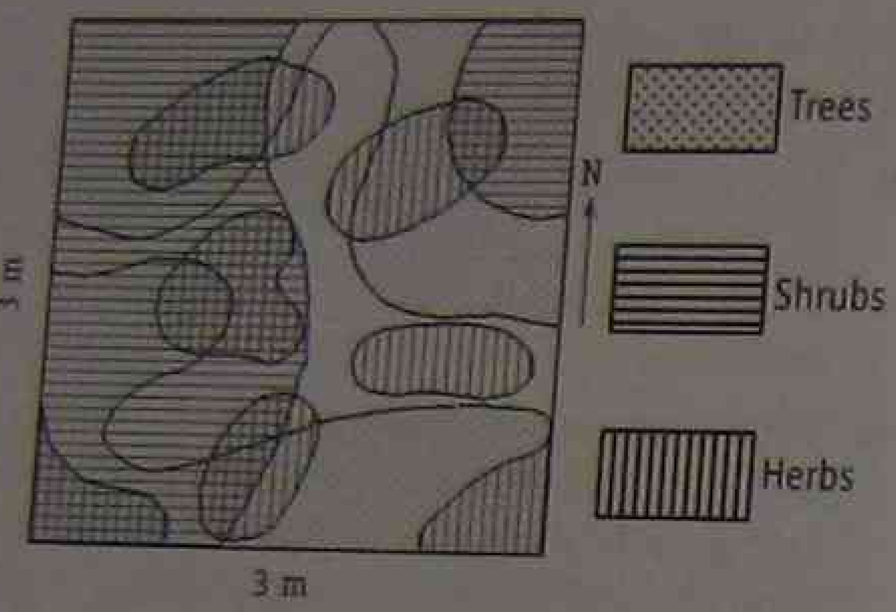


Figure 4.11 A surface map showing an estimate of percentage cover

- pH — use a universal indicator or pH paper or soil pH-meter or a probe on a data logger.
- Measures of human impact such as levels of particulate matter in the water, garden rubbish or household garbage.

Indicator organisms and the chemical purity of water See pages 19 and 22, Chapter 1, for a description of indicator organisms. The chemical purity of water can be tested on-site. Tests include:

(a) Oxygen — half fill a test tube with a sample of water and add a drop of methylene blue (methylene blue detects dissolved oxygen). If the sample does not remain blue, this indicates little or no oxygen is present. Little oxygen in water is an indicator of pollutants. Nutrients from fertilisers, pesticides, organic matter and sewage provide food for decomposer organisms (such as bacteria). If there is a high nutrient load, the decomposer organisms multiply rapidly and use up the available oxygen in the water. If the water smells bad, this can indicate rapid decomposition and lack of dissolved oxygen.

(b) pH of water — pure water is neutral (pH 7); acidic or alkaline water can indicate poor water quality.

(c) Chloride content — half fill a test tube with a sample of water and add silver nitrate to the sample. If chloride ions are present, a white precipitate will form. Chloride in the water is usually an indicator of pollution (unless the water is naturally salty or brackish).

Note:

(a) You can compare the results from your on- chemical testing with samples of distilled wa

(b) Water quality can vary greatly between separated even by short distances. Therefore is a good idea to take samples from a number sites in the study area and compare results make comparisons meaningful, make sure use the same sampling techniques — the same number of samples and so on — at each site.

Trends in population sizes for some plant and animal species within the ecosystem

In ecology, population refers to all the members of species inhabiting an area. **Population size** refers the number of individual organisms. **Population density** refers to the number of individual organisms per unit area (or volume).

The growth of a population is determined by births deaths and movements of individual organisms and out of the area (and is dependent on environmental factors). To determine trends in population size, a species must be studied over time.

If a species or number of species is studied over time in natural ecosystems, the following trends tend to occur:

- The population increases rapidly at first (A). This is because food, space and shelter are available. As population size increases, more individuals compete for resources, hence ...
- The rate of increase slows (B) and eventually diseases and/or competition for limited resources will slow the population growth to a point (C) where the numbers that die are approximately equal to the numbers that are born.

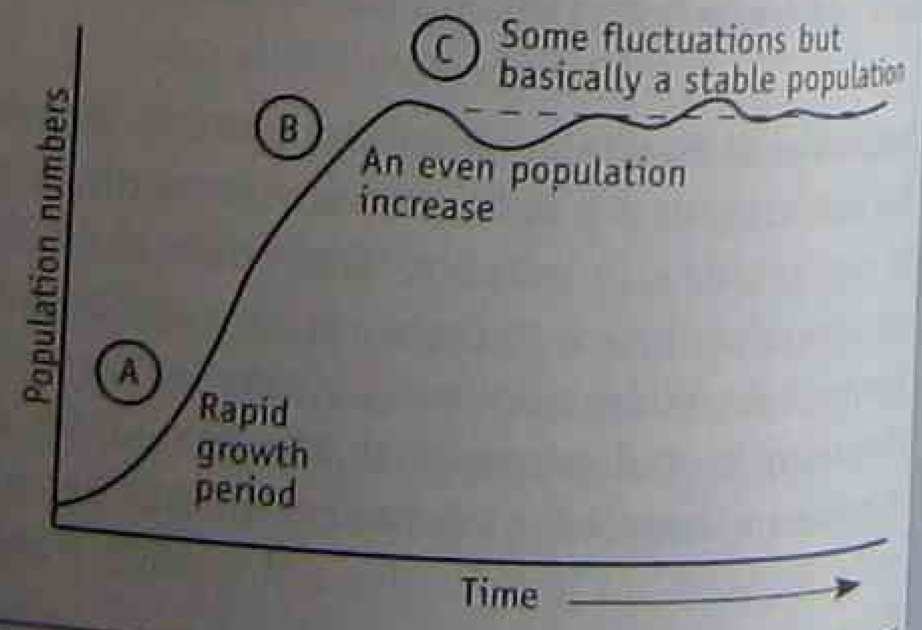


Figure 4.12 The 'S'-shaped population curve represents trends in population sizes in natural ecosystems

Predator and prey populations

Predation is a relationship between members of different species. A predator can directly affect the members of a prey population by consuming the organism for its food. The availability of the food (the prey) also affects the abundance and distribution of the predator. As the number of predators increases, prey population decreases. As a result, predator numbers decrease. With fewer predators, the prey population increases. As a result, predator numbers increase and so on.

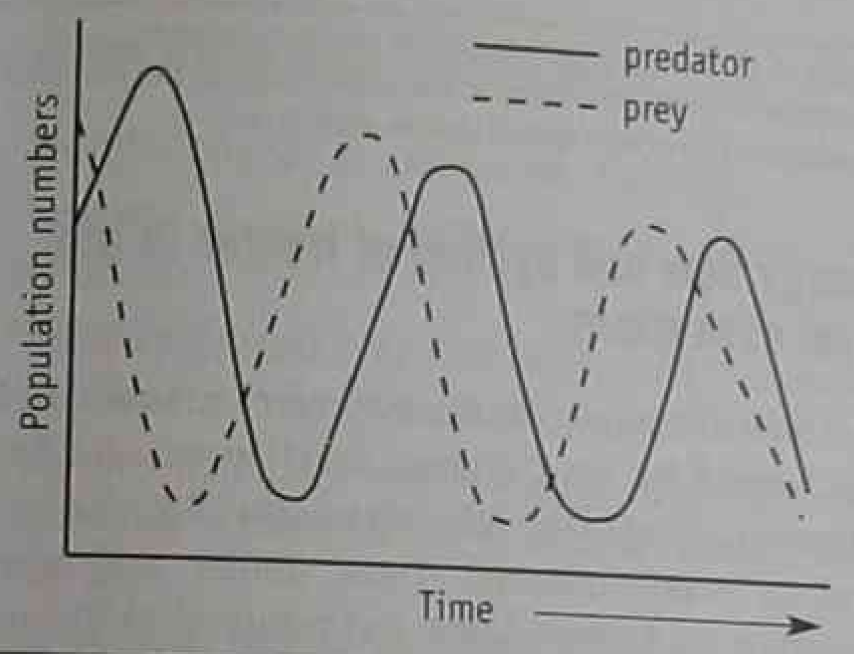


Figure 4.13 Fluctuations in predator–prey population size over time

Parasitism, mutualism and commensalism in the local ecosystem

Parasitism is a relationship between members of different species. A parasite is an organism that lives on (external parasite) or in (internal parasite) another organism and feeds from it. The relationship is harmful to the host, for example, a parasitic vine on a tree.

Mutualism is a relationship between members of different species where both benefit. For example, lichen is made up of a mutualistic relationship between algae (that photosynthesises) and fungi (that absorbs and provides water).

Commensalism is a relationship between members of two different species where one member benefits and the other is unaffected. The advantage for the species that benefits might be to get food or shelter or transport. For example, epiphytes grow on the branches or trunks of trees and use the tree as a base for attachment. They do not 'feed' on the tree and therefore do not harm it.

The role of decomposer organisms in the ecosystem

> Decomposers break down the complex compounds of once-living matter to release simpler substances into the environment. This is essential to continue cycling chemicals in the ecosystem.

Trophic interactions between organisms in the ecosystem

See page 69 for a revision of food chains and food webs, and page 75 for sample food webs.

Pyramids of biomass — in your study of a local ecosystem you may have made an estimate of the numbers of organisms at each trophic level in the food chain or food web that you constructed. This provides you with quantitative information but does not provide information about the size or energy content of each level in the food chain. A more accurate way of understanding feeding relationships is sometimes obtained by measuring the biomass — the weight of organisms — at each trophic level. From this you can construct a pyramid of biomass. A pyramid of biomass shows:

(a) The total weight (biomass) of organisms at each trophic level, and

(b) That biomass decreases as trophic levels increase.

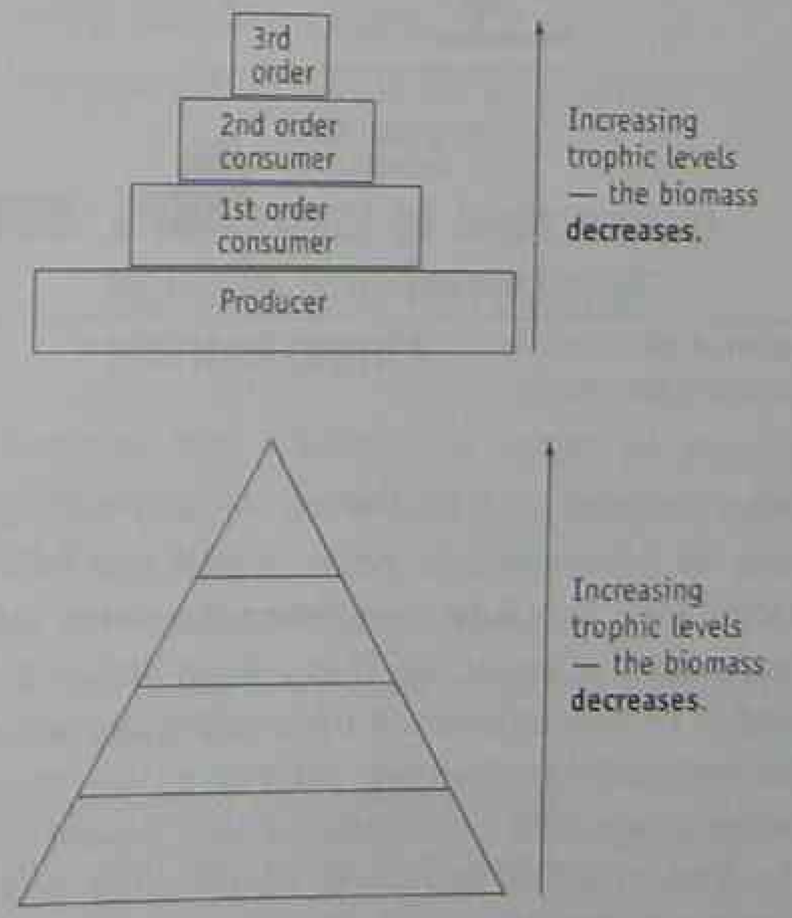


Figure 4.14 Generalised diagrams of a pyramid of biomass

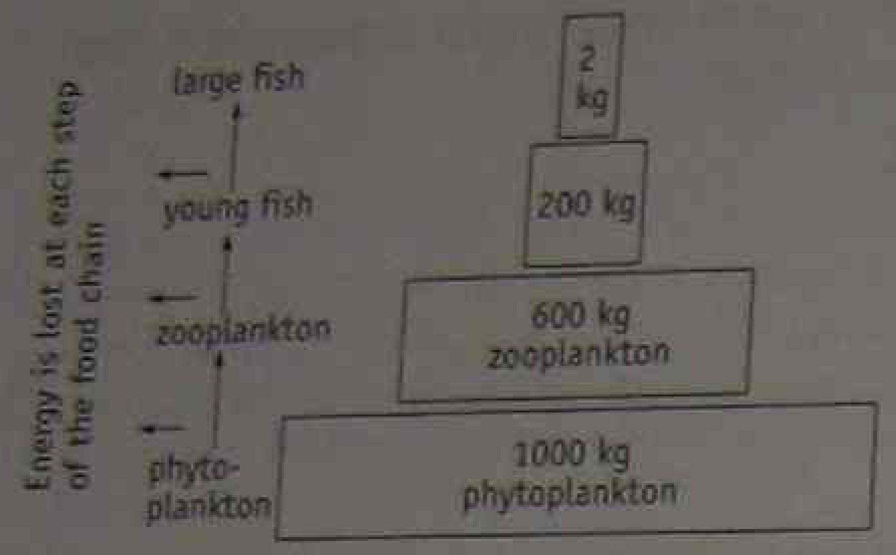


Figure 4.15 An example of a pyramid of biomass. In this example, it takes 100 kg biomass of phytoplankton to support fewer biomass units of zooplankton and so on.

A pyramid of energy best shows feeding relationships in an ecosystem but is harder to construct. To construct a pyramid of energy you must determine the energy value of each level in the food chain. Pyramids of energy show that the transfer of energy from one level to the next is not highly efficient. This is because some energy is lost at each step. Some energy is used by the organism for metabolism; some energy is lost as heat. Each trophic level can only pass on part of its energy to the next level.

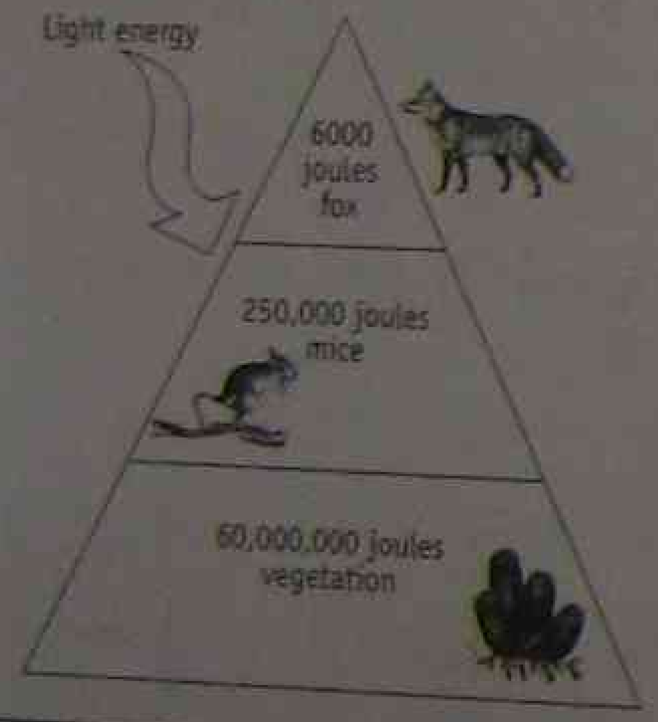


Figure 4.16 An example of a pyramid of energy for a grassland community

Note: Pollution and food webs — many pollutants such as pesticides and heavy metals can exist in nature for a very long time before they break down (see page 11, Chapter 1). They are not broken down readily by decomposers. If these pollutants occur in the environment, they can build up in the tissue of living things. The pollutants are then passed along the food chain or food web. Accumulated poisons will be highly concentrated in higher-order consumers.

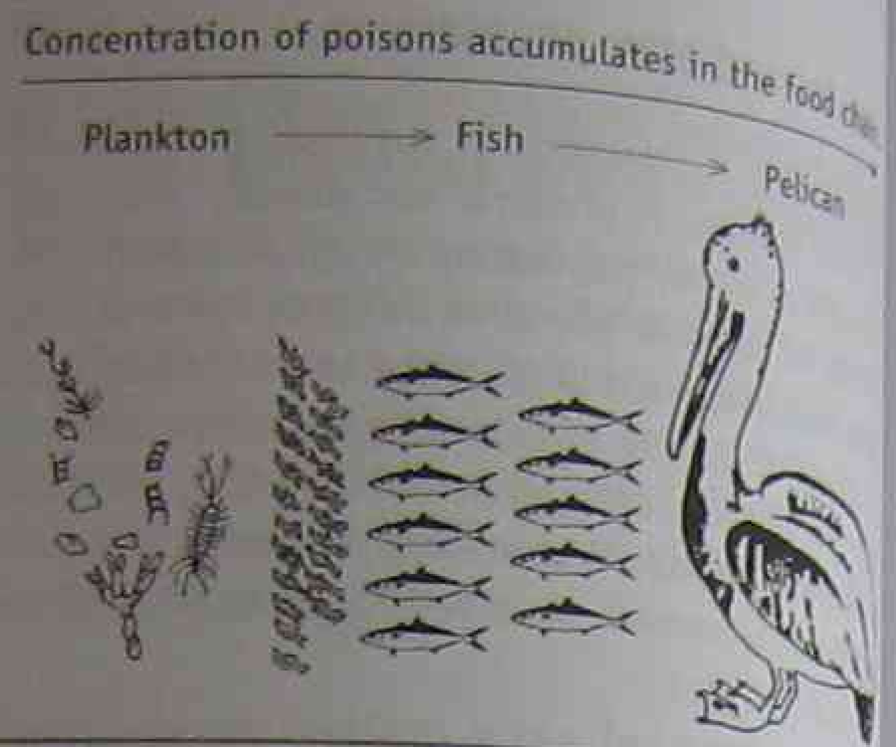


Figure 4.17 The pelican is a higher order consumer. Pesticides in rivers, for example, will accumulate in the tissue of plankton and be concentrated up the food chain.

Energy flow and cycling of matter in the local ecosystem

The flow of energy and the cycling of matter can be represented by food chains, food webs and food pyramids. Eventually all organisms die. Animals produce waste material. Dead matter and waste materials are broken down and returned to the soil.

Note: Energy flow and cycling of matter through natural systems is different from energy flow and cycling of matter through disturbed ecosystems – ecosystems where human activity has impacted on natural processes. More and more energy is being removed from natural ecosystems for human use. The waste materials of human-dominated ecosystems are large in biomass and composed of materials that do not break down easily, such as plastics, pesticides and heavy metals. The enormous population size of human-dominated ecosystems makes waste substances, such as sewage, difficult for an ecosystem to cope with. Energy consumption is enormous in these ecosystems.

Adaptations of a plant and an animal in the local ecosystem

If your field study is in an aquatic ecosystem then you may have looked for adaptations such as:

1. Mechanisms for floating such as:
   - Spongy leaves with air spaces
   - Air-filled stems
   - Large flat leaves which increase the surface area on which the upward force of water can act
   - Fat layers or oil deposits next to the skin
   - A light bone structure
   - Gas floats (for example, in bluebottles)
   - Large flat fins and fin rays which increase the surface area on which the upward force of water can act.
2. Ways that organisms reduce the friction between the water and the body surface, such as:
   - A streamlined body shape
   - A thin body with fins that help fish to move and change direction quickly
   - A mucous layer
   - Scales which point toward the tail.
3. Adaptations for gas exchange, such as:
   - Leaves of water plants having a thin flat structure
   - Brown algae (such as kelp) having flat thin blades to increase the surface area
   - Many plants float on the surface of the water or grow out of the water to be in direct contact with the air
   - Large intercellular air spaces found in the leaf
   - Gills that provide an external gas exchange surface
   - Some insects store a bubble of air under their wings and breathe from this bubble when they are in the water.
4. Adaptations for obtaining light, such as the leaves of some aquatic plants having mobile chloroplasts which move closer to the surface of the leaf to utilise available light.
5. Adaptations for control of water balance, such as:
   - Some aquatic animals prevent water loss or avoid extreme changes in the environment by having a shell (oysters and clams)
   - Some aquatic unicellular organisms have a contractile vacuole which actively expels excess water from their bodies
   - Marine birds and sea turtles excrete excess salt through special glands on the head.

If your field study is in a terrestrial ecosystem then you may have looked for adaptations such as:

1. Mechanisms to support the body
2. Ways to lift the body off the ground for movement — to reduce friction between the body and the surface of the land
3. Adaptations for gas exchange, such as lungs in mammals and air-tubes in insects
4. Adaptations to prevent drying out, such as impermeable skin covering and waxy cuticles on plants
5. Adaptations for obtaining light — for example, leaves are sometimes arranged on plants to receive maximum light.
6. Adaptations for control of water loss (see page 3)
7. Adaptations for maintaining body heat, such as:
   - Avoiding cold conditions by hibernating, burrowing, sheltering or migrating
   - Reducing blood flow to the skin surface or to the limbs
   - Increasing metabolism by eating more food or increasing muscle activity, for example, by shivering
   - Developing insulation (fat, hair, feathers or fur) to reduce heat loss. Some mammals grow thicker coats or increase fat layers in readiness for winter.
8. Adaptations for losing body heat (cooling down), such as
   - Reduced number of sweat glands
   - Avoiding the heat by burrowing or seeking shade
   - Increasing the amount of wet surface area exposed to the air (by, for example, salivating or licking parts of the body)
   - Increasing blood flow to the skin surface.

The impact of humans on aquatic and terrestrial environments

In assessing the effects of a range of human activities on the local environment, you may have looked for:

- Soil erosion and soil degradation
- Clearing of plants for buildings, roads, electricity poles, crops
- Loss of habitats and breeding sites
- Removal of soil, water or nutrients
- Visual pollution from litter, signage or other constructions

- Noise pollution
- Contamination of air, water or soil
- The impact of introduced species, such as pets, feral animals and invasive weeds.

Refer also to Chapter 1 for sources of soil and water pollution.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research methods of plant propagation used to regenerate local areas where appropriate.

Different plant species have different propagation requirements. To regenerate local areas, plant propagation from seeds should be used wherever possible to encourage genetic diversity.

Bush regeneration requires:

- An assessment of the site in terms of abundance and distribution of weed species as compared to native, indigenous plant species; that is, an assessment of the degree to which an area has been invaded and degraded
- Correct identification of local plant species and weed species
- Researching propagation requirements of each indigenous plant species
- Collecting native seeds and cuttings where necessary
- Removal of weed species to allow the bush to come back
- On-going follow-up to eradicate weed species
- Replanting of the area with local species where necessary.

Features of the local environment which may vary in importance for different groups in the local community

An example is provided below:

There are often extreme views on the arguments for bushfire hazard reduction by burning versus environmental protection. Determining and maintaining a fire-management regime which maximises conservation of native bush and minimises bushfire threat is a difficult, complex and usually hotly debated issue. Information about the how and why of burning practices by Aboriginal people prior to European settlement is scarce and still being debated. The adaptation by Australian plant species to fire over millions of years and Aboriginal fire-management practices are often used as a justifying rationale by those who promote the concept of regular frequent burning as being good for the bush.

Some views include:

- Too frequent controlled hazard reduction by burning is a threat to native bushland through loss of species diversity of flora and fauna. Some eucalypts do not regenerate by vegetative means (see page 37) after fire. Therefore if regeneration by seed germination is to be successful, fire must be kept out of young forests or areas of regrowth until trees are mature enough to bear seeds. Some Australian plants (such as banksia species) are obligate seeders. All juvenile and adult plants are killed by fire and they depend entirely on pre-fire seed reserves. If there is insufficient time between controlled burns for seed reserves to build up (10–15 years), the population will decline.
- Regular controlled burning simplifies the ecosystem and modifies the flora, selecting fire-tolerant species that tend to be flammable.
- Fires liberate nutrients. If the area is mismanaged, these nutrients can be lost through erosion and leaching.
- Weeds colonise areas disturbed by slow-burn fires and areas cleared for firebreaks.
- Seeing fuel reduction as the answer to eliminating risk can lead to complacency and does not encourage individuals to take responsibility for non fire-based hazard reduction in and around their own properties.

Conflicting views on the impact of scientific and technological progress

Different groups in a society may hold different views about the rate and types of housing and commercial developments which are appropriate for an area. In some communities there is a shift from the view of development as always positive to an increasing consciousness of the value of the environment which may be affected or destroyed through inappropriate development.

Criteria for local government regulations concerning zoning of the land

The NSW *Environmental Planning and Assessment Act* (EP&A Act) sets up controls over the use to which land may be put. It does this by zoning. Zoning is a method of controlling land use. Land is divided into zones such as residential, environmental protection, recreational or industrial under State planning regulations (from Planning NSW, which was the Department of Local Government and the Department of Urban Affairs and Planning), and each local council has responsibility for its own zoning and development controls in its local area. The council's zoning powers are given to it under the EP&A Act.

Environmental planning instruments (EPIs) set out the type of development permitted on land. There are three types of EPIs: Local Environment Plans (LEPs); Regional Environment Plans (REPs); and State Environment Planning Policies (SEPPs).

The EP&A Act establishes controls over public development by:

- Requiring public bodies to prepare environmental impact statements whenever they propose to do something which is likely to significantly affect the environment, such as industrial or urban development. These documents are usually displayed to the public and comment is sought.
- Giving citizens the right to challenge public bodies who act in breach of the Act.

LEPs normally control development by dividing a local council area into a number of zones — domestic housing, units, schools, commercial developments (shops and hotels), industrial use — and listing what can be carried out without consent, what development requires consent and what is prohibited. For example, in the Blue Mountains City Council the LEP is divided into an inner plan and an outer plan — the environmentally sensitive zone. The outer plan includes restrictions on housing such as the height and colour of a roof and the development of site boundaries, to retain remnant bushland. The inner plan includes common forms of zoning such as Residential 2(a1) and Residential 2(b1). Differences in residential zoning relate to whether the house is allowed, for example, to have a flat.

Other types of land use include public transport facilities, public infrastructures (gas links, transmission lines), commercial developments (shops and hotels), primary produce, hospitals and nursing homes.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research local government regulations on land zoning for domestic, commercial and industrial use.

See: your local council

http://www. duap.nsw.gov.au — the NSW Department of Urban Affairs and Planning for information on land zoning.

http://www.edo.org.au/edonsw/publications — the NSW Environmental Defender's Office for Fact Sheets on Zoning and Development Consents.

As part of meeting the requirements of the course, you are expected to have used secondary sources to trace the use of the local environment over the last 50 years.

See your local council and local library. Your research may have included tracing changes from rural to residential development, or from low-density to medium- or high-density housing (villas, flats and units), development of areas which were once bushland, development or closure of factories, urban sprawl, reclaiming wetlands, rerouting creeks and rivers, and more recent attempts to preserve some areas and regenerate local bushland.

Checklist Key terms for revision

- abiotic
- biotic
- aquatic
- terrestrial
- ecosystem
- distribution
- abundance
- competition between members of the same species
- sampling techniques — transect, random quadrat, capture/recapture, tagging/marking
- water cycle
- carbon/oxygen cycle
- nitrogen cycle
- food chains/food webs
- population
- predator/prey populations
- parasitism
- mutualism
- commensalism
- decomposers
- trophic interactions
- pyramids of biomass and energy
- local government environmental regulations and land zoning
- energy flow
- adaptations
- human impact

Test Local Environment

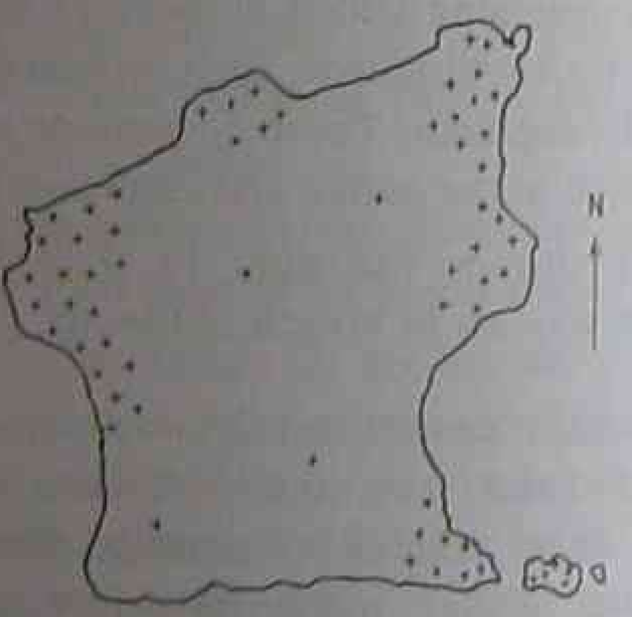
Multiple choice questions

1. In a field study of a certain area, an ecologist captured and tagged a random sample of 50 individual organisms from a population, then released them. After they had time to remix, another random sample of 50 was recaptured and the number of tagged individual organisms counted. In the recapture, 10% of the animals were tagged. From this, the ecologist can reasonably conclude that the population of the species is:

(A) 500 (B) 250
(C) 150 (D) 100

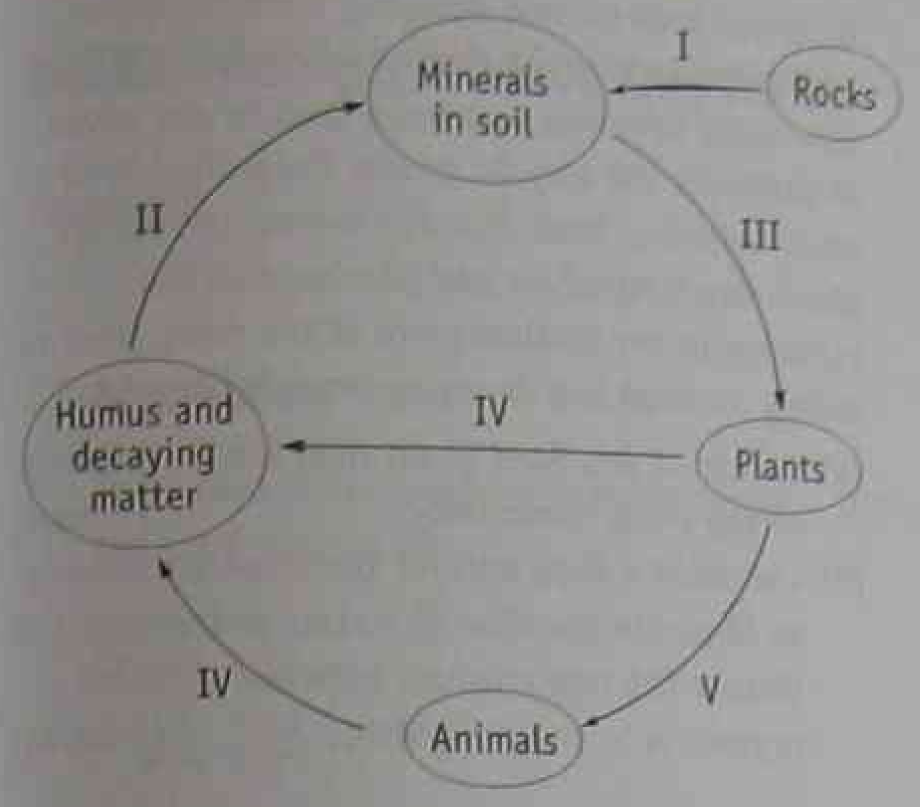
2. The map opposite shows a simulated population of birds on an island. A cross marks the location of every type of bird in the population.

A study of the simulated population reveals that:
(A) The bird is not at all abundant on the island.
(B) All parts of the island form a suitable habitat for the bird.
(C) Weather conditions in the south-west of the island may have placed limitations on the abundance of the bird.
(D) The bird is evenly distributed over the island.



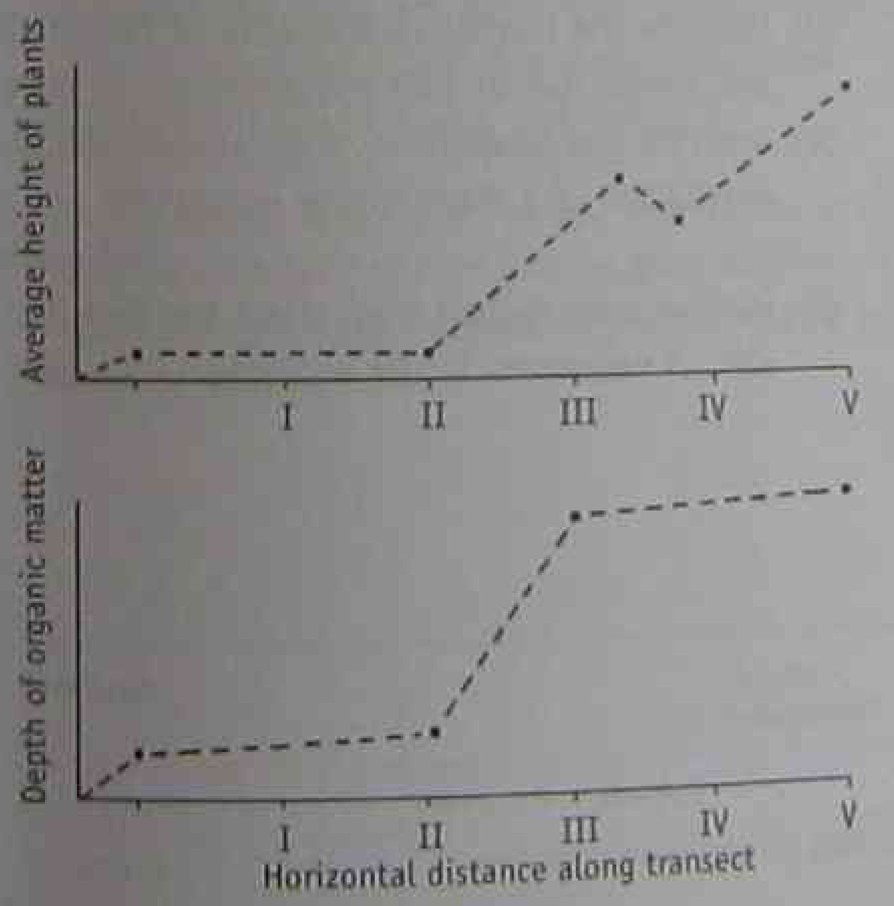
3. During a field study at a rock pool, a student counted the number of crabs as 149 and the number of octopuses as three. Crab is the main food source of the octopus. If we consider the trophic levels of these two organisms, the reason for the large difference in numbers is probably that:
(A) Crabs breed more rapidly than octopuses.
(B) The octopuses have more food than they need.
(C) Crabs are smaller than octopuses and only a small portion of the crab flesh eaten by the octopuses is assimilated.
(D) Predators of the octopus are probably present in large numbers in the pool.

4. The diagram below represents the mineral cycle in nature. The numerals on the arrows stand for the processes that produce the changes.



The processes that depend on bacteria and fungi are:
(A) I and II
(B) II and III
(C) III and IV
(D) II and IV

5. The following graphs show the relative changes in the height of plants and the depth of organic matter in the soil along a transect across a coastal sand dune.



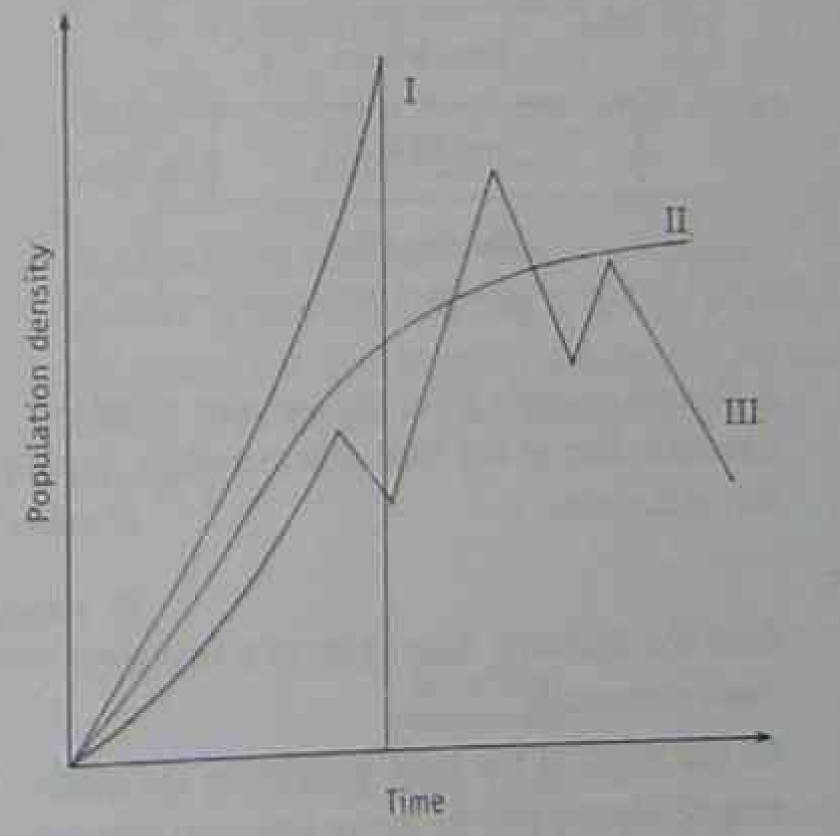
Which statement below best describes the relationship between height of plants and depth of organic matter across the transect?
(A) Generally, as depth of organic matter decreases, plant growth increases.
(B) Generally, as depth of organic matter increases, plants become more abundant.
(C) At location II on the transect, plant growth and depth of organic matter show a definite correlation.
(D) Generally, as depth of organic matter increases, plant growth increases.

Short answer and longer response questions

1. Complete the following table to compare the abiotic characteristics of an aquatic environment with those of a terrestrial environment. (3 marks)

Features	Aquatic environment	Terrestrial environment
Viscosity		
Buoyancy		
Temperature variation		
Availability of gases		
Light penetration		

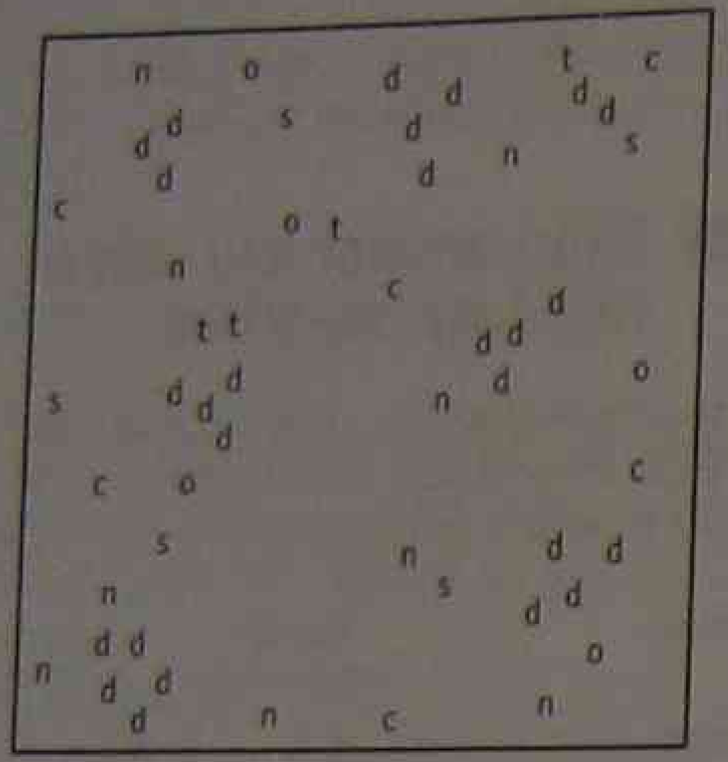
2. (5 marks)
The curves on the graph below show the trends in population size for three different organisms — I, II and III.



(a) Describe the trends in population by describing the shapes of curves I, II and III. (3 marks)
(b) Which graph best represents a population growth dependent on fluctuating resources? Give a reason for your choice. (2 marks)

3. (6 marks)

The map below is a vegetation map of the abundance and distribution of six plant species in an area of 100 m x 100 m.



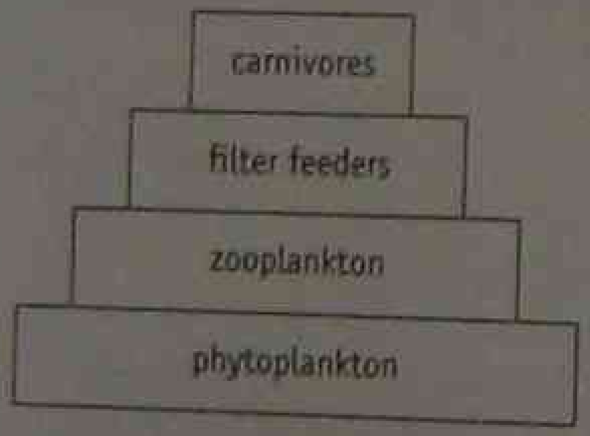
(a) Describe the distribution of species 's'. (1 mark)

(b) Describe the distribution of species 'd'. (1 mark)

(c) Explain how you would carry out quadrat sampling to estimate abundance of organisms in this area. (2 marks)

(d) Describe one advantage and one disadvantage of the quadrat sampling technique. (2 marks)

4. Below is a diagram of a biomass pyramid.



A biomass pyramid gives the biologist a better understanding of the food chain structure. Explain this statement. (2 marks)

5. (6 marks)

Read the following description of a freshwater creek community.

On the edges of the creek grow algae and other aquatic plants. May-fly larvae and small tadpoles can be seen wriggling close to the bank where they feed on algae. Decaying plant material has collected along the still parts of the creek. Midge fly larvae feed on this decaying material. Water beetles visit the creek to feed on larvae. The damsel-fly larva has also been seen to eat larvae, in particular the may-fly larvae. Dragonflies feed on small tadpoles. Small fish dart among the aquatic plants catching larvae and beetles. Crayfish scavenge in the shallow parts of the creek feeding mainly on dead and decaying organic material.

(a) Construct one food chain from the description of the creek community. (1 mark)

(b) Construct a food web for the creek community to illustrate the flow of matter and energy and discuss the relationships between different organisms in the ecosystem. (5 marks)

6. (18 marks)

For the local ecosystem you have studied:

(a) Name a plant population and an animal population in the ecosystem and explain how you estimated the size of one of the populations. (3 marks)

(b) List two occupational health and safety risks that you identified prior to the field trip and describe procedures that were carried out to minimise the risk. (4 marks)

(c) Describe how you measured abiotic variables. (2 marks)

(d) Describe the trophic relationship of two plant and animal species that you observed. (4 marks)

(e) Describe one adaptation of an animal and one adaptation of a plant to the ecosystem. (2 marks)

(f) Outline some factors that affect the distribution of organisms in the ecosystem. (3 marks)

Test answers

Multiple choice questions

Answers

1. A 2. C 3. C 4. D 5. D

Explanations

1. It is reasonable to expect that the 50 were 10% of the total population.

$$EP = T1 \times \frac{T2}{TR}$$

$$= 50 \times \frac{50}{5}$$

$$= 50 \times 10$$

$$= 500$$

So the total population is 500.

2. The bird is abundant on the island but not all parts of the island form a suitable habitat; nor is the bird evenly distributed.

3. Question 3 tests your understanding of the concept that energy is lost at each trophic level.

4. Bacteria and fungi are decomposers. Decomposers play an essential role in the cycling of matter through the environment. See page 77.

5. This question is designed to test your ability to read graphs, to interpret data and to draw conclusions about relationships between organisms and factors in their environment.

Short answer and longer response questions

Answers and explanations

1. See table below.

2. (a) Curve I — the population increases rapidly then dies.

Curve II — the population increases at a fast rate and then the rate of increase slows down.

Curve III — the population growth increases at a fast rate, then fluctuates (goes up and down).

(b) Curve III — because the population fluctuates.

3. (a) Species 's' has sparse distribution; it is found around the margins of the study area.

(b) Species 'd' is well distributed throughout the study area; it is found clumped.

(c) Randomly choose an area 1 m x 1 m (the quadrat). Count the number of each species found in the quadrat. Multiply this number for each species by the large area — 10,000 m^2.

$$\frac{\text{Number in the quadrat}}{\text{Area of the quadrat}} = \frac{\text{Number in total area}}{\text{Total area}}$$

$$\text{Number in total area} = \frac{\text{Number in quadrat}}{\text{Area of quadrat}} \times \text{Total area}$$

You could also carry out a number of quadrat samples by randomly selecting a number of different areas 1 m x 1 m, counting the number for each species in each quadrat and then calculating an average.

Features	Aquatic environment	Terrestrial environment
Viscosity	Water is viscous.	Air is less viscous than water.
Buoyancy	Organisms experience an upthrust and support in water.	Air does not provide the same upthrust or support as water.
Temperature variation	Variation is much less in water than in air.	Temperature variation is extreme on land.
Availability of gases	Oxygen availability is lower in water than in air.	Oxygen availability is higher in air than in water.
Light penetration	Decreases as depth increases.	Light intensity is high.

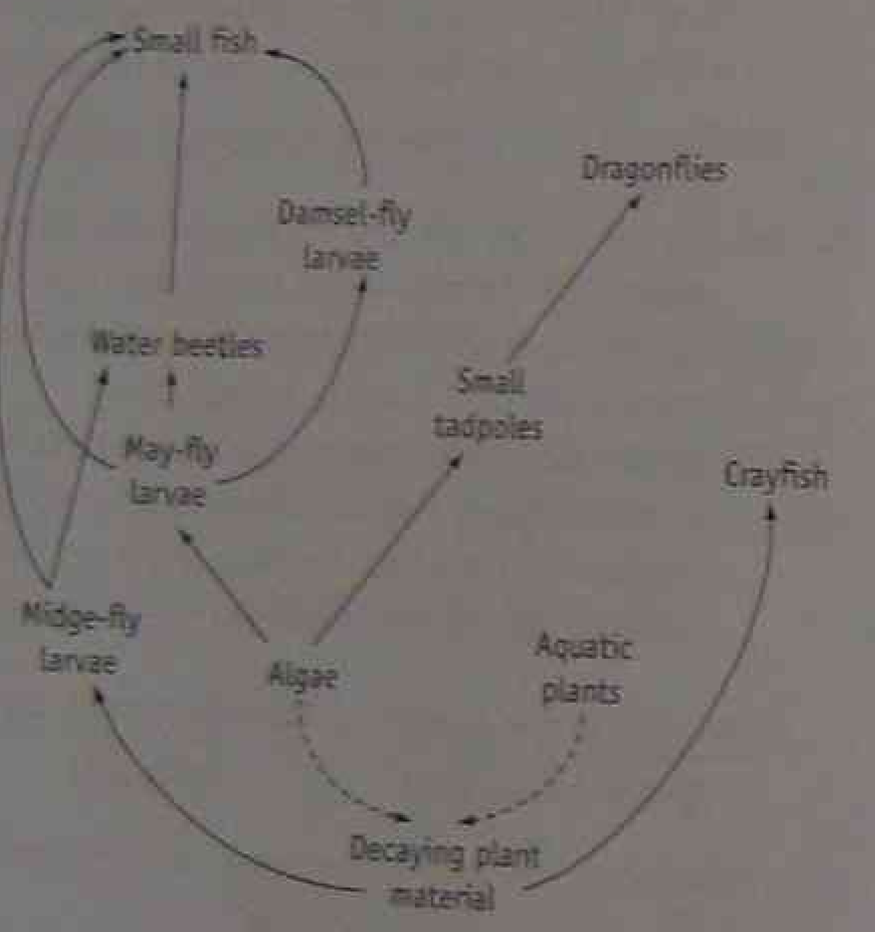
Answer to Question 1.

(d) One advantage — it is a specific way to estimate types and numbers of organisms. One disadvantage — you only record organisms found in the randomly chosen areas. These may not be an accurate representation of the entire study site.

4. Biomass pyramids provide information about the total weight (biomass) of organisms at each trophic level in an ecosystem. It is a more accurate way of understanding feeding relationships.

5. (a) algae ⟶ may-fly larvae ⟶ damsel-fly larvae

(b)



6. The question has many parts. Make sure you answer all parts and answer them in the correct order.

A sample answer for a rock platform ecosystem is provided.

(a) A plant population — green algae (ulva)
An animal population — barnacles (or chitons, Galeolaria, crabs)
To explain how you estimated the size of one of the populations, you could mention techniques such as random quadrat, see page 73.

(b) Occupational health and safety risks include dangers from high tides and waves breaking over the rock platform, poisonous species such as blue-ringed octopus, slips, cuts, the use of chemicals in the field, sunburn (you needed to mention two).

Procedures that were carried out to minimise the risk — checking tides, education about poisonous species and their identification and safe techniques before the field trip, sunblock, hat and sunglasses, sturdy foot wear, education about safe handling of chemicals and environmentally friendly practices in the field.

(c) Measuring abiotic variables — see page 75.

(d) Trophic relationships — crabs are scavengers feeding on seaweed (producers) and decaying animals; chitons are herbivores feeding on algae (see page 75).

(e) Adaptation of an animal — a hard shell to prevent water loss or avoid extreme changes in the temperature; a contractile vacuole which actively expels excess water from the body.

Adaptation of a plant — flat, thin blades to increase the surface area; floating on the surface of the water to be in direct contact with the air.

(f) Some factors that affect the distribution of organisms in the ecosystem — organisms are distributed on the rock platform according to their ability to withstand exposure to sun and drying out when the tide is low. Other factors include change in salinity levels, wave action that can dislodge animals, and availability of shelter and protection.

HSC Core Study Module 1

5 — Lifestyle Chemistry

Introduction

In this chapter you will review the properties and uses of a range of everyday consumer products including cleaning agents, detergents, soaps, shampoos, creams and other cosmetic products as well as products used for medicinal purposes. You will also review changes over time in these types of products and the ways they are used, as well as the environmental and health impacts of some of the synthetic substances produced.

As a result of working through this chapter you will be able to:

— Assess the impact of consumer products on society and the environment

— Identify resources from the Earth which are used in the production of everyday chemical substances

— Identify effects of changes on the human body such as the action of microflora on the skin and the action of medications

— Relate the properties of a range of everyday chemicals to their use

— Relate the structure of skin, stomach and small intestine to their functions

— Discuss advances in understanding of chemical substances that have changed the direction of scientific thinking

— Assess the contribution of advances in chemistry on the development of technologies such as consumer products.

☑ Checkpoint

Before you begin your review you may need to check your understanding of the following:

- Water is important in the body as a solvent. Water dissolves more substances than any other liquid.
- Mixtures — a mixture is two or more substances combined. The different types of chemical substances and how they are combined to make mixtures depends upon their specific physical and chemical properties.

Aqueous mixtures can be defined in terms of the solute, solvent and solution. **Solute** refers to the particles of substances dissolved in the aqueous mixture, for example, salt. **Solvent** is the substance in which the solute is dissolved, for example, water. **Solution** refers to the mixture.

The physical and chemical properties of everyday substances

A wide range of substances are used daily for food, hygiene, entertainment and health. These products have been developed as a result of our increased understanding of chemical substances, chemical reactions and the biochemistry of internal and external body surfaces.

Solutions, colloids and suspensions

Solutions, colloids and suspensions are types of mixtures which occur in a wide range of consumer products.

Solutions are mixtures that contain dissolved substances and are uniform throughout. Examples of solutions include saltwater, household ammonia (a solution of ammonia gas in water), and vinegar (a solution of acetic acid in water).

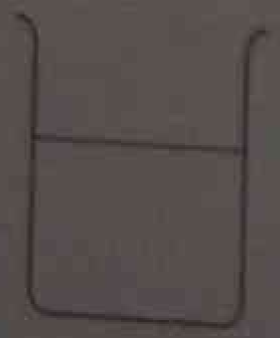


Figure 5.1 In a solution the particles are completely dissolved in the solvent. A beam of light can be passed through a solution without any scattering of the light by particles.

Colloids are cloudy mixtures with particles that remain suspended for long periods of time. In a colloid, the particles of one substance are scattered evenly throughout another. Colloids include oil-in-water mixtures, water-in-oil mixtures, gas-in-liquid mixtures (for example, foams such as whipped cream, which is a mixture of air in cream), and liquid-in-liquid mixtures (for example, milk, which is a mixture of oil in water — see page 91).

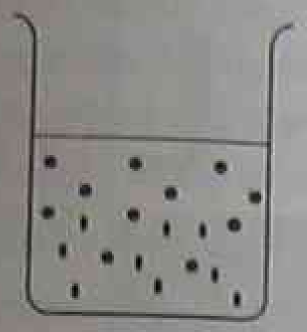


Figure 5.2 In a colloid, the particles are larger than in a solution but smaller than in a suspension. In colloids, the particles do not settle out. The particles are too small to remove by filtering. When a beam of light is shone through a colloid, some of the light is scattered. This produces a bright cloudy effect.

Suspensions are mixtures containing particles that settle out, or form layers, quickly.

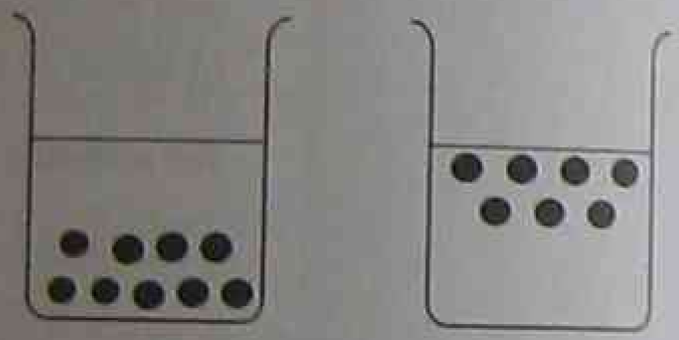


Figure 5.3 In a suspension the particles are larger than those in a colloid and can be removed by filtering.

As part of meeting the requirements of the course, you are expected to have used first-hand and secondary sources to research examples of suspensions and colloids and outline the advantages of each form.

Colloids are classified according to whether a solid, liquid or gas is dispersed and the medium of dispersion.

- A gas dispersed in a liquid forms a foam — for example, shaving lather.
- A solid dispersed in a liquid forms a solid foam — for example, Styrofoam.
- A liquid dispersed in a gas forms an aerosol — for example, hairspray.
- A liquid dispersed in another liquid forms an emulsion, when an emulsifier is present — for example, homogenised milk.
- A liquid dispersed in a solid forms a gel — for example, jellies.
- A solid dispersed in a gas forms a solid aerosol — for example, dust or smoke in air.
- A solid dispersed in a liquid forms a sol — for example, ink.

The advantage of a suspension is that particles eventually settle out and can be separated from the liquid. The advantage of a colloid is that, unlike a suspension, the particles will not settle out.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to make and observe a range of suspensions and colloids that are used in the home including:

- Beaten or whisked eggs
- Salad dressing — oil and vinegar
- Mayonnaise.

Put vinegar and oil in a test tube. Shake (to make a suspension). Allow to settle. Add egg yolk (to make 'mayonnaise'). Shake. Observe.

Shine light through a salt solution, salad dressing and mayonnaise to observe the difference between a solution, a suspension and a colloid.

Surface tension

Surface tension refers to the forces experienced by particles at the surface of a liquid. The forces between the particles at the surface of a liquid make the liquid behave as if it were covered by a stretched invisible skin.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to demonstrate the effect of surface tension on:

- The shape of liquid drops
- The formation of menisci
- The ability of some insects to walk on water. This is similar to floating a needle on the surface of water. The surface tension of the water prevents it from sinking. With the needle demonstration you can also add a few drops of detergent to the water and observe what happens.

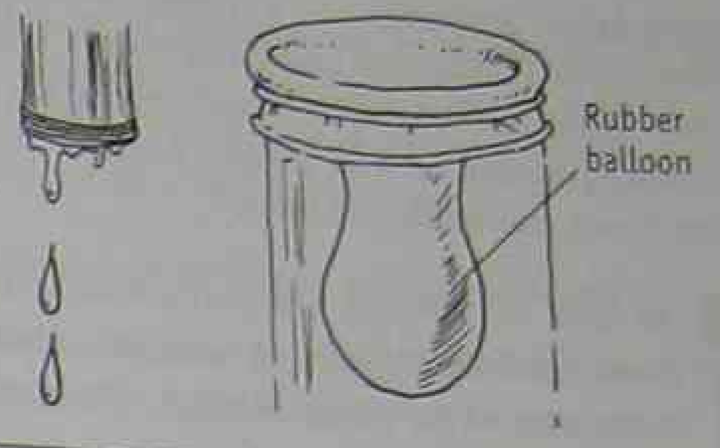


Figure 5.4 (a) Water dripping from a tap. To model a water drop, tie a piece of rubber balloon over the top of a jar. Pour water into the balloon and observe its shape as it stretches.

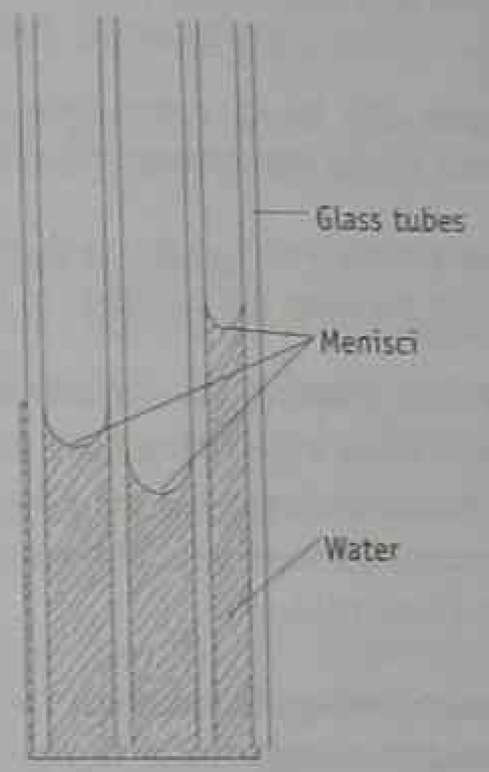


Figure 5.4 (b) Menisci — look carefully at the surface of the water in a beaker or thin glass tube. Notice how the water is curved up at the edges.

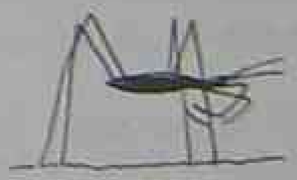


Figure 5.4 (c) Observe insects such as water striders on water. Note how the legs of the insects make tiny indentations on the water.

Surfactants

Surfactants are a group of chemical substances that are **surface-active-agents**. Surfactants affect the surface tension of a liquid, such as water, thereby making water 'wetter'. It is this property that makes surfactants useful as cleaning agents. In the presence of a surfactant, water has greater ability to wet the dirty or oily surface and the dirt or oil can be more easily removed.

Surfactants are used in a range of consumer products including stain and dirt removers, spray-on oven cleaners, shampoos and anti-static and sanitising agents used in friction reducers such as hair rinses and fabric softeners.

As part of meeting the requirements of the course, you are expected to have researched and demonstrated the effects of soaps, skin cleansers and shampoos on the solubility of oil.

1. Put water and oil in a test tube. Shake. Add soap. Shake and observe the difference.
2. Put water and oil in a test tube. Shake. Add skin cleanser. Shake and observe the difference.
3. Put water and oil in a test tube. Shake. Add shampoo. Shake and observe the difference.

You will have observed that the soap, skin cleanser and shampoo increase the solubility of oil.

As part of meeting the requirements of the course, you are expected to have conducted an investigation to determine the pH of the skin's surface and measure the pH values of a range of skin and hair products.

pH is measured using pH indicators such as litmus paper, pH meters or universal indicator.

Universal indicator — the colour of the indicator helps you determine the pH. In acids, universal indicator turns red. In alkalis, universal indicator turns blue. Neutral is green. A colour chart helps you to determine the actual pH.

Indicator paper — litmus paper turns pink in acid and blue in an alkali.

To test the pH of the skin:

1. Dab distilled water on the area to be tested and then test with indicator paper.
2. Test the pH of a salt solution and an oil.
3. Compare your results. (See page 93 for details of the pH of human skin.)

A range of skin and hair products can be tested with universal indicator.

Some examples are provided below.

- Soap is alkaline — pH 9 or 10.
- Shampoo is alkaline — pH 8.5.
- Hair removal cream is alkaline — pH 11.

As part of meeting the requirements of the course, you are expected to have used secondary sources to identify a range of chemicals used in everyday living, and outlined any precautions that may be needed in the use and handling of these chemicals.

Examples include:

- Surfactant cleaners — cleaners such as Spray & *Wipe* contain solvents to dissolve grease, anionic and nonionic surfactants, preservatives, colour and perfume. *Wonder Soaker* contains ingredients which remove dirt from clothes (anionic surfactants), soften water and disperse oils (sodium polyphosphate), remove bleachable stains (sodium perborate), break up greasy dirt (sodium carbonate, sodium silicate), break down protein stains (enzyme), improve product processing (sodium sulfate) and small quantities of brighteners and perfume.
- Lubricants — lubricating oils such as those used in car engines are made up of hydrocarbons (made from oil) with additives such as rust inhibitors, anti-wear agents and dispersants. Dispersants are usually heavy metal soaps (surfactants).
- Degreasers — contain solvents, such as caustic soda and ethanolamine, to dissolve grease.
- Pesticides — in Australia pesticides contain organophosphates. See page 11.
- Solvents — methylated spirits (mainly ethanol) and strong solvents such as paint thinners (liquified hydrocarbon) and mineral turpentine are highly flammable and can damage skin.
- Metal cleaners — such as *Silvo* contain abrasive particles (the polish) in methylated spirits.
- Body hygiene chemicals — such as deodorants often contain aluminium compounds.
- Cosmetics — are made from oil and water with an emulsifying agent. See page 91.

Cleaning products, colloids, surfactants and emulsifying agents

Oily substances and water are examples of substances that do not mix well. When put together they normally form a liquid-in-liquid colloid or suspension. For a cleaning product to be effective, it must change the surface tension of water and dissolve dirt, grease and oil. Emulsifiers (emulsifying agents) are substances which are partly water-soluble and partly oil-soluble. Emulsifiers bring oil and water together.

Soaps and detergents are emulsifying agents and surfactants, that is, soaps and detergents emulsify oils and greases and change the surface tension of liquids.

Emulsifying agents in cleaning products

Emulsifying agents reduce the difference in surface tension between two substances. This enables the substances to mix together. (See the investigations on page 90.) Soap is an emulsifying agent or emulsifier. Soap causes grease to be taken up by water as an emulsion and washed away. The dirt is washed away with the emulsified grease.

The properties of an emulsion

An emulsion is a mixture that contains two substances (such as water and grease) which do not normally mix well. To form an emulsion, an emulsifying agent must be added. Many cosmetics, foods, lubricants, medicines and paints are examples of emulsions. For example, milk is an emulsion of butterfat (oil) in water. The emulsifying agent that enables the butterfat and water to mix together is a protein called casein. Emulsions are not permanently stable. In many emulsions, the liquids will separate after a certain time. The finer the particle size, the more stable and the more viscous the emulsion is.

There are two types of emulsions: oil-in-water and water-in-oil emulsions. The effects of the different combinations of oil and water produce different properties.

Oil-in-water emulsions — oil molecules are dispersed in water. Water evaporates more readily from this emulsion. This emulsion can be dyed by water-soluble dyes, such as food colouring.

Water-in-oil emulsions — water molecules are dispersed in oil, therefore the water evaporates less quickly. This emulsion can be dyed with oil-soluble dyes, such as fuchsin. Oil has a higher electrical resistance than water. For this reason, a water-in-oil emulsion is a relatively poor electrical conductor. See the investigation below.

NOTE: Be careful not to confuse the terms emulsifying agent or emulsifier with the term emulsion.

As part of meeting the requirements of the course, you are expected to have prepared an emulsion and compared its properties to those of a solution and suspension.

Colloids can be distinguished from solutions by:

(a) Their inability to diffuse through a semi-permeable membrane, and

(b) Their ability to scatter light, that is, an emulsion will scatter some light to produce a cloudy effect, while the solution will allow light to pass through with no scattering (see page 88 for a comparison of properties).

An example is provided below. It may not be the same as the emulsion you have made.

To make a paint emulsion:

1. Mix together distilled water and pigment.
2. Grind the mixture. The mixture of pigment and water is a suspension. Observe its properties.
3. Add egg yolk (containing the emulsifying agent) to form an emulsion. Observe its properties.

As part of meeting the requirements of the course, you are expected to have performed an investigation to research the properties of different emulsions and compared those properties, distinguishing between oil-in-water and water-in-oil emulsions.

Face cream is an oil-in-water emulsion and suntan oil is a water-in-oil emulsion. Compare face creams and suntan oil by:

1. Testing the feel of the product on the skin.
2. Using water-soluble dye (litmus solution) and oil-soluble dye (fuchsin).

An oil-in-water emulsion produces a cooling effect and leaves an oily film (because the water evaporates readily); a water-in-oil emulsion produces a warmer feel on the skin. **Oil-in-water emulsions conduct an electrical current, disperse easily in water and become coloured with a water-soluble dye.**

As part of meeting the requirements of the course, you are expected to have used secondary sources to identify the properties of some commercial emulsions.

Some examples are provided below:

- Moisturising creams, lotions and milks, vanishing creams and foundation creams are oil-in-water emulsions.
- Paints contain a pigment, a binder to hold the pigment in place and a solvent such as water (water-based paints) or turpentine (oil-based paints).
- Hair gel is an emulsion of fat in water.
- Peanut butter is an emulsion of peanuts, sugar, salt and vegetable oil. Peanut butter may also contain an emulsifying agent which prevents the oil separating out.

The biodegradability of soaps and detergents

The term **biodegradable** is applied to those substances which can be decomposed (broken down) by fungi and micro-organisms such as bacteria. Soaps are generally more biodegradable than detergents.

Chemicals in hard water react with soap to form scum. When it was found that soaps were not effective in hard water, synthetic detergents were manufactured. Detergents are like soaps but do not create scum.The first detergents were branched-chain alkyl benzene sulfonates, which do not biodegrade in sewage treatment plants. The bacteria used in sewage treatment plants digest unbranched linear chain molecules, such as those in soap. This is why soap is biodegraded more easily than detergents.

Additives in synthetic detergents pose additional problems. For example, phosphates, which are added to remove soluble calcium salts in hard water, cause problems in water systems (see page 17, Chapter 1). Most detergents contain wetting agents which assist transport of pollutants deeper into soils.

More recently, biodegradable, phosphate-free detergents have been developed.

Cleaning products and the human body

Human skin

Skin is the largest organ of the body with a number of important functions.

- **Skin forms an airtight, fairly waterproof covering that protects the body from changes in the external environment.** The skin helps to conserve water. Skin pigments shield the rest of the body from the harmful effects of excessive light. The skin is a mechanical barrier. The outer layer of the epidermis protects the body from minor mechanical injuries.
- **Skin assists in body temperature control** — humans have warm and cold receptors present in the skin. In response to increased temperature, small blood vessels in the skin dilate, increasing the blood flow to the skin and therefore the amount of heat lost by radiation. The activity of the sweat glands also increases. In response to cold, blood circulation through the skin decreases, the activity of the sweat glands decreases, and hairs on the skin become erect to trap an insulating layer of air (seen as goose bumps in humans).
- **Skin protects against disease-causing organisms** — the outer layer of the epidermis forms a barrier against bacterial invasion. Unbroken skin protects other tissues and collects and holds pathogens (disease-causing organisms). Acid pH of the skin discourages growth of many microbes. Oil glands on the skin secrete fatty acids that inhibit the growth of some bacteria and fungi.

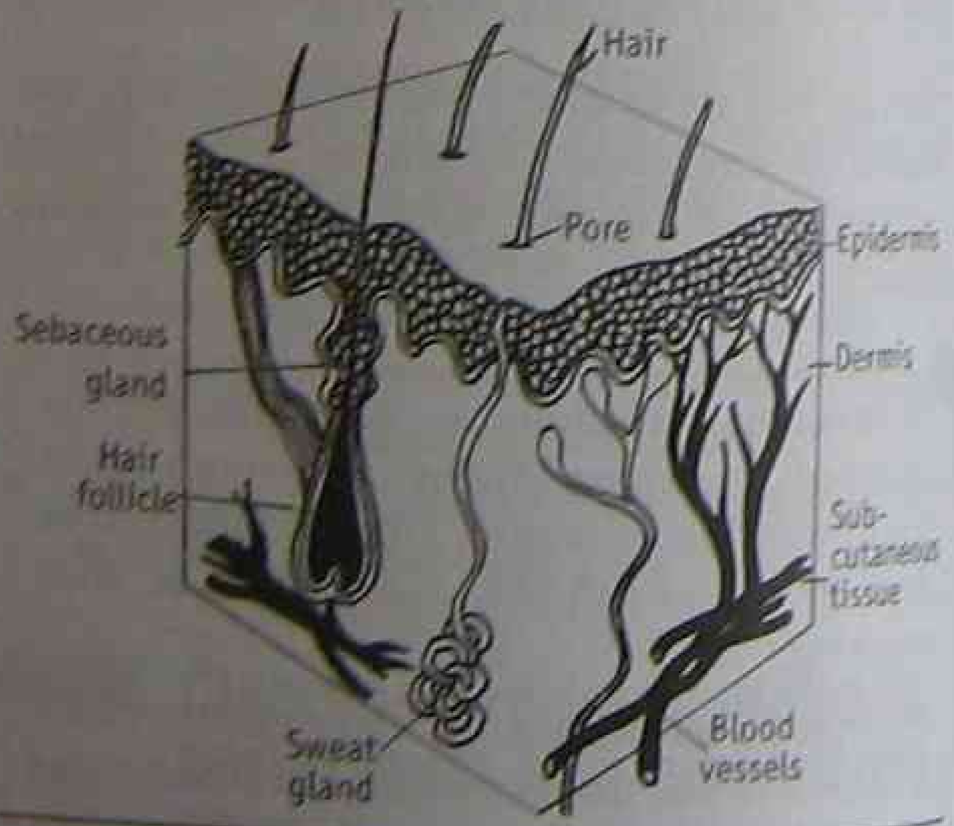


Figure 5.5 A cross-section of human skin

As part of meeting the requirements of the course, you are expected to have examined prepared slides of the skin.

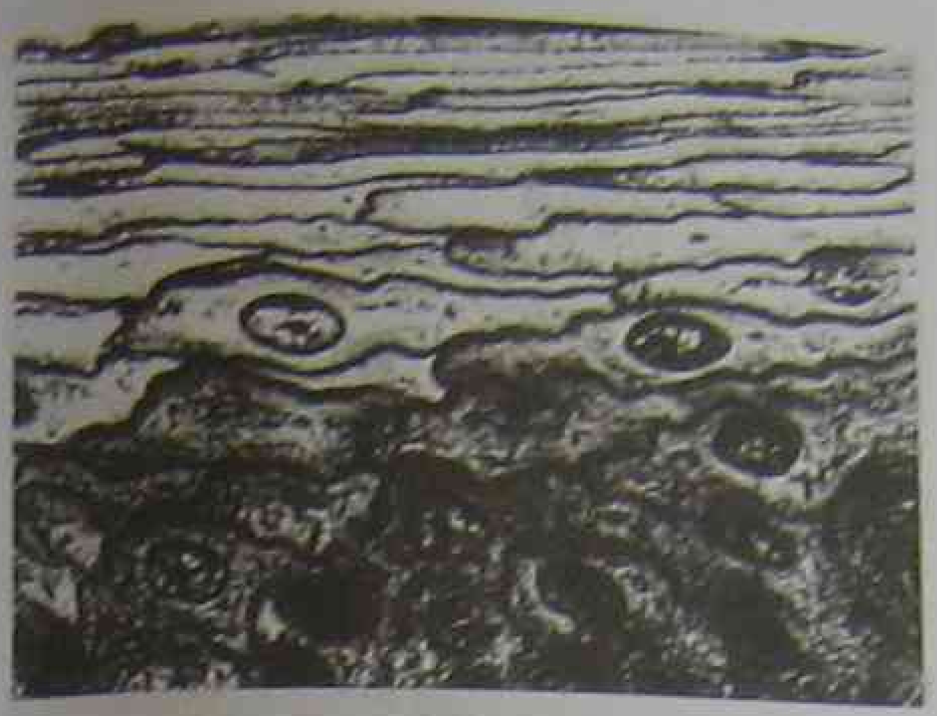


Figure 5.6 A microscopic view of epithelial cells of the skin. The cells are packed tightly together to provide a continuous protective layer.

Microflora on skin

Microflora on skin refers to the populations of naturally occurring micro-organisms (such as fungi and bacteria) that are common in and on the human body. The skin may contain fungi, fungal spores, bacteria and bacterial spores. Some of the bacteria and fungi can be beneficial. Some can be harmful (such as the fungus that causes tinea). Bacteria such as lactobacilli are natural microflora found in the gastrointestinal tract. These microflora can help combat pathogenic (disease-causing) micro-organisms.

An imbalance of microflora in the body or on the skin can cause conditions such as tinea and thrush. Thrush is a disease caused by an imbalance in the growth of the fungus *Candida albicans*. *C. albicans* is one of the natural micro-organisms of the human body which occurs in the mouth, respiratory tract, female genital tract and gastrointestinal tract. An increase in microflora can be brought about by taking antibiotics or steroids, the use of oral contraception (the pill), pregnancy, malnutrition and diabetes mellitus.

pH and the skin

pH is a way of describing the acidity of a substance. pH is measured on a scale from 0 to 14. A pH of 7 is neutral. This means it is neither acidic nor alkaline. High acidity is shown by a low pH level. A strong acid has a pH range of 0 to 3. A weak acid has a pH range of 3 to 7. A strong alkali (or base) has a pH range of 11 to 14. A weak alkali has a pH range from 7 to 11.

The natural pH of the skin is slightly acidic, with a pH range of 4.5 to 6.

The factors which cause skin to have a naturally acidic pH are:

- Sebum — the natural oil produced by glands in the skin. Sebum has a slightly acidic pH.
- Perspiration — the composition of sweat varies according to the stimulus that produced its secretion. Sweat produced by heat is more acidic than sweat in response to exercise. A 'cold sweat' that is secreted in response to intense excitement or fear has a more acidic pH.

The action of microflora such as bacteria can change the pH of the skin. Sweat can also have a slightly alkaline pH.

As part of meeting the requirements of the course, you are expected to have performed an investigation to test the claim that **either**:

(a) Different people have different skin pH values.

(b) The skin pH of a person can vary.

Ideas for both activities are provided below.

(a) *Aim:* To test the claim that different people have different skin pH values.

Method: Test the skin pH of a range of people. Dab distilled water on the area to be tested and then test with indicator paper. Make sure that the same test conditions apply for each person, such as the area tested and the indicator used.

(b) Aim: To test the claim that the skin pH of a person can vary.

Method: Test a person's skin pH in varying conditions, such as:

- Before and after exercise
- Before and after an exam
- During different times of the day, or over a period of time such as a week
- And/or test different parts of the body — skin on the arm, palm, armpit, face, legs, feet.

Skin soaps, cleansers and shampoos

Skin soaps — soap coats the skin in grease-removing chemicals. Soap cleans because it consists of a hydrocarbon chain which is repelled by water but attracted to oil, grease and dirt, and a carboxylic (fatty) acid which is attracted to water. Therefore, soap is made by reacting sodium hydroxide with an animal or vegetable fat such as coconut oil. Skin soaps also contain colouring and perfume.

Cleansers — common components include mineral oil, water and a stearate. Most cleansers also contain a moisture absorber. Cleansers dissolve sebum and loosen particles of grime and dirt.

Shampoos — extra chemicals in shampoo make the lather stay in the hair and remove grease. Common components include coconut oil, some olive oil, alcohol, glycerol and water, detergent or soap and perfume. Sodium stearate (stearic acid) is used in soapless shampoos.

As part of meeting the requirements of the course, you are expected to have tested the manufacturers' claim(s) on a commercial product and used the results to discuss the validity of their claim(s).

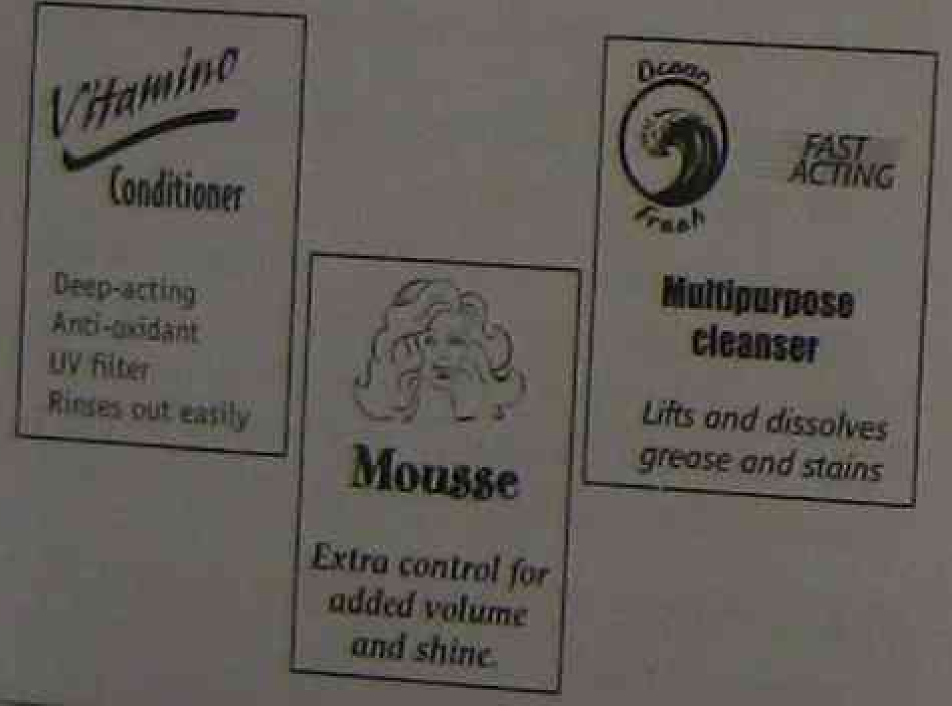


Figure 5.7 Examples of manufacturers' claims

Test claims from products such as cleansers and stain removers by comparing how well they clean and remove stains. You could also compare detergent products with natural (non-detergent) soaps.

The nature of a solvent and its role in the application of a mixture

Solutions may be formed in solvents of liquids, solids or gases by dissolving liquids, solids or gases in them. The most common solvents, however, are either water or alcohol-based.

The use of solvents in cosmetics and external medications

Substances that dissolve in water include moisturising creams and hair gels. Water is used in substances which need to flow. Some substances, however, do not dissolve in water and in these cases alcohol is used as the solvent.

Substances that dissolve in alcohol include after-shave lotion, deodorants, shaving cream, suntan lotions, spray deodorants, face packs, hair lacquers, vapour rubs and menthol rubs such as *Deep Heat*, nail polish and nail polish remover. Alcohol evaporates quickly from the mixture to leave the solute on the skin or nails. For example, nail polish contains a resin, a plasticiser and pigments in acetone. When the nail polish dries the alcohol (acetone) evaporates, leaving behind the sticky solid which stays on the nail.

Alcohol dissolves fat, and therefore can dry the hair and skin when some products are used in excess.

The solubility of materials used in drugs

Drugs are substances that can affect the physical and chemical structure of the body in specific ways. Drug molecules move around the body in two ways:

(a) By diffusion across membranes such as cell membranes, the skin and the walls of the stomach, and

(b) Via the bloodstream.

The rate of diffusion depends on the molecule size and solubility of the drug. Membranes in the body are made up of lipids (fats), therefore fat-soluble drugs diffuse more readily across membranes.

The parts of the digestive system

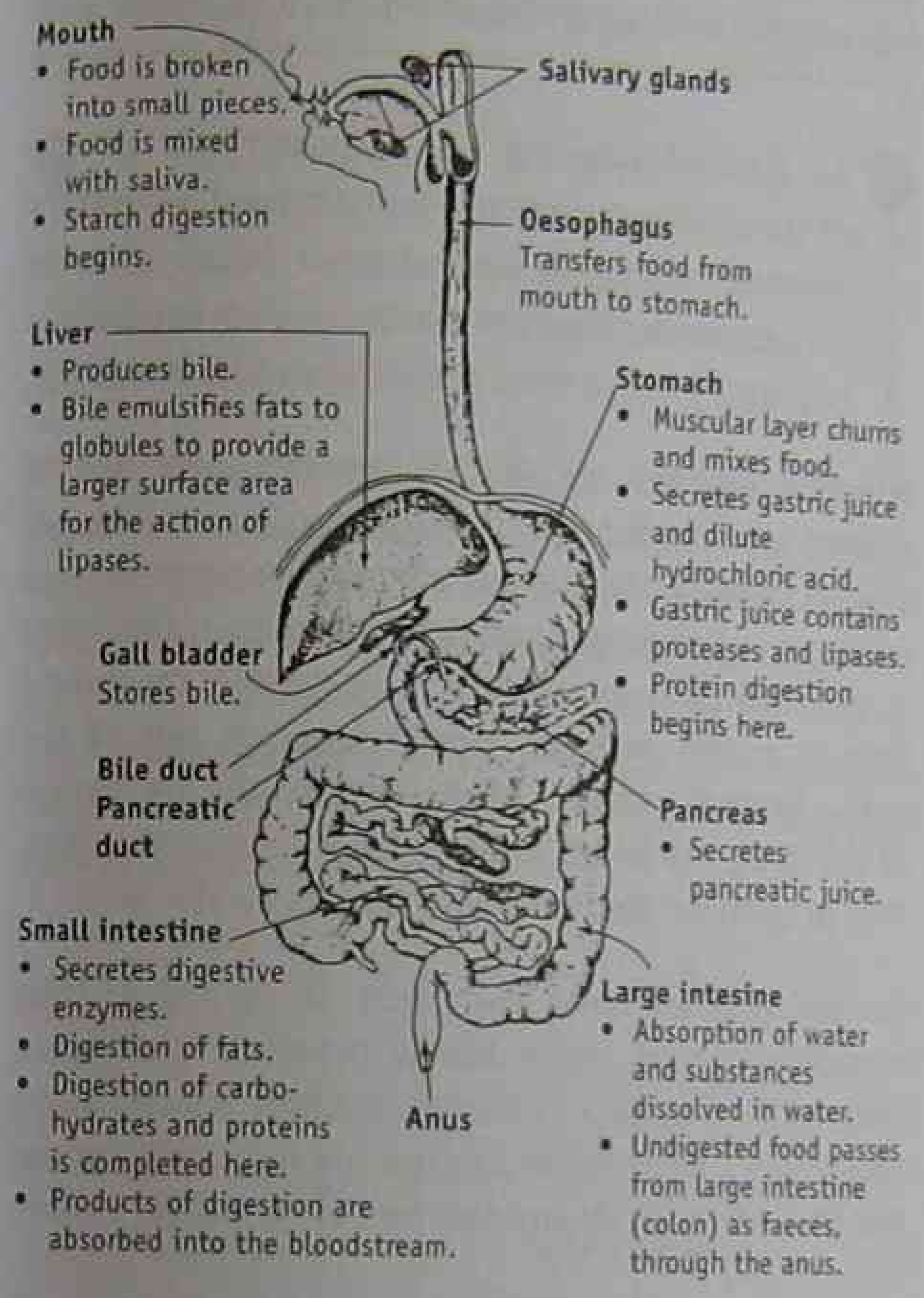


Figure 5.8 The human digestive system

The role of the stomach and the small intestine

The **role of the stomach** includes:

- Storage of food
- Conversion of the food by gastric juice into a soft semi-fluid mass which is released into the duodenum for transfer to the small intestine
- Protein digestion. Food in the stomach is mixed with digestive juices called gastric juice. Gastric juice contains enzymes which begin the breakdown of proteins. Glands of the stomach also produce hydrochloric acid which provides the optimal pH for the action of the enzymes, and mucous which protects the walls of the stomach from the acidic juices.

Only a small amount of water is absorbed in the stomach. A few fat-soluble substances, such as alcohol and drugs, are absorbed.

The role of the small intestine — the breakdown of food (digestion) is completed in the small intestine. Digestive juice (pancreatic juice) from the pancreas and bile from the liver are delivered through ducts to the small intestine. Other enzymes are produced by the wall of the small intestine. In the small intestine, carbohydrates are converted to glucose and protein digestion is completed. Proteins are converted to amino acids. Some fats are converted to fatty acids and glycerol. Most fats are emulsified (broken down to smaller particles) by bile and are absorbed without chemical change.

During the digestion process, most of the water is absorbed in the duodenum and small intestine. Of the 5–10 litres of fluid that enters the small intestine, only about half a litre reaches the large intestine.

The difference in pH of the stomach and the intestine

The glands of the stomach produce hydrochloric acid. Therefore, stomach contents are much more acidic — a lower pH — than the contents in the small intestine. Pancreatic juice in the small intestine is alkaline. This is important in neutralising the contents from the stomach and in providing an optimum pH for the action of enzymes in the small intestine.

Drug design and the solubility of chemicals

The solubility of a drug affects where it is absorbed on or in the body. Many commonly available drugs are taken by mouth for absorption in the stomach or small intestine.

Water-soluble, fat-soluble and alcohol-soluble drugs are absorbed by the walls of the stomach into the bloodstream for distribution around the body. (The drug must not be affected by the pH of the stomach.) Water soluble drugs may also be absorbed by the walls of the small intestine.

As part of meeting the requirements of the course, you are expected to have used first-hand or secondary sources to relate the significance of the solubility of medication to its action on/in the body.

Absorption is the passage of the drug from the site of administration into the bloodstream. The solubility of a drug affects:

- How the body absorbs the drug
- The rate of absorption
- The action of the drug on and in the body
- How the drug is administered and the site for administration.

For example, some tablets and capsules have a coating which dissolves slowly and therefore remains intact for some hours after being taken in order to delay absorption and/or to ensure that the absorption occurs in the small intestine (rather than the stomach).

Solubility and the administration of medications

There are many ways in which drugs can be administered to the body:

- By mouth for absorption by the stomach or small intestine
- By inhalation for absorption by the nasal passages and lungs
- As a skin or dermal patch for absorption by the skin
- By creams or ointments for protection of and absorption by the outer layers of the skin
- As suppositories for absorption by mucous membranes of the rectum or vagina
- By injection directly into the blood or muscle tissue
- By drops (such as ear and eye drops) for absorption by the affected tissue.

Depending on the rate of solubility of different drugs, different means of administration are more appropriate. For example, fast-acting drugs administered by inhalers (such as asthma inhalers) are contained in aerosols or 'puff' powders and must be able to diffuse rapidly across the nasal cell membranes. Drugs given by skin patches or muscle injection are absorbed by the body at slower rates. The rate depends on the substance in which the drug is dissolved or suspended.

As part of meeting the requirements of the course, you are expected to have used secondary sources to identify how dermal (skin) patches (for example, nicotine patches) and subdermal implants release their medication into the body.

Nicotine patches are dermal patches designed to deliver nicotine through the skin and into the bloodstream to help prevent the craving for nicotine that smokers experience when they try to quit. (Nicotine is an addictive component of cigarette smoking.) Skin is meant to keep most chemicals out of the body. Dermal patches work because the molecules of the drug are small enough to penetrate the skin. The drug must also be non-irritating to the skin.

Dermal patches have also been developed to treat motion sickness, high blood pressure and some symptoms of angina (a heart condition which causes chest pain). Subdermal patches are implanted under the skin for slow absorption and long-lasting action.

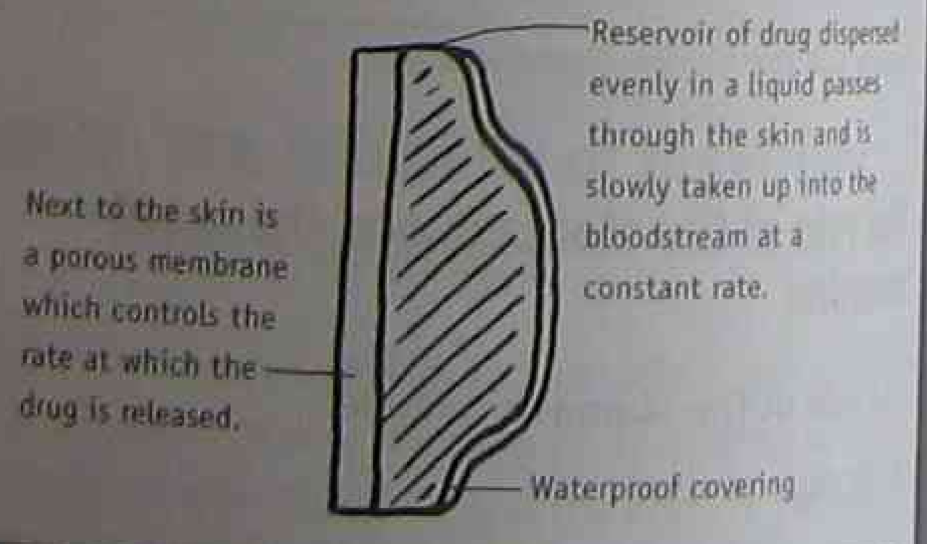


Figure 5.9 An example of a dermal patch

Capsules, tablets, enteric-coated tablets, and slow-release tablets

Drugs are often prescribed in different forms in order to control the rate at which they dissolve and therefore the rate at which they are released in the body and absorbed into the bloodstream. For example, aspirin, which is made up of acetyl salicylic acid, occurs in two forms — in acid solution which is fat-soluble and in neutral or alkaline solution which is water-soluble. Acetyl salicylic acid in fat-soluble form easily diffuses through the stomach wall. However, aspirin can upset the stomach, so acetyl saliylic acid is also manufactured in a form that prevents it from dissolving until it reaches the small intestine.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to compare the solubility of capsules, tablets, enteric-coated tablets, and slow-release tablets.

For example, different forms of aspirin — *Disprin* capsules, aspirin tablets, *Aspro Clear* (a soluble tablet), *Cartia* (an enteric-coated aspirin) — and *Fefol* (delayed-release iron and folate capsules) may be used. An enteric coating prevents the aspirin from being released in the stomach. The aspirin is released in the small intestine where it is absorbed slowly into the bloodstream.

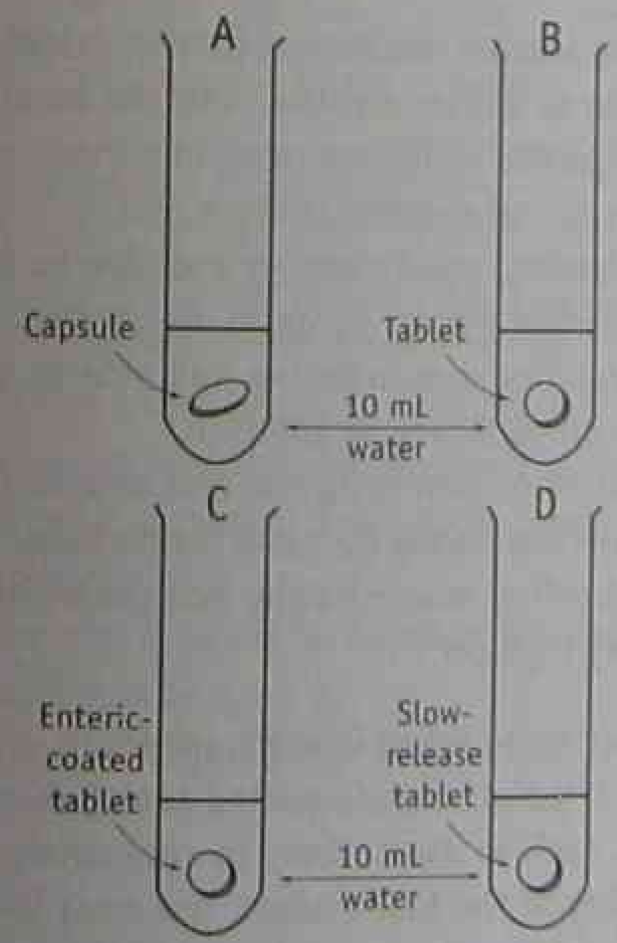


Figure 5.10 A comparison of the solubility of capsules, tablets, enteric-coated tablets and slow-release tablets in water and other substances

1. Dissolve each tablet in 10 mL water (water temperature: 37°C).
2. Record if the tablet dissolves and how long it takes for it to dissolve.
3. Dissolve each tablet in 10 mL dilute hydrochloric acid.
4. Record if the tablet dissolves and how long it takes for it to dissolve.
5. Dissolve each tablet in 10 mL dilute sodium hydroxide (an alkaline solution).
6. Record if the tablet dissolves and how long it takes for it to dissolve.

The greater the surface area of the tablet, the less time it takes to dissolve. Therefore, for more accurate measurements, try to get the same amount of surface area for each tablet.

For a note on controlled experiments, see page 12.

Water-soluble and fat-soluble vitamins

Vitamins are divided into two categories: fat-soluble and water-soluble.

Fat-soluble vitamins are vitamins A, D, E and K. Because they are fat soluble, they can be stored in body tissues.

Water-soluble vitamins are B1 (thiamine), B2 (Riboflavn), Niacin, B6 (pyridoxine), pantothenic acid, biotin, B12, folate (folic acid), and vitamin C. These must be consumed daily because the body will excrete them in the urine rather than storing them.

As part of meeting the requirements of the course, you are expected to have used secondary sources to identify the correct procedures to be followed for treating the ingestion of liquid poisons.

Procedures:

- Try to keep the person calm.
- Identify the poison.
- Phone the Poisons Information Centre.
- Do not induce vomiting until you get advice.

See first aid manuals or phone the Poisons Information Line (13 11 26 — 24 hours from anywhere in Australia) for more information and advice on the treatment of poisoning, bites and stings.

Checklist Key terms for revision

- solute
- solvent
- solutions
- colloids
- suspensions
- surface tension
- surfactants
- emulsions
- emulsifiers
- oil-in-water emulsion
- water-in-oil emulsion
- biodegradability
- skin and hair
- microflora
- pH
- digestive system
- stomach
- small intestine
- solubility of drugs
- fat-soluble vitamins
- water-soluble vitamins
- surfactant cleaner
- lubricant
- degreaser
- cosmetics
- detergent
- soap
- dermal patches

Test Lifestyle Chemistry

Multiple choice questions

1. The table below is a summary of some of the properties of mixtures.

	Property
W	Particles are scattered throughout the mixture.
X	A beam of light can pass through the mixture without any scattering of the light by particles.
Y	Particles can be removed by filtering.
Z	A beam of light shone through the mixture produces a bright cloudy effect.

The answer that provides the correct match for the letters W, X, Y, Z is:

(A) Colloid, solution, suspension, colloid
(B) Suspension, solution, suspension, colloid
(C) Suspension, solution, colloid, solution
(D) Colloid, suspension, colloid, solution

2. Nicotine patches are dermal patches which are designed to deliver nicotine into the bloodstream. The properties which are most important for the drug in dermal patches to work are:

(A) Solubility, non-irritating and able to be absorbed rapidly by nasal membranes
(B) Solubility, non-irritating and able to be absorbed slowly by the skin
(C) Solubility, non-irritating and able to be absorbed slowly by nasal membranes
(D) Solubility, non-irritating and unaffected by a very high pH

3. Aspirin can be taken in different forms — as a capsule, tablet, enteric-coated tablet or soluble tablet, such as *Aspro Clear*. In comparing the solubility of the four tablets, the most likely order from most soluble to least soluble is shown by:

(A) Soluble tablet, capsule, tablet, enteric-coated tablet
(B) Soluble tablet, tablet, capsule, enteric-coated tablet
(C) Enteric-coated tablet, soluble tablet, tablet, capsule
(D) Tablet, capsule, enteric-coated tablet, soluble tablet

4. The following label shows a claim for a cosmetic product.

✓ **Confidence**
pH balanced

24 HR PROTECTION

Cosmetic products are usually alkaline. To create more of a balance closer to the pH of the skin and hair, the pH of the product is sometimes modified. If a student tested this product, what pH would they expect to get?

(A) 6 (B) 2
(C) 11 (D) 8

5. The table below summarises the site of action, activity requirements and reactions for four enzymes 1, 2, 3 and 4.

Look at the table to answer question 5.

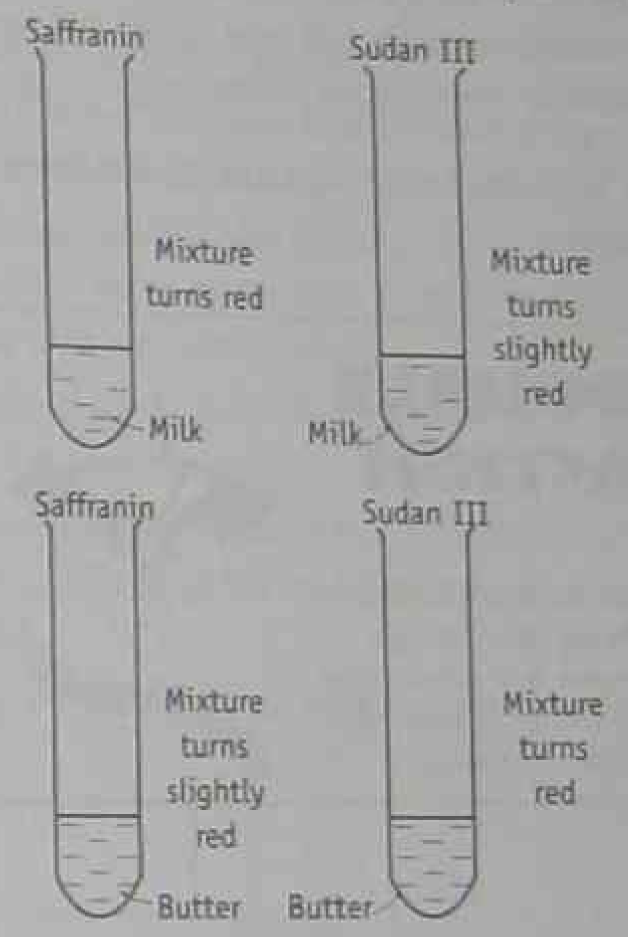
Enzyme	Site of action	Activity requirements	Reaction catalysed
1	W	pH 6–8	Starch → maltose
2	X	pH 1–2	Protein → polypeptides
3	Y	pH 7–9	Fats → fatty acids
4	Z	pH 7–9	Maltose → glucose

Which statement below is most correct?

(A) The site of action for enzyme 1 is the stomach.
(B) Enzyme 4 is most likely to be found in the stomach.
(C) Enzyme 2 would be found at the same site of action as enzyme 3.
(D) The site of action for enzyme 2 is the stomach.

Short answer and longer response questions

1. Saffranin and Sudan III are dyes. Saffranin dissolves in water but not in oil. Sudan III dissolves in oil but not in water. In both cases, the dye gives a red colour to the substance in which it dissolves. A student tested two emulsions — butter and milk — with both saffranin and Sudan III. The results are shown in the diagrams below.



What conclusion might the student have drawn from these results? (2 marks)

2. (7 marks)

Look at the diagram below of the human digestive system. Two parts of the system have been labelled X and Y.

(a) For each part X and Y, briefly outline its role in breaking down food. (2 marks)

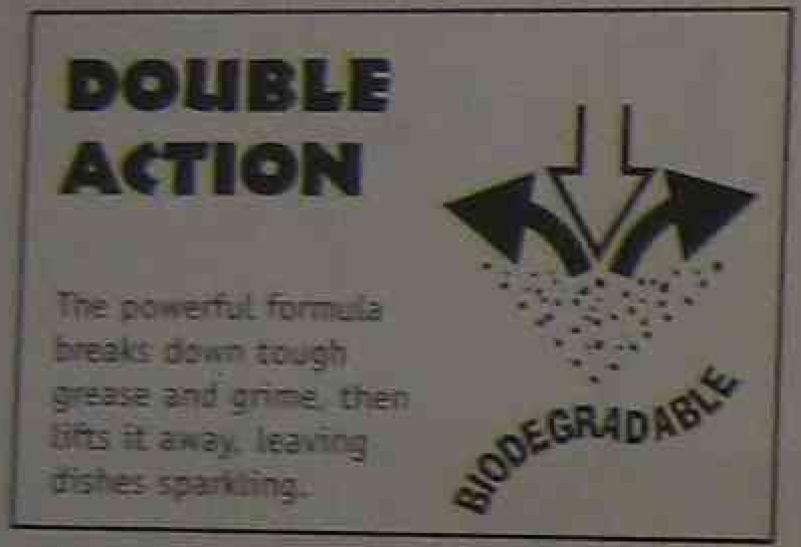
(b) Compare the pH of the contents in X and Y. (1 mark)

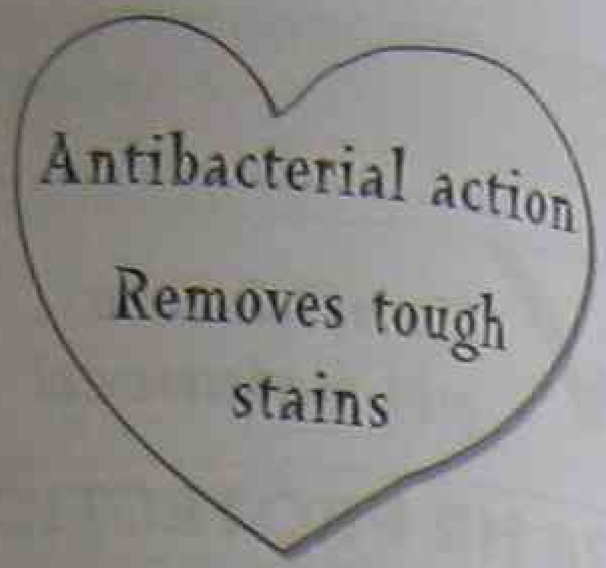
(c) Compare the absorption of drugs in X and Y. (1 mark)

(d) How is the solubility and absorption of a drug related to its action on or in the body? (3 marks)

3. What is the difference between water-soluble and fat-soluble vitamins and how is this difference related to their storage in the body? (3 marks)

4. The following labels are taken from cleaning products.





Describe two tests that you could carry out to test the manufacturers' claim on either one or both of the products. (4 marks)

5. In this module you carried out a number of controlled experiments. Describe one such experiment and outline its aim, the method (using diagrams where appropriate, indicating the variable(s) and the factor(s) you kept constant) and how data was collected and recorded. (6 marks)

6. Draw labelled diagrams to represent the nature of particles in a solution, colloid and suspension. (3 marks)

Test answers

Multiple choice questions

Answers

1. A 2. B 3. B 4. A 5. D

Explanations

1. See page 88 for a summary of the properties of colloids, solutions and suspensions.
2. Dermal patches work because the drug:
   - Can be incorporated in liquid form, that is, it is soluble
   - Has molecules small enough to penetrate the skin but occurring at a slow rate
   - Is non-irritating to the skin.
3. See page 97.
4. The natural pH of the skin is slightly acidic, with a pH range of 6 to 4.5.
5. The glands of the stomach produce hydrochloric acid — a low pH. Therefore, the site for enzyme I is the stomach.

Short answer and longer response questions

Answers and explanations

1. Butter is an emulsion of oil and water.

   Milk is an emulsion of oil and water but contains much more water than oil.

2. (a) X is the stomach. The role of the stomach — storage of food and protein digestion.

   Y is the small intestine. Digestion of food is completed in the small intestine.

   (b) Stomach contents are much more acidic — a lower pH — than the contents in the small intestine. Pancreatic juice in the small intestine is alkaline.

   (c) Fat-soluble drugs are absorbed by the stomach; water-soluble drugs are absorbed in the small intestine.

   (d) The solubility of a drug affects how the body absorbs the drug, the rate of absorption, the action of the drug on and in the body, how the drug is administered and the site for administration.

3. Water-soluble vitamins are dissolved in water and therefore are excreted in urine. They are not stored by the body. Examples are B vitamins and vitamin C.

   Fat-soluble vitamins are dissolved in fat and are therefore stored in body tissue. Examples are vitamins A, D, E and K.

4. There are a number of tests which can be done to validate manufacturers' claims of these products:
   - Do a comparative test of the 'double action' dishwashing liquid: test the same amount of a number of detergents (including pure soap) to wash the same number of dishes with the same amount of grease and grime.
   - Test its biodegradability by observing how well a sample in water (or soil) breaks down over time (test the pH of the soil or water as an indicator of the presence of the detergent).
   - Test how well the stain remover removes a number of different stains.
   - Set up agar plates to culture bacteria. On one of the plates, add the stain remover and observe its antibacterial action (see page X for instructions on how to grow bacterial cultures).

5. A sample answer is provided.

   Aim: To test the claim that different people have different skin pH values.

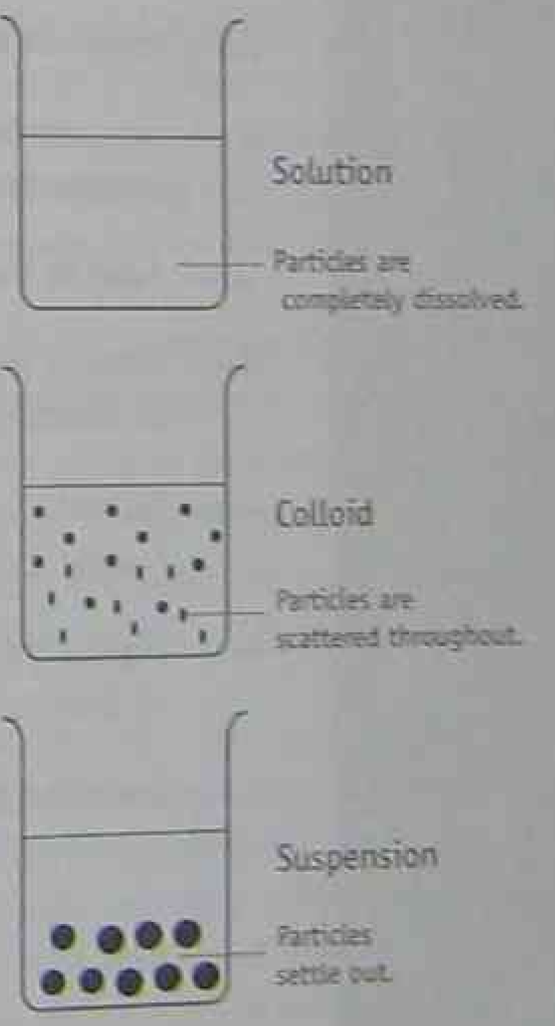
   Method: Test the skin pH of a range of people. Dab distilled water on the area to be tested and then test with indicator paper.

   The variable is the individual differences of each of the persons tested.

   The factors kept constant include the area tested for each person, the type and amount of indicator used.

   Record the pH for each person tested as a table.

6.



HSC Core Study Module 2

6 — Medical Technology: Bionics

Introduction

In this chapter you will review advances in bionics — biomaterials and biomedical devices — and how these advances are related to an increased understanding of chemical structure and the ways in which the body works. You will also look at technologies that have changed the direction and nature of scientific thinking and the impact of bionics on society.

As a result of working through this chapter you will be able to:

- Discuss technological developments that have led to an increased understanding of the ways in which the body works
- Assess the impacts of the application of biomedicine on society
- Identify some of the Earth's resources that are used in the manufacture of biomedical materials and devices
- Identify the effects of changes to heartbeat and blood flow on the human body
- Relate the structure of the circulatory, skeletal and respiratory systems to their functions
- Describe possible future directions of research in bionics.

☑ Checkpoint

Before you begin your review you may need to check your understanding of the following:

- The role of the circulatory system in maintaining humans as functioning organisms. The circulatory system is responsible for transporting digested foods, water and oxygen to all cells and metabolic waste products (carbon dioxide, nitrogenous wastes and water) away from cells.
- The role of the skeletal system, particularly in relation to maintaining an upright stance and protecting vital organs.
- The role of the respiratory system in maintaining humans as functioning organisms. The respiratory system is the organ-system concerned with the intake of oxygen, necessary for cellular respiration and the removal of carbon dioxide, which is toxic in high concentrations. In humans the respiratory system is made up of the lungs, diaphragm, trachea, bronchi, bronchioles and alveoli. (See page 113.)

Biotechnology

Biomaterials are special materials that are biocompatible. That is, they are able to function in contact with living tissue, with minimal adverse reaction or rejection by the body.

Biomedical devices or implants are devices engineered from biomaterials and designed to perform specific functions in the body.

Biomedical engineers work with electronics, the mechanics of the body, the structure and function of materials and an increasing knowledge of the functioning of organs and body systems to develop bionic materials and structures such as artificial body parts (blood vessels, skin, joints), pacemakers, dialysis equipment and limbs.

See: http://www.gsbme.unsw.edu.au — the Graduate School of Biomedical Engineering (UNSW), for a definition of biomedical engineering and information on current research, such as implantable glucose sensors for diabetics and carbon composites for joint replacements.

Some of the issues that need to be considered in evaluating the benefits of advances in bionics include the following:

- Developments in bionics have enabled people with illnesses or disabilities to live more independent and better quality lives and continue to contribute to society.
- Research and development in biomedical technology is very expensive. Where it is funded by big business which patents the technologies, ethical issues can arise regarding who has access to the technologies. Is it fair for only the wealthy or those in developed countries to enjoy the benefits of advances in medical research?
- The high cost of medical devices and materials can place a heavy burden on the health systems involved, and other areas of health care may suffer as a result.
- Research funds and efforts may be diverted from areas of health that may otherwise help large numbers of people but which do not make money, for example health initiatives in developing countries.

As part of meeting the requirements of the course, you are expected to have gathered information on types of implants, the materials used and the part of the body in which they can be used, using a database package to store and retrieve data as it is collected.

Developments in biomaterials and biomedical devices (bionics) have meant that many people who would previously have died, or lived with a serious disability, are now able to survive with a much improved quality of life. These developments have come about through advances in:

- Technologies to study the human body and understandings of human structure and function
- The production of synthetic polymers (see page 140), such as polyurethane, silicone and teflon which have proven to be safe in contact with living tissue, as well as modern plastics that are strong and lightweight

- Metal alloys which are light but strong enough to withstand repeated use
- Understandings in immunology which have led to more successful transplants. Transplantation involves implanting organs or tissues from one person to another. Success depends on the compatibility of the donor and recipient. The major problem with transplants is rejection of the tissue by the recipient's body. The problem of rejection has been overcome to some extent by the development of synthetic compounds that do not trigger an immune response by the body.

Replacing body parts

Some of the devices which can be used to replace damaged or diseased body parts include:

Pins, screws and plates — these are used to replace damaged bones and repair joints: for example, titanium plates are inserted into damaged skulls to protect the brain; titanium-coated stainless steel bone pins are used to repair severe bone fractures; hip screws are used to stabilise fractures of the neck or the thigh bone (the femur).

Artificial joints — such as artificial knee, hip, shoulder, wrist and elbow joints.

Pacemaker implants — electronic devices that send a series of small electric impulses to the heart causing it to beat regularly (see page 107).

Cochlear implants — a cochlear implant is an artificial hearing device. It is sometimes called a bionic ear. Cochlear implants were developed to bypass dead hair cells and electrically stimulate the auditory nerve directly. They consist of three main components: the cochlear implant package and receiver-stimulator, a speech processor and a headset. The receiver is implanted in the patient's skull. A fine wire attaches the receiver to the cochlea. A transmitting coil is implanted and held against the skin by a magnet on the outside of the skull. A microphone behind the patient's ear picks up sounds. These are passed to a sound processor usually worn on a belt or in a pocket. The processor highlights important words making them easier to understand. The processor then transmits the signals to the receiver.

Artificial valves — heart diseases can lead to narrowing or leakage of heart valves. Heart valves can also become stiff. Faulty heart valves can be replaced with biological valves from a human donor or the valve from a pig's heart. Bionic mechanical valves can also be used (see page 109).

Crowns and dentures — dentures are artificial teeth. The teeth are made of metal covered in porcelain. The teeth are set in plastic gums.

Lenses — contact lenses and intraocular lenses. Cataracts are caused by the lens of the eye growing cloudy and eventually becoming opaque. Opaque areas of the lens prevent light from reaching the retina and the sufferer becomes blind. Cataract surgery involves replacing the damaged or cloudy lens with an intraocular lens. For information on an artificial eye that taps directly into the optic nerve, see http://www.abc.net.au/news (Monday, 1 May 2000).

Prosthetic limbs — artificial limbs such as arms/hands and legs/feet. Artificial body parts are also called prostheses. Myoelectric prosthetic limbs use electric signals from the patient's muscles to move the limb. Computers are now used to design tailor-made models for amputees.

See http://www.abc.net.au/science/slab/leg/default.htm for Australian advances in attaching an artificial leg directly onto an amputee's stump.

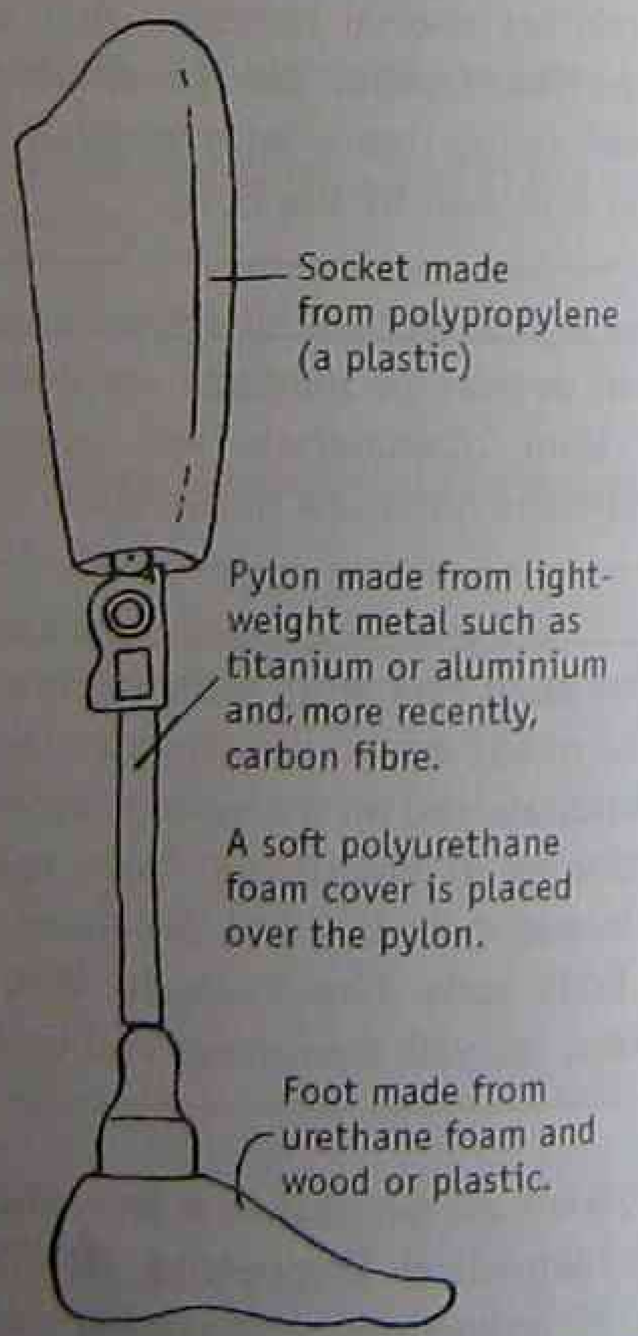


Figure 6.1 An above-the-knee prosthesis

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the development of society's use of biomaterials and implants. Some ideas are provided below.

- The earliest artificial body parts and biomaterials included metal hooks for hands, wooden legs and ivory teeth.
- 1628 — William Harvey put forward the theory of blood circulation. This theory became the basis of modern medical research.
- 1816 — invention of the stethoscope.
- 1952 — first implantable artificial heart valve invented.
- 1953 — heart–lung machine invented.
- 1958 — first implantable artificial pacemaker constructed and installed.
- Early 1960s — modern methods of hip replacement pioneered in England.
- Late 1960s — first coronary bypass.
- 1967 — the first artificial heart transplant (conducted by Christian Barnard). The patient lived for 18 days.
- 1977 — a Swiss physician performed the first angioplasty.
- 1982 — first permanent implant of an artificial heart in the USA. The heart was made of plastic and aluminium. The patient survived for 113 days.
- 1985 — first implantable defribillator became available.
- 1990s — developments in computer technology, minimally invasive diagnostic and surgical techniques (see pages 115–16) and nanotechnology. Nanotechnology involves engineering at the scale of atoms and molecules. 1 nanometre = 1 billionth of a metre (the diameter of a few atoms). The technology will impact significantly on the development of biomaterials — artificial blood, artificial skin, modified blood vessels, 'smart' bandages, contact and intraocular lenses, cochlear implants.

Reference: Cornell B. 'Nanotechnology: the technology of the 21st century', *Australasian Science*, Jan/Feb 2000, pp. 28–32.

See also: *Science and Technology: People, Dates and Events* (1999), George Philip Ltd, London.

Heartbeat, blood flow and the maintenance of good health

The parts of the heart

The heart is made up of valves, the left and right atria (plural atria/ singular atrium) and the left and right ventricles. Blood vessels, veins and arteries, carry blood to and from the heart.

Valves — the flaps in the heart are called valves. Valves ensure a one-way flow of blood. The valves between the aria and ventricles prevent the blood flowing back into the aria as the ventricles contract. The valves in the arteries prevent the blood that leaves the heart from flowing back into the ventricles.

✓

> The tricuspid valve is situated between the right atrium and the opening of the right ventricle.
>
> The bicuspid valve is situated between the left atrium and the opening of the left ventricle.
>
> Three semi-lunar valves are situated between the pulmonary artery and the right ventricle.
>
> Three semi-lunar valves are also situated between the aorta and the left ventricle.

As part of meeting the requirements of the course, you are expected to have examined a heart to observe the function of the valves.

A heart dissection or model will show the function of valves in the heart.

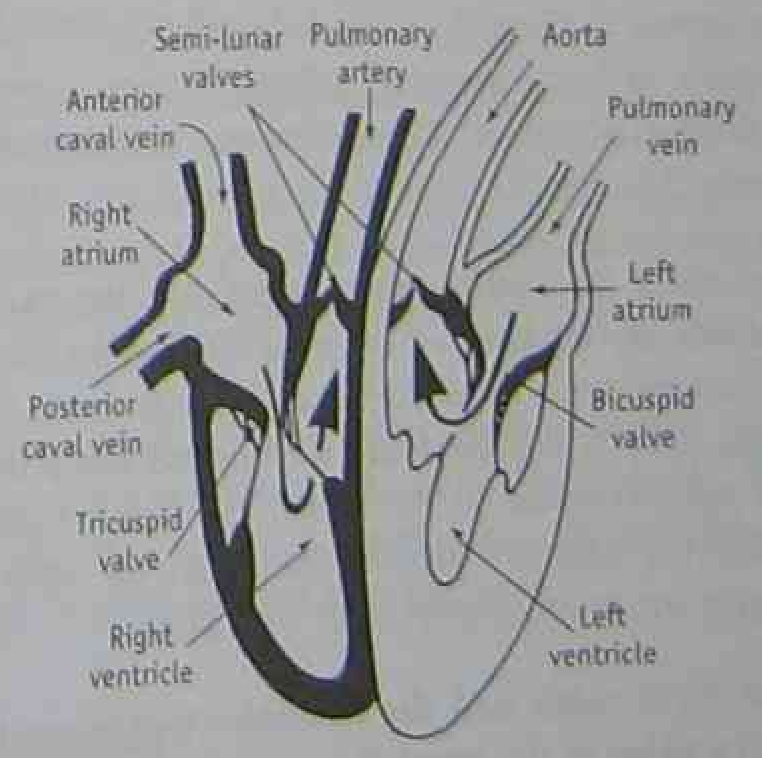


Figure 6.2 Diagram of the heart showing valves, atria, ventricles, major arteries and veins and direction of blood flow through the heart

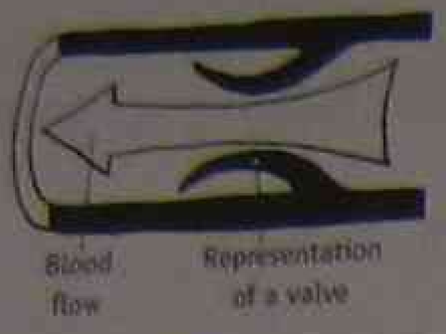


Figure 6.3 Valves allow movement of blood flow in one direction only

Atria — the in-flow chambers. The atria collect the incoming blood and, when they contract, transfer the blood to the ventricles.

Ventricles — the out-flow chambers. When the ventricles contract, blood is pumped away from the heart.

Deoxygenated blood flows through the veins into the right atrium, then into the right ventricle where it is squeezed out to the lungs to pick up oxygen. From the lungs, oxygenated blood flows into the left atrium, then into the left ventricle and then out to rest of the body via the arteries. The chambers of the heart have thick muscular walls made up of cardiac muscle.

Major arteries and veins — include the aorta, the pulmonary artery and the pulmonary vein, the vena cava and the coronary artery.

Arteries carry blood **away** from the heart. The blood is pumped under pressure. Therefore, arteries have thick muscular walls.

Veins carry blood **to** the heart. Blood flows through veins under low pressure. Veins have thin walls. The movement of blood in veins is assisted by the contraction of body muscles. Valves in veins prevent back-flow of blood. (There are no valves in the arteries.)

The aorta and pulmonary artery are the major arteries of the heart. The aorta takes blood from the left ventricle to blood vessels that go to the rest of the body. The pulmonary artery takes blood from the right ventricle to the lungs. Two main arteries called the coronary arteries lead from the aorta to supply the heart muscle itself with blood.

The caval veins and the pulmonary vein are the major veins of the heart. During the relaxing phase, deoxygenated blood laden with carbon dioxide and other wastes, returns to the right side of the heart. This blood enters the right atrium via two large veins — the superior vena cava (from the head, neck and arms) and the inferior vena cava (from the abdomen, pelvis and lower limbs). Blood returns from the lungs to the left atrium via the pulmonary vein. (Figure 6.5 shows other major arteries and veins in the human body.)

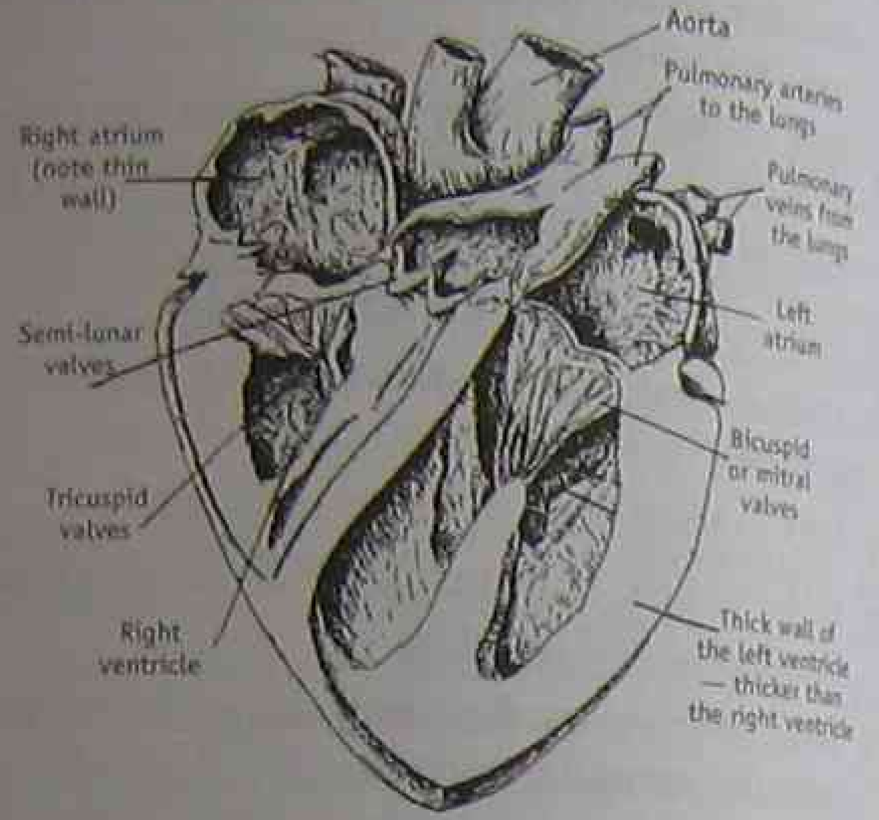


Figure 6.4 A dissected sheep's heart showing valves, atria, ventricles, major arteries and veins

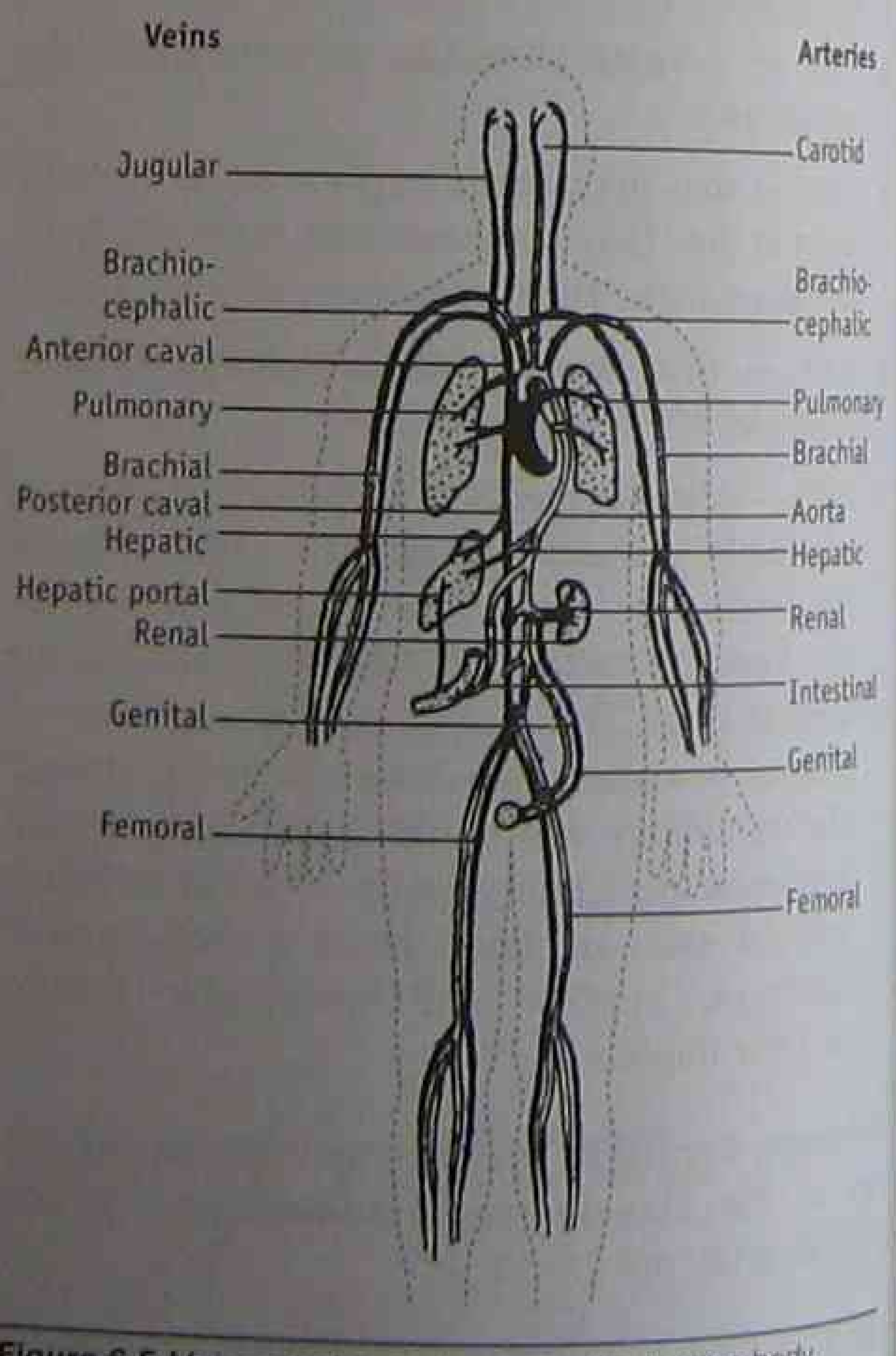


Figure 6.5 Major arteries and veins in the human body

As part of meeting the requirements of the course, you are expected to have carried out an experiment to observe and analyse changes in the rate of the heartbeat during rest and during sustained physical activity.

Your investigation may have involved measuring the pulse rate of a person sitting, standing and after exercise. Pulse rate after exercise increases because the body requires more oxygen and must get rid of carbon dioxide at a faster rate. The heart beats faster and therefore the pulse rate increases.

You may also have compared the changes in heartbeat rate for a number of different people. Your results will be different for different people. The differences arise due to factors such as:

- Levels of fitness; people with high levels of fitness tend to have a faster recovery rate after exercise.
- Food intake before the investigation, which may increase the heart (pulse) rate.
- Individual differences, such as body weight.

Heartbeat

The heart is the pumping centre for blood. The rhythmic pumping is the heartbeat. Cardiac muscle contracts and relaxes involuntarily (we do not consciously think about it). The heart muscles pump every second of a person's life. The heart beats about 70 times per second — 100,000 times per day. In one day, the heart pumps the body's supply of blood through the whole circulatory system.

A small mass of specialised tissue within the heart coordinates and regulates the contractions of the cardiac muscle. These special cells (called the sinoatrial node) are located in the right atrium and are the heart's natural pacemaker.

The heart gets the impulse to contract from electrical signals.

The electrical signal starts in the sinoatrial node. After the impulse starts, it quickly travels from cell to cell in the muscles of the atrium, causing it to contract just before the ventricle does. Special cells delay the impulse long enough for the atrial contraction to fill the ventricle with blood. As the impulse moves through, the chambers relax.

As part of meeting the requirements of the course, you are expected to have planned and performed an investigation to identify individual aspects that comprise the heartbeat.

A stethoscope is used to listen to the sounds from the heart (and lungs). The heart contracts in the systole phase and relaxes in the diastole phase.

Systolic			Diastolic		
Age	Male	Female	Age	Male	Female
16–19	105–135	100–130	16–19	60–86	60–85
20–24	105–140	100–130	20–24	62–88	60–85
25–29	108–140	102–130	25–29	65–90	60–88

Figure 6.6 'Normal' systolic and diastolic blood pressure for the ages 16–29

Interruptions to the normal rhythm of the heart

Problems that can result from interruptions to the normal rhythm of the heart include an irregular heartbeat called arrhythmia. Arrhythmia can be detected using an electrocardiogram. Fibrillations are a type of arrhythmia. The heart fibrillates when individual muscle fibres of the heart's ventricles beat quickly and chaotically (at a rate of more than 100 beats per minute).

Pacemakers are electronic devices implanted under the skin of the chest. An artificial pacemaker helps to produce a regular electrical impulse, and therefore a regular heartbeat.

Many patients with pacemakers suffer from arrhythmia in which the heart beats too slowly. This is usually due to a deterioration in the heart's natural pacemaker as a person ages.

Pacemakers

A pacemaker consists of three parts: a battery-powered generator, circuitry and wires that connect it to the heart. The generator is usually implanted just beneath the skin below the collarbone. The leads are threaded into position through veins leading back to the heart. The pacemaker is sealed in a titanium or titanium alloy case. The lead is made of a metal alloy insulated by a plastic such as polyurethane. The circuitry is usually made of silicon semiconductors.

The material used to construct pacemakers must be biocompatible, inert, non-toxic and able to be sterilised. For example, titanium is suitable for implanting because it is a strong, light and biocompatible material.

See: http://www.cardi.com/articles/pacemaker.htm

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research the historical development of pacemakers and identify the technological advances that made the development of the modern day pacemaker possible.

Early 'pacemakers' delivered an electric shock to the heart of a person in an emergency, such as having a heart attack. The device was plugged into a wall socket. Some of the technological advances that led to the development of the modern day pacemaker include:

- Devices which reduced the amount of voltage and increased the length of time of the electronic pacing.
- Pacemakers with leads attached directly to the outer wall of the heart.
- Portable devices which used a battery as the power source. An Australian physician, Mark Lidwill, together with a physicist Edgar Booth, are credited with inventing the first portable pacemaking unit, demonstrated in 1931 (although there is some debate about this).
- Devices which could be surgically implanted (rather than being worn externally). The first artificial pacemaker was implanted in 1958.
- Techniques for inserting the lead from a pacemaker into a vein and threading the lead into the heart chamber.
- Development of smaller pacemaker units.
- Improvements in design, electrical circuitry, longer lasting batteries and computer technology. A microprocessor is used in modern pacemakers. This means that the pacemaker can be programmed, reprogrammed and monitored from outside the patient's body. The most common pacemaker monitors the heart's activity and takes control only when the heart rate falls below a programmed minimum — usually 60 beats per minute.

See: http://www.bae.ncsu.edu/bae/courses46/1995_projects/sch — for a summary of the history of pacemakers.

The properties of materials used for making artificial body parts

Materials such as **teflon or pyrolytic carbon** must be biocompatible, that is, not rejected by the body's immune system. Teflon is used for artificial blood vessels because it is elastic, porous and strong. It functions like real blood vessels, dilating and contracting with changing blood flow. Other biocompatible materials include titanium, titanium-coated stainless steel, platinum, cobalt, chromium alloys and sili-cone. See page 111 for more details on other materials suitable for use in bionics.

New research in Australia aims to develop new polymers that can be used in a range of biomedical devices including valves. The research aims to combine the strength and good mechanical performance of polyurethane with the flexibility and biostability of silicone.

Reference: *Australasian Science*, September 1999, pp. 32–39.

Faulty valves in the heart

With a leaky or faulty valve(s), the heart must work harder which can cause a heart attack or death. If valves leak, a heart murmur is heard. Symptoms of a faulty valve include shortness of breath during exercise, tiredness, a continual cough and occasional chest pain.

When heart valves become inflamed, this can result in adhesions causing scar tissue which fuses part of the valves together. Rheumatic fever (an auto-immune disease initiated by a bacterial infection) is the most common cause of this type of valve damage, particularly the mitral valve.

See:http://heart-surgeon.com — for videos of coronary bypass, mitral valve and aortic valve surgery.

> As part of meeting the requirements of the course, you are expected to have gathered information from secondary sources to research different types of artificial valves and their functions.

Types of artificial valves include the bileaflet valve and ball-and-cage valve. The bileaflet valve consists of two semi-circular carbon discs which open and close. The ball-and-cage valve consists of a metal housing with carbon discs. Artificial valves are more durable than biological valves, but need anti-coagulant to prevent blood clots forming around the implant.

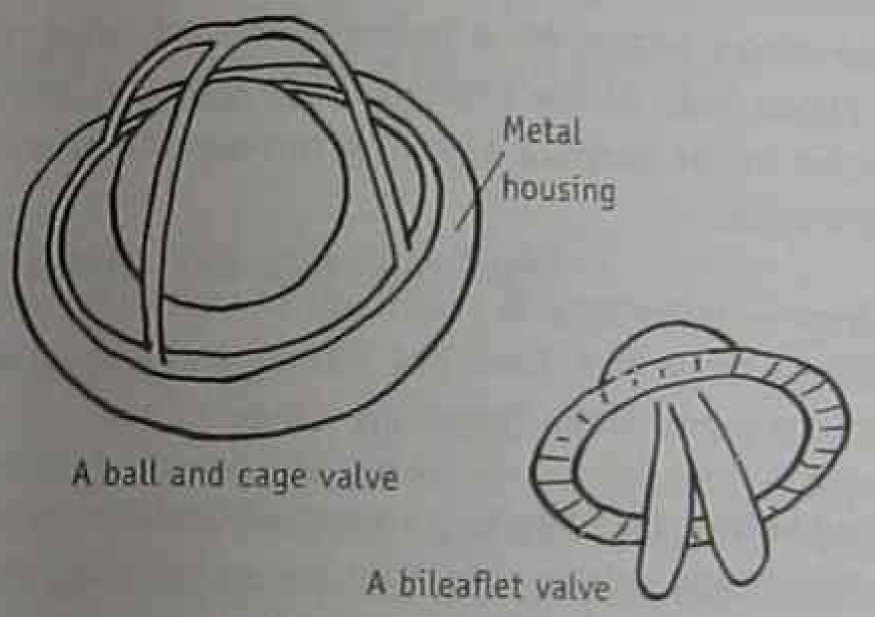


Figure 6.7 Mechanical valves

Biological valves include valves from a human donor or modified from a pig donor. Pig valves are similar to humans'. They do not cause blood clots (as mechanical valves do) but they only have a working life of seven to ten years before the tissue degenerates. The use of pig donor tissue for human transplants is currently being reconsidered following concerns that diseases (such as deadly viruses) can be transferred to humans by implanting pig tissue.

The build-up of plaque and its effect on blood flow to and from the heart

One of the main causes of heart (cardiovascular) disease is the build up of plaque on the inside of the walls of major arteries and veins. The disease is called atherosclerosis. The plaque is made of deposits of fat (cholesterol) and other substances. If plaque builds up sufficiently it can:

- Cause the walls of the artery or vein to become weakened, to bulge or split
- Block the blood vessel(s) completely. If the coronary arteries become blocked, this results in a heart attack.

Since the mid 1980s, surgeons have developed and refined techniques for easing blood flow in weakened and blocked blood vessels. The technique is called **angioplasty** (see details below).

The plaque can be eliminated by:

- Removing the diseased blood vessel and replacing it with an artificial blood vessel or a vein from the patient's leg
- Removing the plaque using a laser beam.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research techniques used to improve blood flow when there has been a build up of plaque.

The techniques include:

Bypass surgery — this involves taking a vein from the patient's leg and using it to construct a new pathway for blood to flow around the blocked vessel.

Replacing the blocked blood vessel with an artificial vessel — a woven plastic artificial graft is soaked in blood and then sewn in place. Body cells (fibroblasts) invade the artificial structure and eventually it becomes 'normal' tissue.

Angioplasty — a technique for easing blood flow.

Laser angioplasty uses a laser beam to remove plaque from blood vessels. This was initially done during bypass surgery. Surgeons now use minimally invasive techniques such as percutaneous laser angioplasty to remove plaque. A catheter containing the laser is pushed under the skin.

Balloon angioplasty is used to improve blood flow by widening the artery. A small cut is made in the arm or groin. A thin plastic tube is inserted into an artery and pushed to the blocked blood vessel. A catheter containing a small balloon is threaded through the tube until it reaches the blockage. When the balloon is inflated it pushes the plaque against the artery wall and the diameter is widened. Balloons are also used to widen the mitral and aortic valves in the heart.

The decision to use a particular technique is based to some extent on the degree to which the blood vessel(s) is blocked.

As part of meeting the requirements of the course, you are expected to have used secondary sources to find out about current research into heart transplants and/or their parts and the impact on society.

See: http://www.victorchang.com.au — for the Victor Chang Cardiac Research Institute in NSW (the Cardiac Mechanics Unit and Transplant Unit) and information on current heart research such as ventricular reduction surgery, as a surgical alternative to transplants, and the trialling of new immuno-suppressant drugs following heart transplants.

http://www.baker.edu.au/html/csru.html — for the Cardiac Surgical Research Unit of the Baker Medical Institute in Victoria and information on current heart research, such as new techniques using the radial artery as a coronary bypass graft, which have proven faster, simpler and cheaper than standard techniques.

Developments in the replacement of damaged parts of the skeletal system

The wide range of movements, the continual absorption of shocks, and certain diseases make the skeletal system vulnerable to damage. In the Preliminary Core Module *Humans at Work* (Chapter 3), you reviewed the muscle/skeletal system including the composition of bones and the role of joints, cartilage, ligaments and tendons (see page 63).

As part of meeting the requirements of the course, you are expected to have carried out an experiment to examine the flexible nature of bones by removing calcium from bones.

Bones consist of living and non-living parts. The non-living part is made up of calcium which keeps the bones hard and rigid. The living part includes strands of protein, called collagen, which gives bones flexibility.

Soak some chicken bones in a dilute acid for one week to remove the calcium and observe their flexibility.

Note safety procedures when using acids.

Synovial joints

Joints occur where different bones come together. The amount of movement of a joint is determined by its structure. **Synovial joints** are designed to allow a large range of movements.

Types of synovial joints are:

Ball and socket — allows movement in many directions. The hip joint and shoulder joints are ball and socket joints. In a ball and socket joint, the rounded head of the humerus fits into the hollow socket of the scapula allowing movement in many directions.

Hinge — movement is restricted to one plane only, like the hinge of a door. The elbow and knee joints and the joints of the finger are hinge joints.

Double hinge — allows movement backwards and forwards and side to side. The base of the thumb is an example of a double-hinge joint.

Sliding — or gliding joints allow sliding movements in all directions because the opposing bones are flattened or slightly curved. Examples of sliding joints include some of the joints in the spinal bones and tarsal bones of the feet.

Pivot — in a pivot joint the end of one bone rotates inside a ring formed by the other bone. The joints in the neck at the base of the skull are pivot joints. The joint between the forearm and the wrist is also a pivot joint.

As part of meeting the requirements of the course, you are expected to have conducted an investigation to demonstrate the different types of joints and the range of movements they allow.

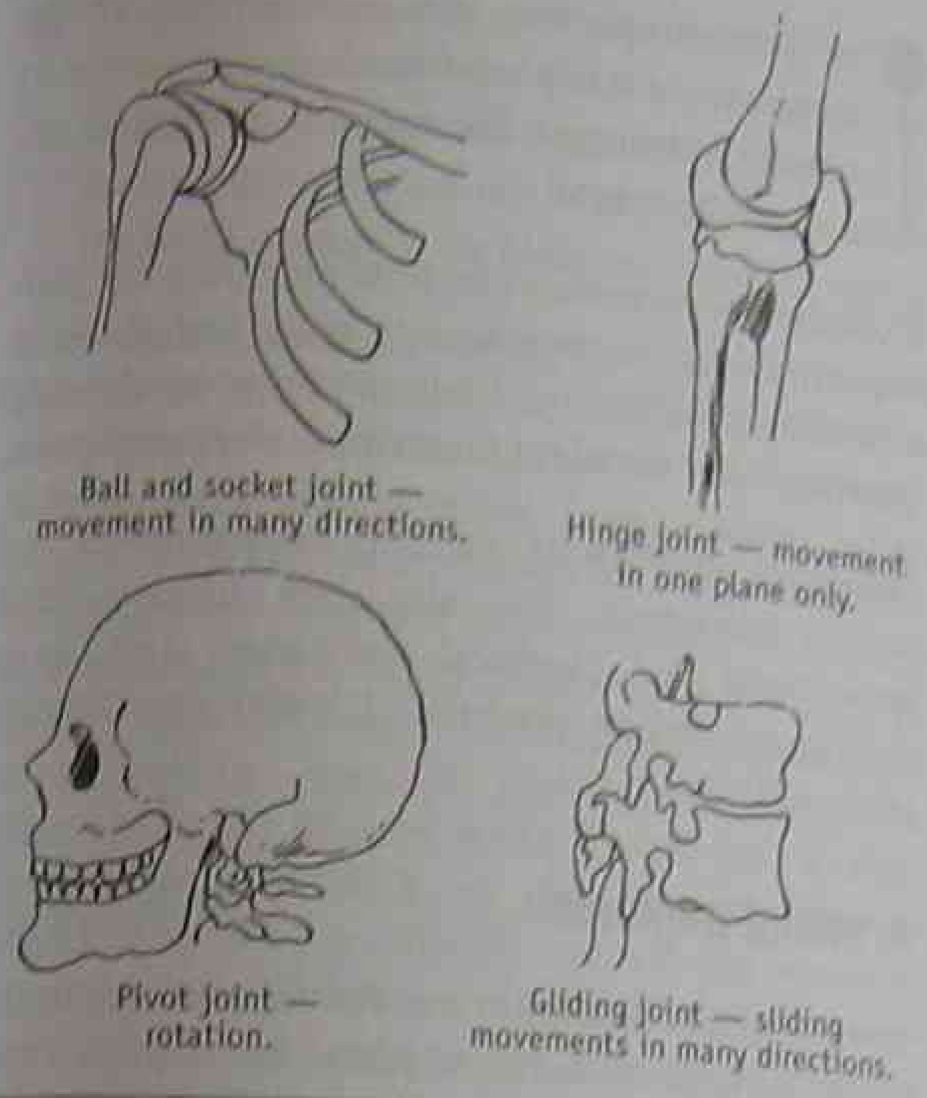


Figure 6.8 Different types of joints and the range of movements they allow

Cartilage and synovial fluid

See also page 62.

Cartilage lines the ends of bones and reduces friction. This allows for smoother movement. If the cartilage is damaged or becomes worn, movement is less smooth and can cause pain. Synovial joints are enclosed by the synovial membrane. This produces **synovial fluid** to lubricate the joint. Damage to the synovial membrane can cause excessive secretion of the fluid, which results in swelling of the joint.

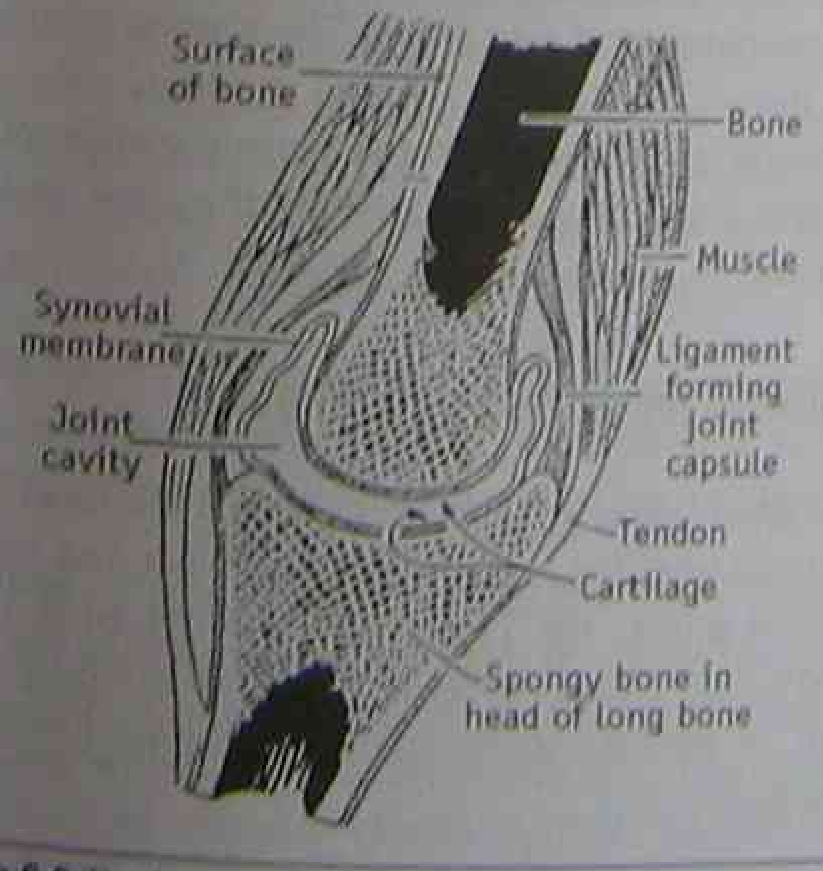


Figure 6.9 The knee joint — an example of a synovial joint

As part of meeting the requirements of the course, you are expected to have examined first-hand, the relationship between cartilage, muscle, tendon and bone in an animal limb. See pages 62 and 63 for details.

As part of meeting the requirements of the course, you are expected to have used secondary sources to compare the shock-absorbing abilities of different parts of bones.

The porous, sponge-like part of a bone is less dense and therefore has lower shock-absorbing ability than the shaft of long bones (such as the arms and legs), which are designed for maximum strength and shock-absorbing under stress or impact.

The properties of silicone and its use in bionics

Organic polymers (see page 138) contain carbon. Because they contain carbon, some organic polymers cause adverse chemical reactions in living tissue and therefore cannot be used for medical transplants. In the 1930s, chemists began to look at ways to replace carbon with silicon in polymer chains. Scientists have now developed a range of inorganic polymers called silicones. Silicones can be made into rubbery materials, oils, greases and harder resins.

Silicones are suitable for use in bionics because they are biostable, have low flammability and are acid resistant and flexible over wide temperature ranges. Some are completely insoluble in water. Some silicone rubbers allow the diffusion of oxygen and because they contain no carbon are less likely to be rejected by living tissue.

Polyurethanes have also been used in bioengineering. Like silicones, they are blood compatible and have good mechanical performance. Soft, flexible forms of these materials do, however, degrade over time particularly if used in weight-bearing areas of the body.

Silicone joints are suitable substitutes for small joints in the fingers and toes that carry little weight because silicone can be bent and stretched many, many times without breaking. It therefore provides the flexibility needed and will last longer in areas of the body that bear little force, but is not strong enough for implanting into weight-bearing parts of the body.

As part of meeting the requirements of the course, you are expected to have investigated the properties of silicone that make it suitable for use in bionics.

Silicone can be bought in silicone tubes from hardware stores. The properties that make silicone suitable for use in bionics include acid resistance, flexibility and imperviousness to water.

Note safety procedures when using acids.

Ultra high molecular weight polyethylene (UHMWPE)

Ultra high molecular weight polyethylene is a suitable alternative to cartilage surrounding a ball and socket joint due to its biocompatibility with surrounding tissue, durability (it can be bent many, many times without wearing), and low friction which allows ease of movement.

See: http://www.matweb.com/SpecificMaterial.asp?bassnum=PSFO78&group=General

Superalloys

Superalloys are made from metals. They combine the 'superior' properties of metals such as iron (Fe), cobalt (Co) or nickel (N) with chromium (Cr), molybdenum (Mo) and titanium (Ti). The resulting properties include high strength, low weight, good compatibility with body tissue and inertness. For example, a Co-Cr-Mo alloy, used in biomaterials, is non-magnetic with high strength, and corrosion and wear resistance.

See: http://www.matweb.com/SpecificMaterial.asp?bassnum=NCAR33&group=General

As part of meeting the requirements of the course, you are expected to have used secondary sources to compare the strength of UHWPE and a superalloy metal.

Properties of superalloys include an extremely high impact resistance, resistance to wear and abrasion, a very low coefficient of friction, very good chemical resistance and excellent low-temperature properties.

Properties of UHWPE include high-abrasion and impact resistance, low slip/stick friction, high stress-crack and chemical resistance, and, apart from anticorrosion products, UHWPE contains no other additives.

Artificial implants

Developments in bionics has led to advances in the ability to remove damaged joints and replace them with artificial ones. As a result, millions of people have been relieved of pain and disability.

Artificial implants can be either cemented or uncemented into place.

The properties of the cement that is used in implants — the glue used in cemented implants is an acrylic cement (such as methyl methacrylate). In early hip replacements the shaft of the artificial hip was glued into place. The glue eventually dried and cracked and the shaft became loose. Newer uncemented implants have a shaft designed to fit into the hollow of the femur.

How an uncemented implant forms a bond with bone — uncemented implants such as an artificial hip are hammered into place. This causes trauma in the bone. As a result of the trauma, the bone responds by growing into the porous surface of the implant forming a bond between the bone and the implant.

Artificial joints and polyethylene

The articulating end or cup in which the head of an artificial joint fits, must withstand wear and tear. In natural joints, the bones are covered in a tough gristle-like, elastic material called articulating cartilage. In artificial joints, polyethylene performs this function.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research how technological developments have affected our understanding of how the body works. Some ideas are provided below.

Early understanding of how the body works was often based on examination of, and experimentation with, corpses (non-living tissue and organs). Technological developments have enabled examination of living tissue, organs and organ systems. Developments include improvements in microscopes and microscopy techniques, diagnostic techniques such as X-rays, thermography, endoscopy, ultrasound and magnetic resonance imaging (see page 116), and devices which record and analyse living processes such as the electrocardiogram (ECG). The ECG graphically records the electrical activity of the muscles of the heart. (The development of this technology was only made possible because of the development of devices which measured the electric potential of living tissue.)

Life support systems

A person cannot live if blood does not continuously flow through the body, supplying oxygen to the cells and removing wastes (such as carbon dioxide). Life support systems are therefore sometimes needed to sustain life during operations or while the body repairs itself.

The respiratory system

The respiratory system is concerned with the intake of oxygen and removal of carbon dioxide and water vapour. The exchange of oxygen and carbon dioxide gases between the blood and the air takes place in the **lungs**. Air is forced into the lungs through a process called inhalation. Air is forced out of the lungs through a process called exhalation.

Trachea — the breathing tube that brings air from the nostrils to the bronchi. The trachea has C-shaped rings of cartilage that stop it from collapsing.

Bronchi — the trachea divides into two bronchi. (Bronchus is the singular.) Each bronchus leads to a lung. The bronchi also have C-shaped rings of cartilage which give the tubes strength. The bronchi divide into smaller tubes called bronchioles. Bronchioles end in tiny sacs called alveoli.

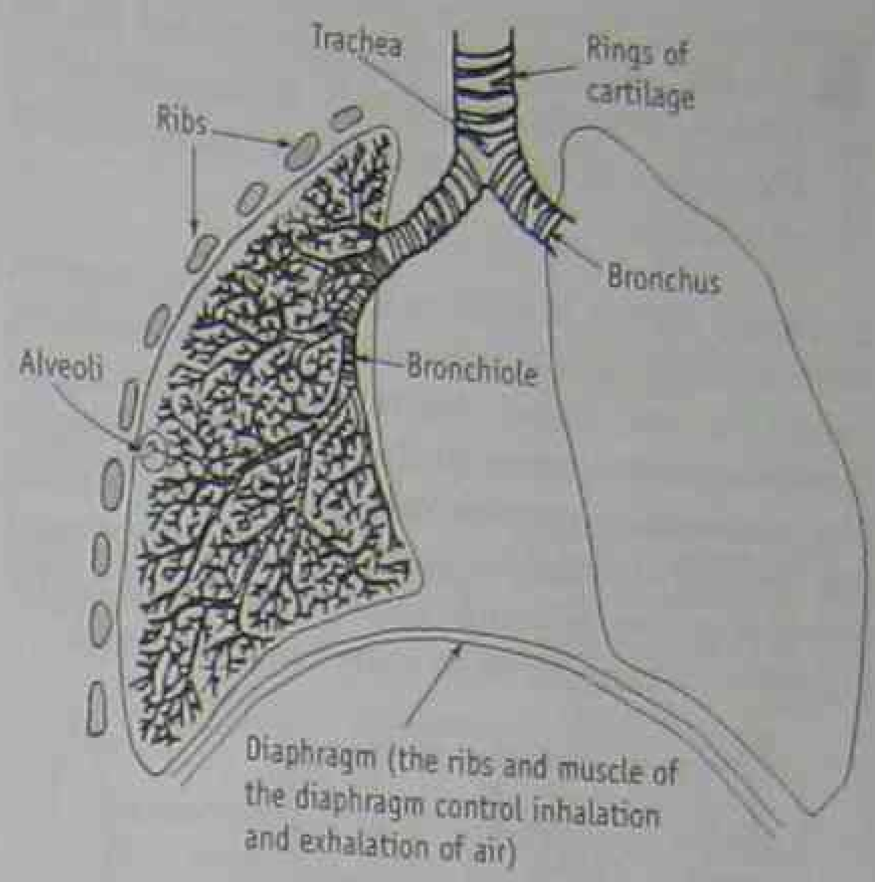


Figure 6.10 The human respiratory system showing trachea, bronchi, bronchioles, alveoli and lungs

Alveoli — are highly folded micro-structures. The actual exchange of oxygen and carbon dioxide between the blood and the air takes place in the alveoli. The highly folded structure of the alveoli provides a large surface area for efficient gas exchange. Around each alveolus (the singular) is a capillary network which provides an extensive supply of blood.

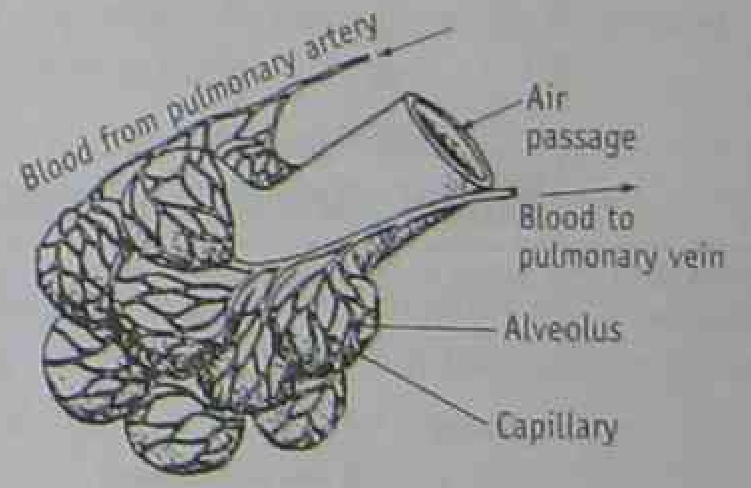


Figure 6.11 Alveoli

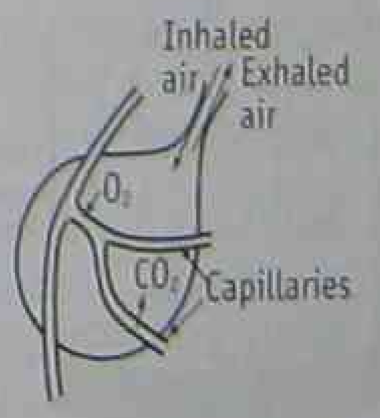


Figure 6.12 One alveolus showing gas exchange

As part of meeting the requirements of the course, you are expected to have investigated the action of the diaphragm in inhalation and exhalation.

Increased carbon dioxide in the blood (for example, from holding your breath) stimulates the breathing centre in the brain. Nerve impulses from the breathing centre travel to the ribs and diaphragm. The rib muscles are stimulated to contract, moving the rib cage up and out and pulling the diaphragm down (see the diagrams below). The chest cavity expands, causing air to be drawn into the lungs.

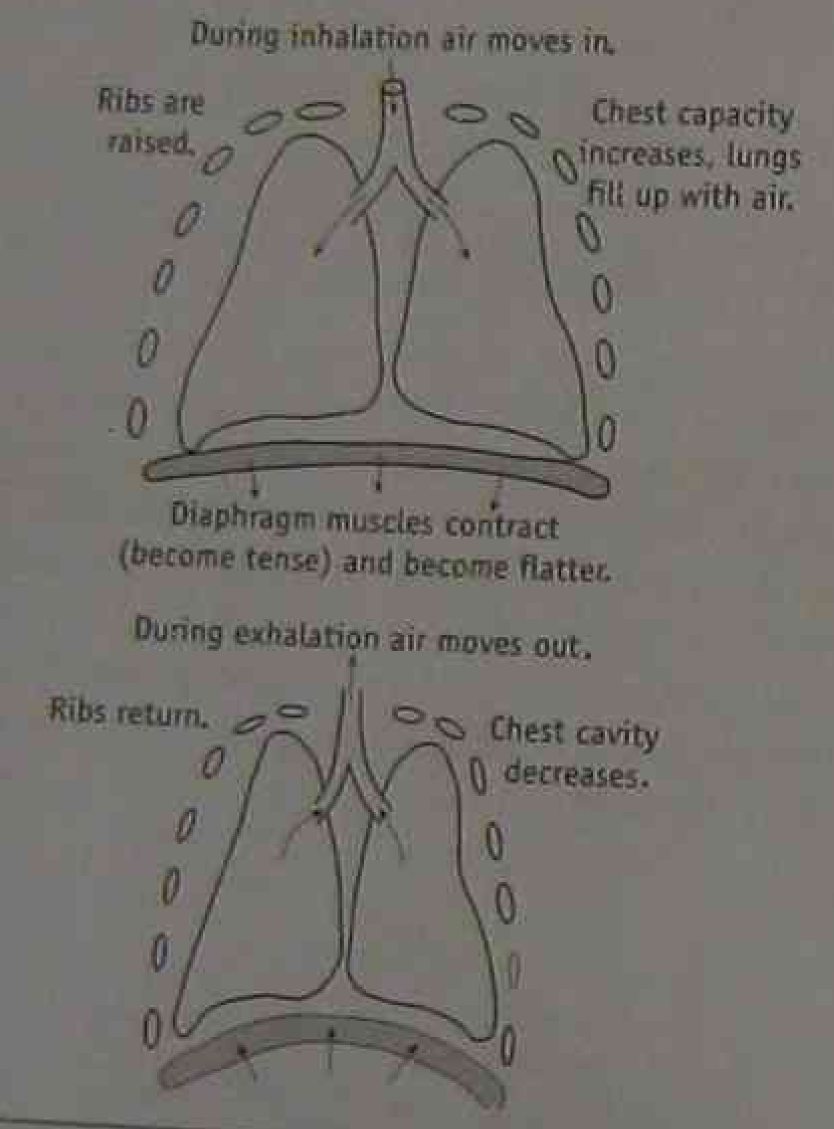


Figure 6.13 The action of the diaphragm in inhalation and exhalation.

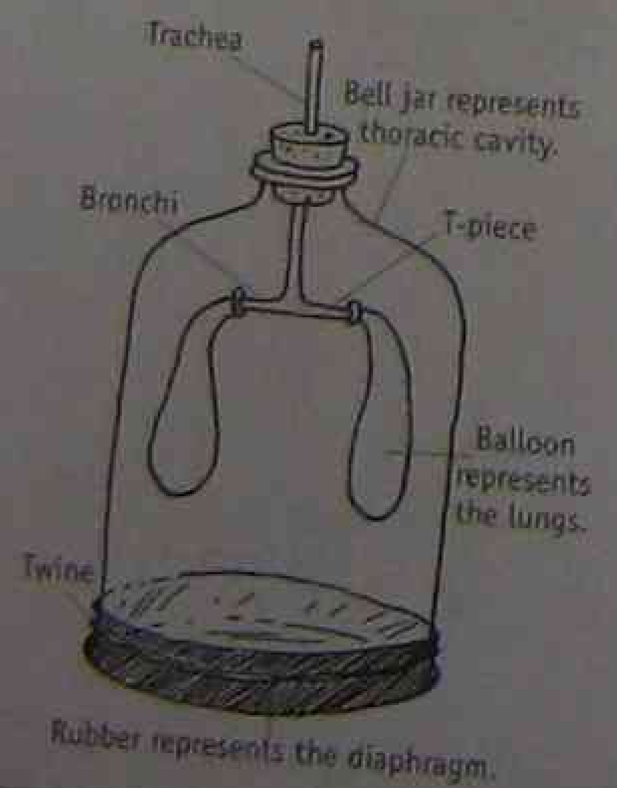


Figure 6.14 A model showing the action of the diaphragm in inhalation and exhalation

As part of meeting the requirements of the course, you are expected to have carried out an experiment to identify carbon dioxide in inhaled and exhaled air and to determine which has the greater concentration of carbon dioxide.

Air we breathe in contains about 21% oxygen and 0.03% carbon dioxide. Immediately exhaled air contains about 16% oxygen and 4% carbon dioxide. In your experiment you would have used lime water to indicate the presence of carbon dioxide. Carbon dioxide turns lime water milky or cloudy. A comparison between the degree of cloudiness in inhaled air and in exhaled air helps determine the differences in concentration of carbon dioxide.

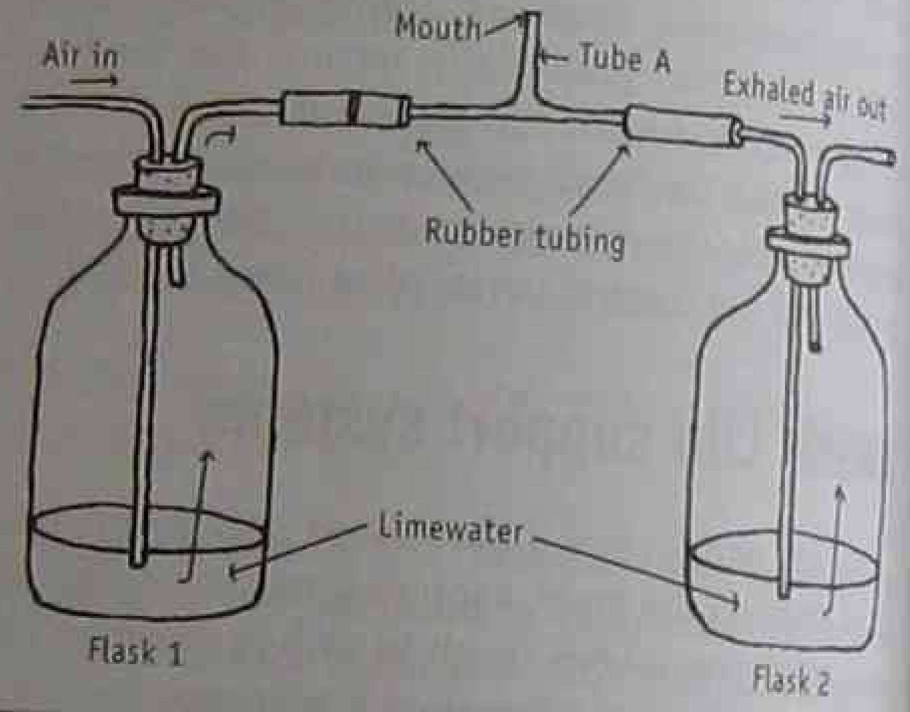


Figure 6.15 Identify carbon dioxide in inhaled air and in exhaled air to determine which has the greater concentration. Breathe in and out through Tube A. Air is drawn in through the lime water in Flask 1 and forced out through the lime water in Flask 2.

Cardiopulmonary resuscitation techniques

All living cells require oxygen. When the heart stops, circulation stops and cells do not receive oxygen. Cardiopulmonary resuscitation techniques, or CPR, can maintain life when the heart has ceased beating.

CPR is a combination of Expired Air Resuscitation (EAR) and External Cardiac Compression (ECC). EAR, mouth-to-mouth or mouth-to-nose resuscitation aims to re-establish or maintain breathing by artificially inflating the lungs. ECC provides artificial blood circulation by putting a rhythmic pressure on the chest at regular intervals. This compresses the heart between the breastbone and the spinal column. ECC along with EAR may be enough to keep the heart and brain alive by providing oxygenated blood even when the heart has stopped. See: *The Australian Red Cross Society First Aid Manual*.

Artificial lungs

Artificial lungs remove carbon dioxide and replace it with oxygen. In a heart-lung machine, tubes are inserted into the main veins. The blood returning to the heart can then be diverted to the heart-lung machine. Oxygenated blood is pumped back into the aorta (and then into the heart) through another tube.

The heart and lungs must be temporarily stopped during surgery for heart transplants and heart implants. A heart-lung machine is used during these operations to perform the functions of the heart and lungs.

Life support systems

Life support systems include:

- Heart-lung machines
- Respirators
- Renal dialysis (kidney) machines
- Ventilators.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research devices used in life support systems and explained their roles in maintaining life.

Life support systems include:

- Monitoring devices such as ECGs and echocardiographs (ultrasonic scans of the structural composition of the heart) which allow heartbeat to be recorded and problems anticipated. For example, echocardiography is used to confirm and determine the seriousness of valve diseases.
- Ventilators — when a person can no longer breathe naturally, an artificial ventilator is used.
- Respirators — machines which induce artificial breathing. Air is transmitted to the lungs via a tube inserted in the trachea.
- Heart-lung machines (see above)
- Renal dialysis — the artificial kidney regulates the concentration of the patient's blood by removing substances (such as urea and other toxins) and adding substances selectively. The basic process is called dialysis. Dialysis treatments are now monitored and controlled by computers.

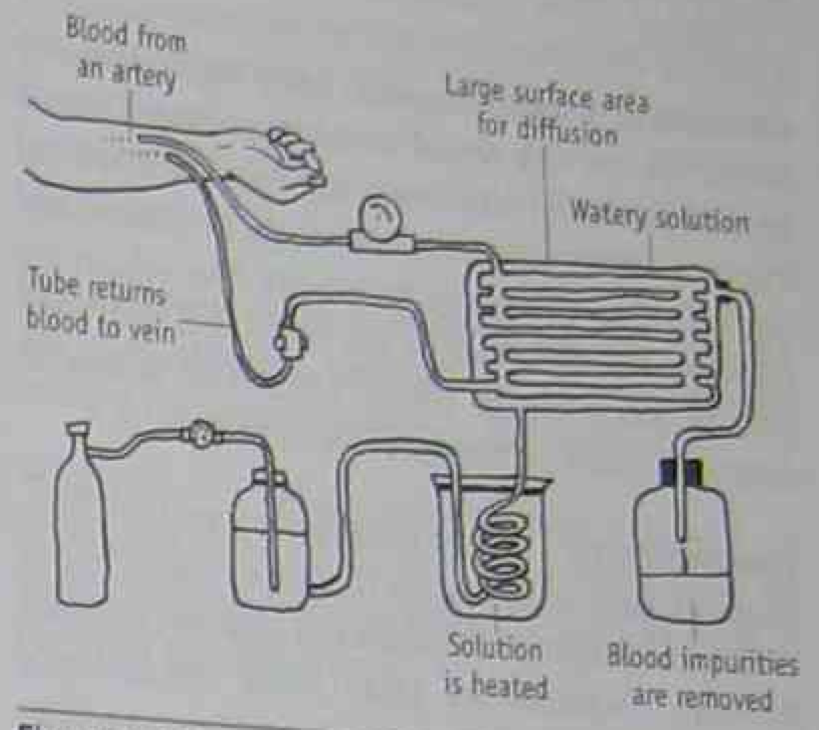


Figure 6.16 Renal dialysis

Non-invasive or minimally invasive medical techniques

Non-invasive and minimally invasive techniques refer to medical techniques which involve minimal trauma to the body. Traditional surgery is invasive, requiring incisions or cuts to enter the patients body. Advances in technology have resulted in alternatives to invasive surgery.

Non-invasive diagnostic techniques

Non-invasive diagnostic techniques include X-rays, ultrasound, thermography and magnetic resonance imaging (MRI).

X-rays — X-rays travel through some but not all materials. For example, they pass through skin tissue but not bone. This property is used in diagnostic medicine to get a clear picture of internal structures, such as the skeletal system and organ placement, without invasive, exploratory surgery.

X-rays are used to diagnose limb or joint injury, fractures of the bone, large tumours and enlarged organs. Mammographies, or breast X-rays are used as both a diagnostic and screening technique for breast cancer.

The disadvantages of X-rays:

- They only provide a two-dimensional view.
- Bones often hide other tissues that cannot be seen with X-rays.
- Over-exposure can damage tissue and cause cancer.

Ultrasound — uses ultrasonic (ultra high frequency) sound waves. The sound waves, transmitted from a probe, penetrate the body and are reflected off internal structures. Different layers of tissues and organs reflect the sound differently. The echoes are received and analysed by the probe and converted into an image on the screen. Ultrasound is used in diagnosis and to study foetuses in the uterus.

Thermography — uses infra-red waves and differences in body temperature to create images, and is useful as a diagnostic technique in locating cancerous tumours. Tumours are more active metabolically and therefore produce more heat. Thermography also helps identify areas where there is restricted blood flow (in this case the temperature of tissue is lower).

Magnetic resonance imaging (MRI) — also called nuclear magnetic resonance. MRI uses radio waves and the body's water molecules to create images. The MRI machine produces a powerful magnetic field which causes hydrogen atoms in water to line up parallel to the direction of the field. The machine then releases radio waves which cause a shift in the hydrogen atoms. The hydrogen atoms are then allowed to return to their earlier position. This brief change is recorded and analysed.

MRI can be used for diagnosis because not all body tissue contains the same amount of water. Hard tissue such as bone, for example, contains little water. MRI is used therefore to clearly identify soft tissue such as the brain and spinal cord which are encased in bone.

Minimally invasive surgery techniques

Non-invasive and minimally invasive surgery techniques include **endoscopy** and **keyhole surgery**, laser and ultrasound technology and microsurgery.

In general, the advantages of non-invasive surgery include:

- Less risk to the patient
- Fewer side-effects and less chance of complications that can occur as a result of invasive surgery
- Faster recuperation and therefore less time needed in hospital. This frees up hospital beds and patients are back at work sooner.
- Less need for medications, or after-surgery care or nursing.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the advantages and disadvantages of non-invasive and minimally invasive medical techniques. Some ideas are provided below.

Endoscopy and keyhole surgery — an endoscope is a thin plastic tube that contains flexible bundles of fibres. In order for the surgeon to see inside the patient, light is shone down one of the bundles and reflected back up another bundle to the surgeon's eye. This illuminates the area, allowing the surgeon to carry out the necessary procedure. A tiny camera can also be placed in the tip of the endoscope. The image is then shown on a monitor screen. Endoscopes are used in a number of ways:

- As a diagnostic tool to carry out observations or biopsy (taking a tissue sample for analysis)
- To treat minor problems using other special tools that are clipped to the end of the endoscope tip (such as a cauterising loop for heating tissue)
- As an optical aid for keyhole surgery.

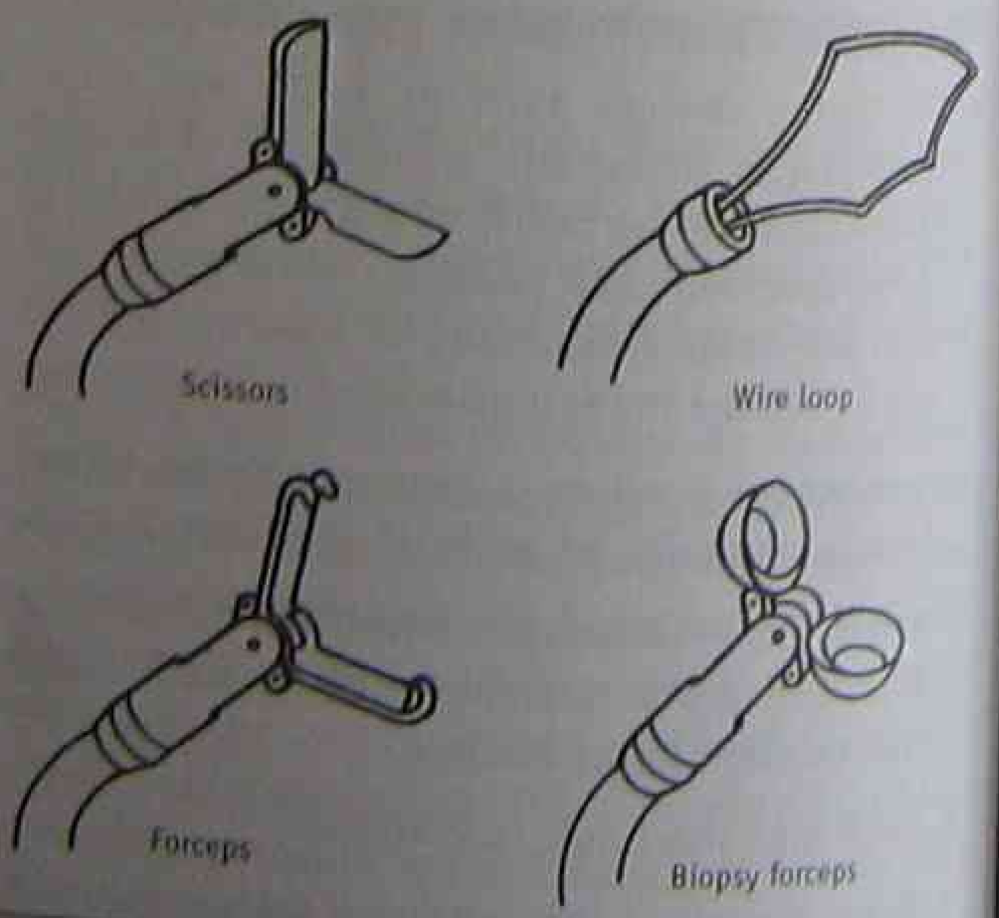


Figure 6.17 Some attachments for endoscopy

Advantages — endoscopes allow the surgeon to view inside the body without having to make large incisions and in some cases without having to make an incision at all.

Disadvantages — endoscopes allow only a small area to be illuminated at a time. A picture of the whole diagnostic area must be built up from smaller parts. Endoscopy may not detect some conditions.

For examples of future directions in endoscopy, see: http://www.abc.net.au/science/news/ for news about scalpels fitted with fibre optics (9/1/2001) or wireless capsule endoscopy trials (19/1/2001).

Laser technology — uses a very thin, high-intensity beam of light to cut and seal tissue.

Advantages — laser surgery can be used with great precision to treat areas without damaging surrounding tissue. There is minimal bleeding and minimal pain and scarring from the incision.

Ultrasound technology — works on the same principle as marine sonar. High-intensity focused ultrasound beams can accelerate blood clotting. In the future, this technology may allow doctors to stop internal haemorrhages (bleeding) without surgery. Traditional methods for controlling internal bleeding involves pinpointing and cauterising the blood vessel. Sound waves can increase blood flow and activate blood platelets, assisting in the formation of blood clots.

Microsurgery — the procedures are very intricate and use miniature precision instruments viewed under a stereoscopic operating microscope.

Advantages — microsurgery allows surgeons to operate on parts of the body that were once inaccessible or too small to work on, such as parts of the brain and spinal cord.

Disadvantages — microsurgery can be very expensive.

Checklist

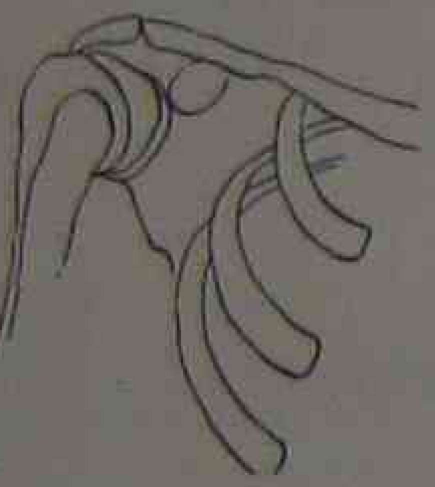
Key terms for revision

biomedical devices	plaque
biomedical material	angioplasty
biocompatibility	joints
bionics	synovial joints
pins, screws and plates	silicone
artificial joints	ultra high molecular weight polyethylene
pacemaker implants	superalloys
cochlear implants	respiratory system
artificial valves	diaphragm
crowns and dentures	alveoli
lenses	cardiopulmonary resuscitation
prosthetic limbs	artificial lungs
valves	non-invasive or minimally invasive surgery
atria	endoscopy and keyhole surgery
ventricle	ultrasound
arteries	X-ray
veins	thermography
cardiac muscle	magnetic resonance imaging
arrhythmia	microsurgery
teflon	laser technology

Multiple choice questions

1. Silicone joints are suitable substitutes for small joints in the fingers and toes. Which of the following features would be most important for selecting silicone?
   (A) Silicone is impervious to water.
   (B) Silicone can be bent and stretched many, many times without breaking.
   (C) Silicone can be made into an alloy with bone.
   (D) Silicone is a good conductor of electricity.

2. The diagram below is an example of:



   (A) A hinge joint
   (B) A sliding joint
   (C) A ball and socket joint
   (D) A pivot joint

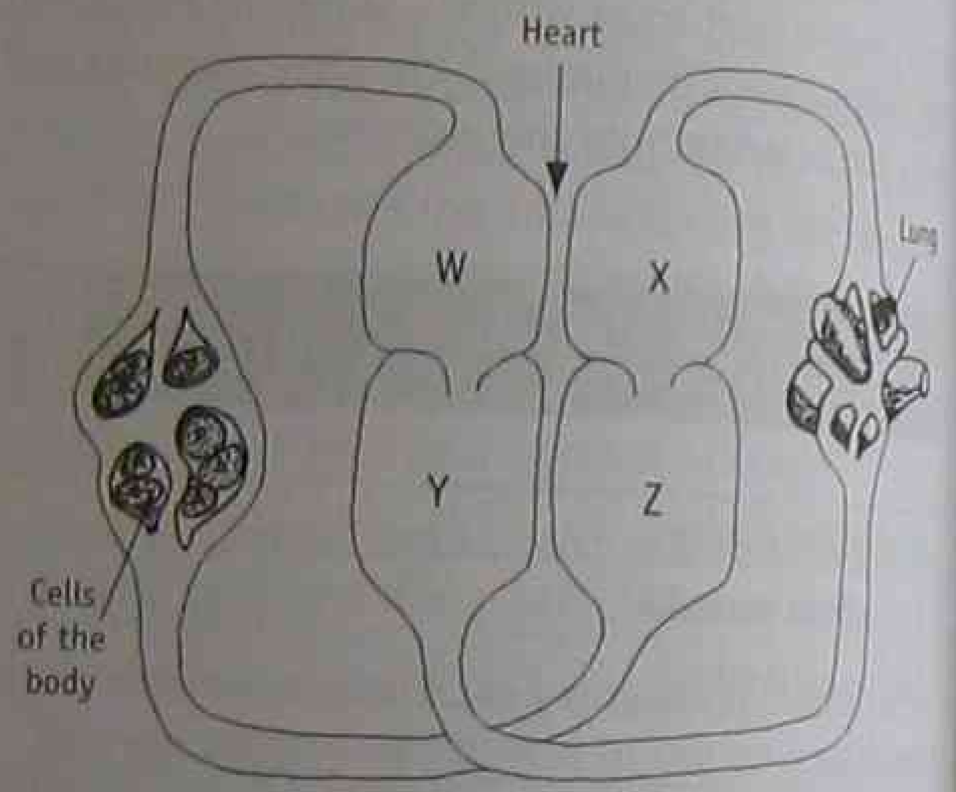
3. Which of the following does not constitute a life support system in major hospitals?
   (A) A heart-lung machine
   (B) Defibrillator
   (C) Ventilator
   (D) Respirator

4. Four technologies below are labelled W, X, Y and Z. Which option below is the correct match for the following in order from W to Z?
   W — uses high intensity beams of light
   X — uses infra-red waves
   Y — uses optical fibres
   Z — uses radio waves.
   (A) Thermography, endoscopy, laser technology, MRI
   (B) Thermography, endoscopy, MRI, laser technology
   (C) Laser technology, endoscopy, MRI, thermography
   (D) Laser technology, thermography, endoscopy, MRI

5. Angioplasty is:
   (A) A technique for easing blood flow.
   (B) A technique for artificial valve transplants.
   (C) A technique for monitoring heartbeat.
   (D) Systolic and diastolic pressure.

Short answer and longer response questions

1. (10 marks)
   Below is a generalised diagram of blood flow through the body.



   (a) Name the heart chambers labelled W, X, Y and Z. (4 marks)
   (b) Indicate with a V the location of two valves in the heart. Name one of the valves and outline its role. (4 marks)
   (c) Use arrows to show the direction of blood flow. (2 marks)

2. (4 marks)
   (a) Name one major artery and relate its structure to its function. (2 marks)
   (b) Name one major vein and relate its structure to its function. (2 marks)

3. Explain the problems that may arise due to a leaky heart valve. Identify two different types of artificial valves. (4 marks)

4. Describe one property of teflon/carbon fibre substances that make them good for manufacturing implants. (1 mark)

5. (3 marks)
   (a) Compare the strength of ultra high molecular weight polyethylene and a superalloy metal. (1 mark)
   (b) Describe where ultra high molecular weight polyethylene and superalloys are used in artificial joints and identify the properties of the materials that make them suitable for their function. (2 marks)

6. Compare two methods of securing artificial hips to the existing bone. (4 marks)

7. Describe the advantages to the patient of two named minimally invasive surgical or diagnostic techniques. (4 marks)

Test answers

Multiple choice questions

Answers

1. B 2. C 3. B 4. D 5. A

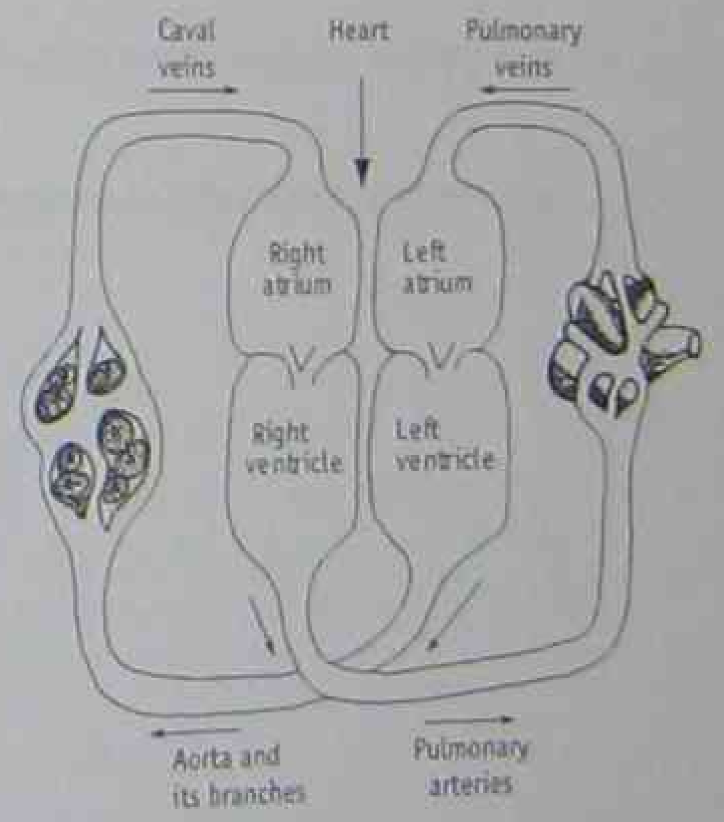
Explanations

1. Silicone joints are suitable substitutes for small joints in the fingers and toes that carry little weight because silicone can be bent and stretched many, many times without breaking.
2. The shoulder joint is an example of a ball and socket joint.
3. A defibrillator is not a life support system as such. A defibrillator or pacemaker helps the heart to produce a regular electrical impulse or heartbeat.
4. Lasers use high intensity beams of light. Thermography uses infra-red radiation. Endoscopes use optical fibres and MRI uses radio waves. See page 116.
5. Alternative A is the only correct statement.

Short answer and longer response questions

Answers and explanations

1. (a) W — right atrium; X — left atrium; Y — right ventricle; z — left ventricle.
   (b) The valve between the right atrium and the ventricle opening is called the tricuspid valve. The valve ensures blood flow in one direction only.
   (c)



2. (a) A major artery is the aorta. The aorta is thick-walled and muscular and pumps blood from the left ventricle to blood vessels that go to the rest of the body.

(b) A major vein is the pulmonary vein. The vein is thin-walled with valves which ensure blood flow in one direction. The thin-walled valves provide the vein with a bigger diameter and greater blood flow capacity. Blood returns from the lungs to the left atrium via the pulmonary vein.

3. With a leaky or faulty valve(s), the heart must work harder which can cause a heart attack or death. Symptoms of a faulty valve include shortness of breath during exercise, tiredness, a continual cough and occasional chest pain. Types of artificial valves include the bileaflet valve and ball-and-cage valve. The bileaflet valve consists of two semi-circular carbon discs which open and close. The ball-and-cage valve consists of a metal housing with carbon discs.

4. Teflon or pyrolytic carbon is inert and bio-compatible — it is not rejected by the body's immune system.

5. (a) Ultra high molecular weight polyethylene and superalloys are both high strength impact resistant materials.

   (b) Ultra high molecular weight polyethylene has high durability — it can be bent many, many times without wearing. It is used as an alternative to cartilage surrounding a ball and socket joint.

   Superalloys made from metal alloys such as a Cobalt-Chromium-Molybdenum alloy are light-weight and provide high strength in extremely high impact parts of the body such as artificial limbs.

6. The shaft of the artificial hip can be glued or cemented into place.

   Uncemented implants such as an artificial hip are hammered into place. This causes trauma in the bone. As a result of the trauma, the bone responds by growing into the porous surface of the implant forming a bond between the bone and the implant.

7. Microsurgery allows surgeons to operate on parts of the body that were once inaccessible or too small to work on, such as parts of the brain and spinal cord.

   Non-invasive surgery such as keyhole surgery is less risk to a patient. There are fewer side-effects, less chance of the complications that can occur as a result of invasive surgery, and faster recuperation.

HSC Core Study Module 3

7 — Information Systems

Introduction

In this chapter you will review the systems used to transmit information from place to place. These technologies are advancing at a rapid pace, with increasing demands for information systems to handle larger and larger quantities of material, delivered in shorter periods of time.

As a result of working through this chapter you will be able to:

- Discuss ways in which different forms of energy, energy transfers and energy transformations are used in communication
- Assess the contribution of scientific advances in the understanding of energy transformations and electromagnetic radiation to the development of information technologies
- Assess the impacts of information technology on society and the environment
- Describe possible future directions in information technology.

☑ Checkpoint

Before you begin your review, you may need to check your understanding of the following:

- There are many forms of energy: light, sound, mechanical, electrical, heat, kinetic (the energy of movement), potential (stored energy), nuclear potential and chemical potential.
- Energy cannot be created or destroyed (except in nuclear reactions). Energy can be changed (transformed) from one form to another.

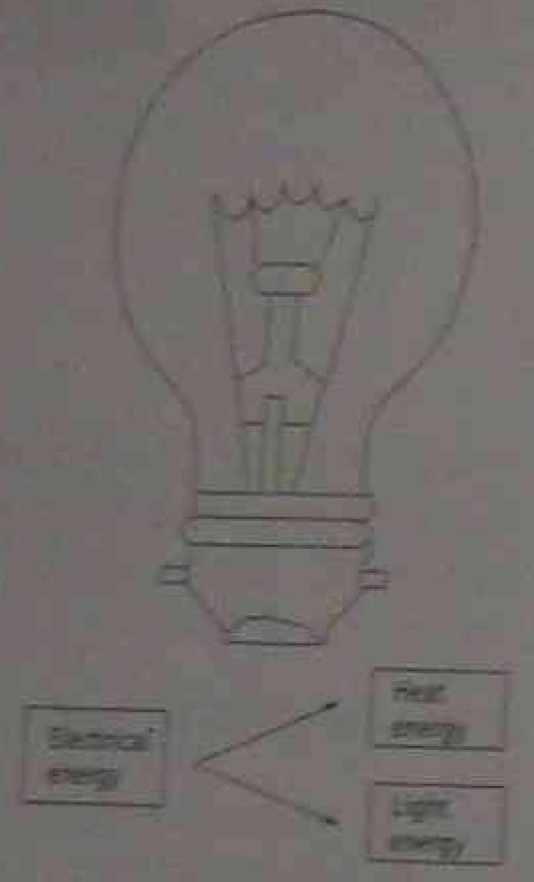


Figure 7.1 A flow diagram of an example of energy transformation. In a light bulb, energy is changed from electrical energy to heat and light.

- Waves carry energy — waves transmit energy from one place to another.
- Waves can be measured in terms of their wavelength, frequency or amplitude:

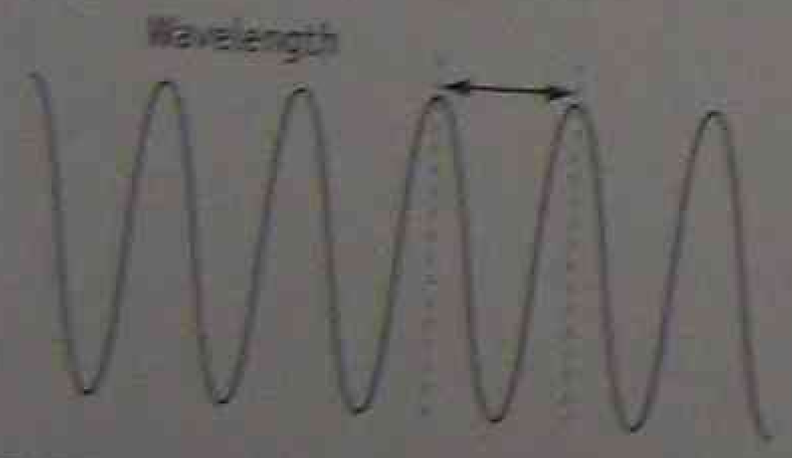


Figure 7.2 Wavelength

Frequency — the number of waves past a certain point in a given time. Frequency is expressed in cycles per second. One cycle per second is called a Hertz (Hz).

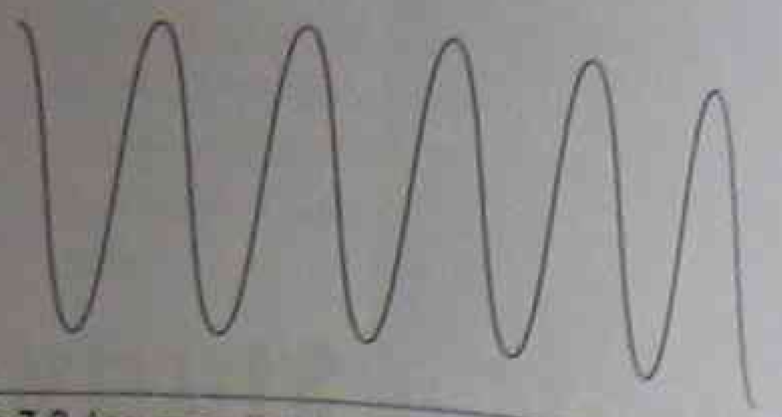


Figure 7.3 Assuming that both these waves travel at the same speed, the frequency of the wave in this diagram is lower than the frequency of the wave in Figure 7.4.

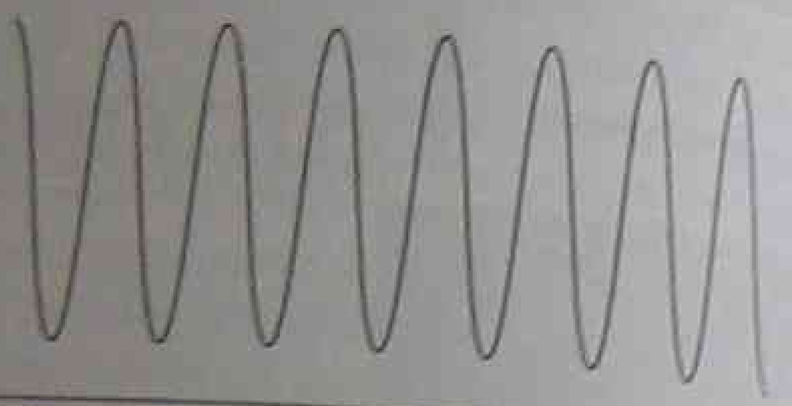
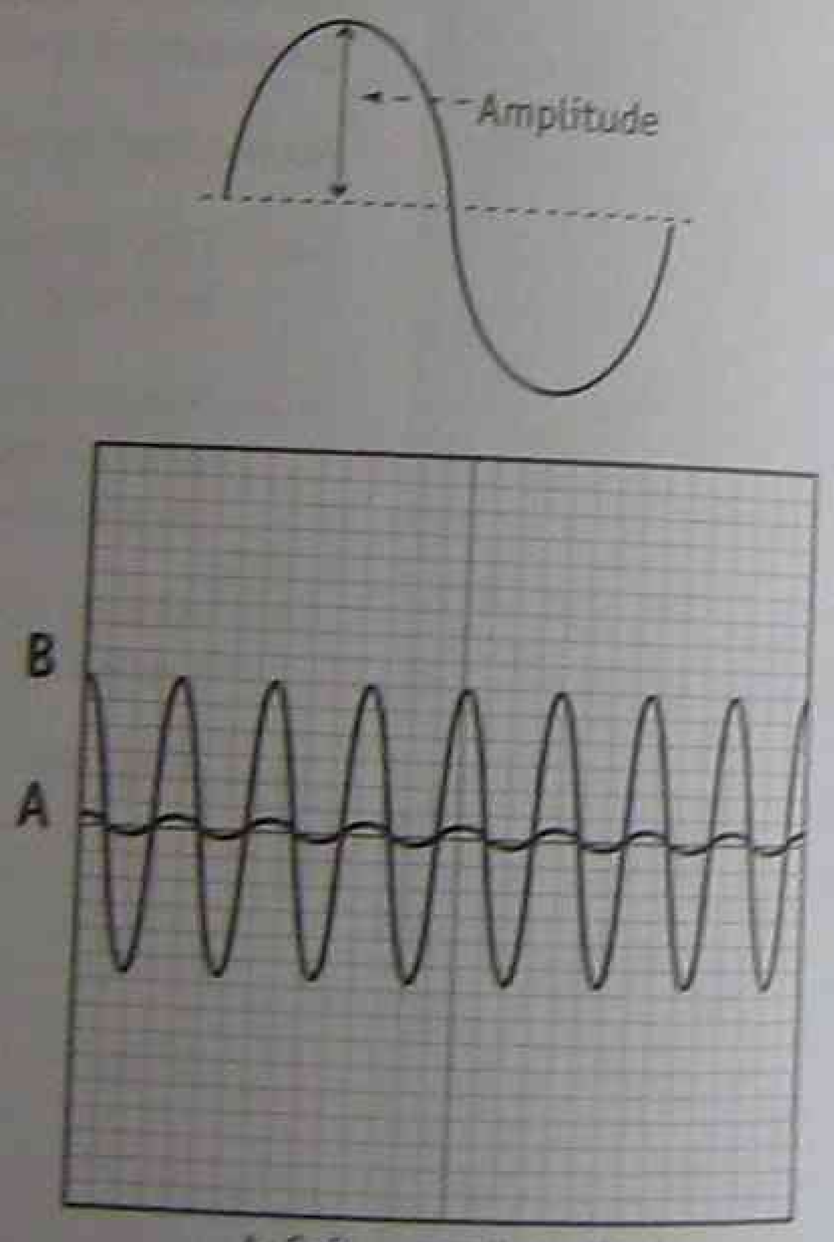


Figure 7.4 Frequency higher than the wave in Figure 7.3

Amplitude — the loudness or softness of a sound is determined by the energy carried by the wave. This is called the amplitude.



A: Soft — small amplitude
B: Loud — large amplitude

Figure 7.5 (a) and (b) Amplitude

- Sound waves are fluctuations which require a medium such as air for their transmission. They are created by vibrating objects. For example the diaphragm in a microphone and the cone in a loudspeaker vibrate to create sound.

- A changing magnetic field produces an electric field. A changing electric field produces a magnetic field. The energy produced by these changing fields radiates out as waves, called electromagnetic waves (see page 127).
- Waves can be refracted — bent.

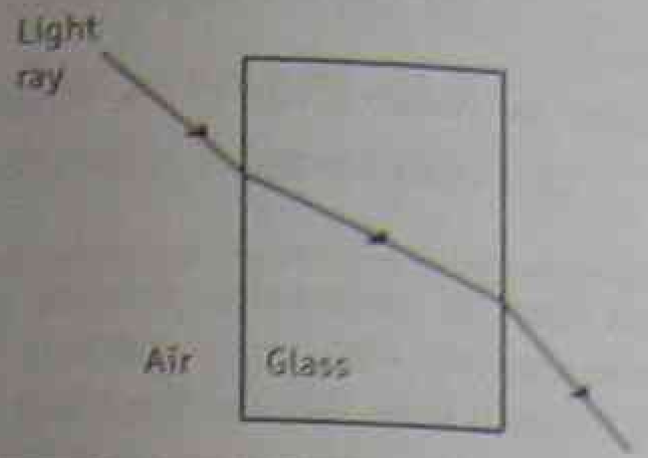


Figure 7.6 Refraction

- Waves can be reflected — bounced off objects.

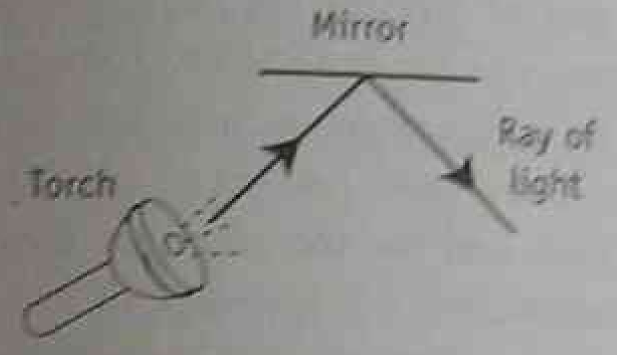


Figure 7.7 Reflection

Information systems

In transmitting information, three key conditions must be met: signals must not be confused, therefore every signal must be sent the same way each time; one signal must be able to be distinguished from another signal; and there needs to be a system that can interpret and coordinate the information received.

The information transfer process, therefore, involves:

- A code common to both parties
- Encoding — creating the message so that it is in a form which can be easily sent (transmitted)
- The transmission of the coded message — the message must be sent and received
- A decoder which puts the message into a form which can be understood.

The speed at which information can be sent depends on the speed of encoding, the speed of the transmission (which carries the message), and the speed of decoding.

The range of information systems used daily can be classified as:

- ***Verbal and non-verbal*** — spoken and written language are the most basic forms of communication. Non-verbal communication includes pictures, symbols, body language and voice tone. Human cultural development has occurred largely because of the capacity for language. Cultural learning, told through story, dance, song and ritual, is recorded or stored in memory and transmitted from one generation to the next.
- ***Short distance and long distance*** — examples of very short distance communication include talking one-to-one and in small groups, or communication involved in teaching or a lecture. In early forms of information technology, simple ways to transmit information over short distances were morse code by light and morse code through a wire. The discovery that information could be transmitted through the atmosphere opened up possibilities for long distance communication and other communication technologies. Metal cables and optic fibre cables also connect people over short and long distances.
- ***Electronic and non-electronic*** — most information that goes through a wire travels as electrical energy. Most long distance information systems, such as telephone, fax, email and television, require electricity. Non-electronic communication includes mail and print media such as newspapers, books and magazines.

The transformation of energy in information transfer

The transformation of energy at each stage of information transfer in a number of everyday devices is summarised below. (Note: sometimes it is not possible to provide a complete representation of complicated energy transformations in simple flow diagrams.)

Mobile phones — are self-contained transmitters and receivers of radio waves. Mobile phones function like a telephone without being connected by wire. A local antennae transmitter (tower) picks up the radio waves in a certain geographical area called a cell. Microwaves are also used to relay transmission of the message.

sound energy (you talk into a mouthpiece) → electrical energy → radio waves → (transmitted via microwaves) → electrical energy → sound energy (you hear the message)

Faxes — light energy is transformed into electrical signals (digitalised) and transmitted through the telephone line where it is converted back to light.

light energy → electrical energy → light energy

Television — a TV camera transforms light energy (visual images) into electrical signals (energy). The signals are amplified and transmitted in the broadcasting network. The TV (in your home, for example) detects the signals and produces an image on the screen. Audio information (sound) is transmitted simultaneously.

light energy & sound energy → electrical energy → light energy & sound energy

or

light energy & sound energy → electromagnetic radiation → light energy & sound energy

Sound systems such as cassette tapes — to record sounds, microphones convert the sound to electrical energy which is then amplified. The record head converts the varying electrical signals from the alternating magnetic fields which create magnetic patterns on the tape. These patterns correspond to the sound. To play back the recorded sound, the magnetised particles on the tape make small electrical signals and, when passed back across a magnet, are amplified and converted to sound by the speakers.

Recording: sound → electrical energy used to produce magnetic patterns

Playing back: movement of magnetic patterns → electrical energy → sound energy

CD players — CDs store information (such as sounds) digitally. The digital signals are coded as binary patterns on the CD. CD players use light from a laser instead of the tone arm or cartridge (used in record players) or the magnetic head (used in tape cassettes) to read the coded message. When we play a CD, the digital signals are then converted from the original signal, amplified and converted to sound by the speaker.

Playing back:

sound energy → electrical energy → sound energy

light energy is the decoder

Having a range of information systems enables us to communicate with many different people in many different ways. We can send and receive sounds, pictures, written words and data in a range of forms over different distances.

As part of meeting the requirements of the course, you are expected to have researched the following systems, including their applications, the basic pattern of the information transfer, and the features that they have in common:

- **Telecommunications** — refers to the methods used to instantaneously send messages and information over long distances. Telecommunication occurs through coaxial (shielded, single strand metal) cables, microwave circuits and telephone lines that transmit information using electrical signals, and optic fibre cables that transmit information using light energy (a form of EM radiation). Applications include telephones and satellite communications.
- **Computer-based communication systems** – use a process called digitisation (see page 131). To input information into a computer, a keyboard, light pen, scanner, mouse, floppy disc, CD or drawing pad is used. Speech recognition technology is also available. The information is stored in the computer memory. Output from the computer is via the screen, print or modem (fax, telephone, Internet). The modem can also provide input. Applications include: EFTPOS, barcodes, email, Internet.
- **Radios** — a radio system consists of a microphone linked to a transmitter and a receiver linked to a loud speaker. The radio receiver is tuned to detect a signal at a particular frequency. Someone speaks into the microphone; the sound waves are converted to electrical signals; the signals are then used to control radio waves. This process of adding information to radio waves is called modulation. The radio station sends out (broadcasts) the signal. An aerial picks up the radio waves.
- **Fax** — see pages 124 and 130.
- **Television** — see page 124.
- **CD players** — see page 124.

All these systems have the following features in common:

- They are electronic, that is, they require electricity.
- They are capable of transmitting information over long distances.

See: http://www.howstuffworks.com — an excellent website to find out how a large range of technologies work (such as modular phones, CDs, faxes, television).

As part of meeting the requirements of the course, you are expected to have used secondary sources to develop a timeline showing the introduction of communication systems in society, and analysed the impact of these systems on society. Some ideas are provided below.

In the course of history, humans have developed language and increasingly complex forms of communication. Language and other forms of communication were developed as the means of survival and cultural transmission. Many of the current communication technologies have become such an integral part of our lives that it is hard to imagine living without them.

- As early as 100,000 years ago *Homo sapiens* (Cro-Magnon) engraved and painted images on walls of caves and developed art — sculptures and ornaments. The earliest known sculptures date back to around 30,000 years. Early civilisations used a message stick, drums, smoke signals and sound horns to send coded messages across distances.
- 1300 BC — the earliest Chinese books.
- 3000 BC — Egyptian clay tablets and papyrus rolls.
- Circa 1456 -- the first printing press.
- 1640 — the first printed book.
- Late 1700s — the development of a French system for transmitting messages using light from a series of relay towers. The system was called a telegraph.
- 1825 — the first electromagnet was invented.
- 1844 — the first electric telegraph line was opened. The message was sent by opening and closing an electric circuit. The receiver recorded the message as dots and dashes on a strip of paper — the morse code. Samuel Morse is credited with building the first electric telegraph.

(**Note**: The invention of the telegraph and telephone was made possible by the invention of electric batteries and the discovery of the relationship between electricity and magnetism.)

- 1854 — Australia's first telegraph system installed.
- 1876 — Alexander Graham Bell patented the first telephone unit.
- 1877 — Thomas Edison invented the carbon microphone used in telephones.
- 1877 — the first commercial telephone system in the USA went into operation. The telephone system expanded rapidly and efficient long distant telephone transmission was made possible by the early 1900s.
- 1877 — the first phonograph record (a rotating wax cylinder) was invented.
- Late 1800s — Australia's first telephone system was installed. Early telephone systems had direct line connections, that is, if you wanted to speak to someone on the telephone you had to have a direct line from their phone to your phone.
- 1880 — Australia's first manual telephone exchange was installed. With increasing numbers of people wanting to communicate by telephone, switchboards were developed and exchanges eventually had to be converted from manual to automatic operation.
- Early 1920s — telephone exchanges became more automated.
- 1901 — Marconi sent morse code messages across the Atlantic Ocean with a high voltage electric spark transmitter.

- 1920s — first amateur AM radio transmissions in Australia.
- Late 1920s — first official AM radio station in Australia began broadcasting.
- Late 1930s and early 1940s — the microwave radio relay system was developed. The system generated high-frequency radio waves that eventually carried telephone messages, telegraph signals, computer data and television programs.
- 1947 — first microwave relay system put into service.
- 1957 — the first commercial microwave system that did not require relay stations was put into service in the USA. The signals used a process in which small parts of the energy were deflected back to Earth by part of the Earth's atmosphere. This opened up the possibility of global communication networks using satellites.
- 1962 — the first active communication satellite, Telstar, was put into orbit. The satellite transmitted telephone messages and transatlantic television broadcasts.
- 1960s — the development of electronic technology and the introduction of the digitilisation system. This allowed the eventual development of multipurpose communication networks such as data transmission between distant computers.
- Late 1960s — Sony developed the first video tape recorder.
- Late 1960s — first integrated circuit developed with the development of the silicon chip (a microcomputer chip).
- 1966 — researchers in England found that silica glass fibres would carry light waves without significant loss of signal.
- 1970 — the first optical fibres were produced.
- 1977 — testing of the first fibre optic cables, leading to their widespread installation beginning in the 1980s.
- 1979 — the cellular telephone was introduced in Sweden.
- 1982 to 1983 — compact discs and players came onto the market.
- 1987— digital audio tape (DAT) cassettes were introduced in Japan.
- 1989 — the transoceanic optical fibre cable was laid between Europe and the USA.
- The 1990s — saw a huge expansion in the communications industry and further improvements in computer chip technology which increased the power and speed of computers. The Internet was established in 1994. In 1997 DVD (digital video discs) became available in the USA.

> Today there is an ever-increasing speed with which messages can be sent and received across great distances. We have mobile communication systems, satellites that enable world-wide television coverage and 'instant' images of events in other countries, digital technologies which have replaced many analogue systems (see page 131), voice mail and telephone call centres, Internet banking, faster push-button dialling, and optical fibres allowing multiple messages to be transmitted simultaneously. The fast pace of change in communication systems has impacted on society in a number of ways. Some of these include:
>
> - Job losses in many outmoded areas
> - Potential for job creation in information technology
> - Laws such as copyright legislation have not been able to keep up with the pace of change
> - Some would argue that reliance on computer technology in communication systems has led to the loss of community, that as a result there is less interaction with other people and a greater sense of isolation in society
> - Many people feel saturated by information overload and choices.

See: http://www.cclab.com/billhist.htm — for a summary of the history of telecommunications.

Information transmission and waves

Many of the developments in information technologies have come about due to advances in our understanding of the different physical properties of waves, and the types of waves in the electromagnetic spectrum.

Electromagnetic (EM) radiation is around us all the time. EM radiation refers to waves of energy which are caused by the varying motions (speeding up, slowing down and changing direction) of charged particles. The waves consist of vibrating electric and magnetic fields.

Electromagnetic radiation comes from the sun, stars and galaxies. It can also be made by humans, for example, for use in microwave ovens, walky-talkies, CB radios and infra-red remotes for controller doors. The EM waves produced by electric motors such as welders or electric razors can be picked up accidentally by radios and TVs as interference.

> EM waves do not need a medium such as air through which to travel. (Sound waves do.) EM waves can travel through 'empty' space (a vacuum) at a uniform speed. Therefore, electromagnetic waves act as wireless conductors of energy.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to show that sound requires air or some other medium to carry the energy.

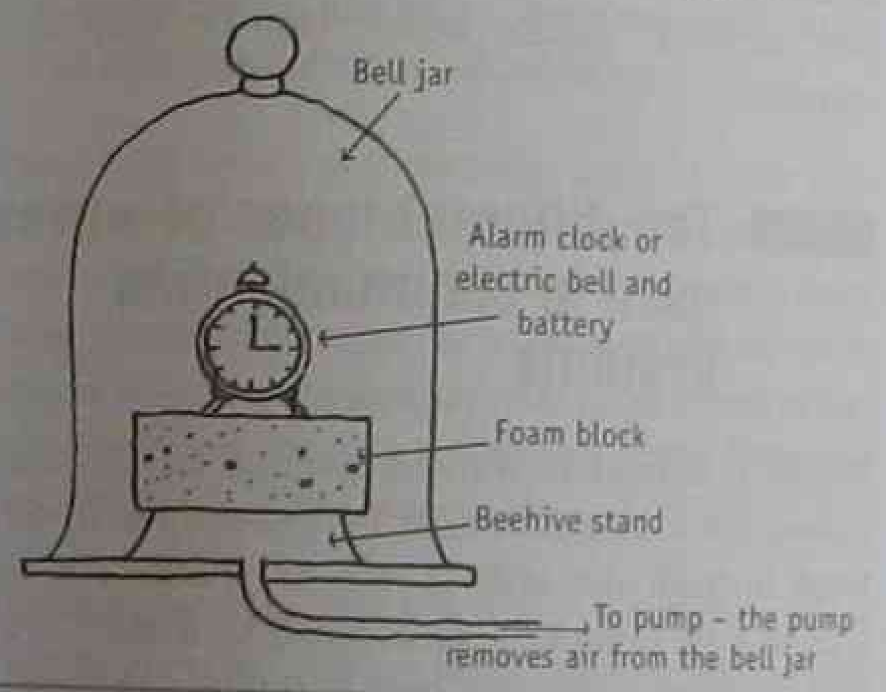


Figure 7.8 A demonstration to confirm that sound requires air or some other medium to carry the energy

The electromagnetic spectrum

Spectrum means a 'range'. The EM spectrum shows the range of different types of electromagnetic radiation (or waves). These wave types all travel at the same speed through the same material, but their speed does depend on the material they pass through. They differ only in their frequency and therefore their wavelength (see page 129). Our eyes can detect a range of particular frequencies of EM radiation — we call this light. The EM spectrum is usually represented as a list or diagram showing the types of waves and their frequency.

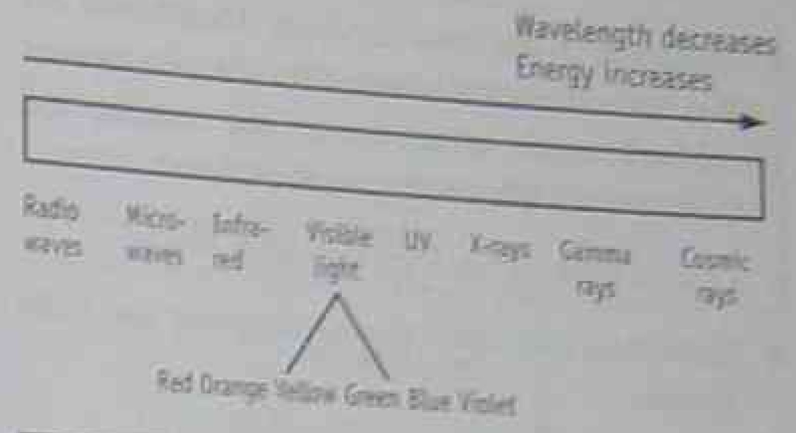


Figure 7.9 The electromagnetic spectrum. The higher the frequency, the more energy the waves have. High energy waves such as X-rays and gamma rays have a greater ability to penetrate objects including organic tissue. The energy level of an electromagnetic field decreases rapidly with the distance from the source. The level is further decreased by objects in its path.

Microwaves and radio waves in communication technologies

Radio waves are used in AM/FM radio, television, CBs, walkie-talkies, and shortwave radios. Microwaves are used in the transmission of telephone and telegraph messages, in communications between Earth and orbiting satellites, and in relaying certain television broadcast signals.

Microwaves and radio waves are types of electromagnetic radiation with low frequency.

Advantages	Disadvantages
■ They can travel through air without requiring a medium such as wire. ■ Therefore, they can be broadcast to a huge audience over large distances. They don't need people to be connected directly to one another or to the source of the information. ■ The frequency in transmission and reception of radio waves can be precisely controlled.	■ Because the waves travel in a straight line and can be reflected, they need transmitter and repeater stations to get around corners and objects. ■ Broadcasting over a wide area means that a lot of energy is wasted; the receiver of the signal must be tuned into the correct frequency. ■ The most effective frequency ranges in the EM spectrum are limited; so there is a lot of competition in those frequencies.

Figure 7.10 The advantages and disadvantages of using microwaves and radio waves in communication technologies

The use of the electromagnetic spectrum for communication purposes

The types of waves in the electromagnetic spectrum currently used for communication systems are visible light, infra-red, microwaves and radio waves, which include: TV, FM radio and AM radio.

- TV remote controls and other remotes (such as those used with roller doors) use infra-red waves.
- Microwaves are used in radar. Microwaves are the main carriers of information between repeater stations, such as mobile phone towers, and between satellites and ground stations.
- Optical fibre technology uses light waves.
- Television and radio communications use radio waves.

As part of meeting the requirements of the course, you are expected to have carried out experiments to observe ways in which waves can be modified to carry different types of information. Two examples are provided below.

(a)

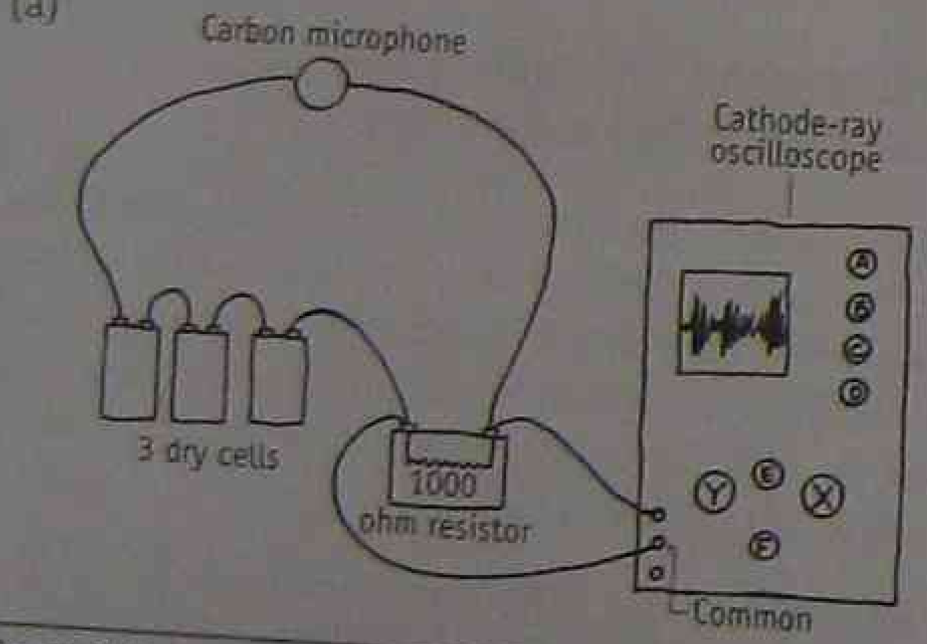


Figure 7.11 An experiment to observe ways in which waves can be modified to carry different types of information such as producing electrical signals from sound.

(b) Sending morse code signals using light is another way to show how waves can be modified to carry different types of information.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the types of information that is carried on barcodes and magnetic strips in Australia.

Barcodes emerged in the 1970s as a way to improve the speed and accuracy of data entry into computers. Barcodes and magnetic strips are used in printing, manufacturing and packaging, airline baggage checking and the retail industry, and can be found on a huge range of items including clothing, library books or any item bought from most stores, such as supermarket goods.

0 12345 67890 5

Figure 7.12 An example of a barcode

In simple terms, a barcode scanner is made of a light source — a laser beam — which consists of a narrow, focused, bright beam which can shine over a long distance. The light is directed toward the barcode, reflected back and recorded on a spinning holographic disc. A light detector converts the light into electrical signals which can be read by a computer.

The different types of waves used in communication systems

Where information systems cannot be physically linked, the information may be transmitted in wave form through the atmosphere or space. The first type of long distance communication without wires (the wireless) used radio waves, which can travel in a direct straight line and can be bounced off the upper layers of the Earth's atmosphere. Modern communication systems use other types of EM waves as well as radio waves to transmit information.

Energy from the electromagnetic spectrum

The properties of energy from the electromagnetic spectrum that make it useful in communication technologies include:

- Its speed of travel — all energy from the EM spectrum travels very fast, 3×10^8 metres per second (written as 3×10^8 ms^{-1}) in a vacuum. This is, of course, the speed of light in a vacuum. The speed will be a little slower in water, glass and so on.
- Its ability to travel in a straight line — energy from the EM spectrum travels in a straight line.
- Its ability to be reflected in a regular way — energy from the EM spectrum can be reflected (bounced off) things such as atmospheric layers.

Some examples are summarised below:

Visible light allows us to see. It is detected by the retina in the human eye and photographic film. The wavelength is 7×10^{-7} metres to 3×10^{-7} metres. Light waves can be reflected, but to see someone we need line-of-sight transmission (we cannot see around corners).

Radio waves which include TV, FM and AM have the longest wavelength (lowest frequency) of the EM waves: 10^{-1} metres to > 104 metres (300 kHz to 3,000,000,000 kHz). Because of their low frequency, radio waves do not penetrate all objects. They can easily be reflected and bend around large obstacles such as buildings and hills. Therefore, radio waves do not need line-of-sight transmission.

Waves used for TV transmission and FM radio have shorter wavelengths, do not reflect as easily and therefore do not bounce off the Earth's atmosphere. These transmissions need a relay such as transmission towers and satellites. AM radio waves reflect well. See below for an explanation of the difference between AM and FM waves.

Microwaves also have a long wavelength (low frequency) = 10^{-2} metres to 10^{-4} metres. Microwaves have limited penetration.

As part of meeting the requirements of the course, you are expected to have conducted an investigation to compare communication using AM and FM radio waves.

A sudden pulse of changing electric current produces a radio wave pulse. The radio waves are sent out in all directions. If, by chance, they meet a suitable receiving aerial, the radio waves generate another alternating current of the original frequency.

The broadcasting of music and voice requires a more controlled signal. The radio waves are converted back to sound in the following way. A radio's receiver is the antenna. The antenna picks up many different signals but its length will be more suited to particular frequencies. When a radio is tuned to a station's frequency, that minute signal is amplified through stages and then it is demodulated. That is, the audio signal is separated from the carrier frequency. It is then sent to an audio amplifier and then to the loudspeaker. In radio, the audio signal is either amplitude or frequency modulated. An AM radio wave can carry a coded message by changing its amplitude. An FM radio wave can carry a coded audio signal by changing its frequency.

A pure radio wave has a constant frequency and amplitude. If modulation involves changing the amplitude, AM radio waves are produced. If modulation involves changing the frequency, FM radio waves are produced.

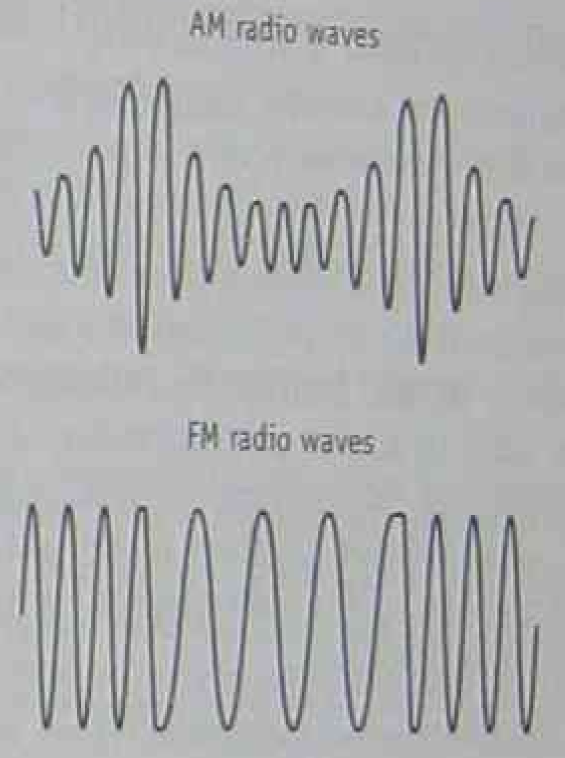


Figure 7.13 AM and FM radio waves

TV uses both amplitude modulation (for the picture) and frequency modulation (for the sound). Each radio wave is given a carrier frequency. When a signal is modulated, side bands are created. The side bands extend above and below the assigned carrier frequency.

Geostationary satellites

A geostationary satellite revolves at a height of 35,200 kilometres above the Earth's surface, staying above the same place on the equator. The satellite's orbit takes 24 hours, (the same time as one Earth rotation), and therefore it is stationary relative to the movement of the rotation of the Earth.

A number of geostationary satellites together can relay information from one side of the Earth to the other side.

The speed of the radio signal is given by the equation:

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

The speed of travel is $3 \times 10^8\ \text{ms}^{-1}$. Using this information and the equation, it is possible to calculate the time delay between the signal leaving one place and arriving at another.

> The satellite must be at a height where its revolution period is the same as that of the Earth's period of rotation. This is because the satellite must remain over the same spot in order to maintain contact with ground stations.

Each geostationary satellite can see a third of the globe, but they have a poor view of polar regions.

> A satellite dish must face the same direction and must remain at the same location with respect to the surface of the Earth. This is because the satellite dish is aimed at a particular satellite. The satellite the dish is in contact with, is always in the same relative position in the sky. The parabolic shape of the dish focuses the signals into the central point.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research the satellites used for 'live' telecasts from other regions of the world to Australia and vice versa, and explain why communication satellites have different orbits and aerials and cover various areas of the planet.

The largest provider of international satellite services is Intelsat. Telecasts to Australia are transmitted by Intelsat satellites. International Earth stations for the Indian and Pacific Oceans are located in capital cities such as Perth and Sydney.

See: http://www.austelguide.com.au — for the Australian telecommunications guide.

http://www.panamsat.com/sat/beam/p8beam.htm — for information on the PanAm satellite PAS-8 Pacific Ocean region.

Information transmission and electrical impulses

Computer-based communication systems used in faxes, barcodes, digital recordings and so on, are examples of communication technologies that transform one type of energy (sound or light energy) into electrical energy. See pages 124 and 127 for other examples.

Fax images

To transmit a message by fax (or facsimile), the pages of a document are put into a fax machine. The pages are moved across a light source. The fax machine scans the document along very thin lines which change the light and dark parts of the written message into electrical signals. The signals are then converted to digital signals.

The signal travels by a telephone line and is received by a fax at the other end, which decodes the signal and makes a replica, then prints the message.

The coding of the image into a series of zeros and ones

Computer-based communication systems, such as faxes, use digital (electrically coded) signals. Computer language code consists of a series of numerical digits. The numbers used are binary: 1 or 0. Each binary digit is called a **bit**. Each bit is represented by a predetermined series of eight binary digits called bytes.

Binary number	2^6	2^5	2^4	2^3	2^2	2^1	2^0
	64	32	16	8	4	2	1
Code used in computer for the number 30	0	0	1	1	1	1	0
and 33	0	1	0	0	0	0	1

Figure 7.14 Examples of binary codes for the numbers 30 and 33.

> Digitisation involves converting sound or light into computer language (a code), transmitting it and converting it back to its original form at the receiving end.

(a) Using an old computer, analyse messages coming out of the printer port on a cathode ray oscilloscope.

(b) Investigate sequencing/audio editing software such as Cubase®, Encore®, or LogicAudio®.

For a computer to transmit information through telephone lines, its pulses of digital information must be converted to a different form. This is done by a modem. To have access to the Internet or email on a computer, it is necessary to have a modem.

> As part of meeting the requirements of the course, you are expected to have conducted an investigation to convert different forms of energy into electrical impulses. Two examples are provided below.

> ***Analogue and digital systems*** — Both systems involve coding information in order for it to be transmitted or stored. In an analogue system, information is transmitted in the form of a wave. In a digital system, the information is represented as numbers — a series of on-offs. For example, when someone speaks into a microphone, small changes in sound pressure are converted to small changes in electrical voltage and the information is transmitted as a wave (analogue). To convert the waveform into a digital form, the information is represented as numbers.

Digital circuits, such as those in computers, cannot process information in the form of waves. Computers can process numbers.

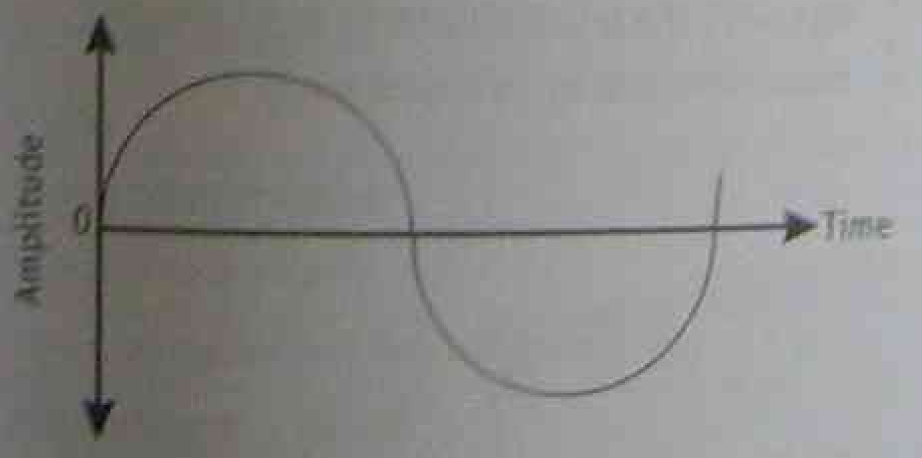


Figure 7.15 A graphical representation of an analogue signal showing the signal level or amplitude.

Analogue circuitry is able to process the information in the wave. To process the waveform digitally, its amplitude must be measured and converted into a number — but the amplitude is continually changing. To represent continually changing amplitudes would require continually changing numbers. A digital circuit cannot process a number that keeps changing. The solution to this is to use a series of numbers to represent the analogue signal's wave amplitude at specific, regular points or in small steps.

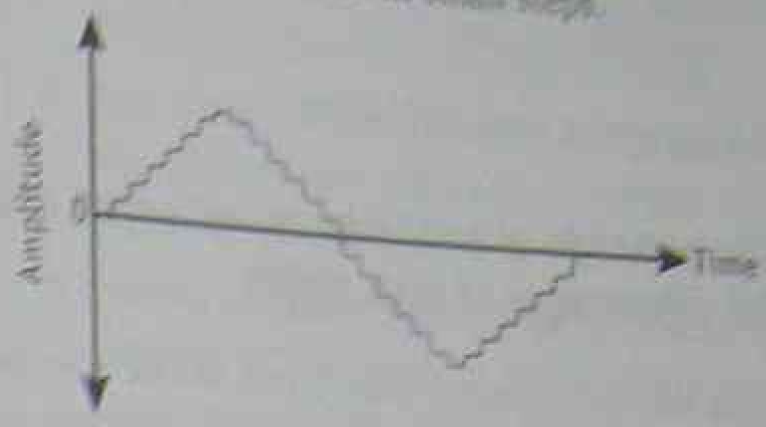


Figure 7.16 A graphical representation of a digital signal. In audio digital technology, the process of measuring the amplitude of the analogue signal at regular intervals is known as sampling.

Optical fibre communication systems

In optical fibre communication systems, electrical energy is converted to light energy.

The properties of optical fibres

> An optical fibre is a single hair-like fine filament made from molten silica glass. The fibres are constructed in such a way that light can be transmitted through them with minimal loss of light energy by total internal reflection (see details below). A fibre optic cable is made up of a large number of individual optical fibres, bound together around a central core.

To transmit a message, a data link centre converts the electrical energy into digital pulses of laser light which travel to another data link where the light energy is converted to an electrical signal.

A pulse travels through an optical fibre at the speed of light, 3×10^8 metres per second every second (in a vacuum). In optical fibres there is some energy lost because of impurities in the glass. After a certain distance therefore, the signal becomes weak and must be strengthened. To strengthen the signal, laser repeaters are placed at certain distances along the cable, particularly when the signal is transmitted over very long distances. On-going research aims to extend the distance that the signal can travel without being strengthened by:

(a) Improving the purity of the glass. Glass with high fluoride content seems to have the best performance, and

(b) Improving laser technology.

The principle of total internal reflection and the advantages of fibre optics

Light travels in straight lines. It can also be reflected and refracted. Light, however, cannot travel around corners (unless it is reflected). The development of optical fibres came about with the discovery that light can be transmitted through a hollow tube even if the tube is curved. As the light travels through the tube, it is reflected (bounced) off the inner walls again and again. In this process, some light energy leaves the tube (rod) and is lost every time the light rays are reflected.

✓ The principle of total internal reflection is used to stop this loss of light energy when light is transmitted through a hollow tube. The tube is really a rod, usually made of glass.

Total internal reflection occurs when the rod (fibre) is made up of different substances with different densities, such as glass (a dense medium) and air (less dense). Total internal reflection takes place at the boundary between the two substances. If the light passing through the solid glass fibre is refracted by more than a certain angle, it will not leave the glass. Instead it will be totally reflected internally.

In an optical fibre, a transparent glass rod forms the inner core and there is an outer coating of different density. All the reflection takes place at the boundary between the inner core and outer coating. The reflecting surface is sealed and kept away from other reflecting surfaces to prevent energy loss.

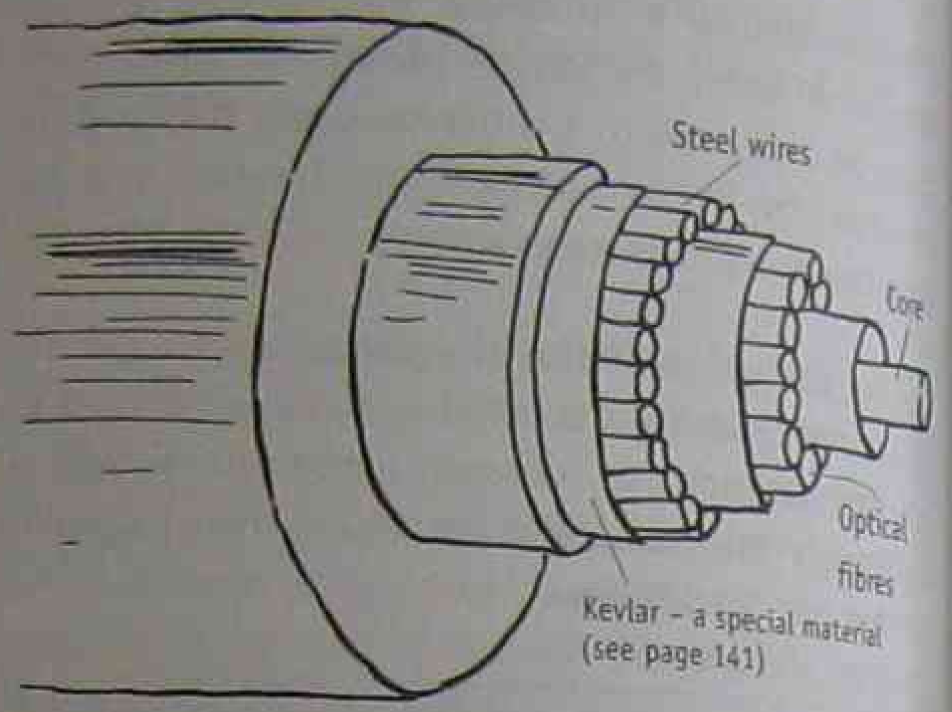


Figure 7.17 A fibre optic cable. The cable is a bundle of optical fibres combined into a cable. When they are combined, each fibre must be shielded from other fibres, otherwise light energy leaks causing distortion and the fibres become scratched.

✓ These properties mean that optical fibres allow images to be transmitted around corners and increase the quantity and accuracy of the transmission of information.

As part of meeting the requirements of the course, you are expected to have observed the transmission of light through an optic fibre, showing total internal reflection, and compared this with the transmission of light through other materials such as nylon or glass.

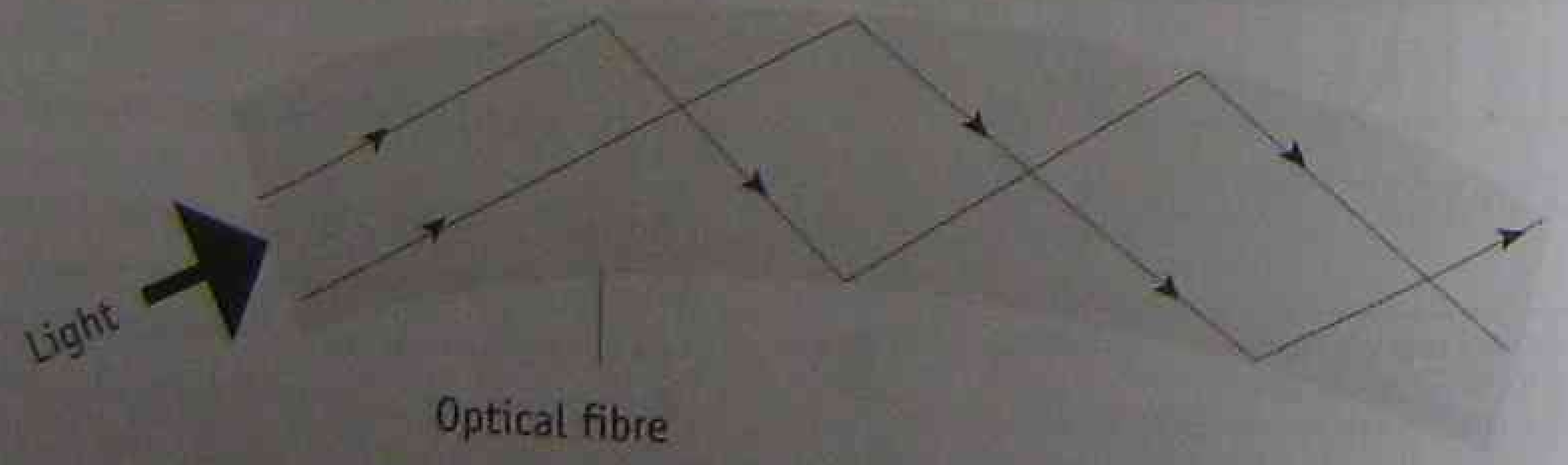


Figure 7.18 A model of internal reflection

Fibre optic cables compared to metal cables

Optical fibres are replacing metal wire as the transmission medium for high-speed, high capacity communication. The differences and relative merits in the use of fibre optic cables and metal cables are summarised below:

Fibre optic cables — carry information as light energy. They can therefore transmit enormous amounts of information per second. Fibre optic cables are able to send more than one call on the same link with the same quality of signal at both ends. The transmission is very fast (virtually the speed of light — the fastest speed possible), and because light energy is used, the transmission is not subject to electrical interference from external sources. Optic fibre cables do require boosters at intervals along their length in order to maintain signal strength.

Metal cables — carry information as electrical energy. The transmission can therefore be subject to electrical interference from external sources, making it a less reliable means of transmission.

As part of meeting the requirements of the course, you are expected to have compared and contrasted copper cables with fibre optic cables in relation to:

- Carrying capacity — greater through fibre optic cables than through copper cables.
- Rate of information transfer — much faster through fibre optic cables than through copper cables.
- Security (in terms of people being able to intercept or interfere with the message) — better through fibre optic cables than through copper cables.
- Cost — greater for fibre optic cables than copper cables.

Checklist **Key terms for revision**

- communication
- encoding information
- transmission of information
- decoding information
- energy
- energy transformation
- telecommunication
- computer-based communication systems
- electromagnetic radiation
- electromagnetic spectrum
- visible light
- infra-red
- microwaves
- radio waves
- AM radio waves
- FM radio waves
- atmosphere
- reflection
- geostationary satellites
- satellite dish
- revolution of the Earth
- rotation of the Earth
- fax images
- digitalisation
- optical fibre
- fibre optics
- total internal reflection

Test

Multiple choice questions

1. Which of the following flow diagrams most accurately represents the transformation of energy at each stage of information transfer in CDs?
   (A) light energy → sound energy → electrical energy
   (B) sound energy → electrical energy → sound energy
   (C) electrical energy → sound energy
   (D) electrical energy → light energy → sound energy

2. Which of the following statements is incorrect? The coding of a signal into a series of zeros and ones is:
   (A) Called digitilisation
   (B) Used in analogue systems
   (C) Used in computer-based communication systems
   (D) Used to transmit a message by fax.

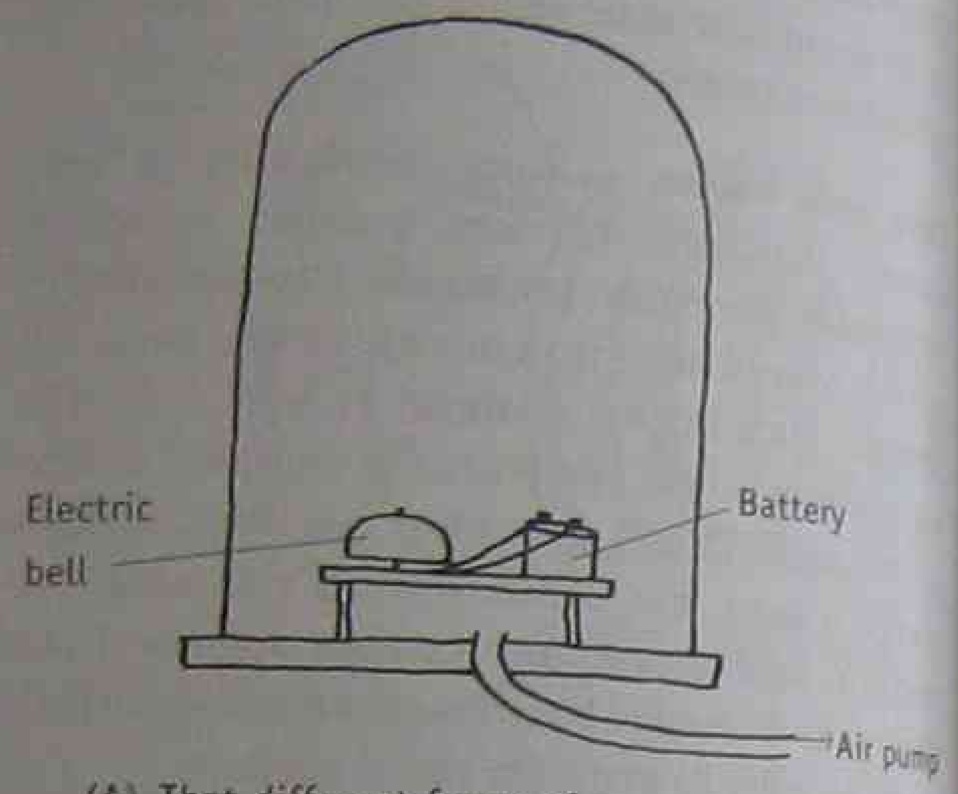
3. The table below lists four different types of electromagnetic radiation (W, X, Y & Z) with an example of how each is used in communication systems.

Type of EM wave	*An example of its use*
W	radar
X	optic fibre technology
Y	remote control
Z	television

The most correct match for the waves W, X, Y and Z is:

	W	X	Y	Z
(A)	light	infra-red	microwave	radio
(B)	light	microwave	radio	infra-red
(C)	microwave	light	infra-red	radio
(D)	microwave	infra-red	light	radio

4. The diagram below demonstrates:



(A) That different forms of energy can be converted into electrical impulses
(B) The principle of total internal reflection
(C) That sound requires a medium to carry the message
(D) Ways in which waves can be modified to carry different types of information

5. The binary code below represents the number:

Binary number

2^6	2^5	2^4	2^3	2^2	2^1	2^0
64	32	16	8	4	2	1
1	0	1	1	0	0	0

(A) 64
(B) 84
(C) 68
(D) 88

Short answer and longer response questions

1. In a fixed telephone, the energy is transmitted in a wire.

   Sound energy → electrical energy → sound energy

   Using diagrams, compare this energy transformation with the energy transformations involved in sending a message with a mobile phone. (3 marks)

2. Outline the properties of the electromagnetic spectrum that make it useful in communication technology. (4 marks)

3. List three impacts that developments in information technology have had on society, and outline one possible future direction in information systems. (4 marks)

4. Draw a simple, labelled diagram to show the principle of total internal reflection and briefly explain its advantage in communication technology. (4 marks)

5. Outline three differences between fibre optic cables and metal cables and the relative merits of each as transmission media. (5 marks)

6. Outline five developments in technology which have led to improvements in information systems over time. (5 marks)

Test answers

Multiple choice questions

Answers

1. B 2. B 3. C 4. C 5. D

Explanations

1. See page 124.
2. For an explanation of analogue and digital systems, see page 131.
3. Microwaves and radio waves are used in radar. Optic fibres use light waves. Remote controls use infra-red and radio waves. Television uses radio waves (and microwaves for some transmissions).
4. The diagram is one way to demonstrate that sound requires a medium to carry the message. When the air is pumped out of the bell jar, the sound of the electric bell becomes fainter. The bell is still ringing but we cannot hear it. When the air is removed, there is nothing to transmit the sound.
5. 64, 16 and 8 add up to 88.

Short answer and longer response questions

Answers and explanations

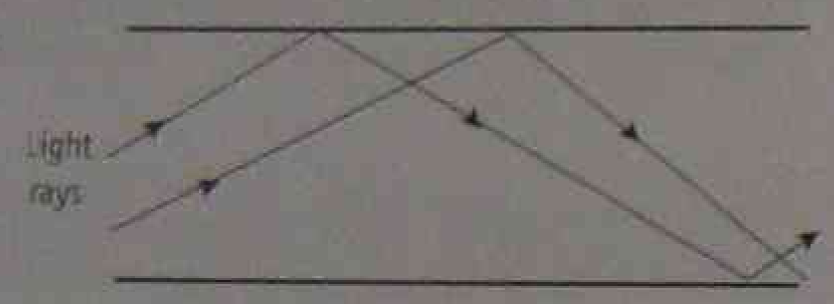
1. Mobile phones are self-contained transmitters and receivers of radio waves. Mobile phones function like a telephone without being connected by wire. A local antennae transmitter (tower) picks up the radio waves in a certain geographical area called a cell. Microwaves are also used in the transmission of messages. This is illustrated below.

2. Properties that make EM radiation useful include:
   - It can travel through space; it does not need a medium for its transmission.
   - It travels very fast: 3×10^8 metres per second.
   - It has the ability to travel in a straight line.
   - It has the ability to be reflected in a regular way, and therefore it can be bounced off things such as atmospheric layers.

sound energy (you talk into a mouthpiece) → electrical energy → radio waves → (transmitted via microwaves) → electrical energy → sound energy (you hear the message)

3. Communication technologies have brought about an accelerated pace of change in society today. We can communicate with ever-increasing speed across great distances. We can get 'instant' images of events in other countries. The use of optical fibres means that multiple messages can be transmitted simultaneously. People no longer need to leave their homes to do shopping or banking or to pay bills. Some of the impacts include loss of jobs, and loss of community because use of communication technologies can mean less direct interaction with other people, and a greater sense of isolation. See page 132 for developments in optical fibre communication.

4.



Total internal reflection means that light can be transmitted through optical fibres without loss of energy. Images can be transmitted around corners and because light is carrying the message, the speed and accuracy of the transmission of information is increased.

5. Fibre optic cables carry information as light energy. They can therefore transmit enormous amounts of information per second. The transmission is very fast. The carrying capacity is greater through fibre optic cables than through copper cables. Fibre optic cables do require boosters at intervals along their length in order to maintain signal strength.

Metal cables carry information as electrical energy. The transmission can therefore be subject to electrical interference from external sources, making it a less reliable means of transmission. Copper cables are cheaper than fibre optic cables.

6. There are lots of ideas you could include in your answer. A sample answer outline is provided below. See also page 125.
   - The discovery of the key features of electromagnetic energy in the last half of the nineteenth century.
   - The development of a microwave radio relay system which generated high-frequency radio waves and eventually carried telephone messages, telegraph signals, computer data and television programs.
   - The discovery that information could be transmitted through the atmosphere. This opened up possibilities for long distance communication and other communication technologies. For example, the development of the first commercial microwave system which did not require relay stations. The signals used a process in which small parts of the energy were deflected back to Earth by part of the Earth's atmosphere. This opened up the possibility of global communication networks using satellites.
   - The development of digitisation which enabled computers to process information.
   - The development of optical fibres which came about with the discovery that light can be transmitted through a hollow tube even if the tube is curved.

HSC Study Option

8 — Polymers

Introduction

You will only review this option if you have studied it. Remember, you only need to study one option for the HSC.

Metals and natural fibres such as fur and silk have long been used for clothing, tool making and shelter. Many of these materials, consisting of large molecules made up of the same repeating unit, are called polymers. As human culture evolved, a broader range of natural polymers was used. Synthetic polymers, developed in the 'Age of Plastics', were made possible by the development of the process called polymerisation. In this chapter you will review the range of natural and synthetic materials used by humans. You will review their properties and how these relate to their uses. You will also review the impact of the development of polymers on society, in particular, their environmental impact and issues related to their future development and use.

As a result of working through this chapter you will be able to:

- Assess the impact of polymerisation on society and the environment
- Explain that extracts from coal, petroleum and other natural resources are used to make polymers and describe the implications for the future of the production of polymers from petrochemicals
- Describe possible future directions of research in the development of new polymers
- Relate the properties of natural and synthetic polymers to their use.

Natural polymers and their uses

A polymer is a chemical substance. The term 'polymer' comes from the Greek word polymeros meaning 'many parts'. A polymer is a large molecule that consists of identical repeating chemical units.

The term 'polymerisation' refers to the process of joining smaller molecules called monomers to form polymers.

The molecules of polymers can be long-chained, or branched or ring structures. Monomers are made up of carbon (C), hydrogen (H), nitrogen (N) and oxygen (O) atoms. Some polymers also include chemicals such as chlorine, silicon, fluorine and sulfur.

Natural polymers include proteins, starch and cellulose. Proteins are made up of many amino acids. Starch and cellulose are polysaccharides, made up of a combination of many simple sugars (monosaccharides and disaccharides). Synthetic (non-natural) polymers include the vast range of plastics, ceramics and synthetic fibres such as nylon and acrylics.

Some natural examples of polymers used in the textiles industry include hair and fur, wools, silk, cotton and flax.

As part of meeting the requirements of the course, you are expected to have modelled a polymer molecule to show its component monomers.

Your investigation may have involved using molecular models from organic chemistry kits. Two examples are provided below.

Protein — proteins are large molecules made up of many amino acids joined together by peptide bonds. Protein is a natural polymer.

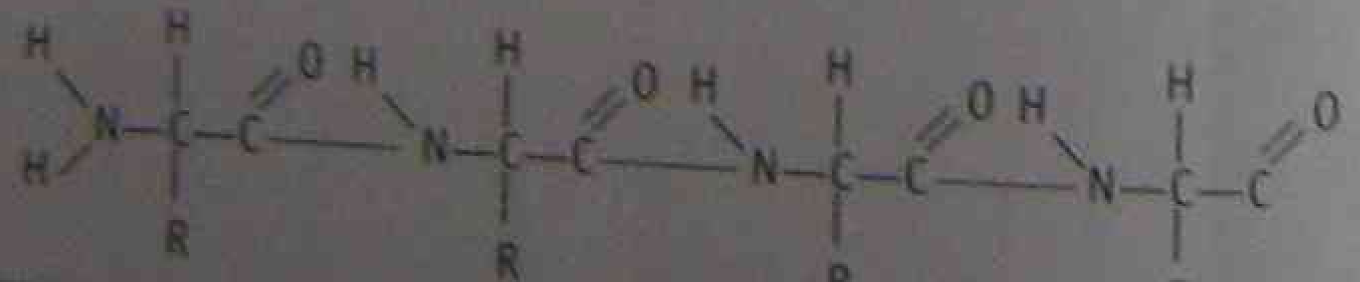


Figure 8.1 A polypeptide chain

Polychloroethene — PVC (Polyvinyl Chloride is an older name) is a polymer made up of the monomer chloroethene. There are around 2000 carbon atoms in each polymer.

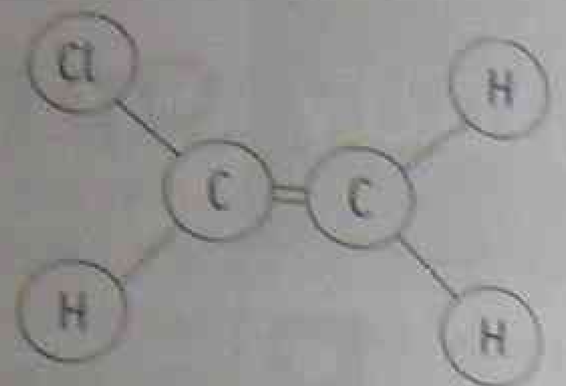


Figure 8.2 Chloroethene is the monomer that is polymerised to form the synthetic polymer PVC.

The properties and uses of some natural polymers

In general, cotton and linen can be washed at high temperatures. The protein fibres in natural polymers such as fur and wool are more sensitive to heat. Silk withstands high temperatures only when dry. Cellulose fibres in cotton and linen are sensitive to acids, but have high resistance to alkalis. They can be washed repeatedly without damage. Protein fibres are more resistant to acid and particularly sensitive to alkalis. Wool, for example, will dissolve in dilute caustic soda. Figure 8.3 on the following page summarises the properties of some natural polymers.

As part of meeting the requirements of the course, you are expected to have tested a range of properties of natural polymers selected from the following:

- Thermal properties — the insulation properties of a polymer, as well as its heat sensitivity. Heat sensitivity determines the temperature at which a fabric can be pressed. Use the heat from an iron to test different fabrics for heat sensitivity. Wool, for example, is an excellent heat insulator.
- Strength — the strength of the fibre. Use a weight to test for fibre strength.

	Thermal properties	Strength	Elasticity	Moisture absorbency	Effects of acids/alkalis
Wool	High insulating value: poor conductor of heat (warm in winter)	Wool is durable and strong	High; wool is flexible	Very absorbent: will take up to 33% of its weight in water	Resistant to acids; sensitive to alkalis
Silk (from the larvae of the moth *Bombyx mori*)	Poor conductor of heat (warm in winter)	One of the strongest natural fibres; lightweight	Not as elastic as wool; doesn't wrinkle easily	Very good absorbency; more absorbent than cotton and flax	Sensitive to strong acids and alkalis
Cotton	Good conductor of heat (cool in summer); withstands high temperatures	Cotton is strong	Cotton fabric wrinkles badly; chemicals are added in the finishing process to make the fibres wrinkle-resistant	Will absorb water	Sensitive to acids; high resistance to alkalis
Flax (fibre from the linseed plant used for making linen, threads and twine)	Good conductor of heat	High strength and durability (finer than cotton)	Linen fabric wrinkles badly	Absorbs water	Sensitive to acids; high resistance to alkalis

	Resistance to biological attack	Dyestuff	Shrinkage	Flammability
Wool	Is attacked by moths	Because of its absorbency, wool takes dye with extreme ease and will generally remain colour-fast	Wool shrinks if washed in hot water	Flame resistant
Silk	Not resistant to biological attack	Very receptive to dyeing; dyers can achieve many hues with silk	Keeps its shape	Moderately flammable
Cotton	Resistant to moulds; not resistant to silverfish	Doesn't take dye as easily as wool or silk; cotton must be treated in the finishing process to make fibres more absorbent for dyeing	Fibres are pre-shrunk during processing to prevent further shrinkage	Flammable
Flax	Attacked by some insects	Doesn't take dye as easily as wool or silk	Low shrinkage	Flammable

Figure 8.3 A comparison of natural polymers for thermal properties, strength, elasticity, moisture absorbency, effects of acids/alkalis, resistance to biological attack, affinity for dyestuffs, shrinkage and flammability.

- Elasticity — the ability of a fabric to return to its original size or shape after stretching. Test different fabrics by stretching each to the same amount of elongation and for the same length of time. Compare their recovery rates.
- Moisture absorbency — the degree to which a fabric will absorb moisture such as perspiration.
- Effects of acids/alkalis — resistance to chemicals determines how a fabric is cared for. For example, wool is resistant to the effects of acids but is harmed by alkalis and therefore should not be washed in strong detergents or put in bleach.
- Resistance to biological attack (see page 144).
- Affinity for dyestuffs — how well the fabric accepts dye. Test different fabrics by dyeing each and comparing how well the colour was accepted. Keep the amount of fabric (surface area), the amount of dye, the temperature and the dyeing time for each fabric the same.
- Shrinkage — the ability of a fabric to retain its shape and size after care (washing or dry cleaning). Wash a range of fabrics in the same amount of water, at the same temperature and for the same time, and compare results.
- Flammability — the ability of a fabric to resist heat or flame.

Look at identification labels on fabrics to confirm the results of your tests.

Note safety precautions when using acids and alkalis or carrying out flammability tests. A fume cupboard should be used for all flammability tests.

Synthetic polymers

Developments in chemistry and technology have made it possible to produce a range of synthetic polymers with specific tailor-made properties that are now used in most aspects of daily life in industrialised countries.

Synthetic polymers include:

Polyamides (nylons) — nylon was the first synthetic polymer to be produced. It was developed as a result of research into a substitute for silk. The properties of nylon include high tensile strength (resistance to breaking) and elasticity.

Polyester — a synthetic fibre formed from the chemical reaction between an acid and an alcohol. Polyester does not absorb water, does not absorb oil and is resistant to many acids. It will not stretch out of shape, has a high tensile strength and resists shrinking. It is easily dyeable and not damaged by mildew. Polyester is used in a wide range of products including clothing, home furnishings, industrial fabrics, computer tapes, cassette tapes and electrical insulation. Textured polyesters are non-allergenic and insulate well. Therefore they are used as fillings in pillows, quilting and sleeping bags. There are two main types of polyester:

- **PET** (polyethylene terephthalate) which is wrinkle and stain resistant, and
- **PCDT** (poly-1, 4 cyclohexylene-dimethylene) which is more elastic and resilient. PET is stronger than PCDT.

Another form of polyester — microfibre — was developed in 1991 and is now used in a wide range of clothing.

Polyethylene — is polymerised from ethylene. There are two forms: high-density polyethylene and low-density polyethylene.

- High-density polyethylene is used in shopping bags, freezer bags, milk bottles, buckets and milk crates. It is hard to semi-flexible, opaque and melts at 135°C.
- Low-density polyethylene is used in garbage bags, squeeze bottles, black irrigation tube and garbage bins. It is soft, flexible, translucent, scratches easily and melts at 80°C.

Polystyrene — there are two forms: polystyrene and expanded polystyrene or polystyrene foam (Styrofoam).

- Polystyrene is used in plastic cutlery, low-cost brittle toys, imitation crystal glassware. It is rigid, brittle, semi-tough, can be clear and opaque and melts at 95°C. It is affected by fats and solvents.
- Expanded polystyrene is used in hot drink take-away cups (foam cups) and take-away containers, foam meat trays, protective packaging. It is lightweight, energy absorbing and heat insulating.

PVA (Polyvinyl Acetate) — is polymerised from vinyl acetate from acetylene. It is used in glues such as water-soluble wood glue (Aquadhere is the trademark of Selleys Pty Ltd).

PVC (Polyvinyl Chloride) — is polymerised from vinyl chloride, usually from ethylene. There are two forms: unplasticised Polyvinyl Chloride (which is hard and rigid) and plasticised Polyvinyl Chloride (which is flexible due to the addition of plasticisers).

- Unplasticised Polyvinyl Chloride is used in electrical conduit, plumbing pipes, clear cordial and fruit juice bottles, bandaids. It is hard, rigid and clear.
- Plasticised Polyvinyl Chloride is used in plastic wrap, garden hoses, shoe soles, cables, watch straps, blood bags and tubing. It is flexible, clear and elastic.

Dacron — lightweight and sheer because of the strength of the yarn. Dacron does not absorb much moisture and therefore will dry quickly.

Lycra — contains elastane fibres which produces high-stretch fabric. Therefore it is used in stretch garments such as stockings and swim wear.

As part of meeting the requirements of the course, you are expected to have made play-dough and slime as examples of natural and synthetic polymers.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research and present information on the properties and uses of specialised polymers such as kevlar/spectra fibres and saran wrap.

As a result of an increase in understanding of the structures of substances and how structure is related to properties, scientists can now develop specialised polymers to replace metals, plastics and glass in a number of products. Developments in polymer science also include polymers to replace human tissues in the body, as well as some of the strongest and most resilient polymers yet developed, such as kevlar and spectra fibres.

Kevlar fibres (poly-paraphenylene terephthalamide) — invented in 1965 and originally intended for use in tyres. Kevlar is a liquid polymer that can be spun with other substances and woven into cloth to give very high-tensile strength. It is used in bullet-proof vests.

Spectra fibres — as a competitor to kevlar, spectra fibres were invented in 1989 and originally intended for use in sails. The fibre is made from polyethylene and is a lighter, stronger non-woven material. Spectra fibres are also used in bullet-proof vests.

Saran wrap — is PVDC (polyvinylidene chloride) polymerised from a mixture of vinyl chloride and vinylidene chloride. The molecules are bound so tightly together that very little gas or water can get through. Therefore, PVDC provides a high degree of protection from moisture and is resistant to oils, greases, oxygen, water, acids, bases and solvents. Saran wrap is used as a barrier to protect food, consumer and industrial products.

See: http://www.inventors.about.com/science/inventors/library/inventors/blsaranwrap.htm

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the commonplace uses of synthetic polymers such as paints, fabrics and textiles, synthetic rubber, insulating materials, adhesives, nail polish, industrial foams, packaging or bullet-proof vests.

Synthetic rubber has special properties which make it resistant to petrol, oil, sunlight and air (natural rubber is harmed by these things). It is used in a wide range of products including car parts, gloves, bathing suits and goggles. General purpose synthetic rubber is a styrene, that is, a butadiene polymer. Butadiene is a gas made from petroleum. Styrene is a liquid made from coal tar or petroleum. Special purpose synthetic rubbers include butyl neoprene and polyurethane rubbers.

Insulating materials are used as thermal (heat) insulators and electrical insulators. Ceramic materials used as electrical insulators (do not conduct electricity) are made from aluminium and porcelain.

Packaging is used in a wide range of applications such as PET bottles (rigid plastics) and cling wraps and bags (flexible plastics). See also page 140.

Coal, petroleum, natural gas and polymers

The products of oil refining (petrochemicals) and extracts from coal and natural gas are used in the manufacture of most synthetic polymers.

Oil is a limited resource. It will eventually run out. Known global fossil fuels are expected to run dry in 80 years, natural gas in 70 years and coal in 700 years. As oil reserves decline there will be increasing pressure to either find new polymers to replace synthetic ones or return to natural polymers.

Biotechnologists are currently researching ways in which living things such as bacteria can be used and even genetically engineered to produce new types of polymers that do not rely on petrochemicals. Plant-derived polymers are also being developed by converting sugars into plastics, producing plastic inside microorganisms, and growing plastics in corn and other crops.

See: Gergross T.U. & Slater S.C. (2000) 'How green are green plastics?' *Scientific American*, August, pp. 25–29 or www.sciam.com .

Plastics

Plastics are one of the main products of the polymer industry. Other products are synthetic fibres and synthetic rubbers. The plastics industry underwent massive expansion after World War II. Up until then, materials such as polystyrene, PVC, PET and PVA did not exist on a global scale.

> Plastics are synthetic polymers that can be moulded and shaped. The word plastic comes from the Greek word *plastikos* which means 'able to be shaped'.

The technology for making plastics has developed rapidly, particularly with the rapid expansion in the computer industry which has created a demand for new types of polymers. Plastics are usually mixtures that contain a polymer and additives such as dyes, reinforcers and fillers (which increase their volume) to give the plastic desirable characteristics.

> The way polymer chains are arranged affects the way a plastic behaves when it is heated. Plastics can either be:
>
> - **Thermoset** — which is hardened permanently by heat. Thermosetting or cross-linked polymer plastics contain polymer chains which are linked together to form a strong network. Thermoset plastics are moulded when they are first made and then hardened. They cannot be softened again by heating. Thermosetting plastics are strong, rigid and more durable than thermoplastics and will not melt under extreme heat. Examples are polyurethane, melamine and epoxy glue.
> - **Thermoplastic** — which is softened by heat and hardened by cooling. The polymer chains are arranged side by side with no links between them. Therefore, thermoplastic melts when heated and sets again when the temperature falls. Thermoplastics can be reformed again and again. Examples are PVC, polystyrene, polypropylene and cellulose-based plastics.

The properties of plastics

Plastic is a versatile material. Plastics:

- Are elastic (easily moulded and shaped)
- Have low density which means they are lightweight
- Are durable — they do not shatter easily
- Do not rot or rust — because they are synthetic, they are less likely to be attacked by decomposers and other living things, such as insects. This means that they last a long time.

The versatility of plastics is further enhanced by including additives in the production process.

> Additives are incorporated in plastic resins to modify their properties for use in a greater range of products. For example, high strength plastics can be made by adding glass fibres (to make fibreglass). This reinforces the plastic and keeps thermoplastics from deforming at high temperatures.

Other examples of additives include:

- Stabilisers are added to help slow down the degrading effects of sunlight and high temperatures.
- Plasticisers are added to make the plastic lighter and more pliable (flexible). For example, PVC is normally hard but is softened by plasticisers to make a huge range of products including raincoats and food wrap. Gas or air injected into the plastic provides a lightweight property and good heat insulation.
- Fire-retardants such as chlorine and bromine are added to plastics for use in products such as sleeping bag covers, paints and clothing.

> As part of meeting the requirements of the course, you are expected to have carried out an experiment to identify the effect of temperature and dye on different polymers.

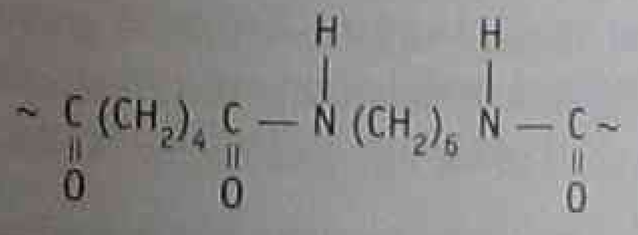
Some polymers are heat resistant. Others soften and melt at certain temperatures. For example, cotton, flax, silk and wool do not melt easily. Cotton can be ironed at higher temperatures than silk or wool. Acrylics, polyesters and nylons soften when heated and generally cannot be safely ironed.

Some polymers are easily dyeable, for example, polyester fabrics. Others are resistant to dyes (and stains). See page 139.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to identify chemicals that are used in the manufacture of plastics. Some ideas are provided below. (See also page 140.)

Bakelite, the first completely synthetic plastic, is made up of phenol (C_6H_5OH) and formaldehyde (HCHO).

Three more examples are provided below. They may not be the same as the ones you have studied.



$$\sim \underset{\underset{O}{\|}}{C}(CH_2)_4\underset{\underset{O}{\|}}{C} - \overset{\overset{H}{|}}{N}(CH_2)_6\overset{\overset{H}{|}}{N} - \underset{\underset{O}{\|}}{C}\sim$$

Figure 8.4 Nylon-6,6 — a polyamide

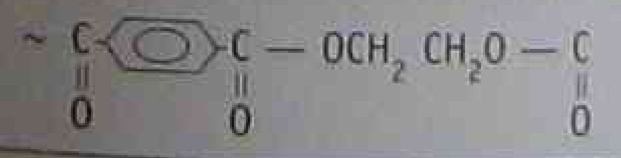
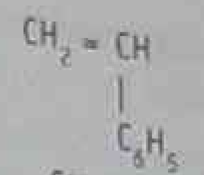


Figure 8.5 Dacron — a polyester



$$\underset{\underset{C_6H_5}{|}}{CH_2 = CH}$$

Styrene

Figure 8.6 Polystyrene. Styrene is made up of benzene and ethylene.

The impact of plastics on society

It is easy to assess the impact of plastics on society. We only have to look at how much plastic humans use in day-to-day living to realise how many developments in technology have been made possible by the synthesis of plastic materials — cars, buildings, furnishings, electrical components and products, air and space travel, packaging, clothing, computer components, cookware, biomedical materials and devices such as artificial limbs.

Plastic packaging is convenient and provides for hygienic handling of food. It minimises spoilage, makes handling and storage easier, holds labels and minimises tampering with the product.

New forms of plastic called 'smart' plastics are now being developed and will impact further on society, particularly in terms of new possibilities for technology (including new lightweight batteries, new current-carrying systems in computers, new biomedical materials, new monitoring processes for industry). These plastics can conduct electricity and respond to or initiate changes in their environment — such as detecting chemical compounds or contracting and expanding in response to small electrical stimuli.

Reference: *Australasian Science*, September 1999, pp. 38–39.

Plastics have also created problems, including the following:

- Most plastics are non-biodegradable and not easily recycled (see page 144).
- Plastics manufacturing involves a range of highly toxic substances that must be stored, handled and disposed of safely.
- Traditional plastics manufacturing requires enormous amounts of energy (supplied by fossil fuels) for the production and transportation of raw materials, products and wastes. Very high temperatures are required in the polymerisation process.

- Plastics manufacturing also requires very large quantities of water.
- The polymerisation process can sometimes result in explosions if not monitored properly. It also produces toxic fumes. Legislation requires that fumes are captured and cleaned before release into the environment. Plastics manufacturing is now often carried out in developing countries where environmental controls are not as strict. This raises concerns about the environmental and societal impacts of these industries on developing countries.
- The foaming process in producing polystyrene foam (Styrofoam) uses chloroflurocarbons — CFCs. When CFCs are released into the atmosphere they contribute to the depletion of the ozone layer — the layer that protects the Earth from harmful UV rays. The depletion of the ozone layer contributes to global warming. The research into ways of reducing CFCs and alternative foaming agents, such as pressurised carbon dioxide, continues.
- There are medical and environmental concerns about the impact of synthetic material (materials that have never existed before) on human health and the health of other living things. For example, plasticisers are added to PVC to make it flexible. It can then be used in products such as food wrap. The plasticisers are organic and inorganic esters which can leach out of the product and be absorbed from the plastic wrap into hot and fatty foods. There is concern that exposure to these chemicals may contribute to diseases such as cancer. For example, the plasticiser phthalate has been identified as a hormone disrupter. Hormone disrupters are linked with a decrease in sperm count and breast, testicular and bladder cancer.
- The breakdown of biodegradable plastics releases carbon dioxide and methane (greenhouse gases) into the atmosphere.
- There are concerns that chemicals formerly used in the manufacturing of plastics and subsequently banned are on-going sources of pollution. For example:
  - Chlorine, which is used in plastics such as PVC pipes, bonds readily with organic matter to form organochlorines. Organochlorines are a group of chemicals that are fat soluble rather than water soluble and very stable. Therefore they stay in the environment for a very long time and increase in concentration up the food chain (see page 78).
  - Polychlorinated biphenyls (PCBs) were once imported for use in electrical transformers. They are now classified as an established cancer-causing substance and have been prohibited in Australia since 1976. Organochlorines and PCBs have been buried in long-forgotten industrial and farm tips and landfill sites. They continue to be potential sources of soil and water contamination.

Polymers and biodegradability

Micro-organisms are part of the natural environment and their role as decomposers is vital in the ecosystem, particularly in the recycling of nutrients and matter.

The term **biodegradable** is applied to those substances which can be decomposed by micro-organisms.

The relative biodegradability of natural and synthetic polymers

Natural polymers are biodegradable. The cellulose in cotton, for example, is attacked by bacteria as well as fungi. (Protein in wool is food for many insects including beetles, moths and silverfish.) Most synthetic polymers are non-biodegradable. They cannot serve as food for insects such as moth grubs, and in general their resistance to decomposing micro-organisms is high.

As part of meeting the requirements of the course, you are expected to have conducted an investigation to determine the amount of plastic material thrown out per day at school and at home.

Examples of household plastics include plastic bags, food wrap, containers, plastic bottles, lids and meat trays.

The impact of synthetic polymers on the environment

In water — plastic waste is discharged directly into water systems through storm water and is dumped as rubbish at sea. Plastics float in the ocean. They are then washed up onto beaches and create visual pollution. Plastic also causes injury and death to marine animals. The plastic rings on six packs do not break down for ten years and can trap marine animals. Abandoned plastic fishing line is responsible for a large percentage of marine entanglements. Marine animals that feed on jellyfish mistake plastic bags for food. The plastic can obstruct digestive tracts or cause ulcers.

The discharge of waste products, as well as heat pollution from plastics manufacturing, are also sources of water pollution (see page 13).

On land — plastics are increasingly contributing to environmental problems. Most plastic packaging ends up in landfill tips where it does not easily degrade. Landfill requires space, which is becoming an increasingly limited resource, at the same time as society's demands for plastic products increases. Therefore, the disposal of plastic waste has become an increasing problem.

There are additional environmental hazards associated with traditional methods of disposal like landfill and incineration. When burnt in incinerators, some plastics produce large amounts of toxic gases. The use of PVC is discouraged by environmental groups because of concerns about the formation of highly toxic dioxin when producing and incinerating PVC. It has become increasingly difficult to find suitable landfill and incinerator sites acceptable to the community.

The development of a few biodegradable plastics and photodegradable plastics, designed to break down in the sun, represents a small step in solving the problem. However, in most cases the photodegradable plastics are buried deep in landfill where they cannot be reached by sunlight.

See: http://www.epa.nsw.gov.au/waste/ — for the Environment Protection Authority and information on the Industry Waste Reduction Plan for Used Packaging.

Note: It is incorrect to assume that natural polymers do not have any impact on the environment. The cotton industry, for example, is under in-creasing pressure from environmental groups because of ecologically unsustainable and environmentally harmful practices, such as broad-acre pesticide spraying and huge demands on water resources. In many cases, natural polymers are also buried deep in landfill and therefore biodegrade at a slower rate.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the viability of recycling plastics including those with additives such as stabilisers, plasticisers and fire-retardants.

All thermoplastics are theoretically recyclable provided that they have not been contaminated by non-recyclable material such as additives. For example, stabiliser additives add to the non-biodegradability of plastics.

See page 143 for information on additives.

See page 144 for concerns about plasticisers in the environment.

Recycling, downcycling and the uses of recycled plastics

Make sure you understand the difference between reusing, recycling and downcycling (which minimises the amount of packaging and waste products involved in manufacturing and consuming the product). We often reuse plastic but recycled plastic only accounts for a very small portion of the total plastic that forms waste or rubbish. Plastics must be sorted before they can be recycled. For example, a plastic shampoo bottle may have a recyclable bottle and a non-recyclable lid. A plastic product may be recyclable but it does not mean that it is financially viable to do so, or that councils or other agencies are willing or able to do so.

Newer technologies include recycling of plastics and polymer sources based on renewable resources such as plants (see page 142). PET can be recycled and used again, for example, in the manufacture of a synthetic fabric called *Polartec*. Biodegradable plastic bottles are made from a polymer of glucose.

Test answers

Short answer and longer response questions

1. Coal, petroleum and natural gas.

   Coal, petroleum and natural gas are non-renewable resources. They will eventually run out. Therefore, the future production of polymers requires research into alternative sources for the chemicals that make up synthetic polymers, research into how renewable substances such as plant materials can be used to manufacture synthetic polymers, and research on how natural polymers can be used in a range of products currently using synthetic polymers.

2. The material is sensitive to heat and to alkalis such as bleach. The material is probably an acrylic, polyester or nylon material because these soften on heating and therefore cannot be safely ironed or tumble-dried.

3. (a) Polymerisation is a chemical process that involves joining many smaller molecules (monomers) together to form a larger molecule (a polymer).

   (b) The polymerisation process requires enormous amounts of energy and water, involves toxic substances which are potentially damaging to land and water environments if released in an uncontrolled way, and produces large amounts of wastes. The products of polymerisation are mostly non-biodegradable and accumulate as pollutants in land and water environments. See page 145.

4. See table below.

5. (a) Biodegradability (short for biological degradability) — refers to the extent to which a substance is broken down biologically by natural decomposers in the environment, such as bacteria and fungi.

   (b) Polymers can be synthetic (such as plastics) or natural (such as fur or wool). Natural polymers contain substances such as protein and cellulose (substances found in living things), and are therefore biodegradable. Most synthetic polymers are non-biodegradable. Plastic products cause pollution of waterways and end up in landfills. Recycling of plastic products would reduce the amount of plastic material that potentially pollutes the environment and takes up space in landfill.

6. See page 138. You need to mention the variables that you tested (the range of fabrics, and the different tests you carried out), the factors that you kept constant (such as the size of the sample for each material, the length of time that you tested each, and so on) and the safety precautions needed (such as using a fume cupboard for flammability tests).

Polymer	Properties	Uses in society
Wool	Excellent thermal properties (good heat insulator). Flame resistant.	Used in winter for clothing, blankets, carpets.
Polyester	Does not absorb water. Does not absorb oil. Is resistant to many acids.	Used for water-, oil- and acid-resistant finishes.
Polystyrene foam	Lightweight, energy-absorbing, heat insulator.	Used in hot drink cups, protective packaging.
Cotton	Good conductor of heat; will absorb moisture.	Used for clothing in hot climates.

HSC Study Option

9 — Preservatives and Additives

Introduction

You will only review this option if you have studied it. Remember, you only need to study one option for the HSC.

As a result of working through this chapter you will be able to:

- Discuss advances in scientific understanding and technology which have changed the direction of food processing and preservation
- Assess the impact of food processing on society and the environment
- Identify some of the Earth's resources used to make preservatives and additives
- Identify the effects of food poisoning on the human body
- Relate the properties of preservatives and additives to their use.

Consumer products and additives

Many food and cosmetic products contain substances known as additives which are used to improve appearance, stability, quality, consistency, texture and taste, to extend the shelf life, and to prevent foods from spoiling or becoming contaminated. Additives include colouring agents, flavouring and fragrances, preservatives, antioxidants and emulsifiers.

> As part of meeting the requirements of the course, you are expected to have examined a range of food and cosmetic products and recorded the ingredients. Your investigation may have involved studying the labels on a range of products. Some examples are provided below.

Cosmetics generally contain:

- Preservatives — which protect against contamination and prevent decomposition. For example, parabens, quaternary ammonium compounds and alcohols.
- Acids, alkalis, buffers and neutralisers — which control pH and prevent skin irritation. For example, citric acid (lowers the pH), ammonium carbonate and calcium carbonate (buffers and neutralisers).
- Humectants — such as glycerine and propylene glycol, which control moisture content and keep the cosmetic from drying out.
- Calcium silicate — which is used in powders to keep the cosmetic dry.

Lipstick is a mixture of oil and wax with dye, flavouring and perfume. The oils include olive, mineral, sesame and castor oil. The wax is often beeswax.

Instant soy drink powder contains soy extract, sucrose, minerals (calcium phosphate, calcium carbonate, zinc sulphate, potassium iodide), emulsifier (soya lecithin) and vitamins (riboflavin, vitamin A, thiamin, vitamin B12).

Food preservation techniques

Food chemically decays and biologically decays because of contamination by fungi and moulds, parasites and other disease-causing micro-organisms such as bacteria and viruses.

> The control of microbial populations is necessary to slow down or prevent spoilage and to reduce or eliminate health risks associated with food. In food preservation, the natural decay process is slowed down and micro-organisms are removed, inactivated or killed.

Physical and chemical means of food preservation

Food preservation involves physical and chemical processes that change the conditions so that food is less susceptible to chemical and biological decay.

> **The physical means of food preservation** involve killing or significantly limiting the growth of micro-organisms through canning, freezing, drying, boiling (heating), irradiation, filtration, high pressure and vacuum packing.

Canning — food is cooked inside sealed metal containers. Canning creates sterile conditions inside the can. Canning uses temperatures of >120°C.

Freezing — food is stored at −18°C. Frozen food can be stored for up to a year at −18°C.

Drying — is probably the oldest method of preserving food. Drying removes the moisture from food by applying heat (sun drying, air drying). Drying is used for foods such as fruits, grains, milk, soup and fish.

Boiling (heating) — heating methods using temperatures above 60°C include sterilisation and pasteurisation. At temperatures above 60°C, micro-organisms begin to lose their viability. Sterilisation kills micro-organisms and sterilises the food. Heat treatment is used to extend the shelf life of food from a few days (such as milk) to a few weeks (such as orange juice). Food is heated at 65°C for 30 minutes or 80°C for 5 seconds.

Irradiation — the treatment of fresh food with ionising radiation is called irradiation. The high energy ionising radiation kills insects, disease-causing micro-organisms, fungi and moulds, without raising the temperature of the food, thereby significantly minimising the physical or chemical effects on the product. The food retains its nutritional value and quality.

Vacuum packing — oxygen is removed from packaging. A high-powered pump creates the vacuum.

> Chemical food preservation involves the use of chemicals to kill micro-organisms. Salts of nitrates, nitrites and sulfites are commonly used in chemical preservation. More recent chemical preservatives include sugar and sodium metabisulfate.

Nitrates and nitrites — sodium nitrate and sodium nitrite are used in curing meats to develop and stabilise the pink colour. Sodium nitrite possibly interferes with iron metabolism in the microbial cell.

Sulfites — used in fruit juice, wine, dehydrated vegetables and dried fruits. Sulfites disrupt many metabolic processes in microbial cells.

> As part of meeting the requirements of the course, you are expected to have carried out an investigation to compare the effectiveness of different physical and chemical means of preservation.

Using the same type and amount of a food, such as a meat or vegetable, treat it with a number of food preservation techniques (refrigeration, boiling, salting, freezing or drying) and determine how well and for how long the food is preserved. Alternatively, obtain samples of the same type of food which have been preserved using different physical and chemical means (such as beef jerky, beef in cans, salted beef, freeze-dried beef). Keep the foods under controlled conditions for a period of time and observe/record how well each keeps.

For a note on controlled experiments, see page 12. Note also safety precautions if handling decaying foods.

> As part of meeting the requirements of the course, you are expected to have carried out an experiment to compare the solubility of sodium nitrate, sodium nitrite and sodium sulfite, relating their solubility to their role as food preservatives in cured meats.

Sodium is a highly reactive element. Sodium salts generally are highly soluble, a property which makes them useful as a food preservative.

Shelf life, texture, appearance and flavour

Foods spoiled by biological or chemical decay do not look, taste or smell fresh. The processes involved in manufacturing and preserving food can also change the look and taste of the product.

> Preservatives and additives are introduced that are specifically designed to make foods easy to buy, safe to use, and attractive to the consumer. Some additives serve a number of functions. Legislation exists to approve the type and amount of additives used in foods (see page 156).

Shelf life — sodium benzoate and sorbic acid slow down the growth of moulds on cheeses and margarine. Antioxidants such as citric acid stop oily foods from going rancid. Common preservatives include benzoic, sorbic, propionic acids and sulfur dioxide. Common preservatives are usually weak acids or salts of weak acids.

Texture — emulsifiers, stabilisers and thickeners give or maintain the desired texture, consistency and thickness, that is, they keep a mixture smooth and uniform. Examples of stabilisers include vegetable gum and gelatin in ice cream, and pectin which is added to jellies and jams. Emulsifiers help to form stable emulsions. Lecithin, a naturally occurring emulsifier, is used in mayonnaise to prevent it separating into two layers. Lecithin is also used in milk chocolate and powdered milk.

Appearance and flavour — a number of additives are used to make food more attractive.

- **Colouring agents** can be natural such as cochineal, saffron and carotene or artificial, such as tartrazine (yellow). Artificial or synthetic colours are controversial because some colours once permitted in foods have been shown to cause cancer in laboratory animals.
- **Humectants** such as glycerine retain moisture.
- **Anti-caking agents** such as calcium silicate prevent lumping and caking. Anti-caking agents are used in powdered foods such as salt and cake mixes to keep them free flowing.
- **Bleaching agents** are used to make some products such as flour look whiter.
- **Flavouring agents** — nitrates and nitrites preserve flavour and colour in processed meats such as ham and bacon. Vitamins and minerals

are added to enhance marketability and replace nutrients lost in processing. Artificial sweeteners are used to provide sweetness as well as body and texture. Saccharin and cyclamate are common artificial sweeteners.

- **Ascorbic acid** prevents canned and frozen food from discolouring.
- **Calcium chloride** is added to canned tomatoes to increase firmness and stabilise their structure during processing.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to compare the ingredients and flow of table salt and cooking salt, and related this to the addition of free-flowing agents.

Anti-caking agents are added to provide free-flowing characteristics. Some foods, such as salt, can absorb moisture, particularly if they are finely granulated. Therefore table salt and cooking salt will usually contain anti-caking agents (such as free flowing agent 554) to prevent lumping.

As part of meeting the requirements of the course, you are expected to have used secondary sources to present information on preservation techniques used by different cultures. Some ideas are provided below.

- Sun-drying is used in areas with abundant sunlight.
- In Japan, soya beans are fermented to make products such as soya sauce and miso (a salty soya bean paste). Tofu, soya bean curd, is made by curdling soya milk. Vegetables are pickled in salt or rice bran. Small fish, seaweeds and mushrooms are among the many products preserved by drying.
- In China, fish and shellfish are preserved by salting, drying or making into pastes such as shrimp paste. Vegetables such as cabbages and turnips are pickled. Meats, such as duck and bacon joints are preserved by smoking. 'Hundred-year-old eggs', a Chinese delicacy, are made by covering eggs in a lime-clay-hay (alkaline) mixture.

As part of meeting the requirements of the course, you are expected to have used natural food colourings to dye eggs, icings and home-made playdough.

Natural food colourings such as cochineal can be purchased, or natural colouring can be made from plant material such as red cabbage.

Microbial activity and food spoilage

Microbial activity refers to the activity of micro-organisms or microbes, such as bacteria, moulds and fungi.

Common microbes that cause spoilage of food include:

Campylobacter bacteria — often transmitted in raw milk and raw meat such as poultry and shellfish.

Clostridium bacteria — found in canned, low-acid vegetables, smoked or pickled meat and high-moisture cheeses. *C. botulinum* spores can grow in aerobic conditions (without air).

Escherichia coli (E. coli) — is a bacteria commonly found in the intestines of mammals. *E. coli* has a high tolerance to acids and can therefore survive in acidic foods such as apple juice and yogurt. It is mainly transmitted from cattle (in undercooked meat such as minced beef and hamburgers).

Salmonella bacteria — largely transmitted in eggs and raw or undercooked meat, particularly chicken.

Some virus strains can also be transmitted in food. A 1997 Hepatitis A outbreak in NSW was associated with oysters.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the causes, symptoms of and treatments for food poisoning.

Illness from food-borne disease can result from either:

(a) A bacterial infection — the pathogen from contaminated food, such as campylobacter, salmonella, some strains of *E. coli*, or shigella, grows in the body, or

(b) The pathogen grows on food and releases toxins that cause illness when eaten. Common causes are *Clostridium botulinum*. Some strains of *E. coli* produce toxins that damage the lining of the blood vessels. A newly discovered toxin-producing *E. coli* strain caused severe bowel infection and kidney failure in 22 children in Adelaide in 1995. The *E. coli* were consumed in mettwurst sausage.

Cause	Symptoms	Treatment
Bacteria in food, such as campylobacter, listeria, salmonella; comes from uncooked or undercooked foods.	Abdominal pain, vomiting, diarrhoea, fever and dehydration.	Bed rest; drink plenty of fluids; sometimes antibiotics are needed.
Poisons produced by bacteria in food such as staphylococcal bacteria and *Clostridium botulinum*. *Staphylococcus aureus* has high heat tolerance. Sources are human nasal passages, throats and hands.	Nausea, vomiting, abdominal pain, low body temperature.	Bed rest; give small amounts of water.
C. botulinum is the most severe form of food poisoning. Approximately 0.01 mg will kill an adult human. Occurs in improperly canned or badly preserved food such as smoked meats. *C. perfingens* occurs in soils and the intestinal tract.	Paralysis, double vision, muscle weakness; sometimes cramps and diarrhoea; difficulty in breathing and swallowing.	Urgent hospitalisation; stomach washed out; support on ventilator and antitoxin administered.

Figure 9.1 Some causes, symptoms and treatments for food poisoning

The factors which determine the rate of micro-organism growth and reproduction include:

- Temperature — see Figure 9.2 below.
- Nutrient availability — the types of micro-organisms that will grow and spoil food depend on the type and amount of nutrients in the food.
- Rate of multiplication — micro-organisms reproduce rapidly under optimal conditions. Under some conditions, the rate of reproduction can be as short as seven minutes. One cell can give rise to millions of cells in 24 hours.
- pH — most food-spoiling bacteria show an optimum growth at pH 7 and therefore do not grow in acid conditions. Foods with low pH (such as tomatoes) do not require as high a temperature or long processing in comparison with foods with less acid.
- Water availability — micro-organisms cannot grow without water. When water is removed few micro-organisms can survive.

As part of meeting the requirements of the course, you are expected to have used first-hand and second-hand information to identify contamination risks in the preparation of food and cosmetics and discuss ways that these risks may be minimised.

Micro-organisms responsible for food spoilage come from various sources such as: microbes in soil, air and water; microbes in plant and animal material; dirty processing equipment; human faecal matter; contaminated ingredients which contain microbes; cross-contamination from other food and packaging materials.

Your investigations may have included attempting to grow agar plate cultures of micro-organisms from food that was prepared in 'sterile' conditions (clean hands and/or clean equipment) and comparing these plates with agar plates containing cultures of micro-organisms grown from food that was prepared in 'non-sterile' conditions (dirty hands and/or dirty equipment). Bacterial colonies can be identified as round, shiny clumps on the agar. Moulds and fungi usually have a furry appearance.

For a note on controlled experiments, see page 12. Note safety procedures when growing micro-organisms — see page 169.

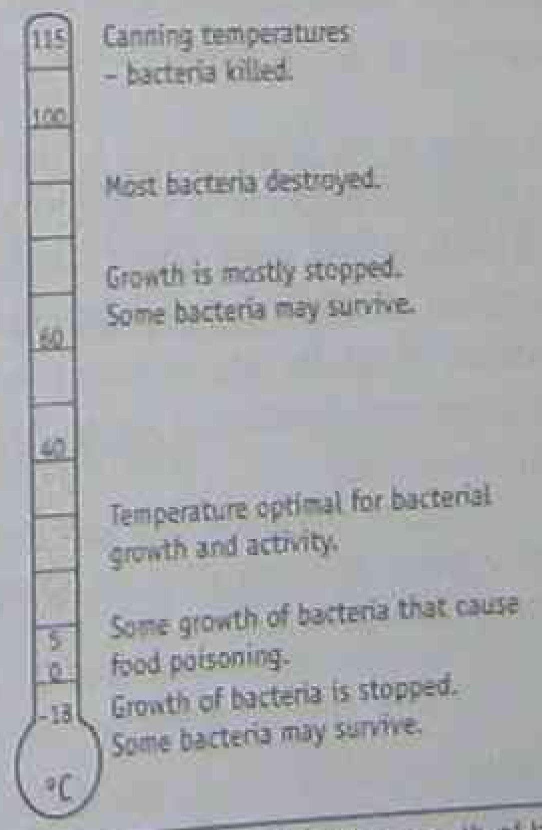


Figure 9.2 Temperature of food and the growth of bacteria

Inhibiting activity by microbes

Some physical methods of preservation include:

Drying — micro-organisms cannot live without moisture. Drying changes the concentration of the food. The amount of water left after drying is usually too low to support the growth of microbes. Provided that the food stays dry, it can be stored for a long time. In most cases, the dried food is also stored in specialised packaging.

Freezing — temperatures are too low for the growth of micro-organisms that are present at the time of freezing.

Refrigeration — keeps food at −1°C to +8°C. This slows down or stops the growth of micro-organisms, but does not necessarily kill micro-organisms.

Pasteurisation — in pasteurisation, the micro-organisms are killed but the food is not sterilised. Therefore, pasteurised food needs to be refrigerated. Foods treated with pasteurisation keep for several months if put into sterilised containers such as cans.

Pickling — involves placing food in solutions of vinegar, a high acid (low pH) environment. Pickling is also combined with physical processes such as canning and boiling.

Salting — removes water from cells through a process called osmosis (see Figure 9.3) and therefore slows down or prevents the growth of micro-organisms (see also page 155).

As part of meeting the requirements of the course, you are expected to have carried out an experiment to model osmosis.

Osmosis refers to the diffusion of a liquid through a semi-permeable membrane to balance the concentration of the liquid on either side of the membrane. The movement of water from a weak solution (low concentration of solute; lots of water) to a strong solution (high concentration of solute; little water) is known as osmosis.

To model osmosis you may have set up equipment as shown in the Figure 9.3.

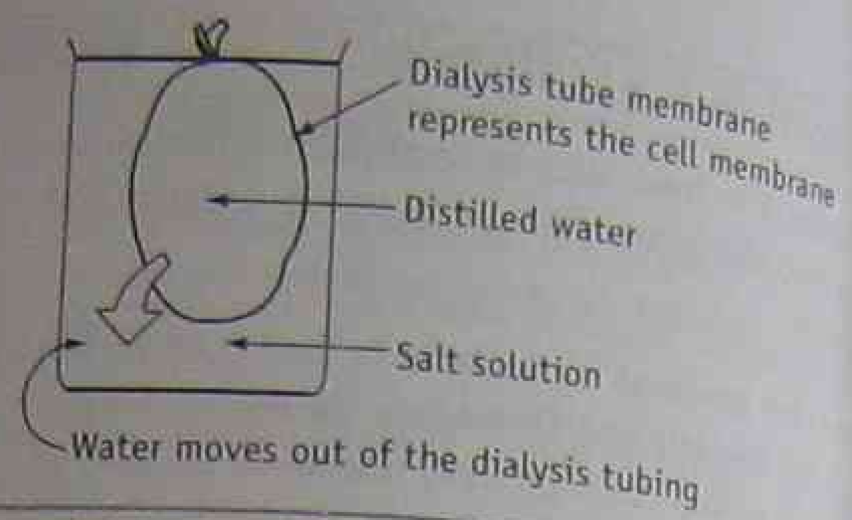


Figure 9.3 An experiment to model osmosis

As part of meeting the requirements of the course, you are expected to have used secondary sources to trace the historical development of our understanding of food spoilage and the need for preservation.

Before the advent of refrigeration and the use of chemical preservatives, people used a variety of methods to prevent food from decomposing. Food preservation techniques like salting, storing food in brine solutions and using vinegar have been used since ancient times. Some early civilisations kept food under snow and in caves where temperatures are lower. In some countries today, food is still stored under snow as a means of preservation.

With the work of Pasteur, Lister and others (see page 167), scientists were able to identify the cause of the decomposition of food — microbes. Once this was known, food preservation techniques began to centre on reducing the activity of these micro-organisms in food to maintain a higher standard of hygiene.

A few key dates are provided below:

- 1809 — food preservation industry began when a French candy maker preserved food in a glass bottle by placing the bottles in boiling water for various lengths of time.
- 1810 — invention of the tin can.
- 1864 — pasteurisation (see Pasteur, page 167).
- 1884 — first mechanical refrigerator.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the discovery of penicillin.

The use of moulds for curing infections and wounds is recorded in ancient Chinese and Greek civilisations and among the Australian Aborigines. However, it was the development of strain isolation methods that eventually led to the first antibiotic — a compound which inhibited the growth of bacteria. The mould that was used to produce the revolutionary drug penicillin is penicillium, a mould that ferments fruit, jam and cheese.

The discovery of penicillin — Fleming discovered that the mould *Penicillium notatum*, accidentally introduced to an agar plate on which colonies of a bacteria were growing, produced an inhibitory effect on the growth of bacteria. Ten years later Florey, Chain and Heatley managed to isolate a stable form of the chemical secreted by the mould and established the effectiveness of penicillin. (Note: Howard Florey was an Australian scientist who received great recognition for his work in this field.)

Penicillin revolutionised ideas about medicine. Before penicillin, it was believed there was no substance that would be powerful enough to kill bacteria cells without also killing human or animal cells. Penicillin was able to specifically attack bacteria cells by attacking the cell walls of the dividing or reproducing bacterium.

As part of meeting the requirements of the course, you are expected to have used secondary information to research the use of ultra high temperatures (UHT) as a preservative technique.

In UHT preservation, food is heated at ultra high temperatures, for example 140°C for two seconds. UHT preservation is used for liquid foods. UHT treated foods can then be stored in sealed containers for several months without refrigeration.

Natural preservatives utilised in cheeses and yogurts

Some food processing methods actually use micro-organisms in order to change the food in such a way that it helps to preserve the food. Non-pathogenic bacteria, yeasts and other fungi ferment foods.

Bacteriocins as natural preservatives

Bacteriocins are chemical compounds produced by a range of micro-organisms which can inhibit the growth of other micro-organisms. Examples include:

- *Lactobacillus acidophilus* and *Streptococcus thermophilus* which are used to preserve milk in a semi-liquid, nutritionally rich form (yoghurt). The production of lactic acid by the bacteria creates an environment that prevents the development of harmful bacteria such as those that cause tuberculosis. *Streptococcus lactis* produces the acid that allows milk curd to settle into buttermilk and some cheeses.
- Meat is cured with salt or brine which stimulates the growth of certain bacteriocins. These bacteriocins prevent the growth of meat-decaying moulds.
- A bacteriocin, nisin, which is used as a preservative in crumpets and pancakes. Nisin disrupts cell membrane function.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to determine the pH of a range of consumer products and, for each product, relate its pH to the possible activity of micro-organisms in the manufacture of that product.

pH is measured using pH indicators such as litmus paper, pH meters or universal indicator. See page 90 for details. Higher acidity in foods can inhibit the growth of micro-organisms and increase shelf-life. Therefore acids, such as phosphoric acid, are added to some foods. Fermentation and some pickling processes encourage the growth of certain micro-organisms which produce acidic conditions, and therefore help to preserve the food.

Test a range of fermented and pickled foods such as yoghurt and sauerkraut. Compare the pH of these foods with non-fermented foods (such as milk with yoghurt) and non-pickled foods (such as raw cabbage with sauerkraut).

Government legislation, labelling and the Australian Food Standards

'Negative labelling'

There is growing concern surrounding:

(a) The ingestion of synthetic chemicals

(b) Food allergies and health risks associated with additives and preservatives

(c) The need for more inclusive labelling of consumer products

(d) The need for labelling to indicate genetically modified foods.

These concerns have initiated new directions in the food and cosmetic industries — the use of non-chemical preservation techniques and the use of natural substances as food preservatives.

Negative labelling is increasingly used as a form of advertising, to appeal to people who want or need (for medical reasons) a diet or cosmetics which are free of certain substances. Negative labelling includes labels such as:

- Contains no additives
- Contains no cholesterol
- Free from preservatives/additives
- No added sugar
- No artificial colouring
- Contains no lanolin
- No MSG
- Has not been tested on animals
- Aluminium free
- Does not contain genetically modified foods.

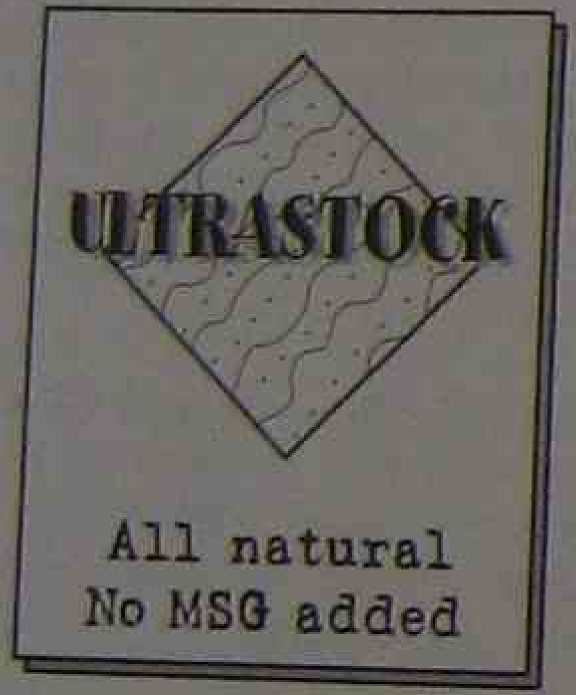


Figure 9.4 An example of advertising using 'negative labelling'.

The use of the words 'juice' and 'drink' as prescribed by the Fruit Juice Standard

The Australian Fruit Juice Standard lays down specific standards for fruit juices. Fruit juices must not contain added water (except concentrated juice that is diluted to its original volume, that is, reconstituted). Fruit juices must not contain more than 4% added sugar unless labelled as 'sweetened'. If the product does not meet these standards, it cannot be labelled as fruit juice.

Australian Food Standards and food labelling

The percentage of chemical preservatives and additives used in prepared food is strictly controlled by law. The Australian Food Standards outlines food producers a general list of standards that have to be adhered to. These standards cover:

- Labelling
- Advertising
- Food additives (shown as codes, see page 157)
- Preserving processes
- Date of making the food.

Australian Food Standards also introduce regulations governing genetically modified foods, with particular attention to toxicity, allergenicity and nutritional values of these foods.

Every label on food offered for sale must include:

1. The name of the food.
2. A list of ingredients.
3. A use-by date.
4. A nutrition information panel — required if certain claims are made for the food.
5. The name and address in Australia of the manufacturer, packer or importer.
6. The food's country of origin or origin of ingredients.
7. Any other information prescribed by the Food Standards Code.

Labels may also be required to list warnings. For example, people with the disease phenylketonuria must be made aware of products containing the artificial sweetener L-phenylalinine, which can cause damage to the central nervous system.

See: http://www.foodstandards.gov.au — the website of the Australian Food Standards, an excellent website for current Australian food standards and codes.

As part of meeting the requirements of the course, you are expected to have used the Australian Food Standards to identify the code for groups of additives and preservatives such as anticaking agents, antioxidants, bleaches, colouring agents, emulsifiers, flavouring agents, humectants, nutrients and sweeteners, and used the code to identify the additives and preservatives in a range of consumer products.

Most direct additives have a code (a numbering system) for their identification. Some examples, from the Australian Standards Food Code, are provided below:

Anti-caking agents have a 500 code, for example:	
• kaolin (anti-caking agent)	559
• calcium silicate (anti-caking agent)	552
Anti-foaming agent	900
Ascorbic acid (antioxidant)	300
Artificial sweeteners, for example:	
• Aspartame (artificial sweetener)	951
• Saccharin (artificial sweetener)	954
Colours, for example:	
• ß-carotene (colouring)	160a
Preservatives have a 200 code, for example:	
• nisin (preservative)	234
• sodium nitrite (preservative)	250
• sodium nitrate (preservative)	251
• sulfur dioxide (preservative)	220
• sorbic acid (preservative)	200
• sodium metabisulfite (preservative)	223
Thickeners have a 1400 code, for example:	
• bleached starch (a thickener)	1403
• oxidised starch (a thickener)	1404
Flavour enhancers have a 600 code, for example	
• maltol (flavour enhancer)	636
Pectin (vegetable gum)	440
Agar (vegetable gum)	406
Calcium oxide (mineral salt)	529
Emulsifiers, for example:	
• glyceryl monostearate	471
• lecithin (emulsifier)	322

See: http://www.anzfa.gov.au for a copy of the Food Additives Shoppers Guide from the Australian and New Zealand Food Authority.

Control and labelling of additives and preservatives

The control and labelling of additives and preservatives is important to:

- Provide a supply of safe food
- Promote fair trading in food nationally and internationally
- Promote consistency of standards
- Provide adequate information for consumers to make informed decisions about nutrition or ingestion of synthetic chemicals
- Provide information that is not misleading.

As part of meeting the requirements of the course, you are expected to have used information from first-hand investigations and secondary sources to identify products which are not allowed to include any preservatives or additives and discuss the reasons for this legislation.

1. Gather a range of products and identify those which are labelled preservative or additive free, including organic foods.
2. See: http://www.foodstandards.gov.au — the Australian Food Standards, as a secondary source of information.

As part of meeting the requirements of the course, you are expected to have used information from first-hand and secondary sources to identify allergic responses to food and cosmetic substances, the cause of the response and the treatments and controls.

Common foods which produce allergic reactions in some people include cow's milk, eggs, peanuts (and other nuts), seafoods, wheat, tomatoes, chocolate and some food additives. For example, monosodium glutamate or MSG (a flavour enhancer) can cause headaches and other allergic reactions; sulfite preservatives can cause allergic reactions in some people; and some people show an intolerance to synthetic food colourings such as tartrazine.

1. Survey a range of people to identify allergic responses to food and cosmetic substances.
2. See: http://www.foodstandards.gov.au — the Australian Food Standards, as a secondary source of information.

Checklist — Key terms for revision

- preservatives and additives
- physical food preservation techniques
- chemical food preservation techniques
- micro-organisms
- microbes
- pH
- emulsifiers
- anti-caking agents
- antioxidants
- colouring agents
- humectants
- flavouring agents
- food spoilage
- campylobacter bacteria
- clostridium bacteria
- *Escherichia coli*
- salmonella bacteria
- moulds and fungi
- food poisoning
- osmosis
- bacteriocins
- food legislation
- Australian Food Standards

Test — Preservatives and additives

Short answer and longer response questions

1. Explain how the physical methods of low-temperature preservation, such as refrigeration and freezing, and high-temperature preservation, such as boiling, inhibit activity by microbes. (2 marks)

2. A report on food poisoning outbreaks in NSW between 1977 and 1984 found the most frequent causes were: *Bacillus cereus* — 39%, salmonella species — 25%, *Staphylococcus aureus* — 23% and *Clostridium perfingens* — 17%.

   For any two of the causes listed, briefly describe the symptoms of and treatment for food poisoning. (4 marks)

3. In the process of freeze-drying, food is preserved by rapid freezing followed by complete dehydration to remove all moisture. It is then placed in a tightly sealed chamber between hollow plates which contain a refrigerant liquid which freezes the food. A high-powered pump creates a vacuum. The ice in the food is turned directly into vapour without turning back into water. Outline how this method of food preservation inhibits activity by microbes and maintains quality of the food. (4 marks)

4. Briefly explain why preservatives and additives are introduced into food production. Give an example of one preservative and one food additive, and outline what they do. (3 marks)

5. (5 marks)

   If food is in a solution which has a concentration higher than that of solutions in living cells, then water diffuses out of the bodies of micro-organisms present in the food and the micro-organisms die.

   (a) What is the name of the process whereby water moves by diffusion? (1 mark)

   (b) Use diagrams to explain this process. (2 marks)

   (c) Describe a food preservation technique that uses this process. (2 marks)

6. Briefly outline the roles of the following in the Australian food and cosmetic industries: (7 marks)

   (a) Government legislation

   (b) Labelling including 'negative' labelling

   (c) The Australian Food Standards Code.

Test answers

Short answer and longer response questions

1. Low temperature preservation involves cooling food to slow down the rate of biological and chemical change. High temperature preservation above 60°C involves heating food to kill micro-organisms.

2. Salmonella — symptoms are abdominal pain, vomiting, diarrhoea, fever and dehydration. Treatment includes bed rest and drinking lots of fluids.

   Staphylococcus — symptoms are nausea, vomiting, abdominal pain and low body temperature. Treatment includes bed rest and drinking small amounts of water.

   See Figure 9.1, page 153.

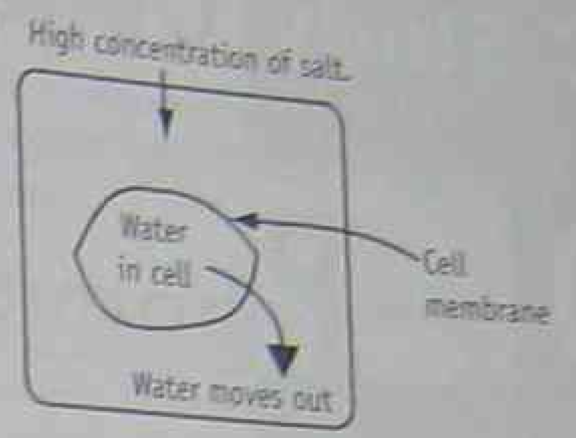
3. Microbial activity is inhibited as a result of low temperatures and lack of oxygen (the food is stored in a vacuum — no air). Freezing normally creates ice crystals which can damage tissue and change the quality of the food when the ice melts. Freeze-drying in which ice is turned directly into vapour without turning back into water, prevents ice crystals from forming.

4. Preservatives and additives are introduced to make foods easy to buy, safe to use and attractive to the consumer.

   - Preservatives include benzoic, sorbic, propionic acids and sulfur dioxide. Common preservatives are usually weak acids or salts of weak acids.
   - Additives include emulsifiers, stabilisers and thickeners which give or maintain the desired texture, consistency and thickness of a food product. An example of a stabiliser is vegetable gum. Lecithin is an emulsifier which helps to form stable emulsions.

5. (a) Osmosis

   (b)



   (c) Salted meat, sugar-crystallised fruit, jams and condensed milk are examples of products in which the process of osmosis is applied.

6. (a) Government legislation outlines to food producers a general list of standards that have to be adhered to (such as advertising and preserving processes), approves the type and amount of additives used in foods, and sets standards for fruit juices.

   (b) Labels provide the consumer with standard information about the product including a list of ingredients, a use-by date, nutritional information and warnings where necessary.

   Negative labelling is used as a form of advertising. Its role is to appeal to people who want or need (for medical reasons) a diet or cosmetics which are free of certain substances such as preservatives, aluminium, additives, and genetically modified foods.

   (c) The Australian Standards Food Code is used so that consumers can identify the additives and preservatives used in a product such as anti-caking agents, antioxidants, artificial colours and flavours. See page 157.

HSC Study Option

10 — Pharmaceuticals

Introduction

You will only review this option if you have studied it. Remember, you only need to study one option for the HSC.

Pharmacology is the study of the way in which the function of living systems is affected by chemicals called drugs. The pharmaceutical industry applies the science and technology of pharmacology. In this chapter you will review a range of natural and synthetic pharmaceutical substances which are effective because they destroy microbes responsible for disease or because they influence the activity of cells, tissues and organs of the body to bring about their effects.

The earliest effective drugs were natural remedies, mostly made from plants. Some of these remedies have been used for centuries. Use of moulds for curing infections and wounds is recorded in ancient Chinese and Greek civilisations and among the Australian Aborigines. Modern methods of drug development enable the extraction, purification and concentration of chemical compounds and the use of computers and genetic engineering in the synthesis of new compounds.

As a result of working through this chapter you will be able to:

— Discuss advances in understanding diseases and their causes which have changed the direction of scientific thinking

— Assess the impacts of applications of pharmacology on society and the environment

— Identify effects of the inflammation response on the human body

— Relate the structure of the nervous and circulatory systems to their function in transporting pharmaceuticals and responding to injury and infection.

The central and peripheral nervous systems

The central nervous system and peripheral nervous system detect and interpret signals from outside and inside the body.

The central nervous system

The central nervous system is made up of the brain and spinal cord.

The peripheral nervous system

The peripheral nervous system is made up of the cranial nerves and spinal nerves. Cranial nerves connect the brain to the sense areas of eyes, ears, nose and mouth. Spinal nerves connect the spinal cord to muscles, skin and the autonomic nervous system. (The autonomic nervous system is the system that controls involuntary actions such as heartbeat.)

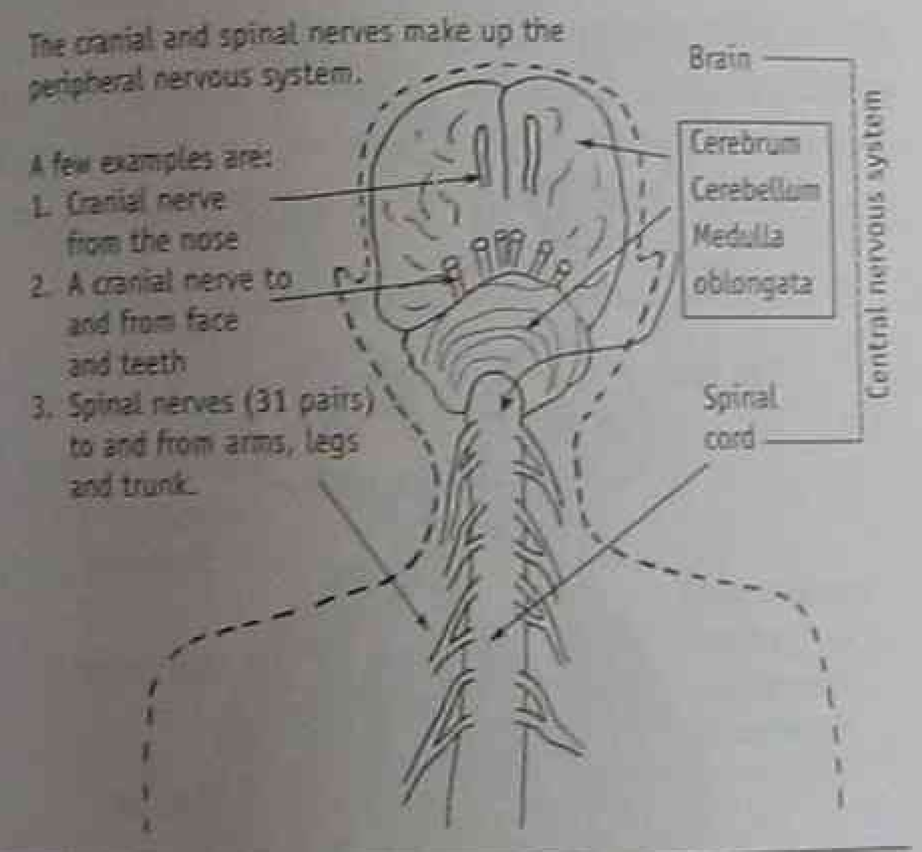


Figure 10.1 (a) The central and peripheral nervous systems in humans

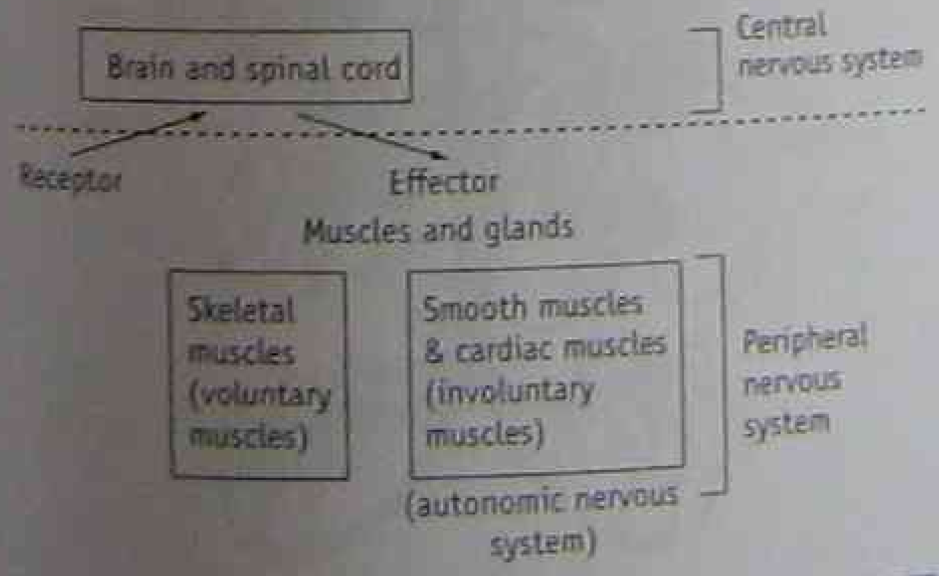


Figure 10.1 (b) The central and peripheral nervous system

As part of meeting the requirements of this course, you are expected to have used secondary sources to name the main components of the nervous system and their functions.

Sense organs

The role of sense organs is to enable the body to detect signals (stimuli) such as light, heat, sound and pressure.

The cells of the nervous system are not all the same. Some cells have the role of detecting changes in the environment. These are called receptors. Receptors detect stimuli. Each type of sense receptor is responsible for detecting a certain type of stimulus — smell, taste, sound, light, cold, heat, and chemicals.

The sense organs are connected to the central nervous system by nerves. Nerves are made up of nerve cells or **neurones**.

The role of neurones

There are three types of neurones:

- The sensory neurones — carry messages to the brain and spinal cord. They connect receptor cells to the central nervous system.
- The motor neurones — carry messages away from the brain and spinal cord.
- The interneurones — are interconnecting neurones which occur in the brain and spinal cord.

Effectors

Nerve impulses (messages) from the central nervous system travel via the motor neurones to muscles and glands which carry out the response. These are called effector organs or effectors.

The reflex arc

A simple nerve pathway by which a message is transmitted to the central nervous system is called a reflex arc. Simple reflexes (responses to stimuli) occur rapidly (see the investigation on page 162). The message is transmitted to the spinal cord and back to the effector before the brain has made a conscious reaction. The same response occurs every time.

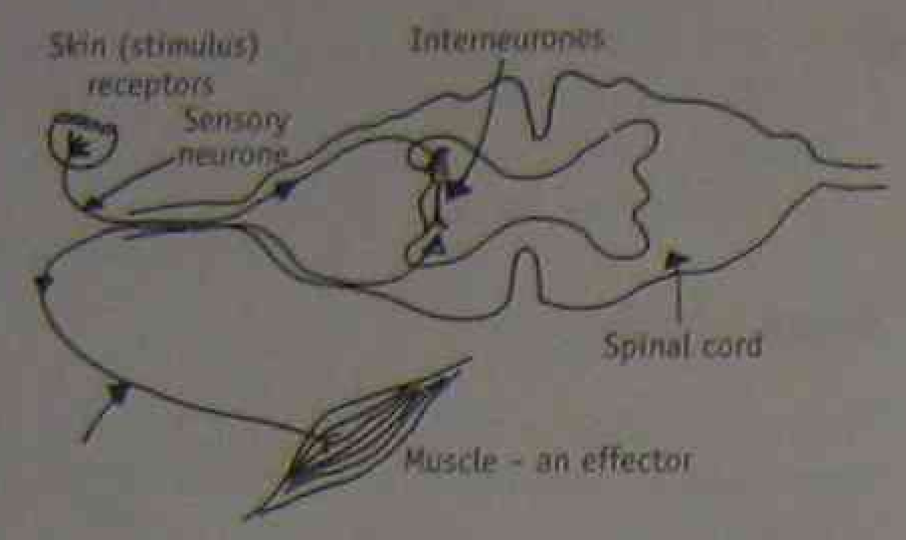


Figure 10.2 A simple reflex arc

The steps involved in the path of the nerve impulse from the stimulus to the muscle are:

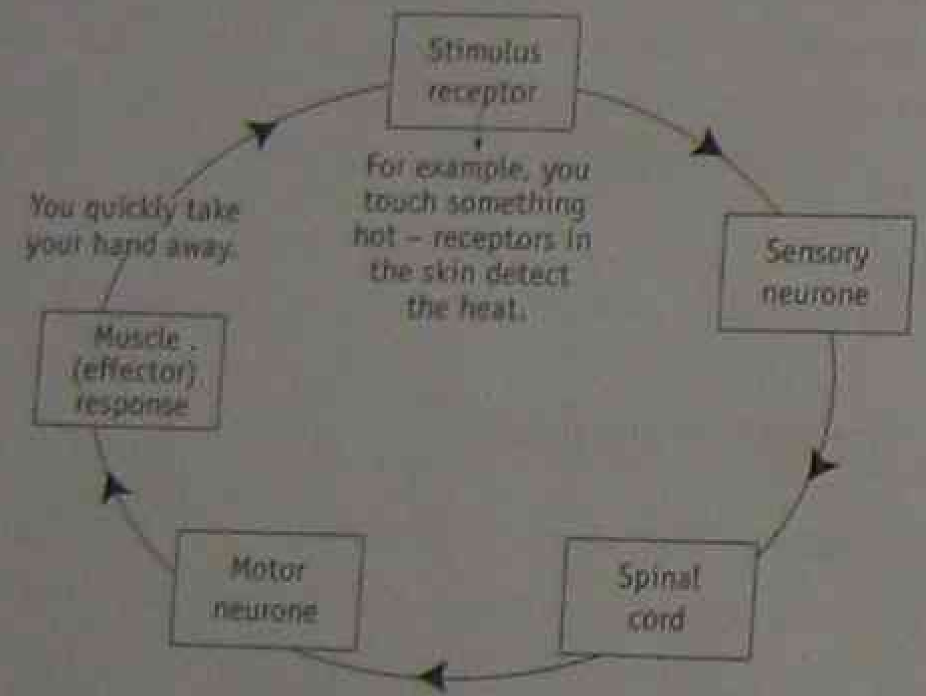


Figure 10.3 Path of the nerve impulse

As part of meeting the requirements of the course, you are expected to have demonstrated the differences in reaction time between a reflex arc and a learned response and relate this to the sequence of events involved.

Time the rate of reflexes such as putting something close to the eye or tapping the tendon below the kneecap.

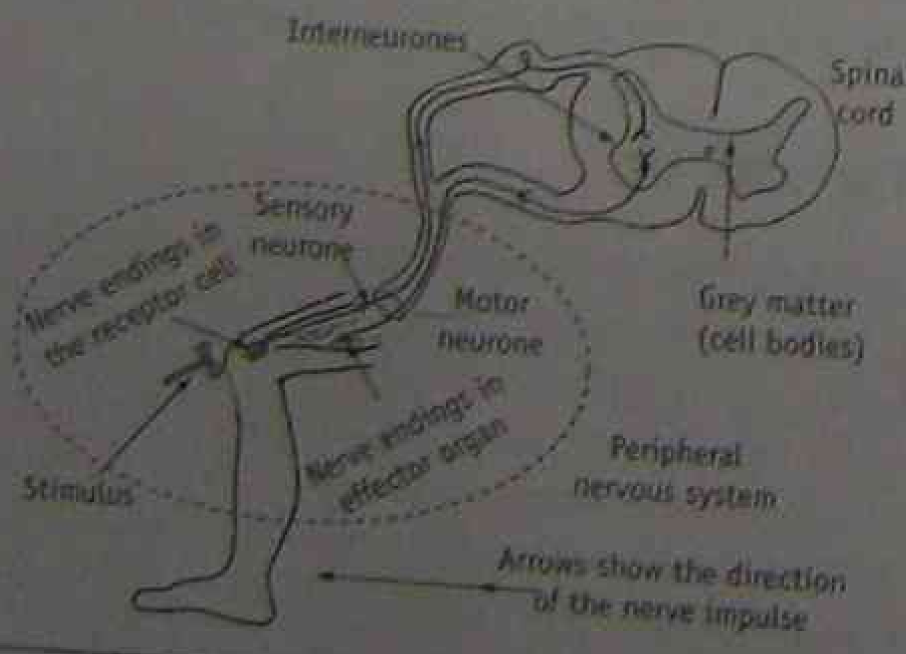


Figure 10.4 Reflexes

Compare the reaction time of a reflex reaction with the time it takes to respond in a new learning situation, such as drawing an object by looking at its reflection in a mirror. The reaction time for a reflex arc is much more rapid than a learned response because in a reflex, the sequence of events is:

receptor ⟶ spinal cord (and then the brain) ⟶ effector

Transmission of a nerve impulse

Nerve impulses travel in one direction only. Neurones are not joined. A nerve impulse travels from one neurone to another through a space called the **synapse**. The nerve impulse is transmitted across the synapse by chemical messengers. The transmission of the nerve impulse across the synapse by a chemical messenger ensures the continuation of the message.

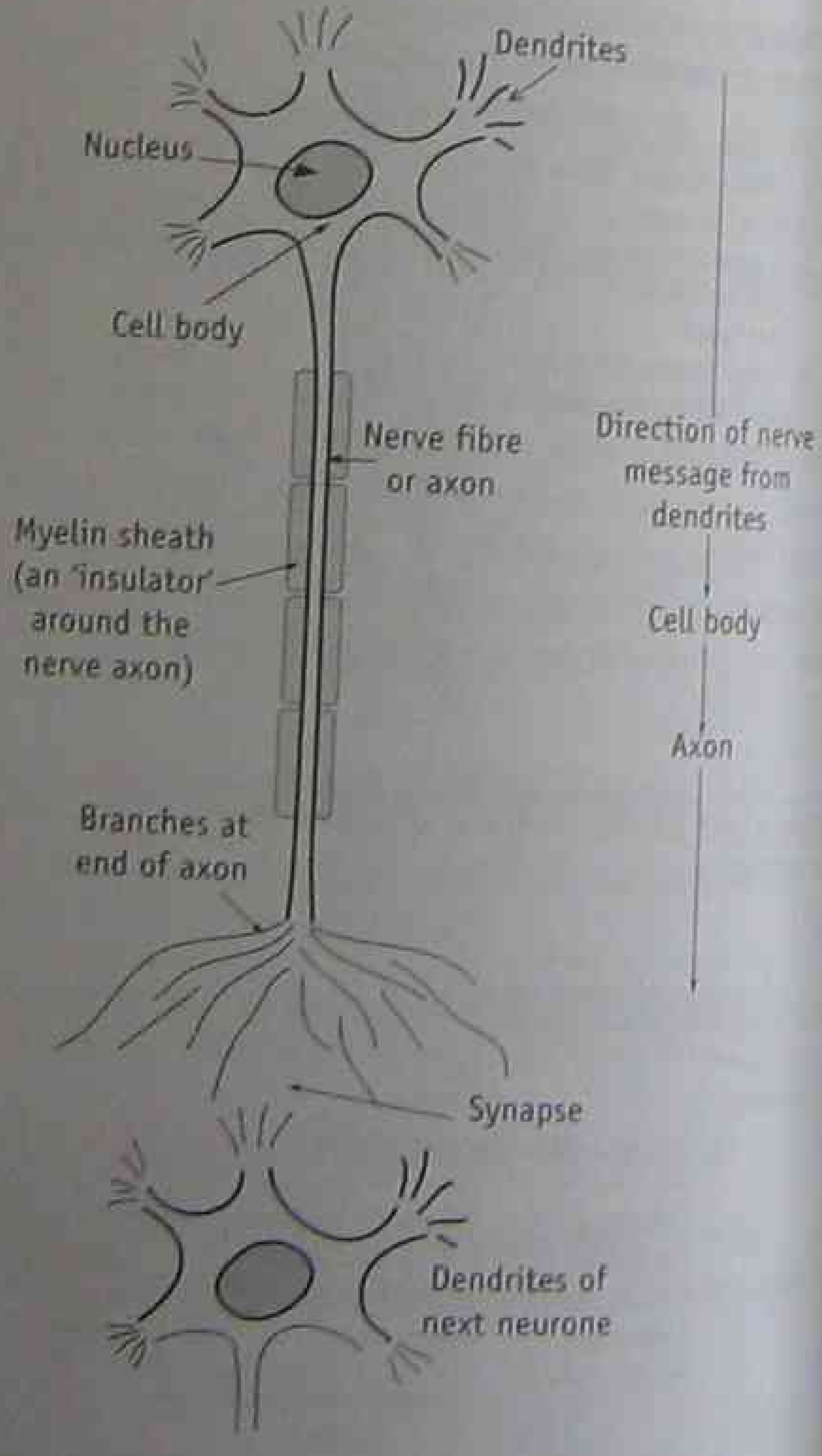


Figure 10.5 The structure of a neurone (nerve cell)

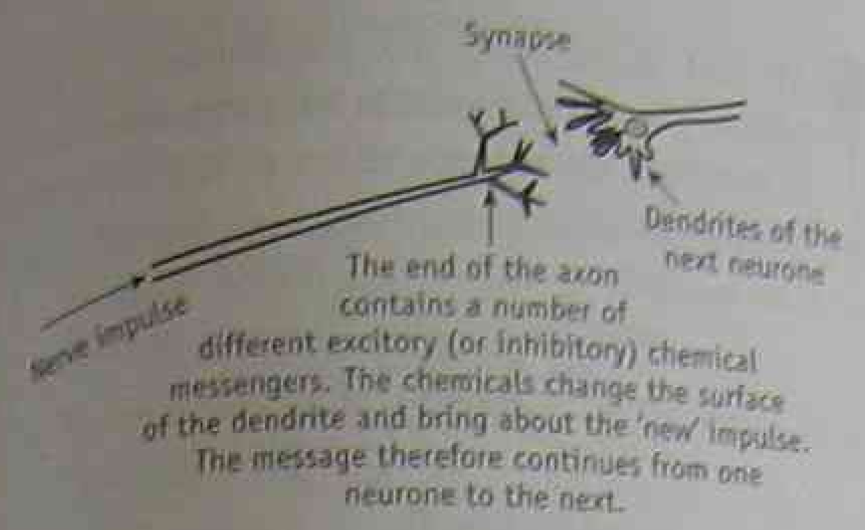


Figure 10.6 Transmission of a message across the synapse. The synapse is important because it selects the impulses that pass through it.

Transporting pharmaceutical substances around the body

The role of the circulatory system

The role of the circulatory system is to transport substances around the body. See pages 105 and 106. The circulatory system is made up of a circulatory fluid (blood), a continuous network of blood vessels and an organ to pump the blood (the heart).

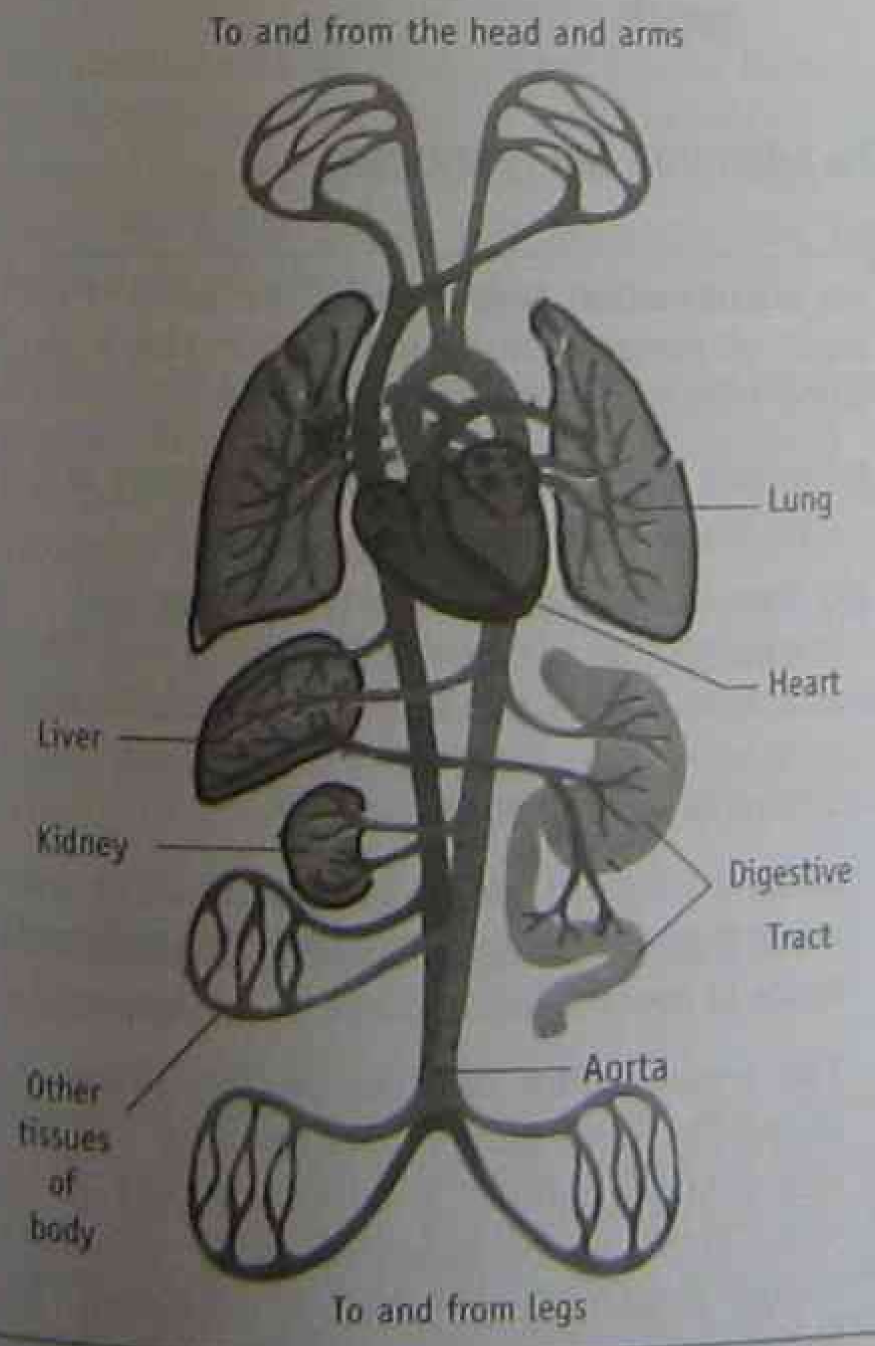


Figure 10.7 A generalised diagram of blood flow

The three main types of blood vessels in the body are **arteries**, **veins** and **capillaries**. Blood is pumped from the heart to the cells through arteries. Veins then carry blood back to the heart. To pass from arteries to cells and from cells to veins, blood must pass through tiny thin-walled blood vessels called capillaries. There are capillaries next to every cell of the body and every entry and exit point of the body. The thinness of capillary walls allows chemicals to diffuse in and out of the blood.

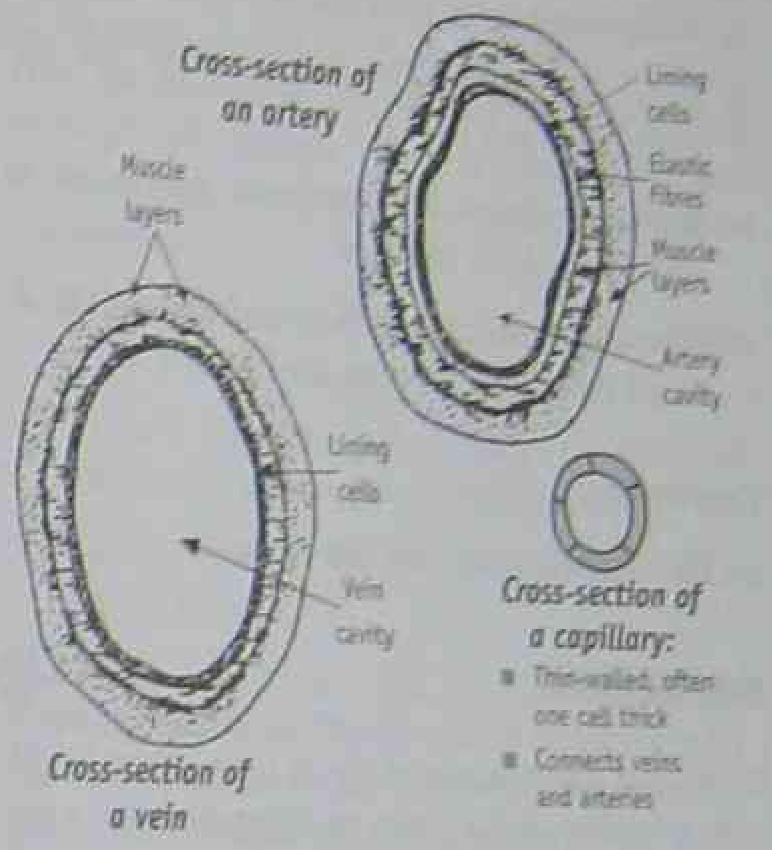


Figure 10.8 An artery, vein and capillary

As part of meeting the requirements of the course, you are expected to have used information from first-hand or secondary sources to describe differences in veins, arteries and capillaries.

Your research may have included a first-hand examination of veins and arteries and/or examination of prepared microscope slides of veins, arteries and capillaries.

Arteries:

- Thick, muscular walls to withstand the high blood pressure near the heart. The internal diameter of an artery is smaller than in veins, therefore the blood-carrying capacity of arteries is lower.
- Carry blood away from the heart
- Carry oxygenated blood (except for the pulmonary artery)

- Blood in arteries is under pressure (it is being pumped)
- No valves present.

Veins:

- Thin walled with a smooth lining and thick, muscular tissue on the outside. The internal diameter of a vein is larger than in arteries, therefore the blood-carrying capacity of veins is higher.
- Carry blood back to the heart
- Carry deoxygenated blood (except for the pulmonary vein)
- Blood is under low pressure. Movement is assisted by body muscles
- Valves are present to prevent back-flow of blood. Blood flows only towards the heart.

Capillaries:

- Thin-walled, often one cell thick.

Human blood

Blood is a mixture of red blood cells, white blood cells, platelets and a range of substances (such as oxygen, water, salts, lipids, nitrogenous wastes and other products of digestion) carried in a fluid called plasma.

The role of white blood cells includes:

- Identification of tissue damage
- Fighting disease by secreting substances that directly destroy particles that are foreign to the body or by secreting antibodies that combine with or neutralise the foreign substance or organism
- Disposing of dead cells and some micro-organisms by engulfing and destroying them.

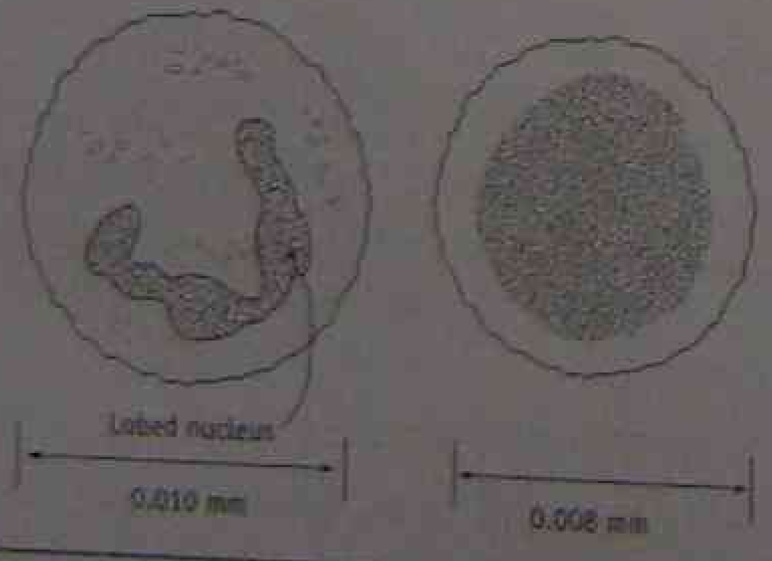


Figure 10.9 White blood cells

As part of meeting the requirements of the course, you are expected to have observed blood in prepared microscope slides to identify white blood cells.

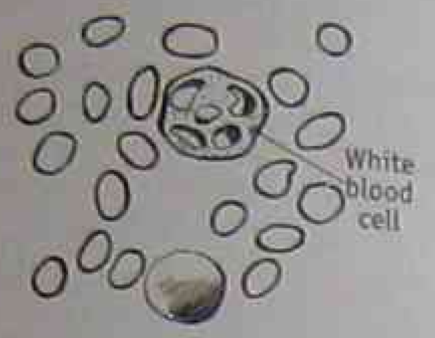


Figure 10.10 A diagram of a microscopic view of blood showing a white blood cell

The advantage of using the circulatory system to transport pharmaceuticals around the body

> The circulatory system provides a very fast, long distance, bulk flow distribution of pharmaceuticals (drugs) around the body and to every cell.

How some pharmaceuticals work

The inflammation response

> An **inflammation response** by the body is the result of complex reactions in the blood and blood vessels that are coordinated to:
>
> (a) Isolate and destroy harmful substances and pathogens, and
>
> (b) Prepare the body's tissue for healing and regeneration.

An inflammation response includes:

- Dilation of small blood vessels to allow more blood flow to the injured tissue. This causes the tissue to become hot and red.
- The accumulation of fluid in the tissue. An increase in fluids immobilises the area. The fluid also contains protein and special cells (white blood cells) which help the body to destroy foreign substances and foreign organisms. The build up of fluid causes swelling and pain.

Inflammation can be caused by:

- Injury, such as cuts, bruises, splinters and sprains
- Infection by organisms such as fungi and bacteria, which can result in diseases such as sinusitis, colds and flus, bronchitis
- Trauma associated with injury or repetitive strain (see page 63)
- Environmental conditions such as presence of allergens (for example, dust and pollen).

As part of meeting the requirements of the course, you are expected to have used secondary sources to draw diagrams showing the inflammation response.

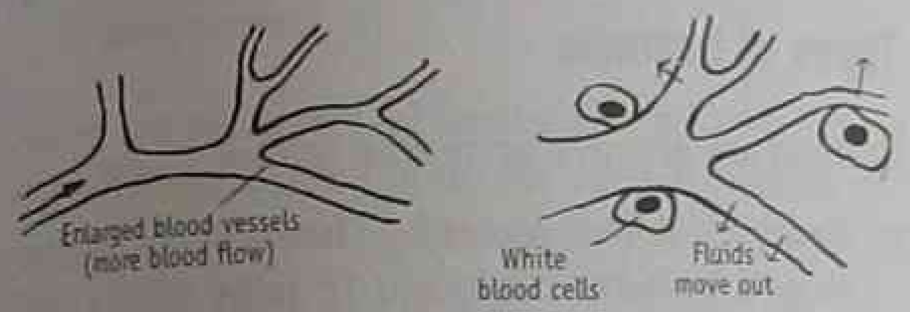


Figure 10.11 Diagrammatic representations of the inflammation response. Small blood vessels become enlarged (dilated), causing more blood to flow to the area. This causes redness.

The permeability of small blood vessels increases. Fluids move out of the small blood vessels into the damaged tissues. A fluid containing proteins and blood cells accumulates. This causes swelling. Pain results from pressure.

White blood cells become attracted to the damaged tissues. These cells release chemicals such as histamine and prostaglandins, which promote the process of inflammation.

Blood flow increases, raising the temperature of the tissue. The tissue feels hot. If a large or significant area is involved, then the person's body temperature rises.

The advantages and disadvantages of inflammation

Inflammation is essential to isolate and destroy foreign particles and prepare the tissue for healing, but it can also cause tissue damage and loss of normal tissue function. For example, inappropriate immune and inflammatory responses by the body are involved in diseases such as arthritis and allergies. In an allergic response, the body's immune system overreacts and produces the inflammation reaction which can damage the tissue. The development of drugs to control these processes is a major concern of the pharmaceutical industry.

Prostaglandins and the inflammation response

Prostaglandins are a group of substances produced by almost all tissues and cells. They have a number of functions including changing blood pressure. They are released in trauma and shock and other types of cell damage. When a tissue is injured, substances such as prostaglandins (and histamine) are released to:

- Dilate the blood vessels and increase blood flow to the area
- Increase vascular permeability so that substances can move out of blood vessels
- Stimulate white blood cell migration to the injured area.

> Prostaglandins are thought to be responsible for the pain and fever that goes with inflammation. The pain results from the pressure of fluids accumulating in the damaged tissue. The substances secreted by the injured tissue also irritate nerve endings.

Pain

> Pain is an interpretation by the brain of messages from nerves sent across synapses from the injury site to the brain.

The awareness of pain is a highly important sensory function. Pain receptors respond to mechanical, heat and chemical stimuli.

Pharmaceuticals or drugs are chemical compounds which modify the body's natural chemical responses.

> Analgesics are a group of pharmaceuticals commonly called 'pain killers'. The principal ingredient in the pain killer aspirin is acetyl salicylic acid (see page 166).

It is thought that aspirin relieves pain by inhibiting the signal crossing the synapse. Aspirin relieves the pain associated with swelling by inhibiting the production of certain chemicals, such as prostaglandins.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the history of the development of aspirin, including a timeline of events, and information on the original source of the chemical.

The compound from which the active ingredient in aspirin is derived was found in the bark of a willow tree — *Salix alba* — in 1763 in England. The compound in the bark is called salicin.

Time line of events:

- 1763 — salicin was discovered and used for pain relief.
- Early 1800s — scientists extracted salicylic acid from salicin and devised a method for producing the compound synthetically.
- 1853 — a primitive form of aspirin was developed. Salicylic acid burned the throat and upset the stomach.
- 1897 — a chemist working for the Bayer company discovered a better method for synthesising aspirin which reduced the side effects on the throat and stomach.
- 1899 — Bayer marketed aspirin.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to determine the rate of solubility of a range of analgesics and to relate their solubility to their dispensing form — soluble, enteric-coated or capsule.

Compare the solubility of soluble aspro, disprin capsules and duenteric-coated low-dose aspirin. An enteric coating prevents the aspirin from being dissolved and released in the stomach. The aspirin is released in the small intestine where it is absorbed slowly into the bloodstream.

1. Dissolve each in 10 mL water (compare water at room temperature and at 37°C).
2. Record if the tablet dissolves and how long it takes to dissolve.
3. Dissolve each in 10 mL dilute hydrochloric acid.
4. Record if the tablet dissolves and how long it takes to dissolve.
5. Dissolve each in 10 mL dilute sodium hydroxide (an alkaline solution).
6. Record if the tablet dissolves and how long it takes to dissolve.

See Chapter 5, pages 96 and 97.

Penicillin and its role in fighting bacteria

Types of bacteria

Bacteria are grouped according to their shape.

- Cocci — sphere-shaped. The cells of sphere-shaped bacteria can occur in pairs (diplococci) or as chain-like structures (streptococci).
- Bacilli — rod-shaped.
- Spirilla — twisted or spiral-shaped.

The structure of bacteria

Bacteria are tiny one-celled procaryotic cells in which the nucleic acid is not contained in a nucleus.

A bacterial cell has:

- A cell membrane
- A cell wall
- Cytoplasm
- Nuclear region.

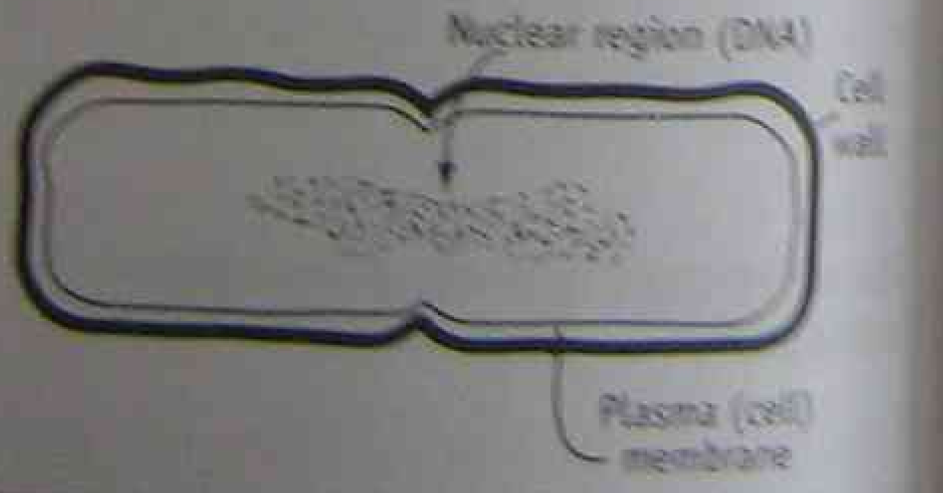


Figure 10.12 A simplified diagram showing the general structure of a bacterial cell. The cell wall protects the bacterial cell from physical damage and osmotic disruption such as a change in water concentration in the cell's environment. Some bacteria also have a protective capsule.

Bacteria can cause disease by:

- Secreting toxins
- Invading cells
- Forming bacterial colonies that disrupt normal cell function.

As part of meeting the requirements of the course, you are expected to have used secondary sources to trace the historical development of the understanding of the role of bacteria in causing disease, including the contributions of two of the following:

- Lister
- Pasteur
- Koch
- Semmelweis.

Before the discovery of lenses and microscopes, it was believed that living matter such as moulds and maggots could come spontaneously from non-living matter. Even after the invention of microscopes, there was very little understanding about infectious diseases and the link between microbes such as bacteria and disease. Pasteur and Koch stimulated the search for microbes as causes of disease.

Semmelweis (1818–1865) — realised that the cause of some deaths in hospitals was due to infectious matter carried on the hands of doctors who treated patients after handling corpses. He introduced aseptic methods such as handwashing and using chlorinated lime, but his ideas were not accepted and he was eventually dismissed.

Pasteur (1822–1895) — among other things, Pasteur discovered that microbes such as bacteria can cause disease. With his famous swan-neck flask experiment (see the diagram below), Pasteur demonstrated that bacteria and mould cannot generate spontaneously.

Lister (1827–1912) — was inspired by Pasteur's work. Lister developed antiseptic surgical techniques.

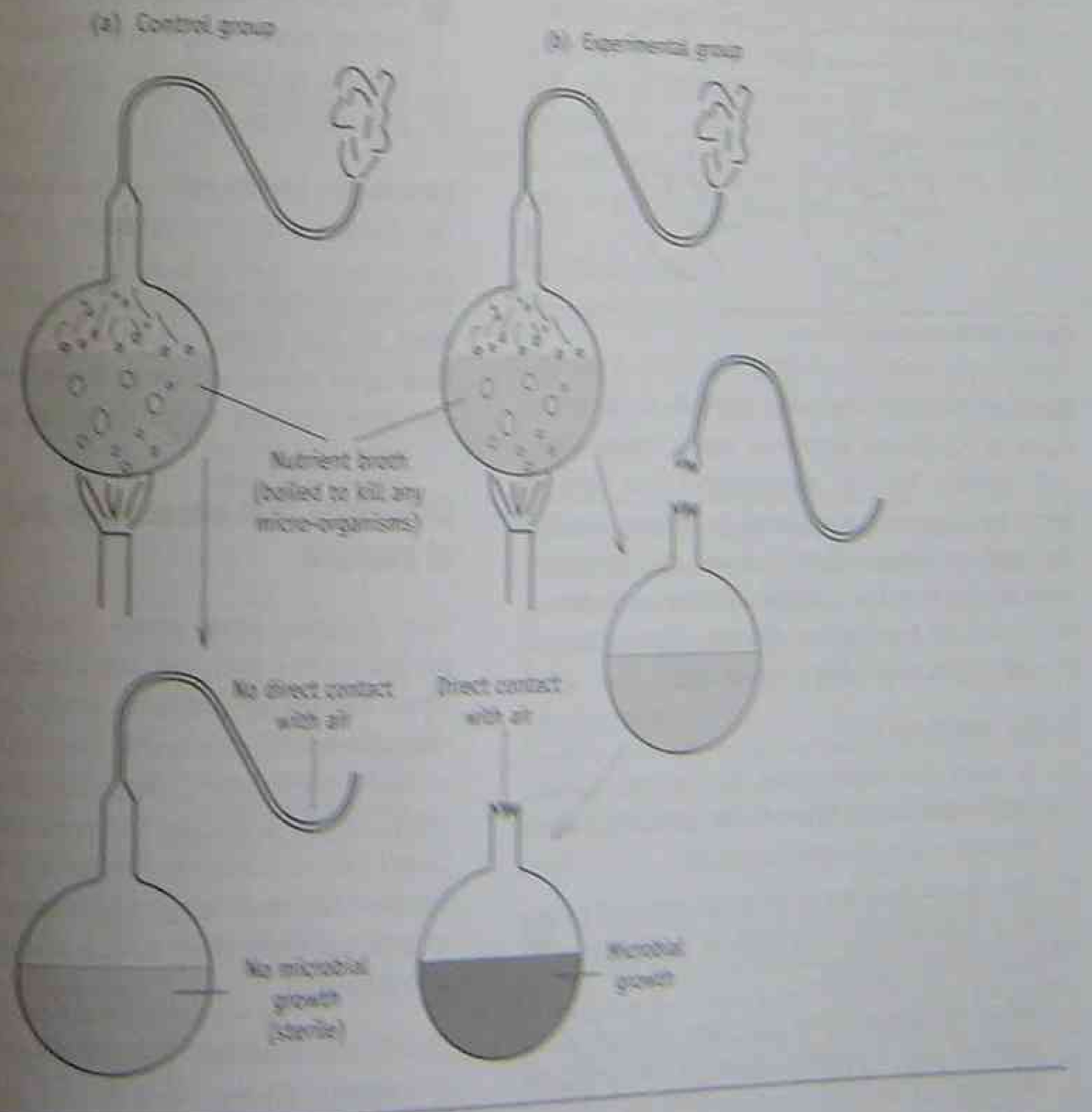


Figure 10.13 Pasteur's classic experiment

He used carbolic acid as a disinfectant to wash the surgeon's hands, instruments and dressings and to bathe infected wounds.

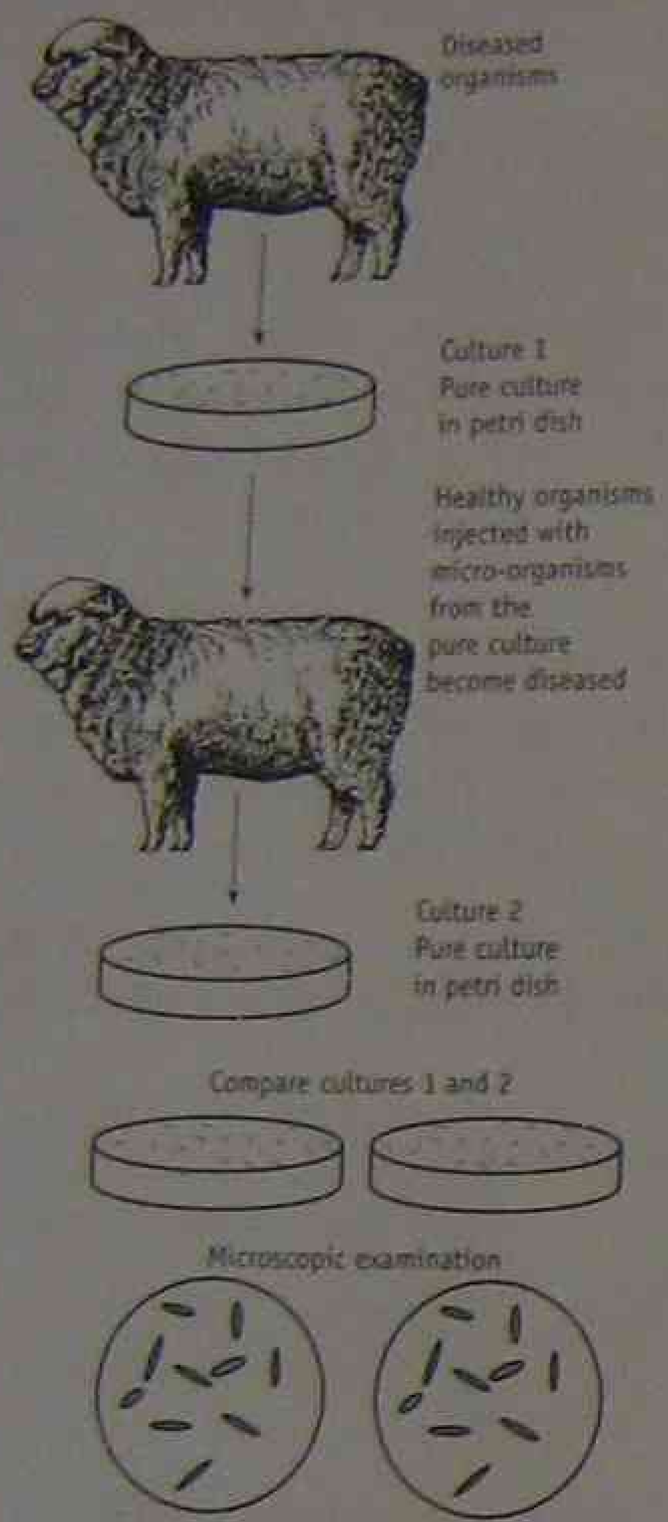


Figure 10.14 Koch's postulates

Koch (1843–1910) — showed that bacteria were the cause of the disease anthrax in horses, cows, sheep and humans. He also demonstrated that bacteria were the cause of tuberculosis in humans. During his work on diseases Koch designed rules of procedure for showing that a particular micro-organism is the cause of a particular disease. These rules of procedure are called Koch's postulates.

Koch's postulates are:

1. It must be shown that the micro-organism believed to be the cause of the disease is always present in the diseased organism.
2. The micro-organism must be isolated and grown in a pure culture — a culture containing only that micro-organism.
3. Micro-organisms from the pure culture when injected into a healthy organism (an organism without the disease) must produce the disease.
4. Micro-organisms are isolated from the experimental organisms, grown in pure culture and compared with the micro-organisms in the original culture and shown to be identical.

Reproduction in bacteria

Most bacteria reproduce by **binary fission** — a type of cell division in which two equal daughter cells with characteristics like those of the parent cell are produced without mitosis. Bacteria have enormous reproductive potential.

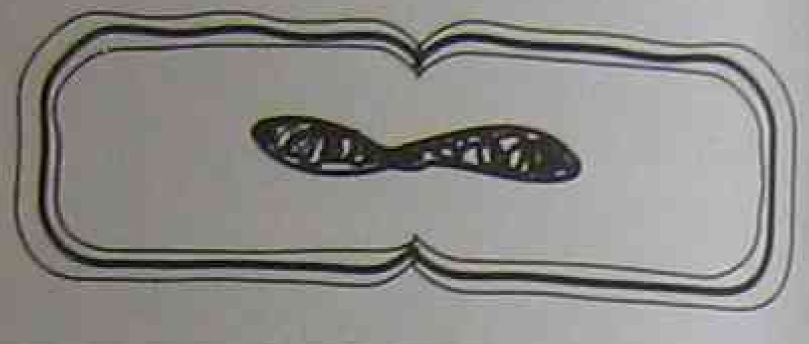


Figure 10.15 A bacterial cell dividing by binary fission. A ring of new cell wall forms on the outside of the cell and grows inward. The cell divides. The nuclear material also divides.

As part of meeting the requirements of the course, you are expected to have used secondary sources to identify the rate of reproduction of different bacteria.

Clostridium perfingens — reproduction rate is one cell division every 7.1 minutes at 40°C to 45°C.

See: http://www.cellsalive.com/ecoli.htm for information on the reproduction rate of bacteria and a time-lapse movie showing how two *E. coli* divide and form a colony of hundreds in just a few hours.

Conditions that encourage the reproduction of bacteria

Most bacteria need some kind of nutrients and oxygen for survival and reproduction. Bacteria that cause disease in humans, such as campylobacter, clostridium and salmonella bacteria, favour temperatures of around 40°C (approximately body temperature). At the optimum temperature and pH and in places rich in nutrients, bacteria will divide rapidly. For example, in 20 hours one bacterium can multiply to produce more than half a million offspring. See also page 153.

Conditions, however, vary between different species of bacteria. (Some bacteria are anaerobic, that is, they do not need oxygen. Some bacteria use ammonia, sulfur, nitrites or hydrogen gas as sources of energy.)

When conditions for growth are unfavourable, some bacteria (such as the bacteria that cause tetanus) change into spores with an extra tough outer wall.

As part of meeting the requirements of the course, you are expected to have carried out procedures to culture bacteria, analysing the risks and relating the growth of the bacterial cultures to environmental conditions such as temperature.

Your first-hand investigation may have involved isolating bacteria by growing cultures on nutrient agar plates. The nutrient agar plates must be heated at high temperatures in a pressure cooker to destroy any existing micro-organisms before you inoculate the plates with the food, soil, water samples and so on from environmental surfaces. Inoculate agar plates using a sterile wire loop. Rub the loop onto the sample (food, water, soil, desk top) and then gently transfer the sample taken onto the agar (see Figure 10.16 (a) below).

It is important that you identify hazards and use safe practices, such as:

- All plates should be kept sealed to prevent contamination.
- All plates should be heated at high temperatures in a pressure cooker after the investigation, to destroy the microbes that you have cultured.

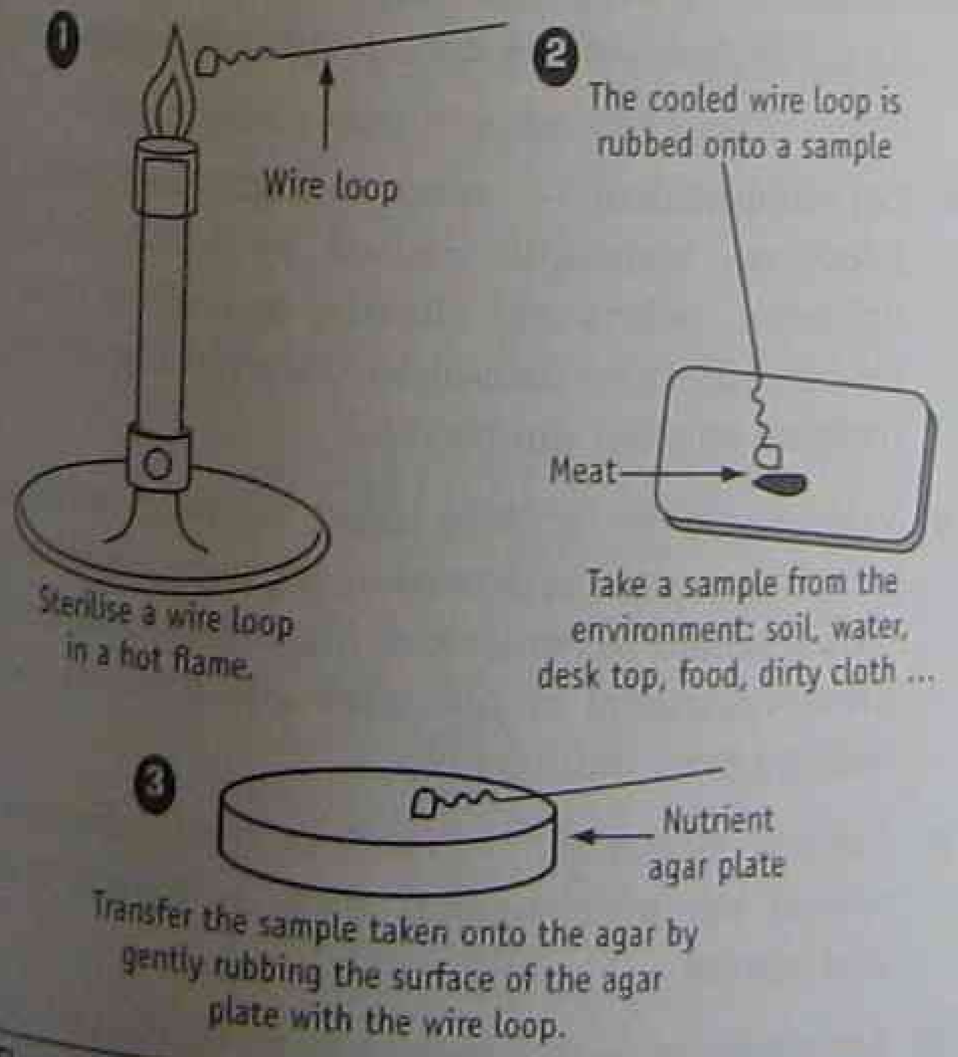


Figure 10.16 (a) Inoculating agar plates

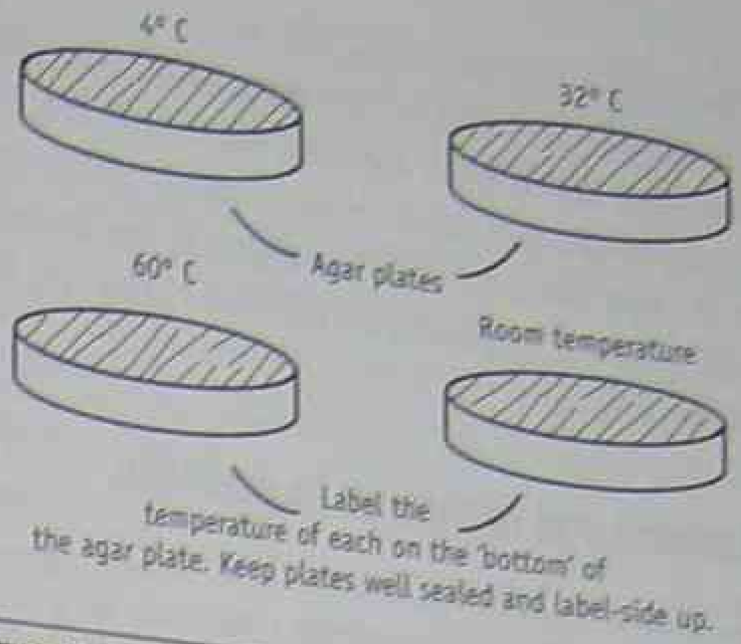


Figure 10.16 (b) Growing cultures of bacterial cells on agar plates at different temperatures. Bacterial colonies can be identified as round and shiny. Different coloured colonies can indicate different types of bacteria

How penicillin works

Antibiotics are compounds that kill or inhibit pathogens. Penicillin is an example of an antibiotic. It is made from a fungus — the penicillium mould (see page 155). Penicillin revolutionised ideas about medicine. Before penicillin it was believed there was no substance which would be powerful enough to kill cells of bacteria without also killing human or animal cells. As the penicillin attacked the cell walls of the dividing or reproducing bacterium, it was able to specifically attack bacterial cells.

Antibiotics either:

(a) Kill bacteria, or

(b) Slow bacterial growth so that the body's immune system can deal with the bacterial infection.

Penicillin is an example of an antibiotic that kills bacterial cells. Penicillin only works on bacteria while they are reproducing because it prevents the bacterial cells from building strong cell walls. The susceptible bacteria take up liquids, swell, burst and die.

Penicillins include amoxicillin, ampicillin and penicillin.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the circumstances surrounding the identification of the substance produced by the fungus *Penicillium notatum*, which appeared to inhibit the growth of bacteria.

The mould that produced the revolutionary drug penicillin is *Penicillium notatum*, which ferments fruit, jam and cheese. **Fleming** discovered that the mould *Penicillium notatum*, accidentally introduced to an agar plate on which colonies of the bacteria were growing, produced an inhibitory effect on the bacteria.

Bacteria and resistance to penicillin

> Bacteria continually develop resistance to antibiotics. Although bacteria reproduce by binary fission, genetic recombination does occur and, therefore, within any population of bacteria there is a variety of characteristics. Species that have rapid rates of reproduction, such as bacteria, are more likely to have offspring with genetic variations that can result in an adaptation for survival. Some bacteria will, by chance, be more resistant to an antibiotic such as penicillin than others. When the bacterial population first encounters the antibiotic, most of the bacterial cells will die. A few bacteria (those that have the 'more resistant' gene) will survive. These bacteria reproduce and pass their characteristics onto their offspring.

The widespread use and abuse of penicillin has caused problems such as:

- The development of resistant strains of bacteria
- The development of allergies and immunity to the action of penicillin by some people.

Widespread use and abuse includes:

- An increase in the use of antibiotics in intensive farm practices as growth promoters, for example in chickens
- Over-prescribing of antibiotics
- Not taking the entire prescription. The symptoms disappear but those bacteria that survive the initial dose may continue to multiply in the body.

The future of penicillin

Penicillin as we know it may no longer be used in the future. New antibiotics and synthetic variations of penicillin will need to be developed. Management of antibiotics and antibiotic resistance will need to be improved. Preventing infections is also an important part of reducing the need for antibiotics. An example of prevention is the development of an effective vaccine program, such as the haemophilus influenza type B (Hib) vaccination program which has virtually eliminated the need for antibiotic treatment because infections are now very rare.

See: Collignon P. (1998) 'Antibiotic Resistance: will bacteria take over?', *Australasian Science*, June, pp. 40–41.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research antibiotics other than penicillin, their source, how they work, and the bacteria they affect. Some ideas are provided below.

Antibiotics have different chemical structures which make them effective against different bacteria. Some have a broad spectrum of activity — they are effective against a wide range of bacteria. Others are more specific.

Examples of antibiotics other than penicillin include cephalosporins, cefaclor, chloramphenicol, vancomycin and antimycobacterials. They are often used when penicillin treatment is ineffective. Some people may also be allergic to penicillins.

- Cephalosporins — broad spectrum antibiotics used to treat septicaemiai, pneumonia and urinary tract infections. Cephalosporin comes from the cephalosporium fungus.
- Cefaclor — a broad spectrum antibiotic, used to treat infections of the ears, respiratory tract and skin.
- Chloramphenicol — used to fight salmonella infections, meningitis caused by *Haemophilus influenza*, rickets and cholera, as well as other serious infections caused by bacterial organisms resistant to other antibiotics.
- Vancomycin — a drug used to treat serious infections caused by strains of staphylococcal bacteria resistant to penicillins. Vancomycin inhibits the development of cell walls and prevents the bacteria from multiplying.
- Antimycobacterials — used to treat infections caused by mycobacteria, such as tuberculosis and leprosy.
- Streptomycin — is a metabolic by-product of the bacteria *Streptomyces griseus*.

Checklist

Key terms for revision

central nervous system
peripheral nervous system
sense organs
receptors
effectors
neurones
sensory neurones
motor neurones
interneurones
stimulus
response
reflex arc
circulatory system
white blood cells
veins, arteries and capillaries

inflammation response
prostaglandins
analgesics
aspirin
acetyl salicylic acid
antibiotics
penicillin
penicillium
bacteria
binary fission
bacterial resistance to penicillins
Lister
Pasteur
Koch
Semmelweis

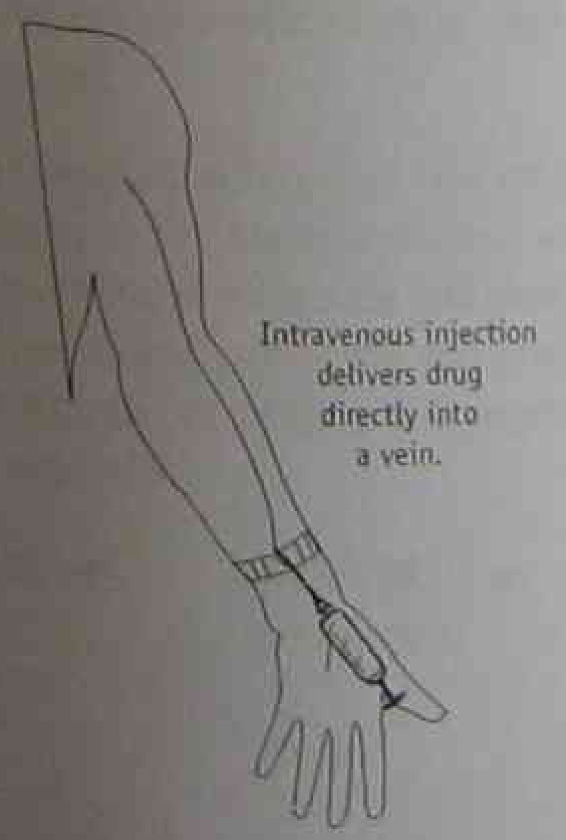
Test

Pharmaceuticals

Short answer and longer response questions

1. (2 marks)

The diagram below shows an intravenous injection that delivers a drug directly into a vein.



(a) From your understanding of the function of veins, give possible explanations as to why the injection is delivered into a vein and not an artery. (1 mark)

(b) What is the advantage of using the circulatory system to transport drugs around the body? (1 mark)

2. (4 marks)

Nerve cells have special sites on their surfaces that analgesics such as morphine can attach to. When they lock on, the neurones that relay pain signals are turned off and the neurones that block pain signals are turned on.

(a) What are analgesics? Give one other example of an analgesic. (2 marks)

(b) What are neurones? (1 mark)

(c) Prostaglandins are chemicals that are thought to be responsible for the pain and fever of inflammation. Explain how an analgesic relieves the pain caused by prostaglandins. (1 mark)

3. (4 marks)

Many hospitals are now encountering *Staphylococcus aureus* (golden staph) infections that resist all treatments, whereas this type of bacterium was once easily controlled using the antibiotic vancomycin. *Staphylococcus aureus* is a virulent bacteria that can produce life-threatening infections. Since the late 1980s, there has been an increase in the antibiotic resistance of *Streptococcus pneumoniae*. This bacteria is the common cause of pneumonia, middle ear infections, sinusitis and bacterial meningitis.

(a) Explain how bacteria can become resistant to antibiotics. (2 marks)

(b) What are some possible implications for the future use of antibiotics such as penicillin? (2 marks)

4. (4 marks)

Injury, infection, trauma and environmental conditions produce an inflammation response in the human body. The response can cause fever as well as damage to tissue such as swelling and redness.

(a) What is the inflammation response? (1 mark)

(b) Use diagrams to show how the response can cause damage to tissue such as swelling and redness. (3 marks)

5. A student carried out a first-hand investigation to demonstrate differences in reaction time for a number of stimulus-response events. For the results of one of the tests, the student wrote the following:

> 'When I snapped my fingers in front of my partner's face, she blinked. The reaction was so fast, it was difficult to time. I repeated this a number of times and she always made the same response.'

Draw a flow diagram to show the sequence of events involved in this demonstration of a stimulus-response. (3 marks)

6. (8 marks)

(a) Name two antibiotics — one from the group called penicillins and one non-penicillin. For each one, describe its source and a disease it is used to treat. (6 marks)

(b) Identify two modes of action that explain how antibiotics work. (2 marks)

Test answers

Short answer and longer response questions

1. A vein carries blood to the heart, therefore the drug will be carried in the blood to the heart for distribution around the body. The blood-carrying capacity of a vein is greater than that of an artery, because the vein has thinner walls and therefore a larger diameter.

2. (a) The term 'analgesics' refers to the group of drugs which relieve pain. Aspirin is a pain reliever.

(b) Neurones are nerve cells.

(c) Analgesics, such as aspirin, work by inhibiting the synthesis of certain substances (prostaglandins) that cause pain and inflammation. Aspirin prevents the growth of cells that cause inflammation. See page 166.

3. (a) In any population (or strain) of bacteria there will be variation of characteristics. Some bacteria will be naturally more resistant to a particular antibiotic than others. When the antibiotic is first given to a patient, those bacteria which are least resistant will be destroyed. Those which are more resistant will survive, particularly if the course of antibiotic is not completed by the patient. These more resistant bacteria will multiply and pass their 'resistant' trait onto their offspring.

(b) In the future, penicillin as we know it today may no longer be used. New forms of antibiotics and synthetic forms of penicillin will be developed.

4. (a) An inflammation response is a set of complex reactions in the blood and blood vessels that are coordinated to isolate and destroy harmful substances and pathogens and prepare the body's tissue for healing and regeneration.

(b) See page 165.

5.

STIMULUS →	RECEPTORS →	SPINAL →	EFFECTOR →	RESPONSE
Fingers snapped	In the eyes	CORD	Muscles in the eyelid	Blinking

6. (a) Penicillin comes from the penicillium mould. Cephalosporin comes from the cephalosporium mould. Penicillin is used to treat a wide number of diseases caused by bacterial infection, such as sinusitis. Cephalosporin is used to treat pneumonia.

(b) Two modes of action:

- Kills bacteria by inhibiting development of a cell wall
- Slows bacterial growth so that the body's immune system can deal with the bacterial infection.

HSC Study Option

11 — Disasters

Introduction

You will only review this option if you have studied it. Remember, you only need to study one option for the HSC.

In this chapter you will review disasters — both natural and those caused by human activity. You will also review some of the signals that forewarn us of many disasters, and look at technological developments which have allowed more precise monitoring and recording of warning signs.

As a result of working through this chapter you will be able to:

- Discuss ways in which different forms of energy and energy transformations are used in warning devices and in monitoring and predicting disasters
- Discuss advances in the scientific understanding of disasters, and technologies for monitoring and predicting disasters
- Assess the contribution of scientific advances in the understanding of energy transmission to the development of technologies, such as computers, radar, lasers and satellites
- Assess the impact on society and the environment of improvements in the technology used in monitoring and predicting disasters.

Disasters

Disasters are catastrophic events associated with large-scale environmental or structural damage and loss of life, often occurring without warning.

Some disasters are part of the continuing evolution and changing face of the Earth and represent events that have occurred and will continue to occur for centuries. Others are initiated by human activity and represent carelessness, failure of technology or ignorance of the long-term consequences of our actions.

Scientists now predict that one of the effects of global climate change will be more disasters — more frequent and intense storms, droughts and floods — as well as the loss of coral reefs, retreating glaciers, melting ice caps, rising sea levels, and the spread of pests and diseases, such as dengue fever and malaria.

See: http://www.climatehotmap.org/index.html — for information on global warming.

Natural disasters

Natural disasters include plagues and epidemics, drought, earthquakes, storms and floods. On September 18 and 19, 1985, two earthquakes hit Mexico City, one registering 8.1 and the second registering 7.5 on the Richter scale. The earthquake killed 5526 people, injured 40,000 and left 31,000 homeless. In January 2001 a devastating earthquake measuring 7.9 on the Richter scale hit Gujarat, India. Early estimates gave the death toll as 22,000 but later estimates suggested a toll in the hundreds of thousands. A series of aftershocks measuring 5.9 on the Richter scale were also recorded.

Some Australian examples are:

Cyclone Tracy — hit Darwin in December 1974. Forty-nine people died, with another 16 missing at sea. The cyclone devastated Darwin, causing hundreds of millions of dollars worth of damage.

The Newcastle earthquake — the earthquake hit at 10.27 am on 28 December 1989 and left 14 people dead. The earthquake measured 5.5 on the Richter scale.

Drought — Australia is the driest continent on Earth and some part of it is always in the grip of drought. Severe national droughts occurred in 1902 and the 1960s. For an 11 month period from April 1982 to February 1983 much of eastern Australia, and in particular Victoria and southern NSW, experienced one of the most severe droughts on record. (The long drought set the stage for the disastrous bushfires in February 1983, see below). 80% of NSW was declared drought-stricken in 1995.

Floods — in 1990 floods swept through more than one million square kilometres of eastern Australia from Queensland, through NSW and into Victoria leaving six people dead and devastating towns, farmland and bushland.

Storms — Sydney's hail storm in April 1999 produced massive hailstones of at least 9 cm diameter and resulted in insurance losses of around $1.5 billion in less than one hour. In total, over 20,000 properties and 40,000 vehicles were damaged during the storm with more than 25 aircraft damaged at Sydney Airport. In dollar terms, this is the most costly natural disaster so far in Australian history. No lives were lost as a result of the hail.

See: http://www.bom.gov.au/weather/nsw/inside/sevwx/public/ — for information on the Bureau of Meteorology and severe thunderstorms in NSW.

Disasters associated with human activity

Disasters associated with human activity include fires, maritime disasters, nuclear and industrial accidents, air crashes, and rail accidents. In 1984 in Bhopal, India, the explosion of the Union Carbide Pesticide Plant resulted in the escape of a poisonous gas, methyl isocyanide. The explosion and gas killed at least 2000 people and left more than 20,000 injured, many of them permanently. In 1988, a terrorist bomb exploded aboard a midair flight above Lockerbie, Scotland, killing all 256 people on board and 11 people on the ground. See also page 24.

Some Australian examples are:

- The Granville train disaster — in January 1977 left 80 people dead.
- Glenbrook train crash — in December 1999 left seven people dead. The accident happened when a peak-hour intercity train bound for Sydney hit the back of the Indian Pacific train. An inquiry into the disaster found that a signal failure caused the accident.
- Air crashes — for example, eight people died in September 2000 when a Beechcraft King Air 200

crashed in north-west Queensland. It is believed that depressurisation of the aircraft caused the crash.

- Oil spills — for example, in August 1999 a tanker leaked more than 80,000 litres of light crude oil into Sydney Harbour at the Shell refinery, contaminating the water system, mud flats and rock shelves.

Some disasters are a combination of nature and human activity

Dust storms, shipwrecks, landslides and some accidents are disasters where nature and human activity have combined. Between 1983 and 1988 in Ethiopia and the Sudan, more than one million people died in a famine that resulted from drought and civil war.

Some Australian examples are:

- Ash Wednesday bushfires — major bushfires in south-east Australia (Victoria and South Australia) in February 1983 left 75 people dead and more than 2000 homes destroyed. The bushfires were the result of human activity, and the long drought and periods of high temperatures and hot dry winds during the summer of 1982–1983.
- Sydney bushfires — in December 1993 and January 1994 bushfires in NSW destroyed 188 homes, burnt out more than 200,000 hectares of bushland and left four people dead.
- The Thredbo landslide — in December 1997, 18 people died in the landslide. An inquiry into the disaster concluded that the landslide was the result of a leaking water pipe, and that the NSW Roads and Traffic Authority (RTA) and NSW National Parks and Wildlife Service were at fault.

As part of meeting the requirements of the course, you are expected to have used secondary sources to create a database of natural disasters that have occurred within Australia to include:

- When it occurred
- Where it occurred
- Consequences of the disaster
- Techniques employed to reduce the incidence of damage in the future
- Techniques employed to monitor disasters in the future.

Techniques employed to reduce the incidence of damage and to monitor disasters in the future include:

- Research to develop a greater understanding of disasters. For example, the study of earthquakes and their effects, where they occur, how big and how often and the study of the nature of bushfires.
- Research into the vulnerability of structures and the development of building designs and regulations which aim to prevent collapse and minimise structural damage (in the event of earthquakes) and minimise damage by bushfires.
- Research into better ways of monitoring the likelihood of disaster, alerting people, providing warnings and alarms, and preparing for emergency responses. For example, alerts are issued when there is a likelihood that a particular phenomenon may occur. In hot windy weather, a bushfire alert is declared. Earthquake alerts may be given when unusual earthquake activity has been detected, and there is a possibility that a larger event may occur. Forecasts give the location, time and size of a future event, together with an estimate of the probability that the event will or will not occur.

Warnings are also issued when an event is occurring but its full impact has not yet been experienced, for example, a cyclone warning. Warnings give estimates of the impact or intensity of the effects and of the time they will occur. Throughout the year, the Bureau of Meteorology operates a Severe Thunderstorm Advice Service for the whole of NSW and the ACT, and a Severe Thunderstorm Warning Service for the greater Sydney area. This service is enhanced with additional staff during the 'severe thunderstorm season' that occurs from September through to March.

See: http://au.yahoo.com/Regional/Countries/Australia/society_and_culture/Environment_and_Nature/ Disasters

http://australiasevereweather.com

http://abc.net.au/news

As part of meeting the requirements of the course, you are expected to have used first-hand and secondary sources to research insurance compensation for natural disasters and 'acts of God' and the definitions and terminology used in insurance contracts.

An 'act of God' refers to an event or occurrence resulting from natural causes which occurs independently of human intervention and either could not be foreseen, or if foreseen, could not reasonably be guarded against, for example, flooding or lightning strike. Acts of God are generally not covered by insurance policies. Damage caused by storms, rain and burst pipes is usually covered.

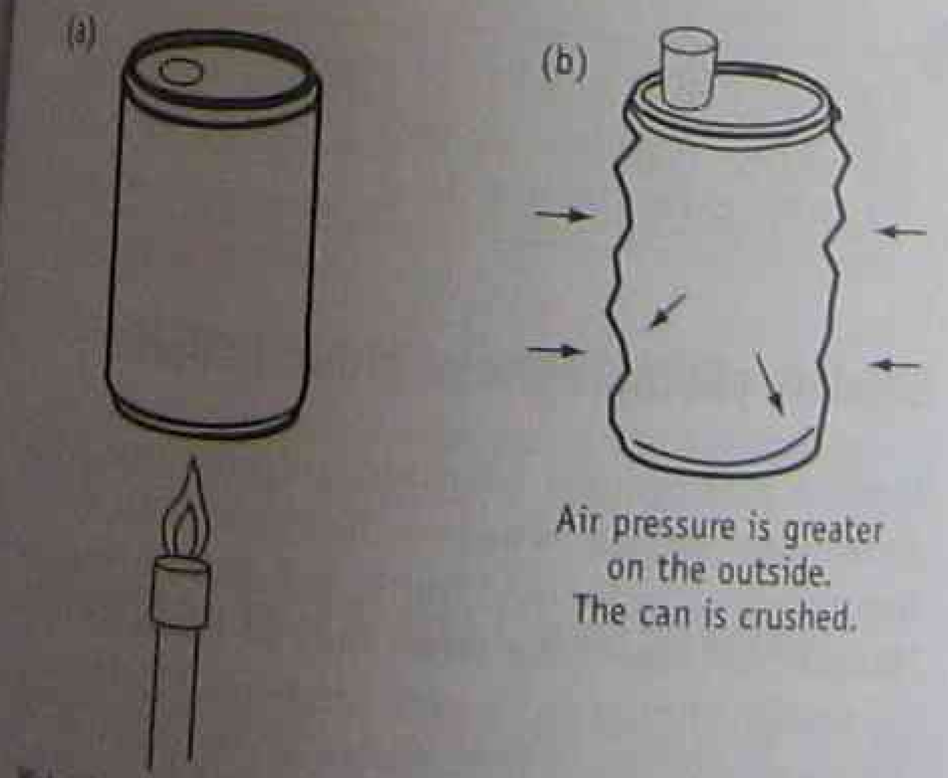
Monitoring and predicting weather patterns

Pressure is the force per unit area exerted on a surface by a liquid or a gas.

Air exerts pressure. The pressure of the atmosphere at any point is the weight of air which lies vertically above the unit area. Air pressure decreases rapidly with height. Hectopascals is the unit of air pressure. (The previous unit was millibars.) An aneroid barometer is used to measure air pressure.

As part of meeting the requirements of the course, you are expected to have demonstrated the effect of differences in air pressure.

We become most aware of the effects of air pressure when it changes — when a wind storm or rain storm is about to occur or when a cold front or warm front moves through. The effects of differences in air pressure can be demonstrated in the laboratory.



Water is heated in a can to drive out the air. The lid is then put on the can or the hole is corked to prevent air from coming back in.

Air pressure is greater on the outside. The can is crushed.

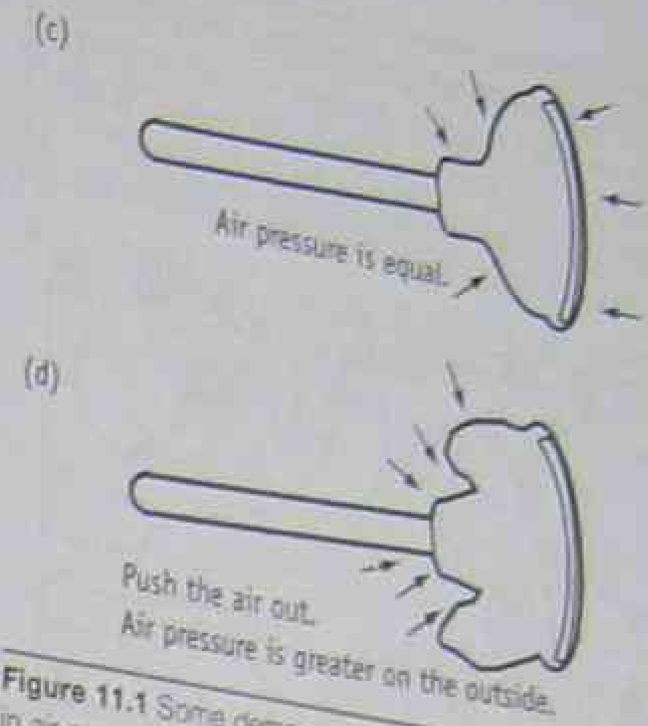


Figure 11.1 Some demonstrations of the effect of differences in air pressure

Weather maps

Weather stations and observers around Australia make their observations and measurements at the same time each day. These are combined with other measurements from satellites and aircraft, for example, and recorded on weather maps. Weather maps show how air pressure changes from place to place at a horizontal level — usually sea level. Isobars on weather maps join places having the same atmospheric pressure. Isobars form highs and lows.

In the southern hemisphere, air currents move anti-clockwise around centres of high pressure and clockwise around centres of low pressure.

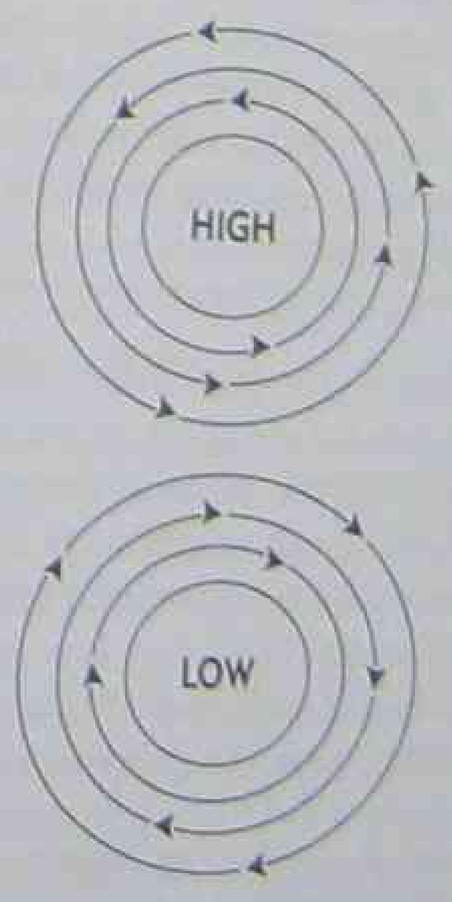


Figure 11.2 Highs and lows showing direction of air flow

The distance between isobars on a weather map indicates the relative amount of atmospheric pressure in an area and the wind speed. Winds are strong where isobars are close together.

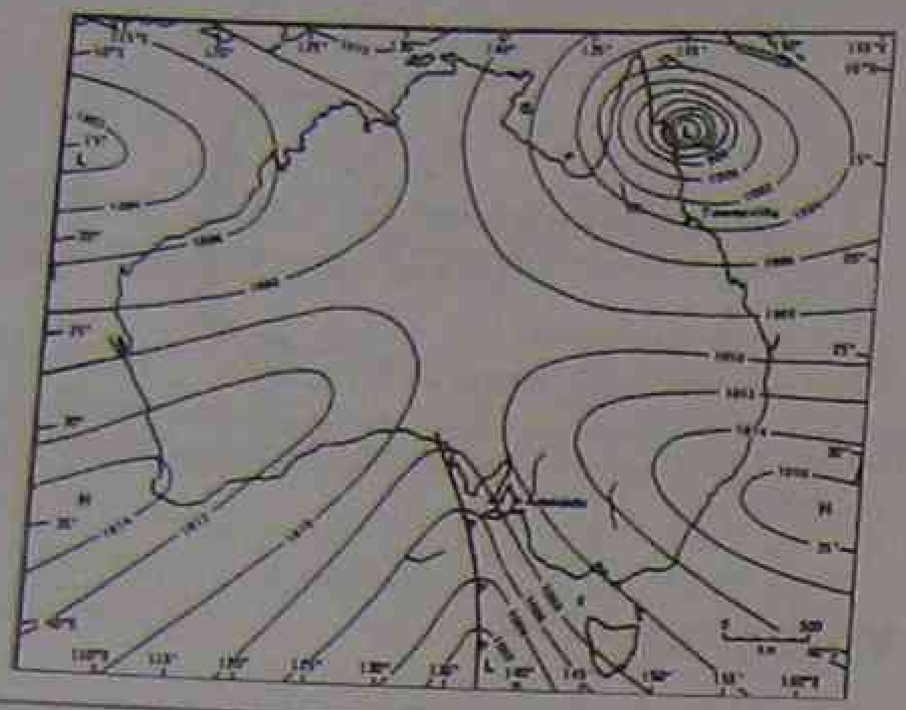


Figure 11.3 A weather map showing isobars. The cold front is shown on the map as a thick black line with arrow heads.

As part of meeting the requirements of the course, you are expected to have used secondary sources to compare changes in the relative air pressure in an area over time and relate these changes to changing weather patterns.

See: http://bom.gov.au — the Australian Bureau of Meteorology for daily weather reports.

Tropical cyclones and tornadoes

Pressure in the centre of a tropical cyclone or tornado is much lower than normal air pressure. Buildings can therefore explode during a cyclone or tornado, as the air inside bursts out toward the area of low pressure.

At the surface of a tropical cyclone, winds spiral inwards towards the eye of the cyclone in a clockwise direction (in the southern hemisphere) and form an intense vortex around the eye. Air pressure rises as the cyclone builds and then suddenly falls dramatically as the eye or core of a cyclone hits. Wind speed increases dramatically. As the cyclone moves away or decays, the air pressure rises again.

See: Crowder B. (1995) *The Wonder of Weather*, Australian Bureau of Meteorology, Canberra.

As part of meeting the requirements of the course, you are expected to have gathered information to trace the movement of a tropical cyclone.

See Crowder B. (1995) *The Wonder of Weather*, Australian Bureau of Meteorology, Canberra — for excellent information and photographs on cyclones such as Cyclone Tracy in 1974 and Cyclone Fran in 1992. The book uses photographs to trace the movement of tropical Cyclone Joy in 1990.

See also http://au.yahoo.com/Regional/Countries/Australia/society_and_culture/Environment_and_Nature/Disasters — for photos and accounts of Cyclone Tracy.

Technological advances in meteorology

Technological advances that have contributed to an increased understanding of meteorology include satellites, radar and laser technology, and computer technology. Computer technology has enabled the Earth's surface and atmosphere to be analysed in detail. The use of computers in weather forecasting began in the 1950s. Before then forecasters could only predict weather about 36 hours in advance. With computers, forecasts can be made six to ten days in advance.

The first weather satellite was launched by the USA in 1960. Before satellites, weather forecasters had few clues about weather conditions. A small number of ships and aircraft provided limited information scattered over very large distances.

There are now a number of weather satellites in orbit which together, provide cloud pictures for the entire globe twice a day.

Satellite photographs of cloud patterns

Satellite photographs of cloud patterns and cloud formations enable weather forecasters to detect fronts such as major cold fronts and cyclone systems. Weather satellites take two types of cloud pictures — visible photographs and infra-red photographs which enable cloud formations to be observed by day and night. Global weather patterns can now be gathered and analysed and long-term predictions can be made.

Monitoring weather patterns by radar and laser light

The predictable reflective properties of radar waves and laser light allow instruments to scan the atmosphere and increase the capabilities of modern weather forecasting. Radar is short for **R**adio **D**etection **a**nd **R**anging. Radio waves are transmitted and reflected from a range of materials including raindrops and ice particles. The reflected wave patterns are picked up by a receiver and fed into computers for analysis.

Radar makes it possible to map the amount, movement and intensity of precipitation and therefore help to track storms. Rain and snow in weather fronts hundreds of kilometres away can be seen using radar. Radar waves are used to observe cloud formation, predict storm movements and measure variation of wind velocity.

Continuous wave radar makes it possible to:

- Map velocity distribution in storms
- Measure horizontal and vertical air circulation
- Better understand upper-level rain and hail circulation patterns.

Highly concentrated beams of light, laser light from laser radar, are also transmitted and reflected from weather fronts and the reflected patterns fed into computers. Laser spectroscopy is used in pollution monitoring.

Some disasters are still not easy to predict

Earthquakes

Earthquakes happen as a result of the shock (seismic) waves of energy which are released by the movement or fracturing of rock in the Earth's crust and volcanic eruptions.

Seismology is the study of earthquakes.

See: http://www.seis.com.au — the Seismology Research Centre, Australia.

Differences in P, S and L energy waves

Earthquakes produce different types of seismic waves: P, S and L waves.

- **P waves** or primary waves are the first seismic waves to arrive, because they travel the fastest: about 8 km/second. P waves can travel through any kind of material whether solid, liquid or gas.
- **S waves** or secondary (shear) waves follow P waves. They travel at a speed of about 3.2–4.5 km per second. S waves can only travel through solids.
- **L waves** are surface waves which travel at 2 km/second. Most destruction comes from the slow moving L waves.

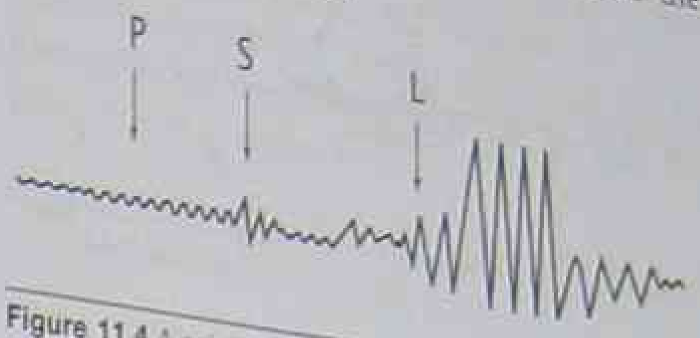


Figure 11.4 A seismograph recording of P, S and L waves

Seismic waves that reach the ocean may trigger seawaves called tsunamis.

Energy transfers and transformations involved in L waves

L waves are longitudinal type waves which cause the material through which they travel to vibrate in the direction of the wave. The medium (in this case the Earth's surface) becomes successively squashed and stretched. The energy carried by L waves is transferred to the Earth's surface and to buildings, roads, bridges and other structures. The energy is transformed into sound energy.

Locating the epicentre of an earthquake

The epicentre of an earthquake is the point on the Earth's surface that lies directly above the focus or origin of an earthquake (see Figure 11.5). Towns and cities in the area of the epicentre will feel the most impact of an earthquake. The difference in time of arrival of P and S waves can be used to locate an earthquake's epicentre.

Seismic waves travel out from the focus in all directions. The further a seismometer is from the earthquake, the greater the time lapse between each type of wave. Seismologists calculate the distance based on their knowledge of the speed of each type of wave. By comparing the data from seismometers in several different places they can measure the earthquake's strength and pinpoint its epicentre.

As part of meeting the requirements of the course, you are expected to have used secondary sources to determine the location of an earthquake's epicentre.

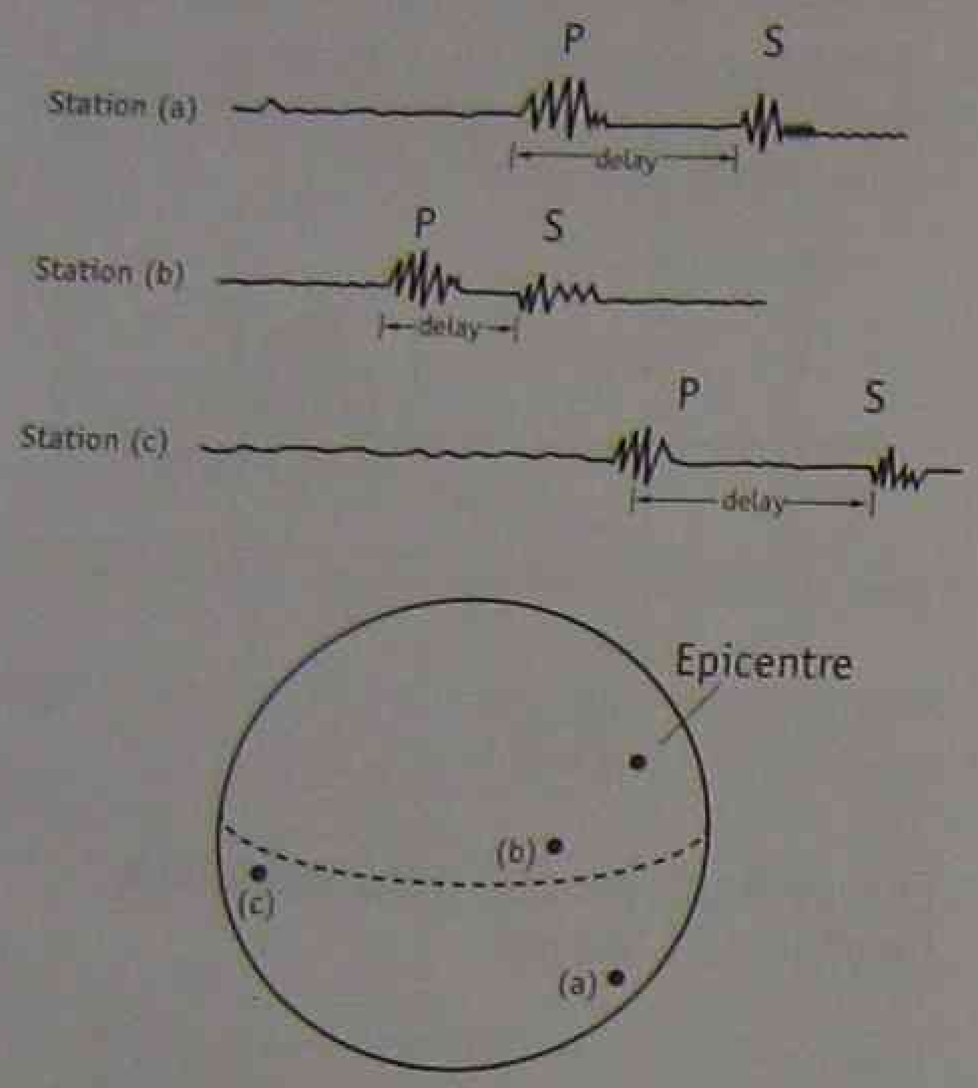


Figure 11.5 The time lag between the arrival of P, S and L waves is used to determine an earthquake's epicentre.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research how seismographs and the Richter scale are used to record and monitor earthquakes.

A **seismometer** receives seismic waves. A **seismograph** records seismic waves. They measure the shocks and vibrations caused by the movement of rocks.

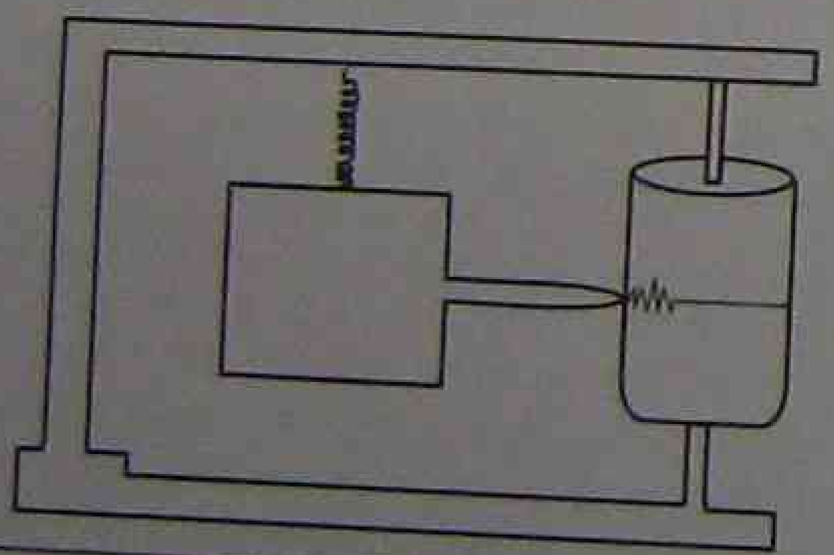


Figure 11.6 A simple representation of a seismograph that records vertical ground motion

The Richter scale provides the most common description of an earthquake's intensity. The scale is a world-wide standard which ranges from 0 to 9 (with a reading of 9 being the most intense earthquake).

The Mercalli scale is also an intensity scale but consists of a series of levels of responses to the earthquake, ranging from Level I (only felt by a very few under especially favourable conditions) to Level XII (total damage — lines of sight distorted and objects thrown into the air).

Monitoring and predicting earthquakes

Even though the nature of earthquakes and major earthquake regions of the world are well understood, scientists cannot predict with certainty the movements of the Earth's crust. These are natural forces beyond human control. Seismic waves travel quite fast, and therefore earthquake warnings are usually too slow to alert people to them.

Many earthquakes give no warning sign. Seismologists have mapped zones on the Earth that show trends and patterns for earthquakes, and these areas are monitored daily. Earthquakes in Australia are difficult to predict because they do not lie in defined earthquake zones. Earthquake activity in Australia is within the centre of stable rigid plates. These types of earthquakes are shallow and therefore potentially damaging.

Bushfires

Uncontrollable wildfire which can destroy life and property occurs in very specific conditions on certain days. The conditions that can combine to trigger a bushfire include dry weather, high temperatures, strong winds, low humidity, and dry vegetation (a drought in winter or spring dries out vegetation).

As part of meeting the requirements of the course, you are expected to have carried out an experiment to compare the flammability of dry and fresh leaves.

Identify safety precautions when carrying out this investigation.

The speed of a bushfire

The speed of a bushfire is determined by factors such as the slope of the land and intensity of the wind. Fire travels twice as quickly up a 10° slope as it does on level ground, and four times as quickly up a 20° slope. This is because as slope increases, flames are carried closer to the fuel (vegetation on the ground), preheating it in advance of the fire. Aspect is also important. Fires are less severe on southerly and easterly slopes.

Reference: *Living with Fire: bushfire management, the environment and the community*, NSW Premier's Department Regional Coordinators Management Group (1998). See also: Planning for Bushfire Protection from the NSW Rural Fire Service, http://www.rfs.nsw.gov.au

Some energy transfers associated with bushfires

Chemical potential energy is the energy stored in fuel (vegetation). Something is needed to trigger the ignition point for the chemical potential energy to be converted to heat energy. (Usually this trigger is heat from, for example, a match.) The heat energy is transformed into light and sound energy.

Controlled burns and backburns

Controlled burns are also known as prescribed burns, fuel-management or hazard- reduction burning. Controlled burns are usually done at times of the year when fires can be controlled. They are cooler burns which aim to:

- Minimise the risk of bushfires
- Make wildfires easier to control by thinning or removing some of the vegetation (fuel)
- Reduce the chances of fire starting
- Minimise the extent and intensity of wildfires
- Improve the safety conditions for fire fighters.

Backburns refer to burning that is done to manage a fire that has already started. Fire management is complex and controversial. Some native plants with hard protective seed coats and fruits require hot fires for seed germination. These natural fires (natural for some parts of the Australian bush) vary in frequency, severity, season and patterns of burning. Controlled burns and backburns happen more frequently and are not a natural part of the Australian ecosystem.

Increasingly there is a need to reassess the way fire management activities are applied. Some argue that we need to more fully understand the interrelationships between fire and Australian ecosystems, and treat the use of fire with extreme caution before continuing to use controlled burning as a primary method of hazard reduction. For example, many studies in the Blue Mountains and elsewhere have demonstrated that although regular prescribed burning can effectively reduce fuel levels, this effect is generally short-lived. Regular burning of forests simplifies the ecosystem and modifies the flora, selecting fire-tolerant species that tend to be flammable and in the long term can increase the risk rather than reduce it.

Reference: *Prescribed Burning: A catch 22 situation?* Blue Mountains City Council, 2000.

See: http://www.nccnsw.org.au/bushfire/projects/masterindex — for a list of bushfire fact sheets from the Nature Conservation Council of NSW.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research the types of native vegetation that promote the spread of bushfires.

Many native plant species (for example, eucalypts and hakeas), particularly those in dry sclerophyll forests, promote the spread of fire. Hard-leafed species produce leaf litter that tends to accumulate on the ground and may assist in the spread of fire. The tough leaves and branches are both flammable and slow to decompose. Eucalypts with rough bark provide a ready-made fuel ladder to the leaves in the crowns of trees.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research natural resources which are used to retard the progress of fire.

- **Water** — is pumped from tankers and backpacks or dropped from the air by helicopters, fixed-wing aircraft and water scooping air tankers.
- **Natural plants** — not all Australian plant species are wildfire prone. Moist eucalyptus forests and rainforests retard progress of fire. Smooth barked eucalypts and some other native species do not provide a ready-made fuel ladder to the crown. Examples of fire-retardant plants include: casuarina species such as swamp oak and river oak, angopheras, brush box and cedar wattle.

Reference: Brown, C. & Tohver, L. (eds) (1994) *Bushfire! Looking to the future*; Papers from the Nature Conservation Council of NSW Seminar, June.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research precautions that can be taken to minimise the likelihood of damage by bushfires.

Non-fire based hazard reduction is both a personal and community-based responsibility.

Precautions include:

- Clearing litter and wood piles from around the house
- Cleaning gutters
- Removing household rubbish and garden clippings, particularly from adjacent bush
- Planting non-flammable screening vegetation
- Fire-proofing the house — installing wire screens, closing off sub-flooring and enclosing eaves, using non-flammable curtain material
- Not building timber decks on the sides of houses exposed to strong, hot northerly winds
- Installing a separate water tank and pump in areas of low water pressure. Have a point in the house where a hose can be attached. Hoses and taps should be fitted with metal fittings. Gather together clothing and equipment in readiness for a fire — cotton overalls; woollen gloves; goggles; sturdy shoes; hat; face mask; buckets; hoses in working order and under cover; small sand bags to plug up gutters so that they can be filled with water; sticks with hessian bags to beat out small spot fires.
- Store flammable liquids such as petrol and oil, and gas cylinders in metal containers.

State and local government environmental planning often includes fire regulations and precautions for urban planning which aim to avoid inappropriate development in areas of high fire risk. They also specify building design and construction material, fire breaks and radiation zones around houses (zones in which radiated heat from fires can dissipate).

See: http://www.rfs.nsw.gov.au — NSW Rural Fire Service for the Rural Fires and Environmental Assessment Legislation Amendment Bill 2002
http://www.npws.nsw.gov.au — National Parks and Wildlife Service
http://www.forests.nsw.gov.au — Forestry Commission.

As part of meeting the requirements of the course, you are expected to have used secondary sources to explain what steps should be taken if caught in a bushfire.

Radiated heat and smoke are the main dangers if caught in a bushfire.

If caught in a bushfire in the open, try to assess the distance, direction and rate of travel of the fire. Avoid dense scrub and undergrowth; stay in a cleared area and keep low to the ground to avoid thick smoke. Cover the body and exposed skin with woollen clothing; cover the nose and mouth with a wet cloth to lessen the effects of smoke. Get into, under or behind any material that will prevent heat reaching your body — for example, wombat holes, tunnels, ditches or dams or rivers. Remember that fires burn quickly uphill. Therefore, if fire is burning up a hill you are on, if possible walk as quickly as you can down the other side. Do not try to run through flames unless you are completely protected from radiated heat and can see well over the top of the flame.

If caught in a bushfire in the house — fill the bath and buckets with water; close the windows and draw blinds and curtains; stay in the house, away from windows; turn off electricity but have a torch at hand; have a battery powered radio for news (and a mobile phone at hand). Damp down areas before and after the fire passes. Wet towels and face cloths and put cotton clothing on. As the fire passes, check around the house and under the roof for burning embers. Put out small spot fires.

Disasters and warning devices

Warning devices can be used to detect disasters associated with human activity. The main idea in warning devices is that a trigger (heat, smoke, light, movement) turns something on (a switch) and electrical energy is converted to sound and/or light.

The energy transfers and transformation involved in some common warning and protection devices are summarised below.

- Smoke detectors — sense the presence of smoke in a building and warn occupants with an alarm. Photoelectric smoke detectors use an optical beam to search for smoke. Smoke scatters light to the sensor and an alarm such as a horn is triggered.

The energy transfers and transformation involved are:

Light energy → Electrical energy → Sound energy

- Fire alarms — sense the presence of flaming fires (with little smoke).

The energy transfers and transformation involved are:

Heat energy → Electrical energy → Sound energy

- Burglar alarms — usually detect movement or heat and movement. Switches in burglar alarms can also be triggered by pressure and moisture. Most burglar alarms have a time delay (for about ten seconds) and a relay in the circuit, so that once the alarm is triggered it cannot be turned off.

The energy transfers and transformation involved are:

Kinetic energy (energy of movement) → Electrical energy → Sound energy

- Sprinkler systems — detect heat.

The energy transfers and transformation involved are:

Heat energy → Electrical energy

As part of meeting the requirements of the course, you are expected to have preformed an experiment to determine the type, specific use, location and maintenance schedule of fire extinguishers located at school and in work environments.

Fire extinguishers located in each area should be selected based on the most likely source of fire in the area:

A type — for rubbish, wood, paper.
B type — for liquids such as oil and grease.
E type — for electrical fires.

As part of meeting the requirements of the course, you are expected to have constructed a working alarm or safety device.

A fire alarm is made up of a small electronic alarm that usually operates on a 9 volt battery, a printed circuit board, a sensing chamber and a small alarm, such as a bell or horn.

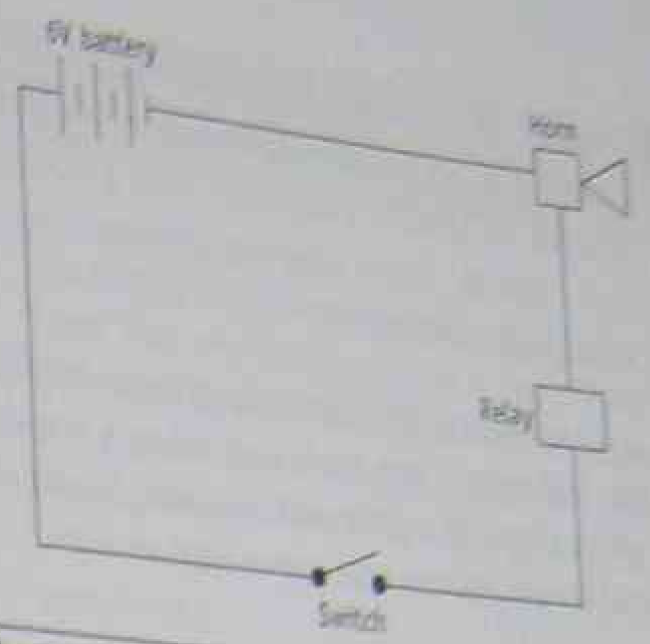


Figure 11.7 A simple alarm

As part of meeting the requirements of the course, you are expected to have identified appropriate locations for smoke and fire detectors at home, school and the workplace.

Smoke alarms and fire detectors should not be installed near appliances such as air vents and air conditioners where the air flow could prevent the smoke alarm from sensing smoke particles. They should be installed in stairwells and in bedrooms and in areas that are most accessible.

Emergency services

Emergency services assist in the prevention and/or minimisation of disasters. Coordinated help services are needed in times of potential disaster. Help services include the police, fire brigade, ambulance, State Emergency Service, Rural Fire Service, community organisations and the Salvation Army.

As part of meeting the requirements of the course, you are expected to have used first and secondary sources to find out:

- The phone numbers for the relevant services in the local region
- The disasters that each service deals with
- The sequence of coordinated help involving these services.

See: http://www.ses.nsw.gov.au — State Emergency Services
http://www.ema.gov.au — Emergency Management Australia

As part of meeting the requirements of the course, you are expected to have used secondary sources to identify evacuation drill procedures and assess their appropriateness in an emergency situation.

In an emergency response all groups involved should understand the risks, and what is possible and what is not. Priorities such as saving lives must be established and misunderstandings avoided.

See: http://www.ses.nsw.gov.au

Technological developments and preparing for disasters

Technological developments have improved our ability to prepare for disasters in the following areas:

Bushfires — improvements in the capacity and speed of data collection and analysis of weather patterns. This enables better prediction of bad fire seasons. For example, we now know that a reversal of normal wind and ocean current patterns in the Pacific causes El Nino which leads to drought along the eastern coast of Australia, and therefore increases the likelihood of bushfires. Fire ecology simulators are being developed by the CSIRO to look at fire management regimes and their consequences in different types of vegetation.

Earthquakes — a global network of more than 3000 seismographs helps scientists to locate the epicentre of an earthquake quickly. The Queensland University Advanced Centre for Earthquake Studies (QUAKES) is a world-class research centre investigating the physics of earthquakes through the use of computer simulations. Researchers at QUAKES are developing computer models for the entire earthquake process.

Meteorology — the precision and detail of observations from weather satellites has improved enormously. Individual thunderstorms can now be identified, and disasters associated with weather systems more closely monitored. Computer modelling can also predict wave heights and storm surge from incoming cyclones. Satellites also observe complete cloud formations associated with cyclones, cold fronts and other weather systems. Computer analysis of weather data uses a three dimensional grid in which the world is divided into about 3000 different squares. Wind speed, temperatures and so on are calculated in each square. Supercomputers use mathematical laws and fluid dynamics (models) to create situations which mimic what occurs in the atmosphere under a given set of conditions. Computer models also make climatic projections far into the future such as predicting how global warming will affect conditions on Earth. The CSIRO's supercomputer, launched in 1997, contributes to the Bureau of Meteorology's global modelling and research into climate change and ozone depletion studies, improved El Nino predictions, and air pollution studies.

Checklist Key terms for revision

- natural disasters
- disaster associated with human activity
- pressure
- atmospheric pressure
- isobars
- low-pressure system in the southern hemisphere
- high-pressure system in the southern hemisphere
- cyclones
- meteorology
- weather patterns
- satellites
- radar
- laser light
- earthquakes
- seismographs
- Richter scale
- P, S and L waves
- bushfires
- controlled burns
- bushfire precautions
- warning devices
- smoke and fire detectors
- fire extinguishers
- emergency services

Test Disasters

Short answer and longer response questions

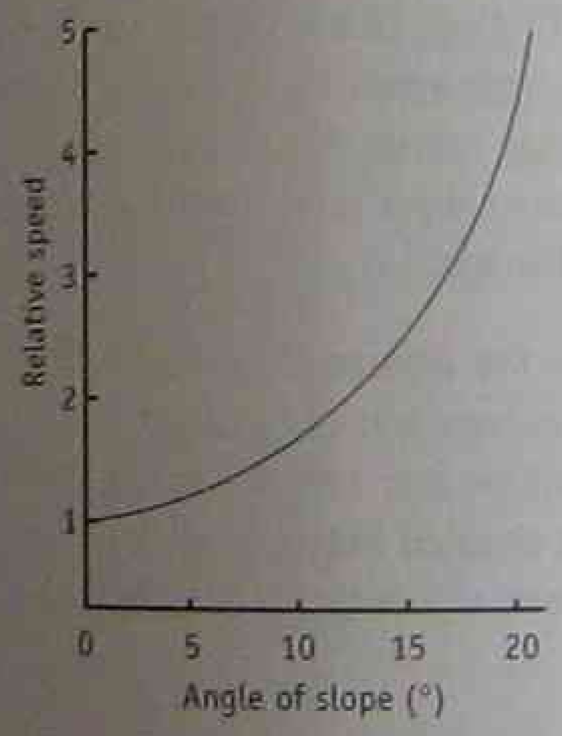
1. Severe tropical Cyclone Vance which devastated the northwest Australian town of Exmouth, produced a measured wind gust of 267 km/h, which is the highest wind speed ever recorded on mainland Australia. From your knowledge of the relative pressures involved in the formation of tropical cyclones, describe the likely air pressure as Vance approached Exmouth, when it hit and when it moved on. (3 marks)

(4 marks)

2. Use flow diagrams to represent the energy transfers and transformations involved in each of the following:
(a) Bushfires (2 marks)
(b) Commonplace warning and protection devices such as a smoke detector. (2 marks)

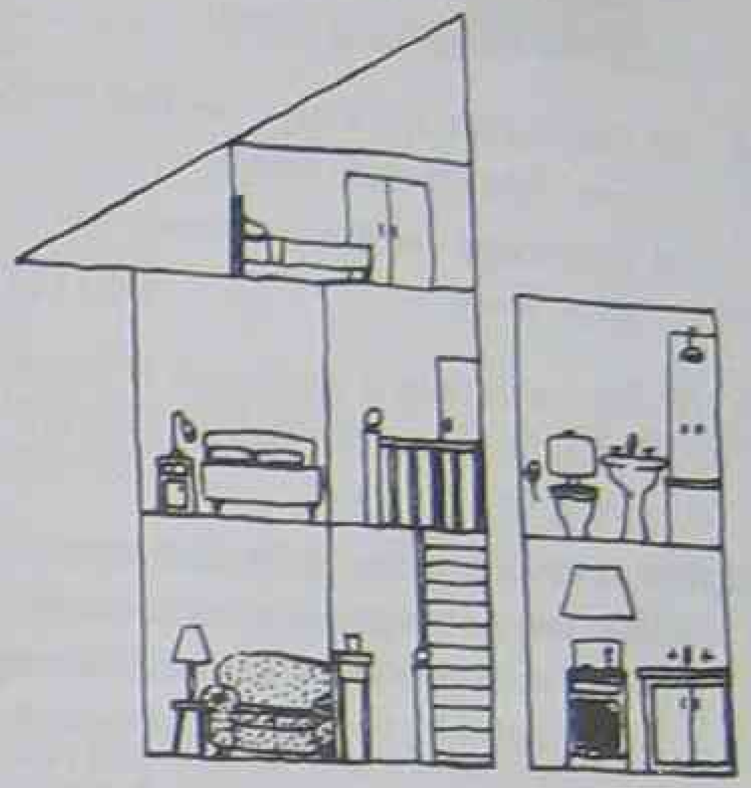
(7 marks)

3. The graph below shows the relationship between the slope of land and bushfire behaviour.



(a) Write a statement to summarise the data shown in the graph. (1 mark)
(b) List three other factors that may promote the spread of bushfire. (3 marks)
(c) Outline three precautions that householders can carry out to reduce the risk of home destruction by bushfire. (3 marks)

4. The diagram below shows a cross-section of a house. Mark on the diagram with a tick (√) four appropriate locations for smoke and fire detectors. Give a reason for your choices of location. Mark on the diagram an X to indicate where you would not locate smoke and fire detectors. Give a reason for your choice. (6 marks)



5. (8 marks)

For one natural disaster that has occurred within Australia, describe:
(a) When it occurred. (1 mark)
(b) Where it occurred. (1 mark)
(c) Consequences of the disaster. (2 marks)
(d) Techniques employed to reduce the incidence of damage next time. (2 marks)
(e) Techniques employed to monitor this type of disaster in the future. (2 marks)

Test answers

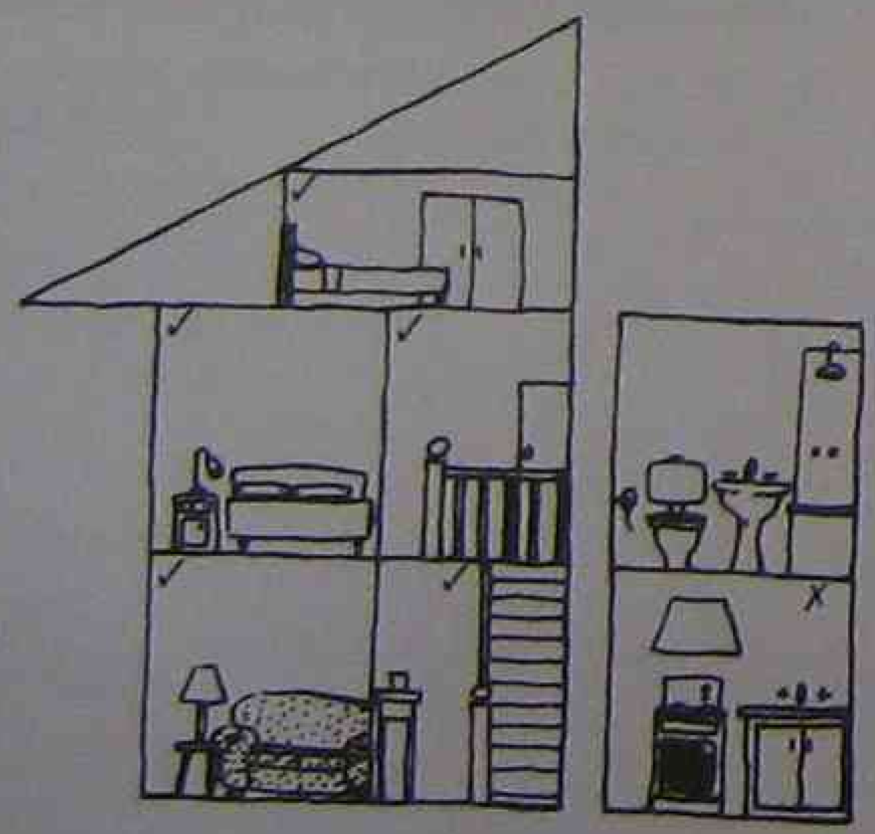
Short answer and longer response questions

1. The air pressure would have risen as Cyclone Vance built and approached the town. When it hit, the air pressure would have fallen dramatically and wind speeds increased dramatically. As Vance moved away, the air pressure would have risen again before returning to normal.

2. (a) Chemical potential energy → Heat energy → Light and sound energy
   (b) Light energy → Electrical energy → Sound energy

3. (a) Fire travels twice as quickly up a 10° slope as it does on level ground and four times as quickly up a 20° slope.
   (b) A build-up of flammable fuel (leaf litter, branches) on the ground; strong northerly winds; some types of native vegetation such as eucalypts with fibrous bark (see page 181).
   (c)
   - Clearing litter and wood piles from around the house
   - Cleaning gutters
   - Removing household rubbish and garden clippings, particularly from adjacent bush
   - Planting non-flammable screening vegetation
   - Fireproofing the house.

4.



Smoke alarms should not be installed near appliances such as air vents and air conditioners where the air flow could prevent the smoke alarm from sensing smoke particles. They should be installed in stairwells and in bedrooms and in areas that are most accessible.

5. (a) Ash Wednesday bushfires — in February 1983
   (b) In south-east Australia (Victoria and South Australia); the largest major fire area was in the south-east district of South Australia.
   (c) 75 people died, several thousand were treated for injuries caused by the fire and more than 2000 homes were destroyed. More than 335,000 hectares of agricultural and bush land was destroyed along with livestock and native flora and fauna. The total monetary value of the damage was somewhere around $430 million.
   (d) An inquiry was conducted into the disaster and recommendations made which included ways to reduce damage such as improving non-fire based hazard reduction techniques (see page 182) and public education. One of the findings coming out of the inquiry was that high winds brought power lines together causing sparks. Power lines now have spacers between them to prevent them touching in high winds.
   (e) Since the disaster, improvements in computer technology and the capacity and speed of data collection and analysis of weather patterns have enabled better prediction of bad fire seasons and better monitoring techniques.

SC Study Option

2 — Space Science

Introduction

You will only review this option if you have studied it. Remember, you only need to study one option for the HSC.

In this chapter you will review technologies which have enabled developments in space exploration and sustained life support systems to allow people to remain in space for extended periods.

As a result of working through this chapter you will be able to:

- Discuss advances in space science that have changed the direction or nature of scientific thinking
- Assess the impacts and implications of space science research on society and the environment
- Identify the effects of microgravity on the human body.

The atmosphere

The Earth's atmosphere

The term 'atmosphere' refers to the gaseous envelope or blanket which surrounds a planet. The Earth's atmosphere extends about 1000 kilometres above the Earth and becomes denser as you approach the surface of the Earth.

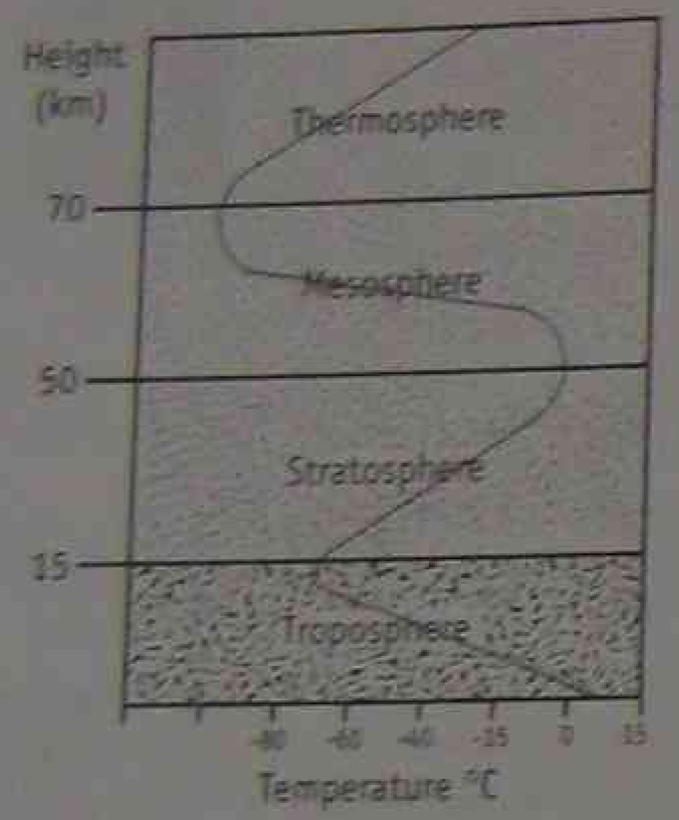


Figure 12.1 Zones of the Earth's atmosphere. More than 95% of the atmosphere's mass is concentrated in a narrow zone, about 15 kilometres high called the troposphere. Air pressure decreases in the upper atmosphere. The density of air is extremely low in the mesosphere and thermosphere.

The Earth's atmosphere contains mostly oxygen and nitrogen.

> The concentration of particles of gases is greatest near the surface of the Earth. Air becomes thinner as the distance from Earth increases.

The Earth's gravitational pull

The Earth's gravitational pull is a result of its magnetic field. The Earth's magnetic field extends up to 60,000 kilometres into space. At the surface of the Earth, acceleration due to gravity (g) is 9.8 metres per second each second.

> The Earth's atmosphere is held in place by the Earth's gravitational pull.

Why there is no such thing as 'empty space'

Space begins somewhere beyond 95 kilometres above the Earth. Outer space is not entirely empty. It contains particles of air, space dust, chunks of metal or stone called meteoroids and radiation.

It also contains a large number of artificial satellites. A range of different gases and escaped comets float between interstellar space (space between stars).

> As part of meeting the requirements of the course, you are expected to have used secondary sources to model the relative distance of particles in a solid, liquid and gas and in space.

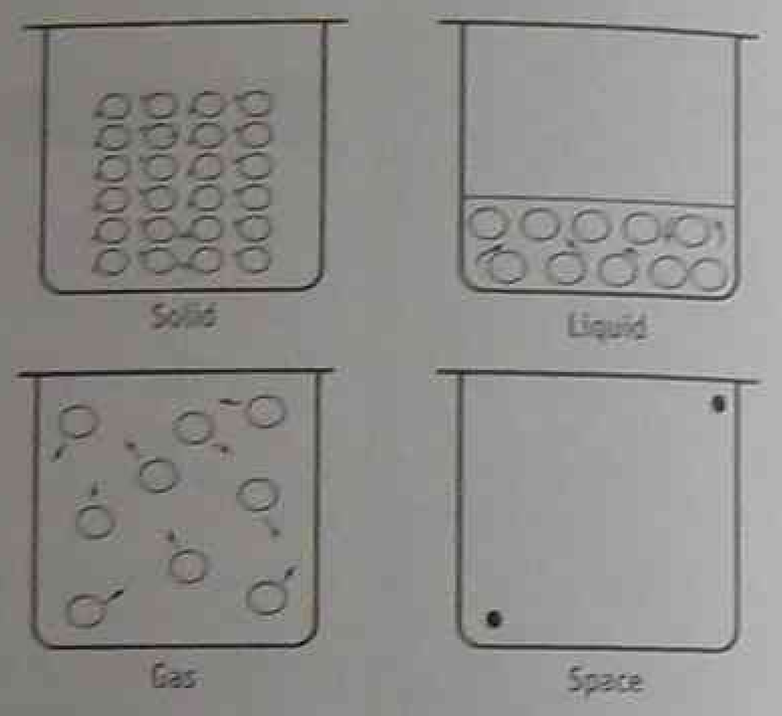


Figure 12.2 Diagrams to represent the relative distance of particles in a solid, liquid and gas and in space

The strength of gravity

The strength of gravity varies at different points in space. The Earth's gravitational pull varies proportional to the distance a body is from the Earth. As the distance from Earth increases, the strength of the gravitational field decreases.

The relationship between mass and gravitational pull

Gravitation is the force of attraction between objects because they have mass. The greater the mass, the greater the force of attraction. Gravitation keeps the planets in their orbit around the sun. It causes objects to fall to the ground. It keeps the moon travelling around the Earth. The moon's gravity causes tides on Earth.

A spacecraft can go into orbit around the Earth when it is at a sufficient distance so that the gravitational attraction is not strong enough to pull the spacecraft back to Earth and yet close enough to keep the spacecraft from travelling further into space.

Planets in our solar system

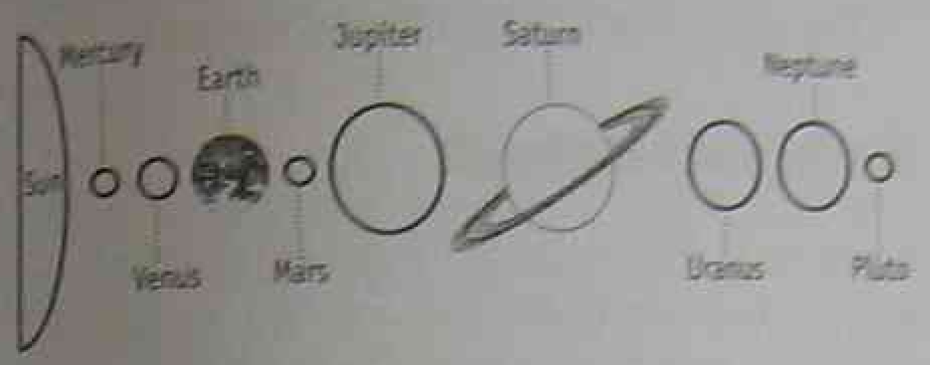


Figure 12.3 The planets of our solar system

Planet	Surface gravity *	Diameter km	→ relative mass*
Mercury	0.37 (Escape velocity — 4.2 km/sec)	4,880	0.05
Venus	0.90 (Escape velocity — 10.36 km/sec)	12,100	0.82
Earth	(Escape velocity — 11.2 km/sec)	12,755	
Mars	0.38 (Escape velocity — 5 km/sec)	6,790	0.11
Jupiter	2.64 (Escape velocity — 60.22 km/sec)	143,000	x318
Saturn	1.16 (Escape velocity — 36 km/sec)	120,000	x95
Uranus	1.2	51,800	x15
Neptune	1.67	49,500	x17
Pluto	?	3,500	

* relative to the Earth

Figure 12.4 A summary of planets in the solar system and their diameter, relative mass and gravity relative to the Earth. The relative mass of each planet is inferred from its gravity and diameter.

Reasons for apparent weightlessness of an object in orbit

> Astronauts and objects in space still have mass (therefore they still have weight and are not 'weightless'). The gravitation in orbit is only slightly less than the gravitation on Earth. So why do they experience weightlessness? Objects in orbit are in 'free-fall' towards the Earth. For example, astronauts experience weightlessness because their spacecraft and everything in it is in 'free-fall'. The spacecraft's tremendous forward speed carries it around the curve of the Earth. Therefore, astronauts experience reduced gravitational pull (or weightlessness).

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research why animals were sent into space before humans.

In the early days of space exploration, the effects of conditions in space, such as microgravity, on living things was not known. Animals were sent into space before humans in order for scientists to research the effects of a range of conditions that include: weightlessness (or microgravity); the absence of Earth-like atmosphere; bombardment by unfiltered ultraviolet radiation, X-rays, gamma rays and high-energy particles which are normally deflected by the Earth's magnetic field or absorbed by the atmosphere before they reach Earth. High-energy particles can penetrate spacecraft and damage living cells. Dust and space debris can also damage vehicles. Spacecraft usually have double hulls to protect against impact in space.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to identify situations on Earth where people experience 'weightlessness'.

Situations include free-fall situations in which a body is accelerating towards Earth at 9.8 metres per second (at the same rate as gravitational pull) and would therefore experience weightlessness — for example, skydiving and at certain points in roller coaster and other fun park rides.

The effects of reduced gravity in space on body function

All organisms on Earth have evolved in Earth's gravitational field. Therefore, gravity plays an important role in the functioning of cells, tissues and organs. Animals and plants have evolved a large number of automatic body responses to cope with the constant stress of living in a downward-pulling world. Only when we decrease or increase the effective force of gravity on our bodies do we consciously perceive the effect of gravity.

Human beings who have spent many months in space have suffered nausea, calcium deficiency, muscle weakening, anaemia and heart palpitation. Conditions of microgravity confuse an astronaut's organs of balance in the inner ear, and therefore their sense of direction. Fluids behave differently. Fluids in the body such as water no longer experience pull and undergo redistribution.

See: http://www.microgravity.com — for microgravity news and research.

Ingestion

Ingestion is swallowing. Ingestion occurs without the assistance of gravity by peristalsis — waves of contracting muscles along the oesophagus or food pipe which push the food down to the duodenum and into the stomach (see 'The digestive system' page 95).

Drinking fluids in a microgravity environment

Air pressure pushing on liquids enables us to drink fluids. In space there is no air and therefore no air pressure. Fluids must be squeezed out of containers. Liquids in space must be contained in squeeze bottles or the liquid will float away. Solid food is eaten from plastic pouches, and meals are packaged as ready-to-eat.

Foods must be lightweight, therefore most solid food is dried and water is added to it when needed.

As part of meeting the requirements of the course, you are expected to have used first-hand research to select the food to be included on a space mission, describing how it is to be stored and justifying your selection.

Your selection of foodstuffs should be based on criteria such as:

- Nutritional value and a balance of foods from the major food groups — proteins, carbohydrates, fruits, vegetables and fats
- Packaging — foods must be lightweight and able to be transported and stored easily
- Size of food particles — fine powdered foods can float away in a microgravity environment.

Gravity and bone health

Bones that are constantly working under impact such as the bones of the arms and legs are designed to provide maximum strength to the body. Gravity helps to maintain the strength and density of bones in the body.

✓ Bones no longer working against gravity (in conditions of microgravity) begin excreting calcium which reduces the density of the bones.

Gravity and muscle tone

Muscles in the body have to work against gravity. Therefore, gravity helps to maintain the strength of muscles.

✓ Muscles no longer working against gravity (in conditions of microgravity) become weak and atrophied (shriveled). The heart muscles, with no gravity to work against, shrink in size and heart and blood vessels become lazy.

As part of meeting the requirements of the course, you are expected to have devised a series of exercises for all major muscle groups of the body that could be performed within the confines of a spacecraft.

Bones and muscles in the legs, feet and arms and the spine which hold the body upright against gravity are the most likely to be weakened in conditions of microgravity. Exercises include walking on an attached, moving walkway (or treadmill) with the astronaut strapped to the walkway, rowing with a rowing machine and cycling on an attached stationary bicycle.

Circadian rhythms

✓ Circadian rhythms are behaviour patterns which match the 24 hour cycle of an Earth day, such as sleep patterns.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research human activities that disrupt circadian rhythms.

The most common disruptions to circadian rhythms in our society are shift work and long distance plane travel. The effects of disruption to these rhythms include lethargy, fatigue, headaches, insomnia and depression.

Maintaining normal circadian rhythms during space travel

Some ways in which normal circadian rhythms can be maintained during space travel include regular work schedules, regular sleeping and waking times which are set to Earth time and eye-shades to block out light while sleeping.

See: http://www.nasa.edu/ssb/csbml.html — for information from NASA on space biology and medicine.

The construction of rockets and shuttles

The components and materials used in the construction of rockets and shuttles must be able to withstand launch and re-entry conditions. Rockets and shuttles must be able to be launched with enough thrust to overcome the Earth's gravity to the point where the vehicle can travel into space and, in most cases, go into orbit around the Earth. Therefore, some kind of propulsion engine is needed. This usually comes from a launch rocket. To reach a height necessary to orbit the Earth, a spacecraft must travel at about 28,000 kilometres per hour. (To escape Earth's gravitational pull from an orbiting position, a spacecraft must travel at a speed of 40,000 kilometres per hour.) When the shuttle is ready to return to Earth, there must be a manoeuvring system to position it for re-entry. When a shuttle re-enters the Earth's atmosphere, the outside of the vehicle is heated to temperatures of 300°C to 5500°C. Therefore, a protective coating or heat shield, made of silica, is needed to prevent the vehicle from melting.

All launch vehicles require two or more rocket sections or stages (a multistage system). The first stage provides the thrust to leave the Earth's surface. The thrust is provided by burning a special mixture of fuel (propellant) and expelling gases. The second stage provides the propulsion needed to put the craft into orbit in space.

Lift-off

During lift-off a rocket must accelerate fast enough to escape Earth's gravitational pull. The maximum acceleration is three times that of gravity. The rocket must be able to escape the Earth's gravity without burning up or veering off course. The amount of fuel needed for combustion of engines and propulsion into space weighs hundreds of tons.

During lift-off (and landing) astronauts must be seated in such a way as to overcome the physical effects of acceleration and deceleration. During lift-off astronauts must be positioned so that their blood is not pulled from their head to their lower body, causing dizziness or unconsciousness.

The Space Transportation System (STS) or space shuttle

The STS or space shuttle is a winged space plane which is designed to transport humans and equipment into space and return to Earth. The shuttle requires a multistage rocket system for lift-off.

✓ The components of the space shuttle include:

- The orbiter with three main engines and a cargo bay.
- Two solid rocket boosters (SRB) which contain enough solid propellant fuel to propel the orbiter and external tank to an altitude of 45 kilometres. The SRB also support the weight of the STS when it is on the ground.
- An external tank which contains liquid propellant (fuel) for the three main orbiter engines.

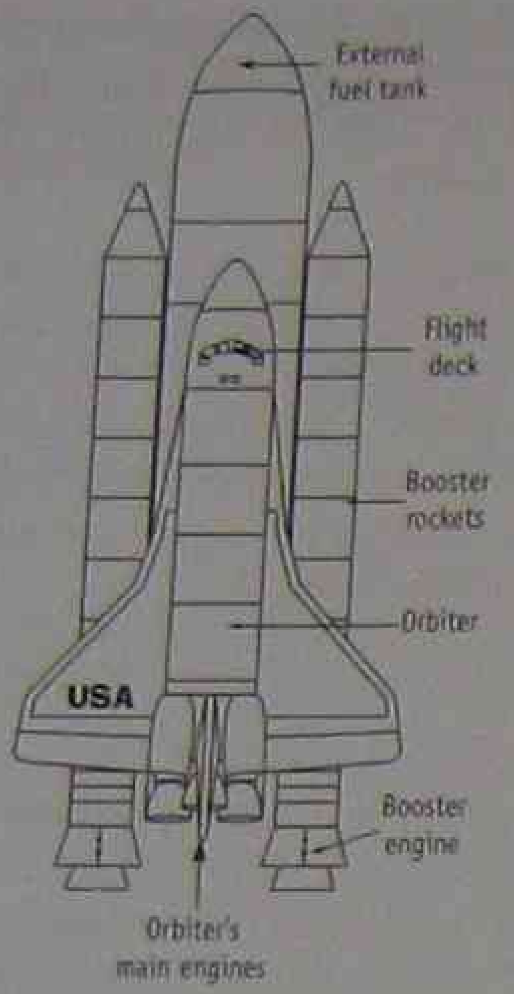


Figure 12.5 (a) The Space Transportation System showing its main components and their functions.

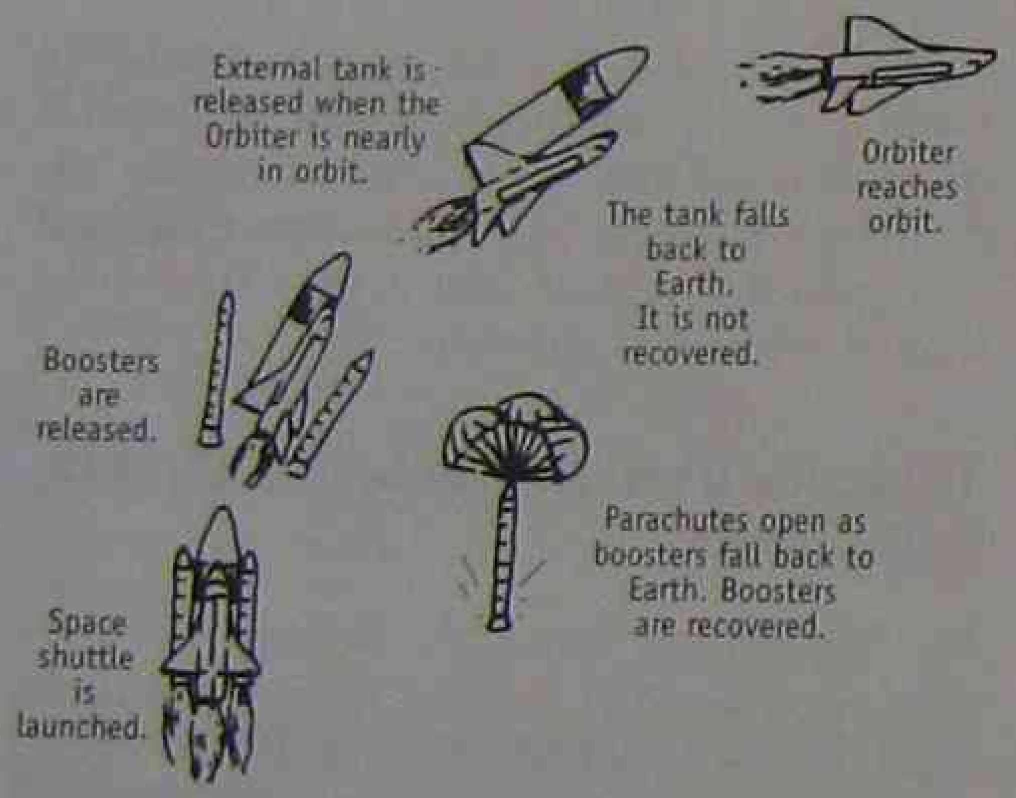


Figure 12.5 (b) The two booster rockets and main engine provide the thrust for take-off. After about two minutes of flight, the boosters separate from the orbiter and return to Earth by parachute. The main engines continue to fire until the orbiter has reached orbital velocity. The external tank is then discarded and falls to Earth. Small engines on the orbiter push the vehicle into its orbit.

As part of meeting the requirements of the course, you are expected to have used secondary sources to:

(a) Trace changes in the type of systems that have been used in space travel, and

(b) Research the advantages and disadvantages of using a shuttle.

(a) To enable space travel, engines had to be designed which did not need to 'use' air from the atmosphere to burn the fuel (a rocket motor), a type of fuel that creates enough thrust to propel a rocket away from the Earth's gravitational pull (propellant) and a way of propelling a rocket in space when there is no resisting atmosphere.

The first type of liquid propellant rocket motor was fired in 1926. The rocket was small and only reached a maximum speed of 97 km/hour but its principle was used to further develop rockets. The rocket principle was then used to develop missiles during World War I. In 1949 the USA launched a rocket which reached an altitude of almost 400 km.

Between 1954 and 1975, the cold war between the Soviet Union and the United States of America influenced the development and high rate of progress in space technology. This was known as the space race. In 1969 the USSR launched the first person into space. The rocket orbited the Earth once in 89 minutes at a height ranging from 180 km to 301 km before returning to Earth. Early rockets were unreliable, often exploding during lift-off or on re-entry. Rockets are now more reliable and less likely to explode. One of the reasons for this, is developments in technologies in how to make, combine and supply fuel to boosters and engines, as well as developments in material science, such as silica fibre tiles.

See: http://au.yahoo.com/science/Space/Exploration/History

http://liftoff.msfc.nasa.gov — lift-off to space exploration.

(b) The first space shuttle *Columbia* was launched in 1981. One of the most famous shuttles was *Challenger* which exploded at take-off in 1986, killing all seven people on board.

The advantage of the shuttle is that the orbiter can return to Earth and be re-used many times. For example, space shuttles transport astronauts, supplies and modules to and from space stations and carry re-useable space laboratories.

The disadvantage of the shuttle is the expense of launching the spacecraft. A huge amount of money is wasted when launching a multistage rocket because much of it, such as the large external tank, is lost (not re-used).

Booster rockets

Large booster rockets contain enough of the propellant fuels that are needed to provide the thrust, to accelerate a rocket fast enough to escape Earth's gravitational pull and push the spacecraft into orbital velocity.

As part of meeting the requirements of the course, you are expected to have carried out an experiment to show why a large booster rocket is required during lift-off but not on re-entry.

On re-entry, the Earth's gravitational forces pull the space vehicle down to Earth, so the rocket is not required. Returning to Earth, however, presents other problems that include:

- Decreasing a spacecraft's speed
- Getting the right direction for re-entry into the atmosphere and
- Protecting the spacecraft from the heat that results when air is squeezed in front of the spacecraft.

Materials used in the STS

The materials used in the STS include:

- **Solid rocket fuel** which is shaped into pellets and contains both an oxidant and fuel. The oxidant is needed for the fuel to burn and release energy. The fuel is packed into a container in such a way that it can provide maximum burning surface area and therefore maximum thrust for lift-off.
- **Liquid rocket fuel** which produces more thrust for every second than solid propellant but is more difficult to handle. The external tank contains liquid hydrogen fuel and liquid oxygen (the oxidant). On lift-off, the propellant fuel accounts for nearly 90% of the weight of the STS. This provides extra fuel for the orbiter engines during lift-off.
- **Special heat-resistant tiles** which cover the orbiter and provide for thermal protection on re-entry. Some tiles provide insulation and protect the hottest parts of the orbiter such as the edges of the wings and the nose tip. Some tiles have a shiny black coating to re-radiate re-entry heat.

As part of meeting the requirements of the course, you are expected to have researched the plans for future space vehicles.

Future space vehicles will include **single-stage-to-orbit spacecraft and nuclear powered spacecraft** which use modern technologies, such as light but very strong materials, new rocket engine designs and new lifting body designs.

Single-stage-to-orbit spacecraft do not need multi-stage rockets, such as the shuttle's boosters and external tank, for lift-off. It is hoped that this type of space vehicle will help to reduce some of the costs of space travel.

See: http://www.space.popsci.com/space — for missions planned between 2000 and 2005.

Space stations and probes

Space stations and probes are sent into space to gather information about planets, the moon, comets and asteroids. Information from instruments such as cameras, carried on the space station or probe, is sent back to Earth as radio signals and detected by radio telescopes. Some probes are also designed to land on planets.

Space stations

Space stations are designed in such a way that astronauts can live and carry out research in space for long periods. The first space station, *Salyut 1*, was launched by the Soviet Union in 1971. The United States launched *Skylab* in 1973.

Information is transmitted between Earth and space stations via satellites.

Space stations used in space include *Mir* and the International Space Station (ISS).

The ***Mir (Peace) Space Station*** was the culmination of the Russian space program's efforts to maintain long-duration human presence in space. The core module was launched in 1986 and other modules continuously added to it over time. Since 1987, some astronauts spent more than a year at a time in the station. *Mir* floated at 390 km above Earth. By the year 2000, it had completed over 82,150 orbits.

Research on *Mir* focused on the effects of microgravity on humans and observational sciences such as atmospheric, topographical and oceanic studies. The results of research on space stations such as *Mir* have led to the design and development of new technology such as new space platforms and new debris protection materials and devices.

Mir was decommissioned and taken out of orbit in March 2001.

See: http://www.maximov.com/Mir/homepage.asp — for information on *Mir*.

The ISS was launched by the USA and Russia in 1998. Other countries have since contributed elements to the station. It can be seen at certain times as the second brightest object in the night sky. The ISS carries a permanent crew. Astronauts from many countries carry out a wide range of research programs such as the effects of microgravity on fluids and materials and on processes such as cellular metabolism and air flow. Crew members also perform space walks. Space shuttles visit the station and bring new elements to the construction. Solar energy powers the station. The ISS circles the Earth once every 90 minutes and has completed 9000 Earth orbits since 1998. Reference: *Engineers Australia*, July 2000, pp. 24–27.

See: http://www.nasa.gov/index-n.html — for information and updates on ISS.

Sustaining human life on space stations

The requirements that are necessary to sustain human life include:

- Life support systems — food, oxygen, water and systems for removing wastes such as carbon dioxide, urine and faeces. Fuel cells generate electricity and produce pure water. Dehumidifiers remove water from exhaled air. Portable life support systems are used for work outside the space station.
- Systems for minimising infections and diseases, dealing with injury and maintaining health.
- Air pressure at a level close to that on Earth and a system for circulating the air. (In conditions of microgravity, hot air does not rise and droplets of water, dust and other 'escaped' objects float about.)
- Temperatures which maintain comfort levels.
- Ways to store and keep track of rubbish.
- Special exercise equipment to prevent loss of bone strength, loss of muscle tone and maintain good circulation.
- Protection from harmful direct sunlight and forms of high-energy radiation, high-energy particles and extreme changes in temperature. Cosmic radiation can cause weak bones, weak immune systems and cancer.

Optical telescopes

Optical telescopes can be ground-based or orbiting on satellites.

> ✓ Ground-based optical telescopes must be situated on high mountains where the sky is dark and where there is a clear, stable, transparent atmosphere and no interference from artificial light and natural light such as the aurora. Factors to consider when choosing a site for a large, optical telescope also include the number of good clear nights in the local area, the part of the sky to be examined and the amount of dust and water vapour in the atmosphere.

Telescopes, satellites and probes

The Hubble Telescope — the Hubble telescope is a space telescope in orbit 600 km above the Earth's surface. The Earth's atmosphere distorts light that reaches ground-based telescopes. Being above the atmosphere, the Hubble telescope has much greater resolution (see page 195). The Hubble telescope is a reflecting telescope which gathers images, such as star formations, from space. It also contains cameras and spectrographs which are sensitive to infra-red, visible light and ultraviolet. Hubble, for example, has discovered a star that is 10 million times as bright as the sun.

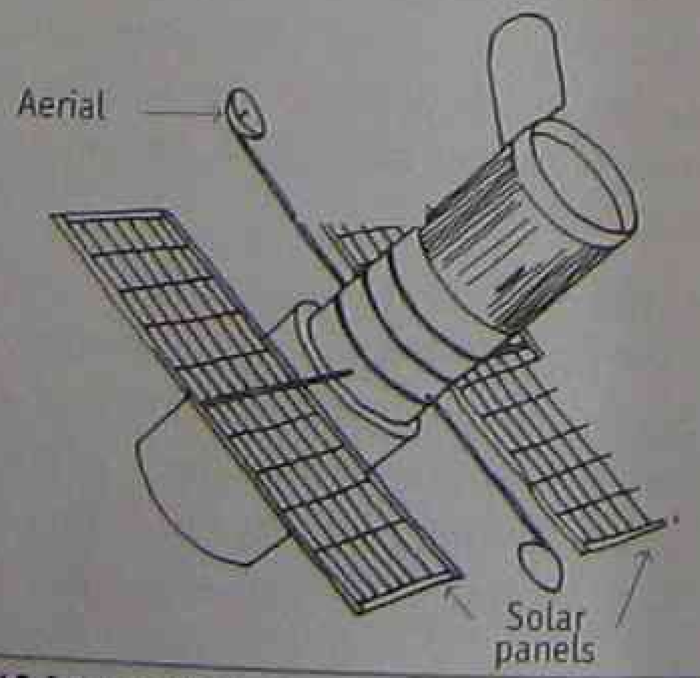


Figure 12.6 A simplified diagram of the Hubble Space Telescope

ttp://www.hubble.gsfc.nasa.gov and www.opposite.stsci.edu/pubinfo/latest.html updates on the latest Hubble Space telescope ations.

Long Baseline Array (VLBA)

Long Baseline Interferometry or VLBI) — the wavelength of radio waves is much than that of visible light (see Chapter 7), the on (the degree to which a photo has clear images) of a radio telescope is much lower that of an optical telescope of the same eter. Radio interferometry is a technology can produce extremely sharp images. In radio ferometry, computers at a central receiving combine the data from a number of radio es. The combined data is equivalent to that could be received from a very large dish — a much larger than any that exists and which d need a diameter roughly equal to the diameter the Earth. The VLBA consists of a system of ten ectors spread across one side of the Earth. The BA in New Mexico is the world's most powerful nd-based radio telescope.

e space VLBI is a new satellite technique which ends radio interferometry baselines into space. e VLBI Space Observatory Program is led by the itute of Space and Astronautical Science, USA d the National Astronomical Observatory of Japan. e first VLBI satellite was successfully launched in 97. The satellite was renamed HALCA (**Highly vanced Laboratory for Communications and tronomy**) after successfully deploying an 8 metre meter radio telescope in orbit. HALCA enables BI observations on baselines up to three times ger than those achievable on Earth.

ormation gathered by the VLBA includes observations of nearby stars, images of distant quasars, measurements of gamma-ray bursters and photographs of supernovae and extended stellar atmospheres.

See:

ttp://www.nrao.edu/vlba/obstatus/obssum.vlba/obssum.vlba.html

ttp://www.aoc.nrao.edu/vlba/html

ttp://www.vsop.isas.ac.jp/

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research the roles of the Voyager 1 and Voyager 2 space probes in furthering our understanding of space.

Voyager 1 was launched by NASA on September 5 1977 and made its closest approach to Jupiter on March 5 1979 and Saturn on November 12 1980 before heading into interstellar space.

Voyager 2 was one of the most successful space probes. Voyager 2 left Earth in August 1977, visited Jupiter (in July 1979), Saturn (in August 1981), Uranus (in January 1986), and Neptune (in August 1989). In each case, the probe used the gravitational field of one planet to propel it toward the next without the need for additional rocket motors. Thrusters were used to align the probe and its instruments.

The Voyager probe measurements included:

- The strength, shape and direction of planets' magnetic fields
- UV rays, visible light, infra-red and radio waves given off by the planets and their satellites.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research the developments in technology that have helped us identify the different aspects of the night sky.

Humans have long gazed with amazement at the night sky. Ancient star gazers mapped the stars and made constellation patterns — zodiacs. Before telescopes, humans were able to calculate relative distances of the sun and moon and directly observe the planets Mercury, Venus, Mars, Jupiter and Saturn. Developments in technology have enabled us to identify and explore an increasing number of different components in the night sky. Scientists have discovered new galaxies and spatial phenomena such as active galaxies, quasars, and neutron stars because of the assistance of telescopes in space and the use of electromagnetic spectra and X-ray emissions devices.

Some further ideas about developments in technology are listed below.

- One of the most important technological developments in astronomy was the optical telescope.

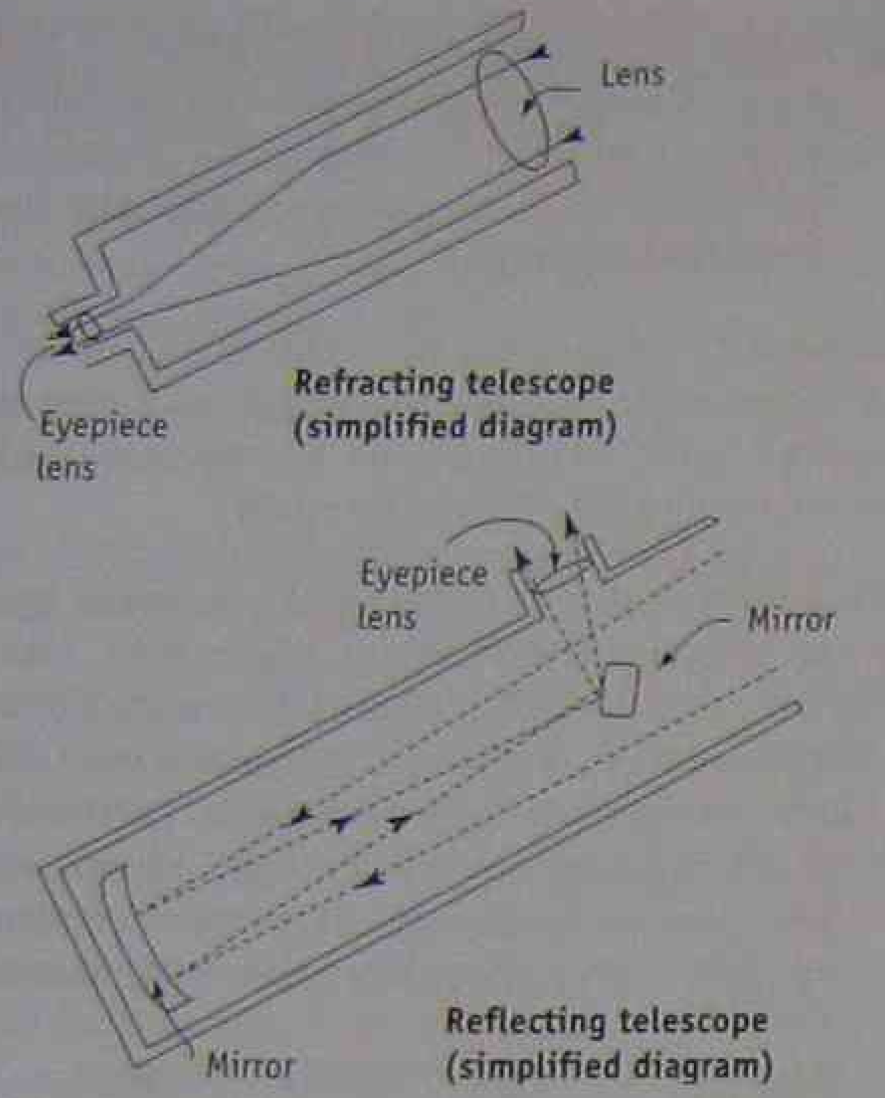


Figure 12.7 Two types of optical telescope: **refracting** telescopes developed during the first decade of the seventeenth century, and **reflecting** telescopes, the first example of which was made by Sir Isaac Newton in 1671.

- The optical telescope uses visible light from a body such as a star so that we can see its detail. Telescopes have a much larger aperture than the human eye and therefore can collect much more light.
- Giant telescopes were developed and housed in observatories. These enable large areas of the night sky to be photographed.
- Up until the 1920s, astronomers relied on visible light coming from objects in space. Visible light makes up only a small part of the electromagnetic spectrum (see Chapter 7). Many objects in space emit other types of wavelengths. Most infra-red radiation, some radio waves, ultraviolet, gamma rays and X-rays are absorbed by the Earth's upper atmosphere. Therefore, ground-based optical telescopes only provide us with information about some of the components of the sky.
- In 1931, the discovery of radio waves from the Milky Way led to the development of radio telescopes. Radio telescopes enable astronomers to identify components from greater distances such as pulsars (which emit regular beats of very high intensity radio waves), quasars and galaxies beyond our solar system.
- Radar telescopes provide information such as the rotation periods and surface conditions of planets.

> The development of telescopes which can detect infra-red, X-rays, ultraviolet and gamma rays and can be launched in orbit beyond the Earth's atmosphere has led to an ever increasing understanding of the universe.

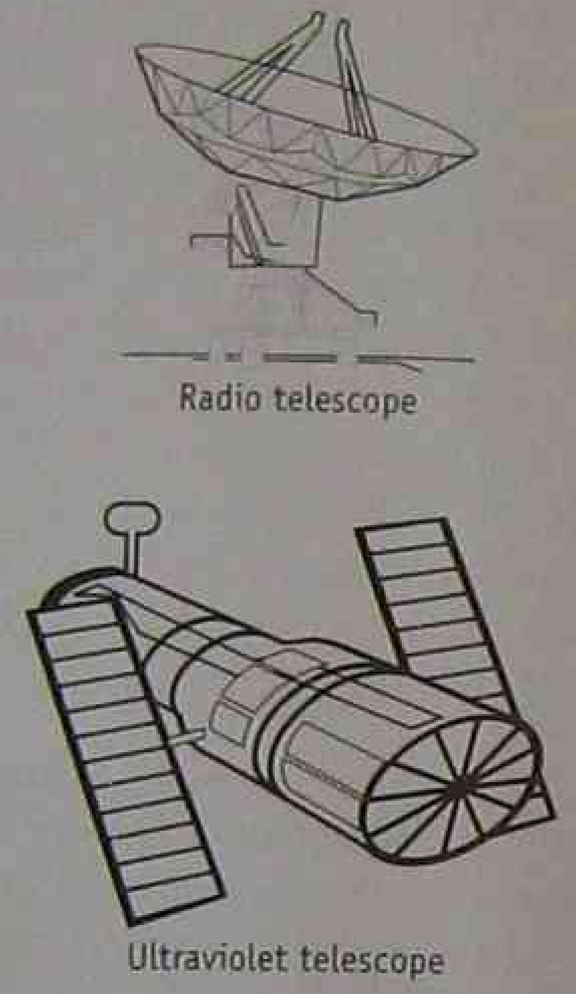


Figure 12.8 The radio and ultraviolet telescopes

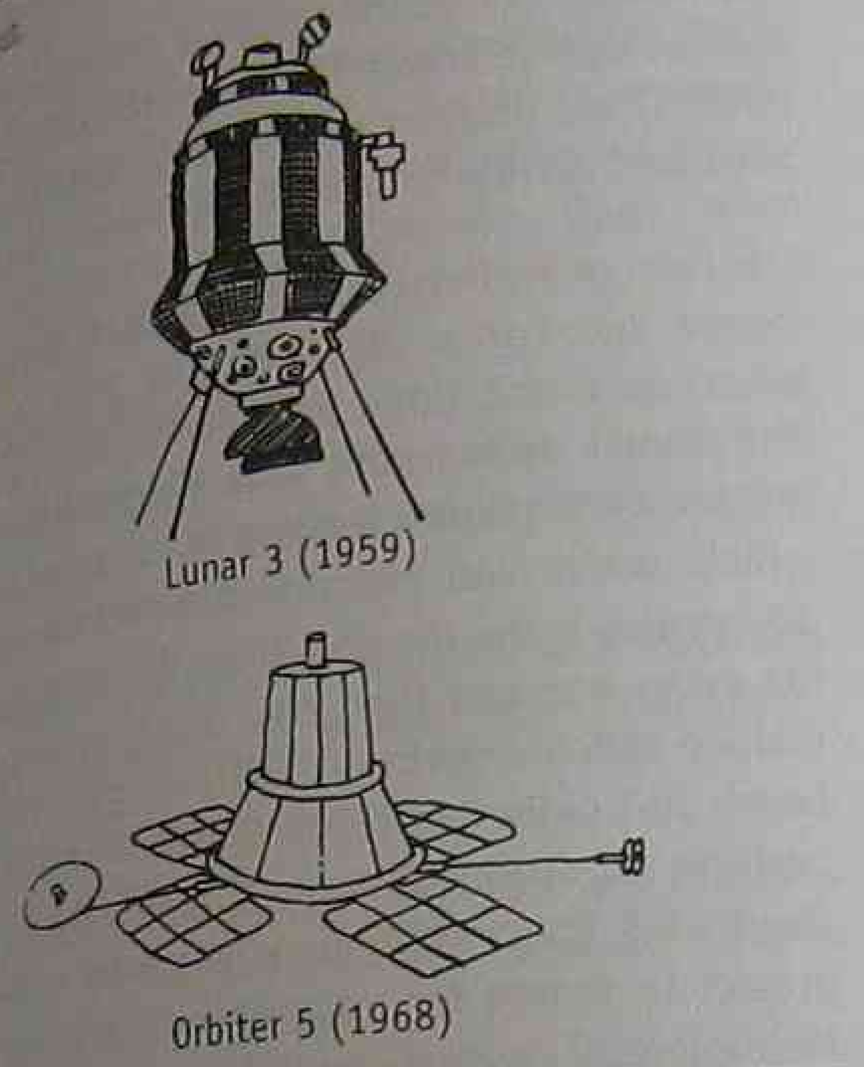
Infra-red research has provided information about the evolution of star systems. X-rays and gamma rays are emitted by galactic centres and black holes.

- In 1995 the USA launched the X-ray telescope, XTE, into the Earth's orbit.
- Developments in ground-based telescopes make it possible to correct the blurring of images caused by the atmosphere. These adaptive optical systems correct the wavefront of light before it reaches the focus of the telescope.

> As part of meeting the requirements of the course, you are expected to have used secondary sources to research ways in which information about our solar system and beyond has been collected over time.

More than 4000 spacecraft have been sent into space since 1957 to collect information about our

system and beyond. Most of these spacecraft rried telescopes and cameras. They include s, probes, piloted spaceships and space Some of these spacecraft have returned to Others such as the Voyager 2 space probe have d beyond the solar system into interstellar Some satellites re-enter the Earth's atmo- and burn up. Others are left to forever orbit



re 12.9 Early space probes

me further points are listed below.

- The world's first artificial satellite was launched by the Soviet Union in 1957. *Sputnik 1* was about the size of a football and carried a radio transmitter.
- In 1959 the Soviet Union launched three unmanned space probes (Lunar 1, 2 and 3) to collect information about the moon. Lunar 9 landed on the moon in 1966 and provided information that the moon's surface was firm enough to support the weight of a space vehicle. Lunar 16 landed on the moon in 1970 and collected lunar rocks before returning to Earth.
- In 1962 the USA probe Mariner 2 sent back information to Earth about the surface of Venus.
- In 1964 the USA probe Ranger 7 sent back close-range photographs of the moon before crashing onto the moon's surface.
- In 1965 the USA launched the first successful space probe to Mars.
- In 1969 the USA landed men on the moon in Apollo 10. The Apollo program was the first of a number of lunar landings with astronauts.
- In 1971 the USA launched Mariners 8 and 9. Mariner 9 was the most successful Mars probe to date and contained Earth-controlled cameras which collected new information about the planet.
- In 1974 the USA's Mariner 10 sent back pictures of Venus and Mercury.
- Two Soviet probes landed on Venus in 1975 and transmitted pictures to Earth via an orbiting section of the probe.
- The USA's Pioneer 10 was launched in March 1972. It reached Jupiter in December 1973 and sent back information about Jupiter's magnetic field and radiation zones. Pioneer 11 passed Saturn in 1974.
- In 1976 two Viking landers were sent to Mars. The landers relayed information to Earth via an orbiter.
- In 1986 two Soviet probes flew past Venus and studied Halley's Comet as it passed by the sun.
- In October 1989 the Galileo probe was launched. It passed Venus in January 1990 and reached Jupiter in 1995.
- In 1993 the US space probe mapped the moon from orbit.
- In November 1996, NASA launched the Mars Global Survey probe to map the planet's surface.
- In December 1996, NASA launched the Pathfinder probe which landed on Mars in July 1997. The probe carried the Sojourner vehicle which was wheeled onto the surface of Mars to gather data. Information from Sojourner was transmitted to the Pathfinder probe and then to Earth.
- In December 2000, a far-ultraviolet camera on board NASA's IMAGE spacecraft captured images of normally invisible ion auroras.

See: http://www.sciam.com — *Scientific American* for articles on space exploration such as 'The Galileo Mission to Jupiter and its Moons' (February 2000) and 'A New NASA Satellite' (April 2000).

See also: http://www.abc.net.au/science/news for updates.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research Australia's involvement in space exploration.

- In November 1967, Australia developed and launched a small scientific satellite (WRESAT) from Woomera, making Australia only the fourth country to launch its own satellite.
- In 1969, the Parkes telescope took part in the world-wide transmission of pictures of the first landing on the moon. In July 2001, the Parkes radio telescope measured the distortion of space-time 450 light years from the Earth.
- CSIRO's Australia Telescope is the first radio telescope in the Southern Hemisphere which is able to make detailed pictures of evolving galaxies and the birthplace of young stars.
- In December 2000, scientists from the Anglo-Australian Observatory and the UK and USA announced the discovery of three new planets comparable in size to Jupiter and about 150 light years from Earth. Eight new planets were discovered in October 2001 as part of the Anglo-Australian Planet Search (AAPS).

For updates on Australia's involvement in space exploration such as radio astronomy and SETI, see:

http://www.abc.net.au/science/news

http://www.powerup.com.au/~woomera/wresat.htm — for information on WRESAT

http://au.yahoo.com/regional/countries/australia/science/space/satellites — for the history of Woomera

http://www.atnf.csiro.au — the Australian Telescope National Facility

http://www.csiro.au — the CSIRO site.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research some of the precautions necessary to protect against radiation in space.

Space flight involves high levels of radiation. An astronaut spending one year in a moderately inclined, low-Earth orbit would receive a radiation dose ten times greater than the average dose received on the ground. The sun gives off dangerous radiation (see page 189), which we are largely protected from on Earth by the atmosphere. (Holes in the ozone layer are getting bigger and allowing greater amounts of UV radiation to penetrate to Earth.) Filters are installed on spacecraft windows to protect against radiation. Astronauts can also retreat to special shielded rooms. Thermal control systems inside the spacecraft regulate the temperatures. Helmets worn in space walks have filters to block solar radiation.

The search for extraterrestrial life

The Search for Extraterrestrial Intelligence (SETI) and the Optical Search for Extraterrestrial Intelligence (OSETI) are projects which aim to identify life and advanced civilisations in the universe.

Life has not yet been found anywhere in the universe except on Earth. In 1995 and 1996 however, scientists found three new planets in our galaxy. The planets circle nearby stars. The two most recently discovered planets seem to be at a temperature at which water can remain in liquid state. These discoveries make the possibility that extraterrestrial life exists stronger than ever. Search missions now include optical searches (OSETI) using high-powered lasers and radio telescopes across the world which perform an all-sky survey. In 1989 NASA initiated the HRMS (high resolution microwave survey), a project to search for microwave radio evidence of technological civilisations in space.

See: http://www.seti-inst.edu/ — for the SETI Institute

http://www.coseti.org/ — for the Columbus Optical SETI observatory.

The impact of technologies developed for space exploration

Spacesuits

Spacesuits are designed for different conditions in space. A spacesuit designed for space walks is very different, for example, to a spacesuit designed for wearing inside a space vehicle. Spacesuits generally must:

- Be high temperature-resistant and airtight
- Be projectile resistant
- Protect the wearer from powerful solar radiation
- Provide some kind of in-built cooling mechanism and ventilation

- Provide for ease of movement and mobility
- Provide life-support systems — oxygen and water and a way to get rid of carbon dioxide
- Have a way of maintaining air pressure
- Have in-built communication systems
- Have tough outer coverings to prevent tears.

Spacesuits consist of:

- Many layers of material with tight mechanical seals; suits designed for space walks are made up of 21 layers of material. The layers are made of materials such as nylon and teflon which are flexible, strong and lightweight. Suits worn inside spacecrafts have only six layers.
- Flexible heat reflectors
- Gloves which are thin and flexible but protect the astronaut from radiation, temperature extremes and projectiles
- A helmet which protects against solar radiation and, at the same time, provides good visibility
- Liquid-cooled underclothes
- A backpack which provides oxygen and removes carbon dioxide and moisture, and contains a radio for communication.

Many of the spin-offs from space programs that have impacted on consumers include life support systems, pacemakers, thermal blankets, ceramics, miniaturisation of computer systems, calculators, mobile phones, composite materials from carbon fibres, foodstuffs, and packaging materials.

- During the 1960s and 1970s, advances in electronic communication and space travel required new kinds of ceramics. The introduction of high-speed spacecraft required heat-resistant ceramic coatings and engine linings. These developments led to the discovery of ceramic superconductors in 1986. Superconductors are substances which conduct electricity with no resistance at extremely low temperatures.
- The process of freeze-drying food was first used in the 1950s to provide lightweight ration packs for astronauts.

See: http://Lsda.jsc.nasa.gov — for the NASA life sciences data archives and space flight experiments conducted since 1961.

As part of meeting the requirements of the course, you are expected to have used secondary sources to research spin-offs from space programs and their impact on society, and debated the value in continuing the space program.

Some more spin-offs from space programs include:

- Microgravity experiments with fire which will lead to greater understanding of the mysteries of combustion. Combustion is extremely important in our modern society yet little is known about the process. One thing we do know is that gravity plays an important role, therefore studying flames in zero gravity can help scientists to better understand the process.
- Greater insights into protein structure and function. In conditions of microgravity, protein crystals can be grown with a purity that is impossible on Earth. By analysing the space-grown crystals, it is possible to map their structure and learn how they operate in the human body.
- An increased understanding of how the human body works on Earth, which has come about by studying the effects of microgravity on the body in space. For example, loss of balance and loss of bone mass (which occurs in women after menopause) is now better understood.
- Greater insights into the ageing process on Earth. The effects of space travel on the body resemble some of the conditions of ageing.
- The development of ZBLAN, a new substance with the potential to revolutionise fibre optics communications. ZBLAN fibre optic cable is manufactured in space and has the potential to carry 100 times the amount of data conveyed by conventional silica-based fibres.
- Developments of other new materials such as Aerogel, an extremely good insulator and the lightest solid known to humans.

Many would argue that the value of spin-offs from space research justifies the continuation of investigations into space. Others argue that the cost of space research is far too great and takes funding from more important areas of research and development, such as solutions to global warming, ozone depletion and environmental degradation on Earth.

Checklist — Key terms for revision

- the Earth's atmosphere
- gravitational pull
- planets in our solar system
- ingestion
- reduced gravity and body functions
- circadian rhythms
- the Space Transportation System (STS)
- advantages and disadvantages of using a shuttle
- lift-off and re-entry
- the MIR space station
- the International Space Station (ISS)
- optical telescopes
- the Hubble telescope
- Very Long Baseline Array (VLBA)
- ground-based satellites (GBS)
- the Search for Extraterrestrial Intelligence (SETI)
- Optical Search for Extraterrestrial Intelligence (OSETI)
- Voyager 1 and 2 space probes
- Australia's involvement in space exploration
- radiation in space
- spacesuits and their properties
- spin-offs from space programs
- Highly Advanced Laboratory for Communications and Astronomy (HALCA) satellite

Test — Space Science

Short answer and longer response questions

1. Silica fibre tiles are used to cover about 70% of the orbiter of the Space Transportation System. The silica fibre tiles can withstand heat between 648°C and 1260°C. How is the property of this material related to conditions encountered in re-entry? (2 marks)
2. Discuss the reasons for apparent weightlessness in orbit. (2 marks)
3. Where on Earth could you experience weightlessness? (1 mark)
4. A variety of plants grown in orbit are deficient in lignin. Lignin is the structural fibre which helps plants grow upright against gravity. Explain how the loss of lignin in plants is similar to the effects of apparent weightlessness on the human body, and describe two other impacts of apparent weightlessness on body function. (4 marks)
5. Discuss two advances in space science that have come about as a result of developments in technology. (4 marks)
6. Assess the impacts and implications of space science research on society. (4 marks)
7. Describe the functions of the three main components of the Space Transportation System (STS), commonly called the space shuttle. (6 marks)
8. What is SETI? Describe two technologies that are used in SETI. (3 marks)

Test answers

Short answer and longer response questions

1. When a shuttle re-enters the Earth's atmosphere, the outside of the vehicle is heated to very high temperatures. The silica material provides a protective coating which helps prevent the orbiter from melting.
2. Apparent weightlessness in orbit comes about because of reduced gravitational pull as a result of the object being in free-fall towards the Earth or being placed at a very great distance from massive objects like Earth.
3. In free-fall situations in which a body is accelerating towards Earth at 9.8 metres/second (at the same rate as gravitational pull) — for example sky-diving and at certain points in a roller-coaster ride.
4. Bones in conditions of apparent weightlessness begin excreting calcium which reduces the density of the bone tissue. Apparent weightlessness confuses an astronaut's organs of balance in the inner ear, and therefore their sense of direction. Muscles no longer working against gravity become weak and shriveled.
5.
   - The use of radio telescopes — radio telescopes enabled astronomers to identify components from greater distances such as pulsars (which emit regular beats of very high intensity radio waves), quasars and galaxies beyond our solar system.
   - The use of satellites — enabled scientists to launch telescopes into space above the Earth's atmosphere. (The Earth's atmosphere distorts light that reaches ground-based telescopes and absorbs radiation from other bodies in space). See page 196.
6. Impacts include:
   - Developments in rocket technology are used in weaponry — missiles and other weapons which are capable of mass destruction from great distances.
   - Spin-offs such as everyday consumer products which were developed specifically for space travel (such as space blankets, freeze-dried food and mobile phones).
   - Greater understanding about the human body as a result of space medicine, see page 199.
   - The development of new substances in space, such as new fibre optic technology (see page 199), which would not be possible to make on Earth.
   - The development of new plant crops in conditions of microgravity.
7. The components of the space shuttle include:
   - The orbiter with three main engines and a cargo bay. Small engines on the orbiter push the vehicle into its orbit.
   - Two solid rocket boosters which contain enough solid propellant fuel to propel the orbiter and external tank to an altitude of 45 kilometres.
   - An external tank which contains liquid propellant (fuel) for the three main orbiter engines.

   The two booster rockets and main engine provide the thrust for take-off.
8. SETI stands for the Search for Extraterrestrial Intelligence — projects searching for life in our galaxy and the universe. The searches use optical telescopes which use high-powered laser technology, radio telescopes and microwave technologies. See page 198.

Practice HSC-style

Trial Exam

Section I Total marks (75)

Part A — Multiple choice questions (15 marks)

Answer all questions.

1. Which of the following does NOT use EM radiation for transmission of information?
   (A) Non-verbal communication between two people in a room
   (B) Mobile phone
   (C) Fax machine
   (D) Verbal communication between two people in a room

2. A substance which contains small solid particles that easily separate out of the mixture is a:
   (A) Solution
   (B) Surfactant
   (C) Stabiliser
   (D) Suspension

3. The reason why soaps and detergents must be emulsifying agents and surfactants is best summarised in which of the following statements?
   (A) Emulsifying agents and surfactants emulsify oils and greases.
   (B) Emulsifying agents and surfactants are partly water-soluble and partly oil-soluble.
   (C) Emulsifying agents and surfactants change the surface tension of water and dissolve dirt, grease and oil.
   (D) Emulsifying agents and surfactants bring oil and water together.

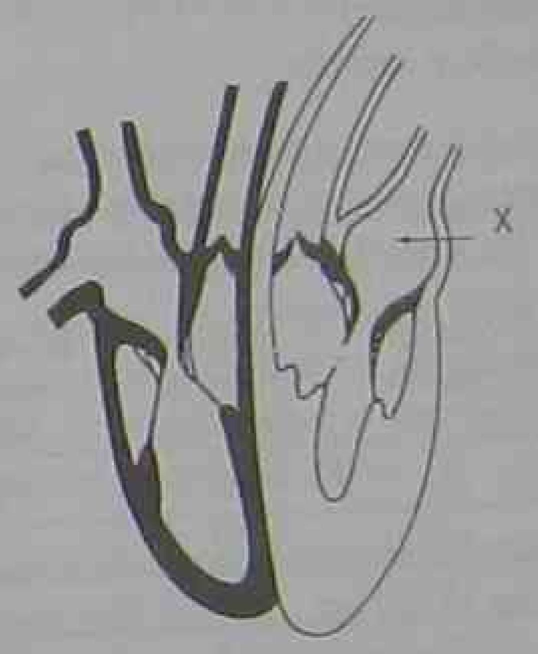
4. The speed of the radio signal is given by the equation:

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

A radio signal is transmitted by a radio station and picked up by a receiver 200 km away. The speed of travel is 3×10^8 ms. Using this information and the equation above, what is the time delay between the signal leaving the station and arriving at the receiver?
   (A) 0.00067 seconds
   (B) 0.001 seconds
   (C) 0.67 seconds
   (D) 0.00007 seconds

5. The skin is a large sensory organ. It also has which of the following roles?
   (A) It secretes microflora.
   (B) It assists in body temperature control.
   (C) It carries external messages to the brain.
   (D) It helps drugs to dissolve in the body.

6. Look at the diagram of the heart below.



The part labelled X has the following function:
   (A) It functions as an out-flow chamber.
   (B) It functions as an in-flow chamber.
   (C) It carries oxygenated blood to the heart.
   (D) It carries deoxygenated blood away from the heart.

7. Which of the following flow diagrams most accurately represents the transformation of energy at each stage of information transfer in television?
   (A) Light and sound energy → Electromagnetic/electrical energy → Light and sound energy
   (B) Light and sound energy → Magnetic/electrical energy → Light and sound energy
   (C) Light energy → Sound energy → Magnetic energy → Light energy
   (D) Light and sound energy → Electromagnetic energy → Sound energy

8. A student carried out a first-hand investigation to test the claim that the skin pH of a person can vary. In performing the experiment, the student must keep which of the following factors constant?
   (A) The area of the skin tested
   (B) The conditions under which the person is tested such as before or after exercise
   (C) The time of day
   (D) The way of testing for pH

9. One of the major causes of cardiovascular disease is the build-up of plaque on the inner wall of the arteries. Which of the following technological advances has NOT been involved in the techniques to remove plaque and/or ease blood flow in the artery?
   (A) Angioplasty
   (B) Laser technology
   (C) Mammography
   (D) Artificial implants

10. A student performed an experiment to distinguish between oil-in-water and water-in-oil based emulsions. The student obtained the following results.

Emulsion	Conducts electricity	Disperses easily in water	Becomes coloured with a water-soluble dye
W	✗	✗	✗
X	✓	✓	✓
Y	✓	✓	✓
Z	✗	✗	✗

From the results, the student can conclude that:
   (A) Emulsion X is a water-in-oil emulsion.
   (B) Emulsion Z is an oil-in-water emulsion.
   (C) Emulsion Y is a water-in-oil based emulsion.
   (D) Emulsions W and Z are water-in-oil emulsions.

11. The name of the system which allowed the development of multipurpose computer-based communication is:
   (A) Digital coding
   (B) Analogue coding
   (C) Decoding
   (D) Barcoding

12. Pacemakers are sealed in a titanium case and implanted under the skin. The properties of titanium which make it suitable for implantation include:
   (A) It is strong, light and a semiconductor.
   (B) It is strong, light and biocompatible.
   (C) It is non-toxic, highly flexible and sterilisable.
   (D) It is non-toxic, highly flexible and biocompatible.

13. The role of synovial fluid and cartilage in the operation of joints is best described by which of the following statements?
   (A) Synovial fluid and cartilage allow for a wide range of joint movements.
   (B) Cartilage lubricates the joint, and synovial fluid reduces friction.
   (C) Cartilage lines the ends of bones and reduces friction, and synovial fluid lubricates the joint.
   (D) They both allow for smoother movement.

14. The correct order from highest frequency to lowest frequency for the different waves below is:
   (A) Radiowaves, microwaves, infra-red, visible light, X-rays, ultraviolet
   (B) X-rays, ultraviolet, infra-red, visible light, radio waves, microwaves
   (C) X-rays, ultraviolet, visible light, infra-red, microwaves, radio waves
   (D) Radiowaves, microwaves, infra-red, visible light, ultraviolet, X-rays

15. Which of the following non-invasive diagnostic techniques can be used to detect a tumour?
   (A) An endoscopy
   (B) X-ray
   (C) Thermography
   (D) Keyhole surgery

Part B — Short answer and longer response questions (60 marks)

Answer all questions.

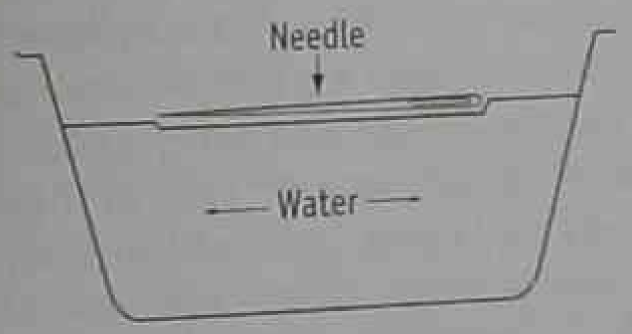
16. (5 marks)

Oil-in-water emulsions spread easily on the skin and are favoured in warm climates because of the cooling effect on the skin caused by the evaporation of the water.
   (a) What is an oil-in-water based emulsion? (1 mark)
   (b) Give an example. (1 mark)
   (c) List three properties of an oil-in-water emulsion. (3 marks)

17. (4 marks)

In the core unit 'Information Systems' you carried out a number of first-hand investigations. For one of these investigations:
   (a) State the purpose of the investigation. (1 mark)
   (b) Briefly outline the methodology using labelled diagrams where appropriate. (2 marks)
   (c) Write a conclusion from your investigation. (1 mark)

18. Below is a diagram of a needle floating on water.



What does the diagram demonstrate? (2 marks)

19. (6 marks)

Use labelled diagrams to describe:
   (a) The effect of shampoo on the solubility of oil. (3 marks)
   (b) The action of soap on a greasy surface. (3 marks)

20. (4 marks)

Duenteric-coated low-dose aspirin is prescribed to people to protect them from problems caused by clotting in the bloodstream. The tablet is taken orally and absorbed gradually in the small intestine. The gradual absorption is believed to be necessary for the best anti-clotting effect.
   (a) What is the function of the coating on the aspirin? What special property does the coating need? (2 marks)
   (b) In this course you carried out an experiment to compare the solubility of capsules, tablets, enteric-coated tablets, and slow-release tablets. Compare the solubility of the duenteric-coated aspirin with the solubility of one other type of aspirin that you have tested. (2 marks)

21. By using diagrams, explain the difference between the terms AM and FM as applied to radio broadcasts. (4 marks)

22. One of the spin-offs from space research is the development of ZBLAN, a new substance with the potential to revolutionise fibre optics communications. ZBLAN fibre optic cable is manufactured in space and has the potential to carry 100 times the amount of data conveyed by conventional silica-based fibres.

Briefly describe how fibre optics communication was developed, including the role of total internal reflection and use a simple diagram to sketch a conventional silica-based optic fibre cable. (4 marks)

23. In your HSC course, you are expected to have gathered, processed and analysed information from secondary sources for a range of topics. Choose one area or topic that you have studied and list four steps that you undertook in gathering, processing and analysing the information. (4 marks)

24. (4 marks)
   (a) What is a pacemaker implant? (2 marks)
   (b) Describe one advantage and one disadvantage of a pacemaker implant to the patient. (2 marks)

25. Describe TWO technological developments that have led to an increased understanding of the ways in which the body works and TWO impacts of the application of biomedicine on society. (4 marks)

26. A student carried out a first-hand investigation to observe and analyse changes in the rate of the heartbeat during rest and during sustained physical activity. The following results were obtained.

Pulse sitting: 72 beats per minute

Standing: 80 bpm

After exercise: 140 bpm

Explain why the pulse rate increases after exercise. (2 marks)

27. (6 marks)

Shaving cream contains: surfactants (stearic acid and triethanolamine); an emulsifier (lanolin) which holds water to the skin; and glycerin (a solvent and emollient) which makes skin softer and more supple.

(a) What is a surfactant? How does a surfactant work? (2 marks)

(b) What is an emulsifier? Give one other example of an emulsifier and a product in which you would find it. (3 marks)

(c) What is a solvent? Give one other example of a solvent. (1 mark)

28. (5 marks)

Scientists first discovered the key features of electromagnetic energy in the last half of the nineteenth century. Since then, they have found hundreds of ways of using it.

(a) What property of electromagnetic radiation makes it an important tool of modern technological society? (1 mark)

(b) From your study of each of the core units 'Information Systems' and 'Medical Technology — Bionics', list four ways in which scientists have found electromagnetic radiation can be used. (4 marks)

29. Make a table that identifies the part of the body being replaced, a disease that caused the need for replacement, and the materials used in the construction of the following biomedical devices:

(a) Cochlear implant

(b) An artificial valve (6 marks)

Section II

Each question is worth 25 marks

Options

Attempt one question.

Option 1 — Polymers

(25 marks)

1. (5 marks)

Model-making glue contains polystyrene molecules dissolved in a solvent. The solvent evaporates when the glue is applied and the polystyrene molecules form a bond. If the model joint is warmed, the glue melts.

(a) What type of plastic is model-making glue? Give a reason for your answer and use a diagram to represent the structure of this type of plastic. (4 marks)

(b) What are the monomers that make up polystyrene? (1 mark)

2. The instructions on a detergent packet are:

Do not soak silk or woollens
Take particular care with polyester/viscose.

From what you can infer from the washing instructions and from the tests you have carried out to compare the properties of different polymers, describe the properties of silk, woollens and polyester/viscose in terms of the effect of acids/alkalis. Compare the effects of acids/alkalis on wool with the effects on cotton. (2 marks)

3. Identify the source and the chemicals that are used in the manufacture of two named plastics. (4 marks)

4. Describe the properties of plastics which make them useful in modern society and, using three examples, outline how the versatility of plastics is further extended by including additives in the production process. (5 marks)

5. Draw up a table to summarise the properties and uses of two specialised polymers which you have studied. (4 marks)

6. Using examples, assess the impact of plastics on society. (5 marks)

Option 2 — Preservatives and Additives

(25 marks)

1. (10 marks)

(a) What is the purpose of food preservation? (1 mark)

(b) Describe early means of food preservation. (1 mark)

(c) Outline the factors which determine the rate of micro-organism growth and reproduction. (3 marks)

(d) Describe two physical means of food preservation and, for each, explain how its method is related to creating unfavourable conditions for microbial growth and reproduction. (3 marks)

(e) Describe one chemical means of food preservation and explain how this method is used to create unfavourable conditions for microbial growth and reproduction. (2 marks)

2. (8 marks)

In this option you examined a range of food and cosmetic products and recorded the ingredients. Create and draw an imaginary food product label. The label must include the following features:

(a) Every item that all labels on food offered for sale must include according to government legislation, including a list of ingredients. (4 marks)

(b) The list of ingredients which includes at least three additives and their Australian Standards Food Code. (3 marks)

(c) An example of 'negative' labelling. (1 mark)

3. (5 marks)

Listeria monocytogenes is a micro-organism that can cause food poisoning. It can grow over a wide range of temperatures (0°C to 45°C) and tolerates high salt concentrations. It is found in soft cheeses, dips, pre-prepared salads, meats and seafood.

(a) Outline some of the contamination risks in the preparation of foods such as pre-prepared salads, and discuss ways that these risks may be minimised. (2 marks)

(b) Name two other micro-organisms which can cause food poisoning. For each one named, outline the food in which it is commonly found and some symptoms of food poisoning. (3 marks)

4. Outline two developments in technology, scientific understanding and technological processes that have contributed to our understanding of, and improved the methods for, food preservation. (2 marks)

Option 3 — Pharmaceuticals (25 marks)

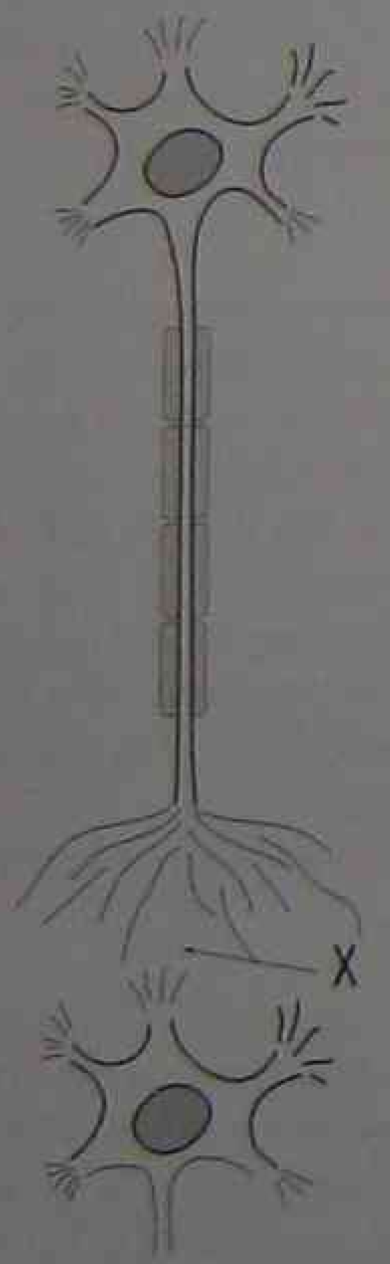
1. (2 marks)

What is a pharmaceutical? (1 mark)

Describe one advance in scientific understanding which has led to developments in pharmaceuticals. (1 mark)

2. (8 marks)

The diagram below represents a neurone.



(a) What is a neurone? (1 mark)

(b) Describe the roles of three types of neurones. (3 marks)

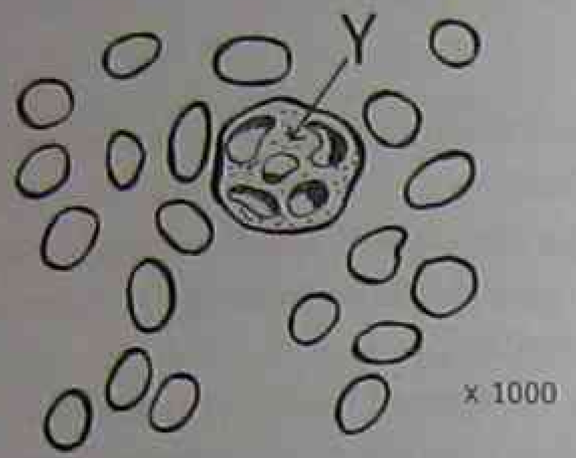
(c) Draw an arrow on the diagram to indicate the direction of the nerve message. (1 mark)

(d) What is the name of the part labelled X on the diagram? How is the part labelled X related to:

(i) The transmission of a message from one neurone to the next?

(ii) The action of some drugs such as pain relievers? (3 marks)

3. The diagram below shows human blood cells.



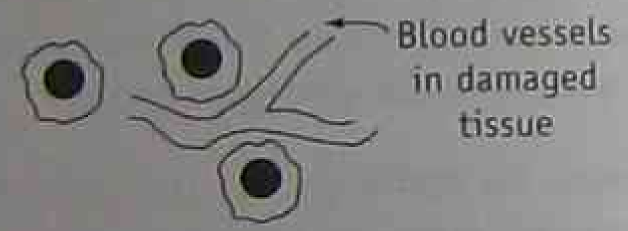
Name the cell labelled Y. Outline its role in fighting disease and repairing damaged tissue. (3 marks)

4. (6 marks)

An inflammation response by the body is the result of complex reactions in the blood and blood vessels that are coordinated to isolate and destroy harmful substances and pathogens, and prepare the body's tissue for healing and regeneration.

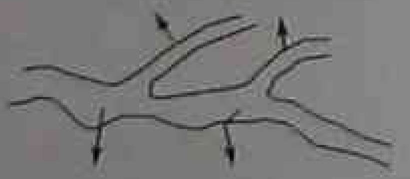
The diagrams I, II, III and IV below are representations showing the inflammation response.

I

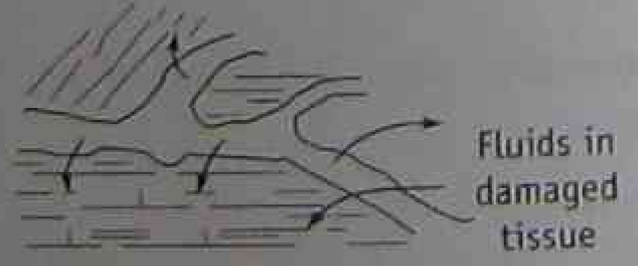


II

III



IV



(a) What causes an inflammation response? (2 marks)

(b) Write a brief explanation for each of the diagrams I, II, III and IV to outline the inflammation response. (4 marks)

5. Explain the relationship between the following terms:

- Pain
- Prostaglandins
- Analgesics. (3 marks)

6. Describe the circumstances which led to the identification of the substance produced by the fungus *Penicillium notatum* which appeared to inhibit the growth of bacteria. What is the pharmaceutical which was developed from this discovery?(3 marks)

Option 4 — Disasters (25 marks)

1. (3 marks)

Most fire-related deaths occur at night when people are asleep and cannot smell the smoke.

(a) What technological devices have been developed in an attempt to reduce the incidence of death and injury associated with house fires? (1 mark)

(b) Name and describe the energy transformations in one other warning device and use an example of the device in your answer. (2 marks)

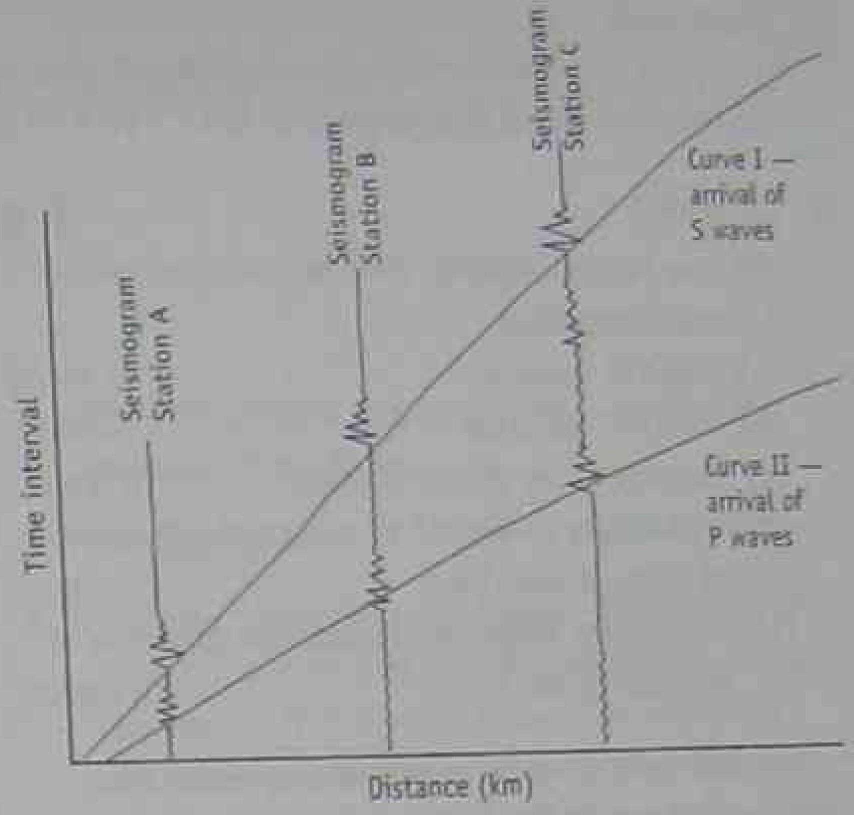
2. (7 marks)

(a) P waves travel at approximately 8 km/hour and S waves at 5 km/hour. After an earthquake, a seismograph records the P and S waves. The P waves arrive in 125 seconds, the S waves in 200 seconds. What is the time gap between the arrival of the P waves and S waves? How far have the waves travelled? (2 marks)

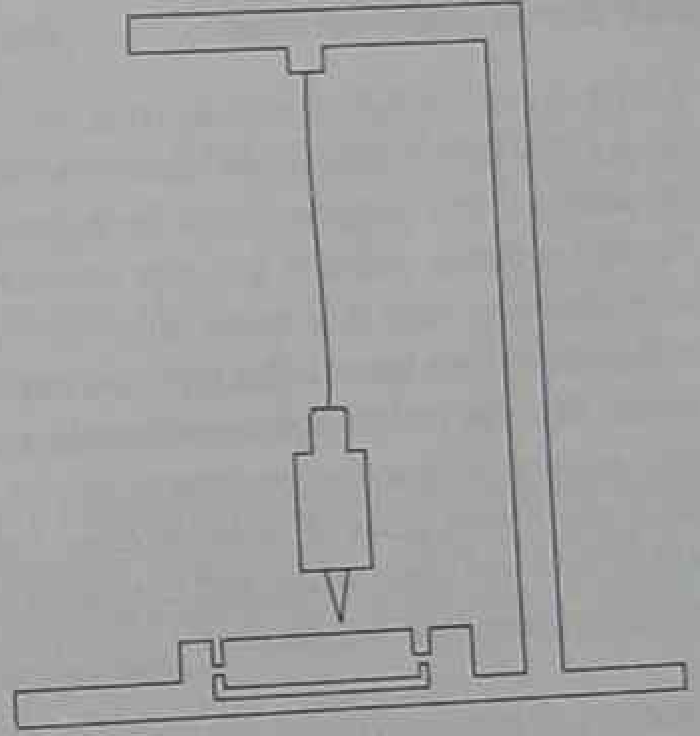
(b) The graph in the next column shows seismograms at three different stations A, B and C.

(i) Write a statement to explain what the curves I and II tell us.

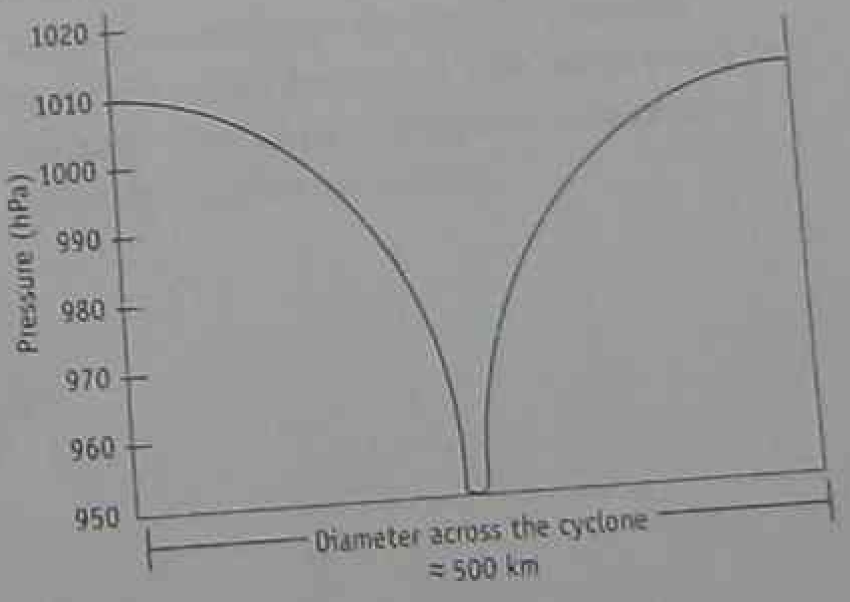
(ii) How is this kind of information used by seismologists? (3 marks)



(c) Name and describe the function of the technology shown in the diagram below. (2 marks)



3. The graph below shows the variations in atmospheric pressure across a tropical cyclone.



Interpret the graph to explain the changes in air pressure as a tropical cyclone moves over an area. (2 marks)

4. Summarise the conditions that can combine to trigger a bushfire and the natural resources which are used to retard the progress of fire. (2 marks)

5. (8 marks)

For one natural disaster that has occurred within Australia, describe:

(a) When it occurred (1 mark)
(b) Where it occurred (1 mark)
(c) Consequences of the disaster (2 marks)
(d) Techniques employed to reduce the incidence of damage next time (2 marks)
(e) Techniques employed to monitor this type of disaster in the future (2 marks)

6. Outline technological developments which have improved our ability to prepare for disasters. (3 marks)

Option 5 — Space Science (25 marks)

Except for visible light and some radio frequency ranges, the Earth's atmosphere absorbs many forms of radiation. This protects life on Earth from harmful radiation, but also prevents astronomers from observing objects in space which emit types of radiation other than visible light and radio waves. Describe technological developments which have enabled astronomers to observe objects in space which emit types of radiation other than visible light and radio waves and to observe space without atmospheric interference. (4 marks)

2. Discuss why scientists are interested in the effects of apparent weightlessness on an object in orbit. Using examples in your answer, draw up a table to summarise some of the short- and long-term effects on body functions of weightlessness. (5 marks)

3. Explain some of the difficulties experienced during lift-off but not on re-entry into the Earth's atmosphere. (2 marks)

4. List two properties of materials used in the STS and for each, describe how the properties relate to conditions experienced during lift-off or re-entry. (4 marks)

5. List six requirements that would be necessary to sustain human life for months or even years on a space station. (6 marks)

6. Draw a sketch of the main components of the STS and describe the function of two of the parts.

List one advantage and one disadvantage of the STS. (4 marks)

— End of practice trial exam—

Section I

Part A — Multiple choice questions

Answers

1. D	2. D	3. C	4. A	5. B
6. B	7. A	8. D	9. C	10. D
11. A	12. B	13. C	14.C	15.C

Explanations

1. Verbal communication uses sound energy.

2. See page 88.

3. Soaps and detergents must change surface tension. Surfactants are wetting agents. The main action of a surfactant is to stimulate emulsification. The soap or detergent emulsifies the grease or oil — the grease is lifted from the oily surface, broken down into droplets and dispersed in the water for removal. The dirt is removed with the emulsified grease.

4. 200 kilometres = 200,000 metres

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

$$3 \times 10^8 = \frac{200{,}000}{\text{time}}$$

$$\text{therefore time} = \frac{200{,}000}{3 \times 10^8}$$

time = 0.00067s

5. The role of skin is in excretion; protecting the body against the external environment; helping to regulate body temperature; and protection against disease. The skin does not secrete microflora.

6. The part labelled X is an atrium — an in-flow chamber of the heart.

7. See page 124.

8. The area tested, the conditions under which the person is tested and the time of day can all be *variables* in this investigation. The constants would include: the same person, the same method (the way the pH is measured); the length of time for each measurement.

9. Mammography is a term for breast X-rays; diagnostic and screening techniques for breast cancer.

10. See page 91 for properties of emulsions.

11. See page 91.

12. See page 91.

13. A and D are correct. The best description of roles, however, is alternative C.

14. The correct representation of the electromagnetic spectrum is alternative C. High frequency = shorter wavelengths. Low frequency = longer wavelengths.

15. Thermography uses infra-red rays to produce pictures that show the warm and cool parts of the body (or an object) as different colours. Thermography is used to detect cancer.

X-rays are not always accurate in detecting tumours because bones can 'hide' other tissue in the body. Endoscopy and keyhole surgery are minimally invasive techniques.

Part B — Short answer and longer response questions

16. (a) An oil-in-water emulsion contains dissolved fatty substances dispersed with the aid of an emulsifier as fine droplets in water. The water is used to dissolve the water-soluble ingredients.

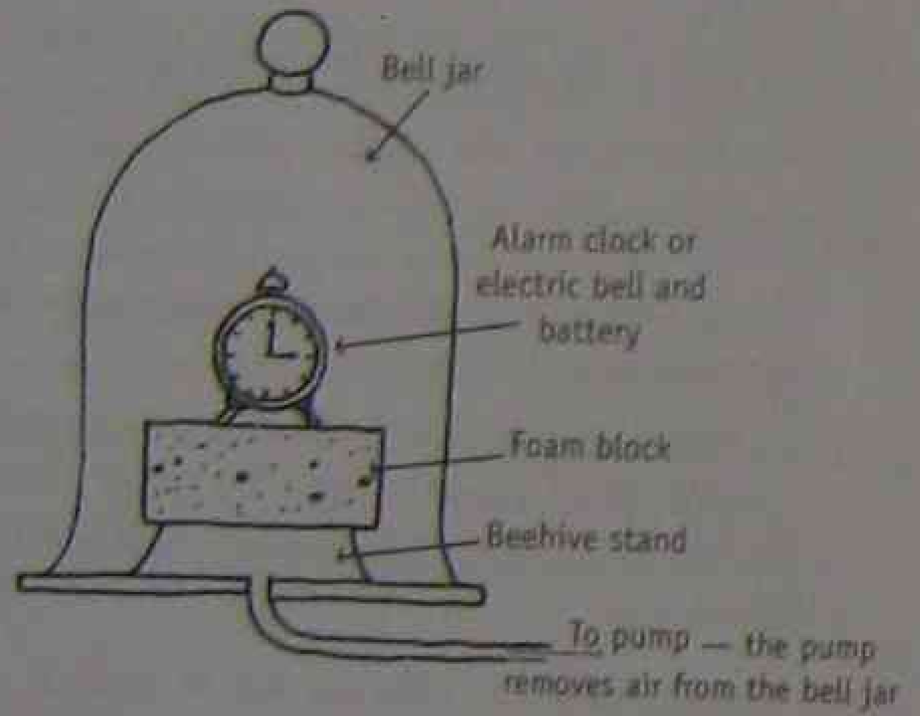
(b) Most cosmetic creams are oil-in-water based emulsions.

(c) Oil-in-water emulsions will disperse easily in water, conduct electricity and become coloured with a water-soluble dye.

17. Sample answer:

(a) Purpose — to show that sound requires air or some other medium to carry the energy.

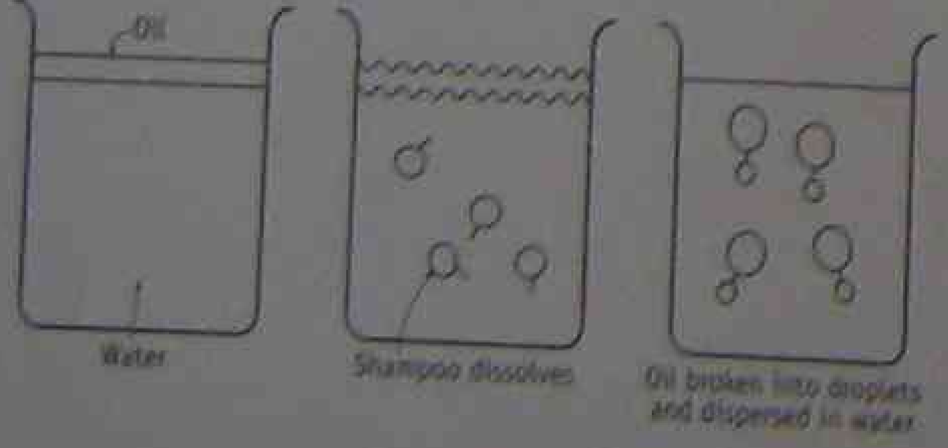
(b) Method —



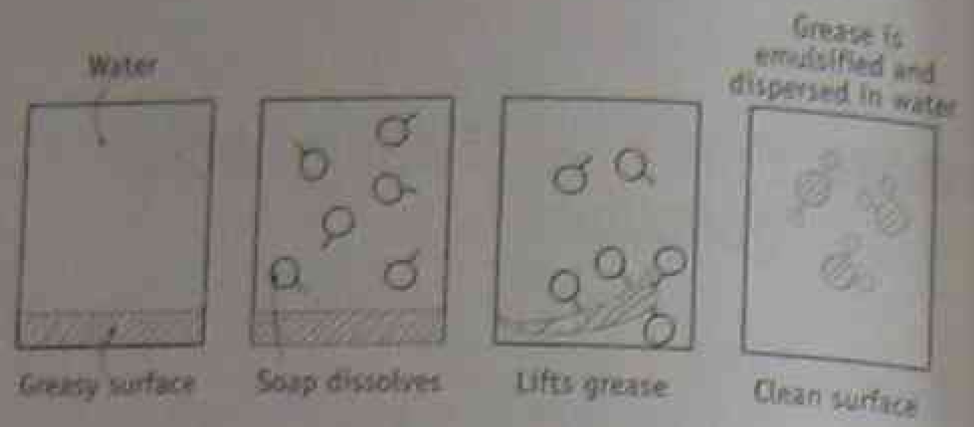
(c) Conclusion — sound requires air or some other medium to transmit energy.

18. Surface tension— the forces experienced by particles at the surface of the liquid. See page 89.

19. (a)



(b)

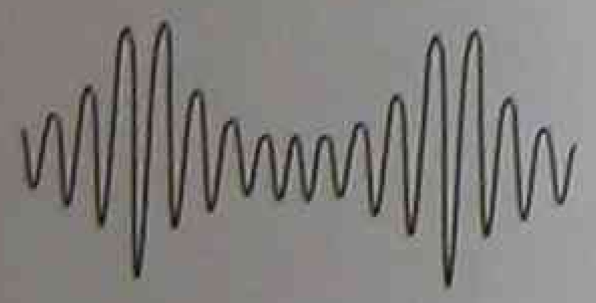


20. (a) The coating prevents the tablet from dissolving in the stomach, enabling the tablet to remain in the digestive tract long enough for it to reach the small intestine. The coating needs to be insoluble (or slow to dissolve) in acidic solutions and soluble in alkaline solutions.

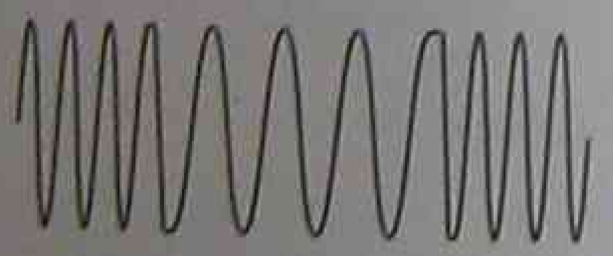
(b) An aspirin which is designed to dissolve in the stomach will have a faster rate of solubility than an enteric-coated tablet. See page 97.

21. If modulation of a radio wave involves changing the amplitude, AM radio waves are produced. If modulation involves changing the frequency, FM radio waves are produced.

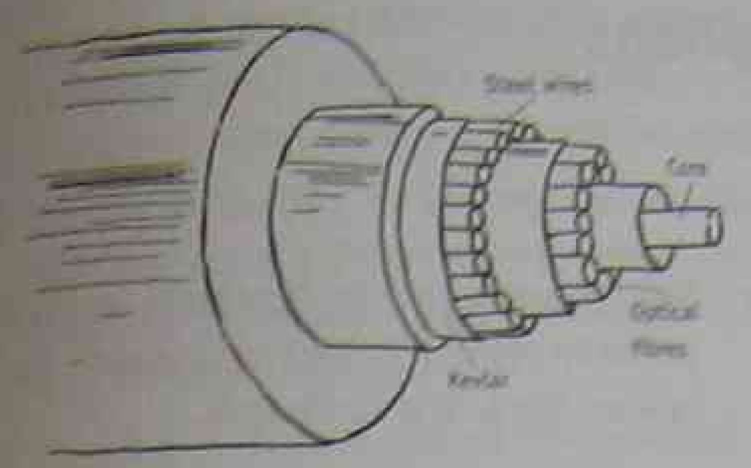
AM radio waves



FM radio waves



22. The development of optical fibres came about with the discovery that light can be transmitted through a hollow tube even if the tube is curved. As the light travels through the tube, it is reflected (bounced) off the inner walls again and again. In this process, some light energy leaves the tube (rod) and is lost every time the light rays are reflected. The principle of total internal reflection is used to stop this loss of light energy.



23. This is a different kind of question to the ones you may be used to. Your answer could include:

- How you defined what you were trying to find out — how did you work out what it was exactly you were looking for?
- How you located the information — how did you go about narrowing your search?
- How you then selected what you needed from the information you found — what did you use to decide if something was relevant? How did you make sense of the information?
- How you analysed the information — what evidence did you find to support what you were trying to find out?

24. (a) An electronic device which helps to produce a regular electrical impulse and correct the condition called arrythmia in the heart.

(b) One advantage: the entire implantation procedure requires only a local anesthetic, and takes a short period of time. One disadvantage: pacemakers only have an effective life of seven to 12 years.

25. Two technological developments include:

- Improvements in microscopes and microscopy
- Developments and improvements in diagnostic and monitoring techniques.

Impacts include:

- Developments in bionics which have enabled people with illnesses or disabilities to live more independent lives and continue to contribute to society.
- High costs of medical devices and materials and therefore high costs for health systems.

26. Pulse rate after exercise increases because the body requires more oxygen and must get rid of carbon dioxide at a faster rate. The heart beats faster and therefore the pulse rate increases.

27. (a) Surfactants are surface-active-agents that affect the surface tension of liquids. One end of the surfactant molecule will not dissolve in water but attracts dirt and grease, and one end attracts water.

(b) Emulsifiers or emulsifying agents reduce the difference in surface tension between two substances. This enables the substances to mix together. Emulsions such as milk contain an emulsifying agent. Lecithin is also an emulsifier used in many food products, such as mayonnaise.

(c) Solvents are the substances in which the solute is dissolved. Common solvents are water and alcohol.

28. (a) Electromagnetic energy can travel through space without a conducting medium. This has made it an important tool of modern technological society.

(b) Your answer may have included:

- Mobile phones
- Radar
- Pulsed radio-frequency energy is used to heal bone fractures. New findings reveal that it may also be used to speed the healing of flesh wounds and the regeneration of nerve tissue, and ultimately to reduce the size of cancerous tumors. (Radio frequency imaging may soon replace X-rays in some biomedical applications).
- Thermography uses infra-red radiation. See page 116.
- Other applications include automatic door openers, intrusion alarms, remote control of toys and models.

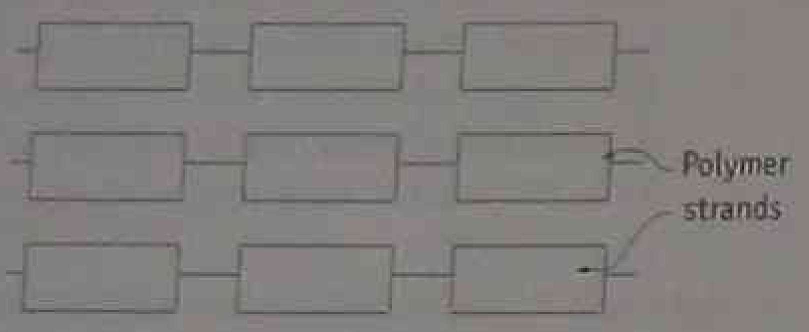
29. See table below.

The part of the body being replaced	*A disease that caused the need for replacement*	*Materials used*
(a) Cochlea implant	Damaged auditory nerve, deafness	Transmitter, microphone & sound processor
(b) Artificial valve	Faulty valve, heart murmur	Carbon discs which open and close to act like a natural valve

Section II — Options

Option 1 — Polymers

1. (a) Thermoplastic — it becomes soft when exposed to enough heat and hardens on cooling. This property is retained no matter how many times the plastic is heated and cooled.



Thermoplastics have no linking between polymer strands.

(b) The monomer is styrene.

2. Detergents are alkalis. Silk, woollens and polyester/viscose are sensitive to alkalis and therefore should not be washed in strong detergents or put in bleach. Cellulose fibres in cotton and linen are sensitive to acids, but have high resistance to alkalis. They can be washed repeatedly without damage. (Wool is resistant to the effects of acids but is harmed by alkalis.)

3. Polyvinylchloride — source of chemicals is crude oil and salt; the chemicals are ethene and chlorine.

Polystyrene — source of chemicals is crude oil; the chemicals are ethene and benzene.

4. Plastic is a versatile material. Plastics are easily moulded and shaped, they are light-weight and durable — they do not shatter easily and do not rot or rust. They last a long time.

Additives are added to plastic resins to modify their properties for use in a greater range of products. Examples of additives are:

- Plasticisers are added to make the plastic lighter and more pliable (flexible). For example, PVC is normally hard but is softened by plasticisers to make a huge range of products including raincoats and food wrap.
- Fire-retardants such as chlorine and bromine are added to plastics for use in products such as sleeping-bag covers, paints and clothing.
- Strengtheners such as fibreglass which is added to styrene-polyester polymers for use in canoes, boats and surfboards.

5.

	Properties	*Uses*
Kevlar fibres	Very high tensile strength	Used in bullet-proof vests
Saran wrap or PVDC	Highly resistant to water, oils, greases, oxygen, acids, bases and solvents	Used as a barrier to protect food, consumer and industrial products

6. Impacts include positive and negative impacts.
   - Many developments in technology have been made possible by the synthesis of plastic materials such as electrical components, computer parts and biomedical materials and devices such as artificial limbs.
   - Plastic packaging is convenient and provides for hygienic handling of food. It minimises spoilage, makes handling and storage easier, holds labels and minimises tampering with the product.
   - Plastics have also created problems, for example: they are mostly non-biodegradable and not easily recycled, and plastics manufacturing involves a range of highly toxic substances that must be stored, handled and disposed of safely.

Option 2 — Preservatives and Additives

1. (a) The purpose of food preservation is to slow down the natural decay process of food and to remove, inactivate or kill micro-organisms which cause food decay and/or food-borne illnesses.

(b) Very early civilisations kept food under snow and in caves where temperatures are lower. Early methods include salting, storing food in brine solutions and using vinegar. Drying is probably the oldest method of preserving food.

(c) Factors include temperature (many micro-organisms grow best at room temperatures and body temperature), nutrient availability, pH (most food-spoiling bacteria show an optimum growth at pH 7) and water availability — micro-organisms cannot grow without water.

(d) Boiling or heating — at temperatures above 60°C micro-organisms begin to lose their viability. Sterilisation kills micro-organisms and sterilises the food.

Canning — food is cooked inside sealed metal containers. Canning creates sterile conditions inside the can. Canning uses temperatures of >120°C to kill micro-organisms.

(e) The addition of sulfites — used in fruit juice, wine, dehydrated vegetables and dried fruits. Sulfites disrupt many metabolic processes in microbial cells.

2. (a) According to legislation every label on food offered for sale must have:
   - The name of the food
   - A list of ingredients
   - A use-by date
   - A nutrition information panel — required if certain claims are made for the food
   - The name and address in Australia of the manufacturer, packer or importer
   - The food's country of origin or origin of ingredients.

(b) For a list of some additives and their Australian Standards Food Code, see page 157.

(c) Examples of 'negative' labelling include: 'no added sugar', 'no preservatives', 'no artificial flavourings'.

3. (a) Contamination can occur if foods such as pre-prepared salads are stored at temperatures between 0°C and 45°C. Contamination can also occur through dirty hands, containers and utensils. Contamination risk is minimised when food is stored well below 0°C; when food is handled hygienically; and for pre-prepared salads in particular, when there are strict rules about disposing of the food if it has not been used in a short period of time.

(b) Salmonella bacteria — found in raw milk, water, eggs and meat. Symptoms include an enlarged spleen, diarrhoea, vomiting, abdominal pain and septicaemia.

Escerichia coli is found in undercooked meat and raw milk. Symptoms include bloody diarrhoea, anaemia, and renal failure.

4. Developments in technology and scientific understanding may include:
   - The development of the microscope, the discovery that living things were made of cells, and that micro-organisms were the cause of the decomposition of food (the work of Pasteur, Lister and Koch). Once this was known, food preservation techniques began to centre on reducing the activity of these micro-organisms in food to maintain a higher standard of hygiene.
   - The use of moulds for curing infections and wounds
   - The discovery and use of bacteriocins for preserving food
   - The development of methods to produce substances such as penicillin that can kill bacterial cells without also killing human or animal cells
   - An increased understanding of biochemical processes. This enables the development of chemical preservatives which disrupt cellular processes in micro-organisms.

   Developments in technological processes could include:
   - The invention of the tin can
   - The pasteurisation process
   - Freeze drying
   - Ultra-high temperature (UHT) processes
   - The development of plastics for packaging.

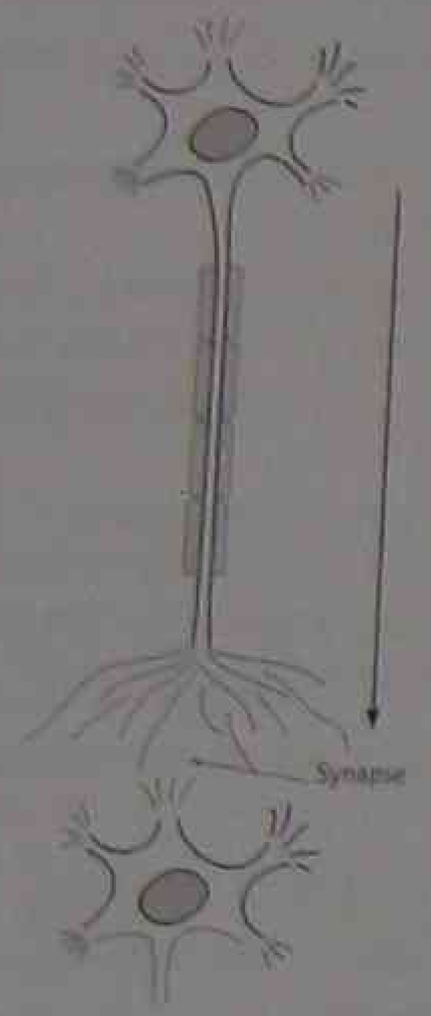
Option 3 — Pharmaceuticals

1. A pharmaceutical is a drug — a substance which destroys disease-causing organisms or influences the activity of cells, tissues and organs of the body to bring about their effects, such as pain killers.

   There are many answers to this question. Some examples are:
   - The development of the microscope
   - The discovery that living things were made of cells
   - The discovery that micro-organisms were the cause of many diseases and procedures for identifying the disease-causing organism — the work of Pasteur, Lister and Koch
   - Developments in chemistry and biochemistry such as strain isolation methods.

2. (a) Neurones are nerve cells.
   (b)
   - The sensory neurones carry messages to the brain and spinal cord. They connect receptor cells to the central nervous system.
   - The motor neurones carry messages away from the brain and spinal cord.
   - The interneurones interconnect neurones which occur in the brain and spinal cord.

   (c) Nerve impulses travel in one direction only.



   (d) X is the synapse.
      (i) Neurones are not joined. A synapse is the connection that functionally links one neurone to the next. A nerve impulse travels from one neurone to another through the synapse. A neurone sends its message down the long axon. This releases a chemical in the synapse which excites or inhibits the 'downstream' message.
      (ii) Some drugs relieve pain by inhibiting the chemical signal crossing the synapse.

3. Y is a white blood cell. The role of white blood cells is to:
   - Identify tissue damage.
   - Fight disease by secreting substances that directly destroy particles foreign to the body, or by secreting antibodies that combine with or neutralise the foreign substance or organism.
   - Dispose of dead cells and some micro-organisms by engulfing and destroying them.

4. (a) It is caused by injury, infection, trauma or environmental conditions such as the presence of allergens.
   (b) Diagram I — white blood cells migrate to the injured area.
   Diagram II — small blood vessels dilate to allow more blood flow to the injured tissue. This causes the tissue to become hot and red.
   Diagram III — the permeability of small blood vessels increases.
   Diagram IV — fluids accumulate in the tissue. An increase in fluids immobilises the area. The build-up of fluid causes swelling and pain.

5. Pain is an interpretation by the brain of messages from nerves sent across synapses from the injury site to the brain. Prostaglandins are thought to be responsible for the pain and fever that goes with inflammation of tissue. The pain results from the pressure of fluids accumulating in the damaged tissue. The substances secreted by damaged tissue also irritate nerve endings.

   Analgesics are a group of drugs commonly called 'pain killers'.

6. *Penicillium notatum* is the mould which ferments fruit, jam and cheese. The mould was accidentally introduced to an agar plate on which colonies of bacteria were growing and produced an inhibitory effect on the bacteria. The pharmaceutical which was developed from this discovery is the antibiotic penicillin.

Option 4 — Disasters

1. (a) Household warning devices such as smoke detectors and fire alarms.

   (b) Burglar alarms. The energy transfers and transformation involved are:
   Kinetic energy (energy of movement) ⟶
   Electrical energy ⟶ Sound energy
   Types of burglar alarms vary depending on the trigger — movement or heat, pressure or moisture.

2. (a) The time gap is 75 seconds.

$$\text{Speed} = \frac{\text{distance}}{\text{time}} \qquad 8 = \frac{X}{125}$$

$$8 \times 125 = 1000$$

   The waves travelled 1000 km to the seismograph.

   (b) (i) The curves I and II tell us the time interval between the arrival of P waves and S waves. The curves show us how travel times of P and S waves increase with an increase in distance.
      (ii) The time interval between P and S waves increases with the distance from the epicentre. Knowing the distance from the three stations A, B and C, a seismologist can locate the epicentre of the earthquake.
   (c) It is a seismometer. A seismometer receives and records seismic waves. This seismometer measures horizontal ground motions.

3. Pressure in the centre of a tropical cyclone or tornado is much lower than normal air pressure. Air pressure rises as the cyclone builds and then suddenly falls dramatically as the eye of the cyclone hits. As the cyclone moves away or decays the air pressure rises again.

4. The conditions are dry weather, high temperatures, strong winds, low humidity, and dry vegetation (a drought in winter or spring dries out vegetation).

   Natural resources are: water which is pumped from tankers and backpacks or dropped from the air by helicopters, fixed-wing aircraft and water scooping air tankers; and fire-retardant plants such as the swamp oak and river oak, angopheras, brush box and cedar wattle.

5. (a) Sydney bushfires in December 1993 and January 1994.
   (b) In many different areas in and around Sydney — Hornsby, Royal National Park, Menai, Lindfield, Terry Hills, Blue Mountains.
   (c) The fire destroyed more than 200 homes, damaged many other homes and buildings, burnt out more than 200,000 hectares of bushland and left four people dead.
   (d) A coronial inquiry into the disaster made recommendations such as:
   - Improved coordination and cooperation between fire-services
   - Increased powers for the NSW Fire Brigade to require private landowners to clear bushfire hazards
   - Adoption of Australian Standards for building development in bushfire-prone areas.

   (e) The coronial inquiry into the disaster also recommended:
   - The need for improved planning for bushfire suppression and mitigation. The plans should include maps showing fire history and hazard-reduction work in different areas and detailed operational information.
   - The need to improve communication between fire services for monitoring purposes.

6. See page 184.

Option 5 — Space Science

1. Your answer may have included:
   - The development of telescopes which can detect infra-red, X-rays, ultraviolet and gamma rays and can be launched in orbit beyond the Earth's atmosphere
   - Space telescopes, such as the Hubble telescope, in orbit 600 km above the Earth's surface. The Hubble telescope is a reflecting telescope which gathers images such as star formations from space. It also contains cameras and spectrographs which are sensitive to infra-red, visible light and ultraviolet.
   - Orbiting platforms, such as the ISS which can be placed above the Earth's atmosphere.

2. Scientists are interested in studying objects in orbit and apparent weightlessness because many physical, chemical and biological processes work differently in a low-gravity environment.

Short-term impacts	*Long-term impacts*
Nausea and dizziness Organs of balance in the inner ear become confused and therefore sense of direction is confused.	Bones begin excreting calcium — reduction in density of the bone tissue; muscles become weak and shrivelled.

3. Overcoming gravity is the biggest problem a spacecraft has at lift-off. It must be launched with a particular speed and direction. A launch vehicle or booster rocket helps the space vehicle overcome gravity. During lift-off a rocket must accelerate fast enough to escape Earth's gravitational pull. The maximum acceleration is three times that of gravity. The rocket must be able to escape the Earth's gravity without burning up or veering off course.

4. Solid rocket fuel which is shaped into pellets and contains both an oxidant and fuel. The oxidant is needed for the fuel to burn and release energy. The fuel is packed into a container in such a way that it can provide maximum burning surface area and therefore maximum thrust for lift-off.

   Special heat-resistant tiles which cover the orbiter and provide for thermal protection on re-entry. Some tiles provide insulation and protect the hottest parts of the orbiter such as the edges of the wings and the nose tip.

5. Life support systems — food, oxygen, water and systems for removing wastes such as carbon dioxide, urine and faeces.

   Air pressure at a level close to that on Earth and a system for circulating the air.

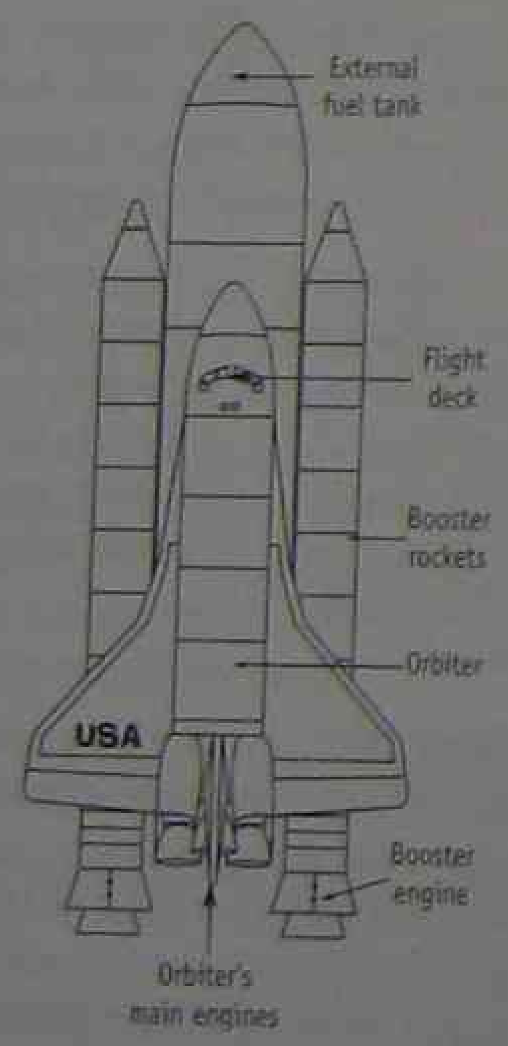
   Temperatures close to those on Earth.

   Ways to store and keep track of rubbish.

   Special exercise equipment to prevent loss of bone strength, loss of muscle tone and maintain good circulation.

   Protection from harmful direct sunlight and forms of high-energy radiation, high-energy particles and extreme changes in temperature.

6.



The components are:

- The orbiter with three main engines and a cargo bay
- Two solid rocket boosters (SRB) which contain enough solid propellant fuel to propel the orbiter and external tank to an altitude of 45 kilometres. The SRB also support the weight of the STS when it is on the ground.
- An external tank which contains liquid propellant (fuel) for the three main orbiter engines.

The advantage of the shuttle is that the orbiter can return to Earth and be reused many times.

The disadvantage of the shuttle is the expense of launching the spacecraft. A huge amount of money is wasted when launching a multistage rocket. See page 192.

Glossary — HSC Core Modules

alveoli	tiny air sacs in the lungs surrounded by an extensive capillary network; the site of gas exchange
AM radio waves	amplitude modulated waves
angioplasty	surgical techniques for easing blood flow in weakened and blocked blood vessels
arrhythmia	abnormal heart rhythm; the rhythm may be faster or slower than normal
arteries	blood vessels which carry blood away from the heart
artificial joints	joints made from biomaterial used to replace damaged or diseased joints
artificial lungs	a machine used during operations to perform the functions of the lungs
artificial valves	biological valves or mechanical valves used to replace damaged or diseased valves in the heart
atmosphere	the gaseous envelope surrounding the Earth
atria	plural for atrium; in-flow chambers of the heart
biocompatibility	a property of materials which can be used in the body without the body's tissue rejecting the material as foreign to it
biodegradability	the extent to which substances such as detergents and waste products can be broken down (decomposed) by biological influences such as bacteria and fungi
biomedical devices	devices engineered from biomaterials and designed to perform specific functions in the body
biomedical material	special materials able to function in contact with living tissue, with minimal adverse reaction or rejection by the body
bionics	a field of medical technology which researches and develops biomedical materials and devices such as artificial hearts and limbs
cardiac muscle	muscles of the heart
cardiopulmonary resuscitation (CPR)	causes pressure on the chest which forces air in and out of the lungs
cochlea implants	an artificial hearing device; also called a bionic ear
colloids	mixtures in which particles are dispersed in a medium as the particles are too large to dissolve; there are different colloid solutions depending on the type of medium and particles: liquid and solid, liquid and liquid, gas and solid and so on
communication	involves any interaction that transmits information between at least two animals
computer-based communication systems	used in faxes, bar codes, digital recordings, and so on; transforms one type of energy (sound or light energy) into electrical energy
controlled experiments	has a part of the experiment lacking the factor being tested to make comparisons and test the effect of the variable
crowns and dentures	artificial teeth

decoding information	changing the message received into a form that can be understood.
degreaser	a cleaning agent
dermal patches	designed to deliver a drug through the skin and into the bloodstream at a slow rate
detergent	synthetic detergent (as compared to soap) used in solution with a surfactant; effective in hard water.
diaphragm	a sheet of tissue, muscle and tendons which separate the thorax cavity (heart and lungs) from the abdomen; the diaphragm plays an important role in the breathing mechanism
digestive system	the system in which complex food stuffs are broken down into simpler compounds for absorption into the bloodstream
digitilisation	the process of converting information into binary notation; numbers and letters are coded into groups of digits consisting of only 1 and 0
electromagnetic radiation	radiation consisting of waves of energy associated with electric and magnetic fields
electromagnetic spectrum	the range of frequencies of electromagnetic radiation — the lowest frequencies are radio waves; high frequencies produce gamma and cosmic waves
emulsifiers (emulsifying agents)	substances which stabilise an emulsion.
emulsions	a mixture that contains two substances (such as water and grease) which do not normally mix well; to form an emulsion, an emulsifying agent must be added
encoding information	creating a message so that it is in a form which can be easily sent (transmitted)
endoscopy and keyhole surgery	minimally invasive surgery which uses an endoscope — a thin plastic tube containing flexible bundles of fibres which enable the surgeon to see inside the patient's body and carry out surgical procedures through small incisions or through parts of the body which require no incision at all
energy	the capacity for doing work
energy transformation	energy cannot be created or destroyed, but can be changed from one form to another
fat-soluble vitamins	vitamins A, D, E and K; because they are fat soluble, they can be stored in body tissues
fax (facsimile) images	identical copies of the image sent through a fax machine
fire optics	technology which involves the use of optical fibres
fibrillation	a type of abnormal heartbeat caused by ventricular tachycardia, in which the ventricle beats quickly (more than 100 beats per minute)
FM radio waves	frequency modulated waves
geostationary satellites	meteorological satellites which orbit the Earth at the same rate as the Earth rotates (23 hours and 56 minutes) and therefore appear to be stationary relative to Earth; the satellites orbit at an altitude of 35,800 km
infra-red	a form of electromagnetic radiation
joints	occur where the bones come together; along with muscles and bones, joints allow movement
laser technology	laser stands for Light Amplification by Stimulated Emission of Radiation; laser technology produces a powerful beam of highly concentrated light which is used in many technologies such as laser surgery and communication technologies
lenses	devices which cause a beam of light to converge (convex lenses) or diverge (concave lenses)

magnetic resonance imaging	MRI uses radio waves and the body's water molecules to create images; used to clearly identify soft tissue such as the brain and spinal cord which are encased in bone
micro-flora	refers to populations of micro-organisms present on internal and external surfaces of the body
microsurgery	procedures which are very intricate and use precision, miniature instruments viewed under a stereoscopic operating microscope to repair microscopically-sized parts of the body such as nerve tissue
microwaves	electromagnetic radiation with wavelengths from 30 cm to 1 mm
non-invasive or minimally invasive surgery	medical techniques which are alternatives to invasive surgery
oil-in-water emulsion	emulsions in which oil molecules are dispersed in water
optical fibre	a single hair-like fine filament made from molten silica glass. Fibres are constructed in such a way that light can be transmitted through them with minimal loss of light energy by total internal reflection. A fibre optic cable is made up of a large number of individual optical fibres, bound together around a central core.
pacemaker implants	electronic devices implanted under the skin of the chest to help produce a regular electrical impulse and therefore a regular heartbeat
pH	a measure of the acidity or alkalinity of a solution
pins, screws and plates	biomedical devices used to replace damaged bones and repair joints
plaque	made of deposits of fat (cholesterol) and other substances; plaque can build up on the inside walls of blood vessels causing blockages
prosthetic limbs	artificial limbs such as arms/hands and legs/feet
radio waves	a form of electromagnetic radiation which has the longest wavelength (lowest frequency)
reflection	of radiation such as light rays and radio waves; bouncing back or returning of rays at an angle
respiratory system	the breathing system
revolution of the Earth	the movement of the Earth around the sun; one revolution takes approximately 365 days
rotation of the Earth	the movement of the Earth on its axis; one rotation takes approximately 24 hours
satellite dish	devices which receive, gather and focus (as well as transmit) signals.
silicone	a polymer which contains hydrogen, carbon, oxygen and silicon; used as a lubricant and in bionics; properties include biostability, low flammability, acid resistance and flexibility over wide temperature ranges
skin	refers to the outer protective layer or covering of the body
small intestine	part of the alimentary canal in which digestion is completed and almost all absorption of digested products occurs
soap	a surfactant made by the action of sodium or potassium hydroxide on fats
solubility of drugs	the extent to which a drug (the solute) will dissolve in solvents such as fats (lipids), water and alcohol

solute	a substance that is dissolved in a solvent to form a solution
solutions	a mixture of two or more substances in which a solute dissolves in a solvent
solvent	a substance which has the capacity to dissolve other substances in it
stomach	enlarged part of the gut or digestive tract which has muscular walls to churn food and lining cells which secrete pepsin and hydrochloric acid; digestion begins in the stomach.
superalloys	substances used as biomaterials which combine the superior properties of metals such as iron (Fe), cobalt (Co) or nickel (N) with chromium (Cr), molybdenum (Mo) and titanium (Ti). The resulting properties include high strength, low weight, good compatibility with body tissue and inertness.
surface tension	the open surface of a liquid is under tension, therefore the surface shows properties which are similar to a stretched elastic field over the surface
surfactants	surface-active-agents which when added to a liquid affect (increases) the spreading, wetting and surface tension properties of the liquid
surfactant cleaner	such as soap and detergents which change the surface tension of liquids
suspensions	a mixture which consists of very small solid particles in a liquid medium; the solid particles do not dissolve
synovial joints	joints which allow a great range of movements; enclosed by the synovial membrane
telecommunication	short for telephone (or telegraph) communication; communication by electrical wires, optical fibres or radio transmission
teflon	thermoplastic material (tetrafluoro ethylene); used in biomedicine
thermography	uses infra-red waves and differences in body temperature to create images; thermography is useful as a diagnostic technique in locating cancerous tumours
total internal reflection	occurs when the rod (fire) is made up of different substances with different densities, such as glass (a dense medium) and air (less dense)
transmission of information	the sending of information from its source to a receiver
ultra high molecular weight polyethylene	a biomaterial used as an alternative to cartilage surrounding a ball and socket joint due to its biocompatibility with surrounding tissue, low friction, which allows ease of movement and durability
ultrasound	uses ultrasonic (ultra high frequency) sound waves; the sound waves transmitted from a probe penetrate the body and are reflected off internal structures
valves in the heart	flaps which prevent back-flow of blood
veins	blood vessels which carry blood to the heart
ventricles	out-flow chambers of the heart
visible light	the frequencies of electromagnetic radiation which are visible to humans and other animals
water-in-oil emulsion	emulsions in which water molecules are dispersed in oil
water-soluble vitamins	vitamins B1 (thiamine), B2 (Riboflavin), Niacin, B6 (pyridoxine), pantothenic acid, biotin, B12, folate (folic acid), and Vitamin C; not stored by the body
X-ray	electromagnetic radiation with a wavelength of approximately 5×10^{-9} metres to 6×10^{-12} metres. X-rays are absorbed by different materials depending on the materials' density. X-rays are used to photograph bones.

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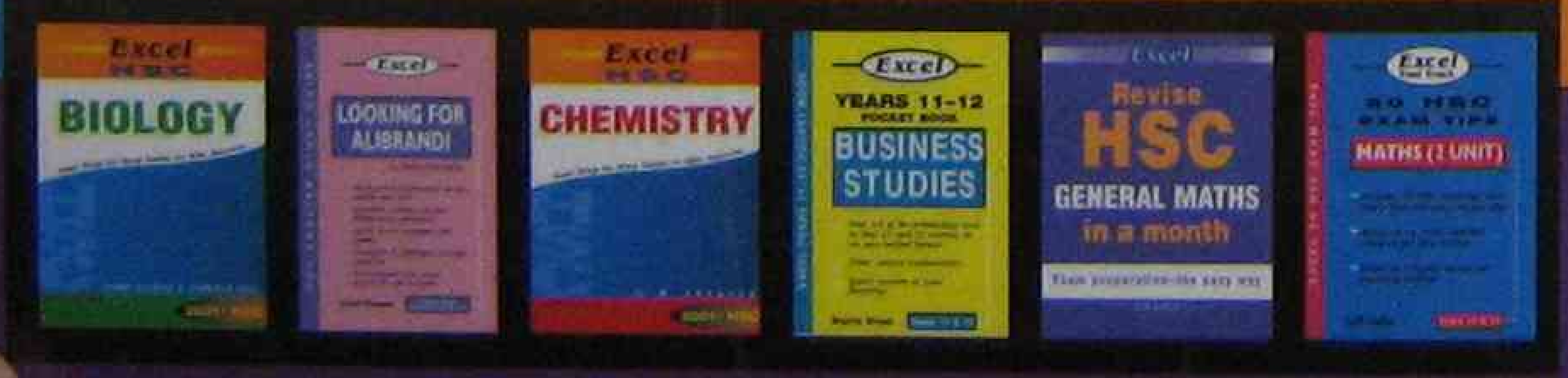

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