UEENEEE104A

DC Circuits

Transposition, Graphs
Numerical Expression and
The Electrotechnology Industry

ELECTRICAL PRINCIPLES

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Formulae Sheets

$R_x = \frac{R_A R}{R_B}$	$C = \frac{Q}{V}$	$\tau = RC$
$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	$C_T = C_1 + C_2 + C_3$	$C = \frac{A\varepsilon_o \varepsilon_r}{d}$

Electromagnetism & DC Machines

$F_m = IN$	$H = \frac{F_m}{l}$	$B = \frac{\Phi}{A}$
$\Phi = \frac{F_m}{S}$	$S = \frac{l}{\mu_o \mu_r A}$	$V = N\frac{\Delta\Phi}{\Delta t}$
$e = Blv$	$L = \frac{\mu_o \mu_r A N^2}{l}$	$L = N\frac{\Delta\Phi}{\Delta I}$
$V = L\frac{\Delta I}{\Delta t}$	$\tau = \frac{L}{R}$	$F = Bil$
$T = Fr$	$E_g = \frac{\Phi Z n P}{60a}$	$P = \frac{2\pi n T}{60}$
$t = \frac{1}{f}$	$f = \frac{np}{120}$	$V = 0.707 V_{max}$

$I = 0.707 I_{max}$	$V_{ave} = 0.637 V_{max}$	$I_{ave} = 0.637 I_{max}$
$v = V_{max} \sin\phi$	$i = I_{max} \sin\phi$	$I = \frac{V}{Z}$
$Z = \sqrt{R^2 + (X_L - X_C)^2}$	$X_L = 2\pi f L$	$X_C = \frac{1}{2\pi f C}$

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Formulae Sheets

$V = L\frac{\Delta I}{\Delta t}$	$\tau = \frac{L}{R}$	$F = Bil$
$T = Fr$	$E_g = \frac{\Phi ZnP}{60a}$	$P = \frac{2\pi nT}{60}$

AC Theory

$t = \frac{1}{f}$	$f = \frac{np}{120}$	$V = 0.707V_{max}$
$I = 0.707I_{max}$	$V_{ave} = 0.637V_{max}$	$I_{ave} = 0.637I_{max}$
$v = V_{max}\sin\phi$	$i = I_{max}\sin\phi$	$I = \frac{V}{Z}$
$Z = \sqrt{R^2 + (X_L - X_C)^2}$	$X_L = 2\pi fL$	$X_C = \frac{1}{2\pi fC}$

$\cos\phi = \frac{P}{S}$	$\cos\phi = \frac{R}{Z}$	$S = \sqrt{P^2 + Q^2}$
$S = VI$	$P = VI\cos\phi$	$Q = VI\sin\phi$
$f_o = \frac{1}{2\pi\sqrt{LC}}$	$V_L = \sqrt{3}V_P$	$I_L = \sqrt{3}I_P$
$S = \sqrt{3}V_L I_L$	$P = \sqrt{3}V_L I_L\cos\phi$	$Q = \sqrt{3}V_L I_L\sin\phi$
$\tan\phi = \sqrt{3}\left(\frac{W_2 - W_1}{W_2 + W_1}\right)$	$Q = mC\Delta t$	
$V' = 4.44\Phi fN$	$\frac{V_1}{V_2} = \frac{N_1}{N_2}$	$\frac{I_2}{I_1} = \frac{N_1}{N_2}$

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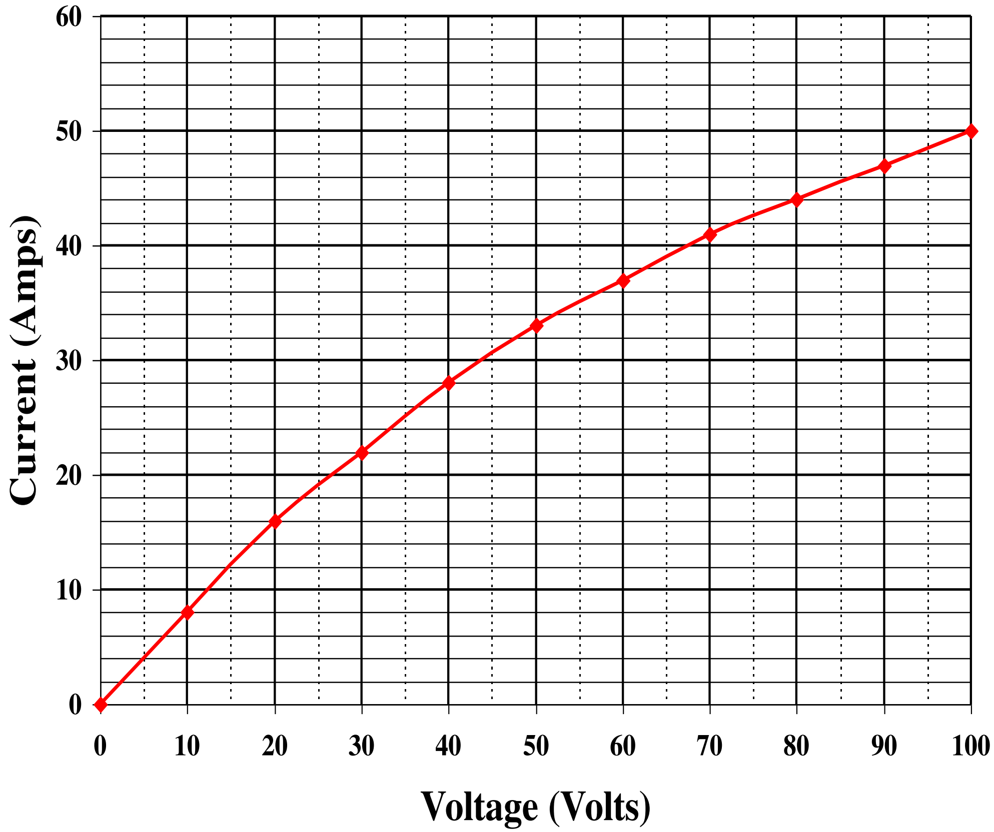
Lesson 1



Transposition, Graphs and Numerical Expression

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Objectives

At the end of this section students should be able to:

1. State and apply the rules of Transposition to simple mathematical equations.
2. Identify common types of and components of Graphs.
3. Draw graphs and extract information from graphs.
4. Convert whole numbers to Scientific, Engineering and Standard Notation.
5. State the metric system of multiples and sub-multiples.
6. Convert numbers between conventional numbering systems.

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Basic Rule for Transposition

What you do to one side of the equation you must also do to the other side.

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Steps for Transposition

1. Remove Root (√) Signs

$$I = \sqrt{\frac{P}{R}} \quad \Rightarrow \quad I^2 = \left(\sqrt{\frac{P}{R}}\right)^2 \quad \Rightarrow \quad I^2 = \frac{P}{R}$$

$$Z = \sqrt{R^2 + X^2} \quad \Rightarrow \quad Z^2 = R^2 + X^2$$

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Steps for Transposition

2. Remove Fractions

$$I^2 = \frac{P}{R} \quad \rightarrow \quad P = I^2 R$$

$$P = \frac{V^2}{R} \quad \rightarrow \quad V^2 = PR$$

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Steps for Transposition

3. Remove Brackets

$$W = E(b + c) \quad \Rightarrow \quad W = Eb + Ec$$

$$A = h(b_1 + b_2) \quad \Rightarrow \quad A = hb_1 + hb_2$$

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Steps for Transposition

4. Collect like terms
   Get the desired term on one side of the equation

$$r\underline{s} = f\,\underline{s} + fr \quad \Rightarrow \quad fr = rs - fs$$

$$5F = \underline{9C} + 160 \quad \Rightarrow \quad 9C = 5F - 160$$

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Steps for Transposition

5. Remove the new subject as a common factor

$$fr = r\underline{s} - f\,\underline{s} \quad \Rightarrow \quad fr = s(r - f)$$

$$b = a\underline{x^2} + c\underline{x^2} \quad \Rightarrow \quad b = x^2(a + c)$$

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Steps for Transposition

6. Divide both sides by the co-efficient of the new subject

$$fr = \underline{s}(r - f) \quad \Rightarrow \quad s = \frac{fr}{(r - f)}$$

$$aw^2 = 100\underline{x} \quad \Rightarrow \quad x = \frac{aw^2}{100}$$

$$R = K\underline{V^2} \quad \Rightarrow \quad V^2 = \frac{R}{K}$$

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Steps for Transposition

7. Take roots of both sides

$$V^2 = \frac{R}{K} \quad \Rightarrow \quad V = \sqrt{\frac{R}{K}}$$

$$V^2 = \frac{ma}{K} \quad \Rightarrow \quad V = \sqrt{\frac{ma}{K}}$$

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Steps for Transposition

1. Remove Root (√) Signs
2. Remove Fractions
3. Remove Brackets
4. Collect like terms
   Get the desired term on one side of the equation
5. Remove the new subject as a common factor
6. Divide both sides by the co-efficient of the new subject
7. Take roots of both sides

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Graphs

What is a Graph?

A pictorial representation of two or more related sets of data.

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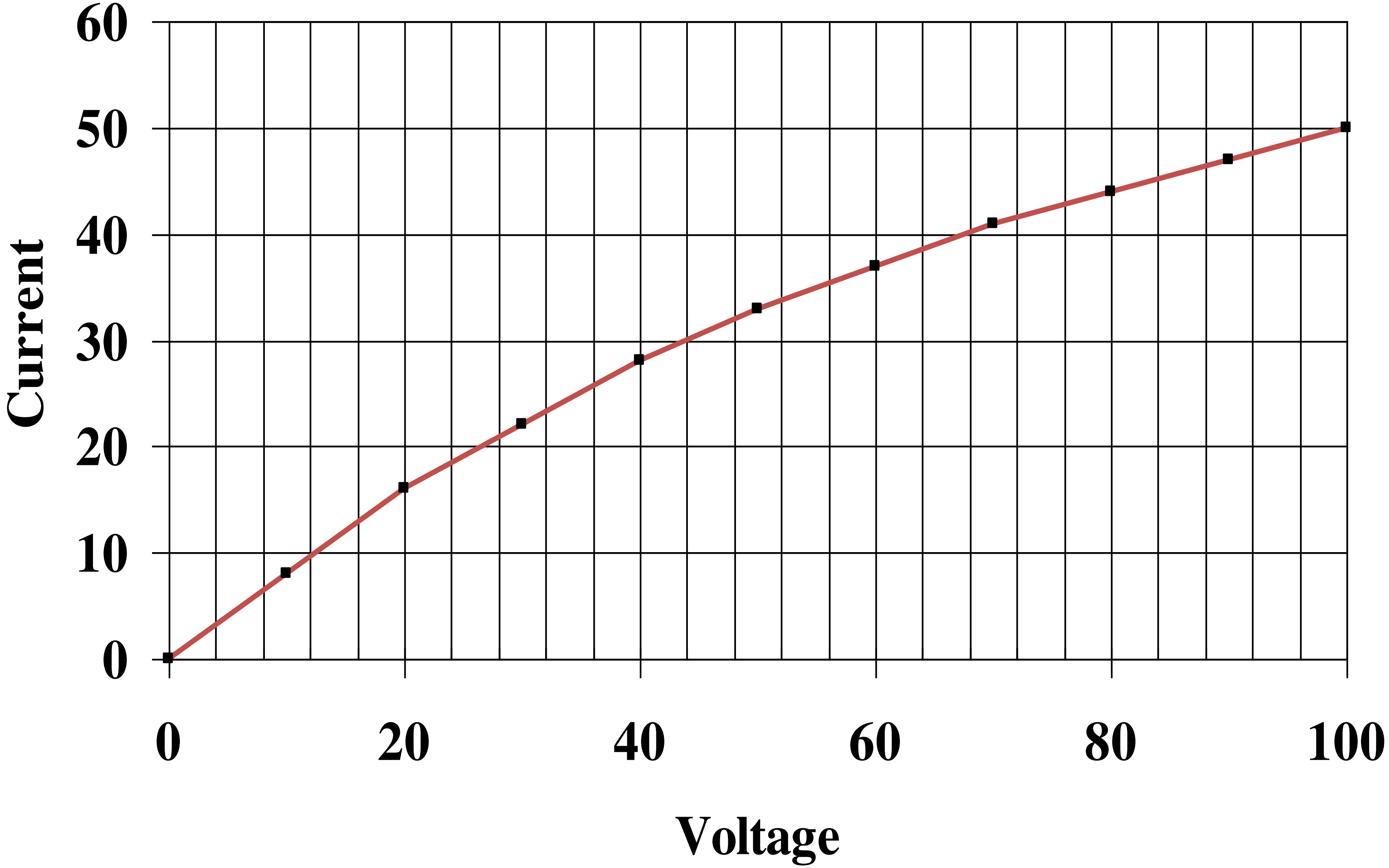

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Parts of the Graph

1. The Axes

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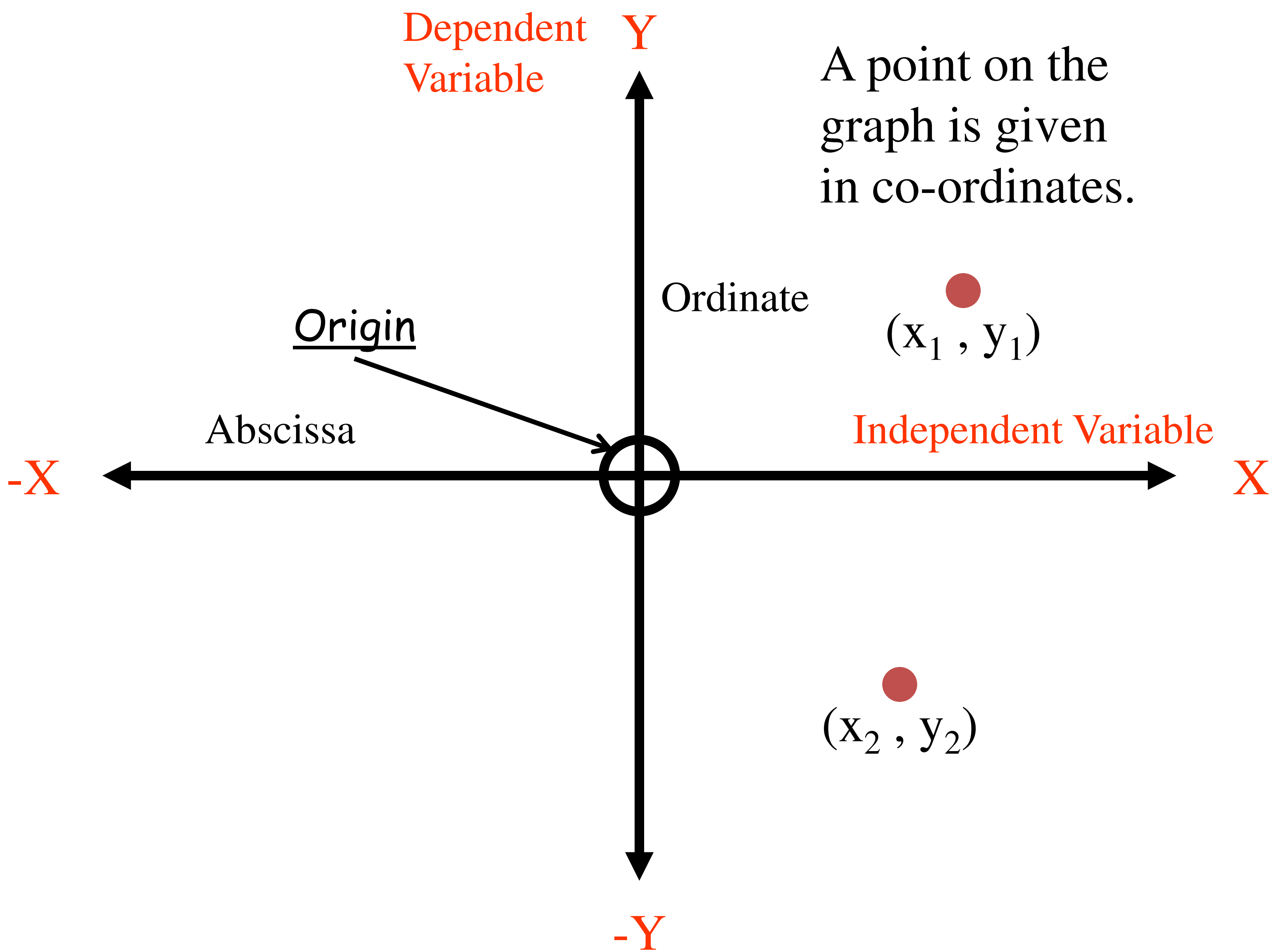
A point on the graph is given in co-ordinates.



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Parts of the Graph

1. The Axes
2. The Path

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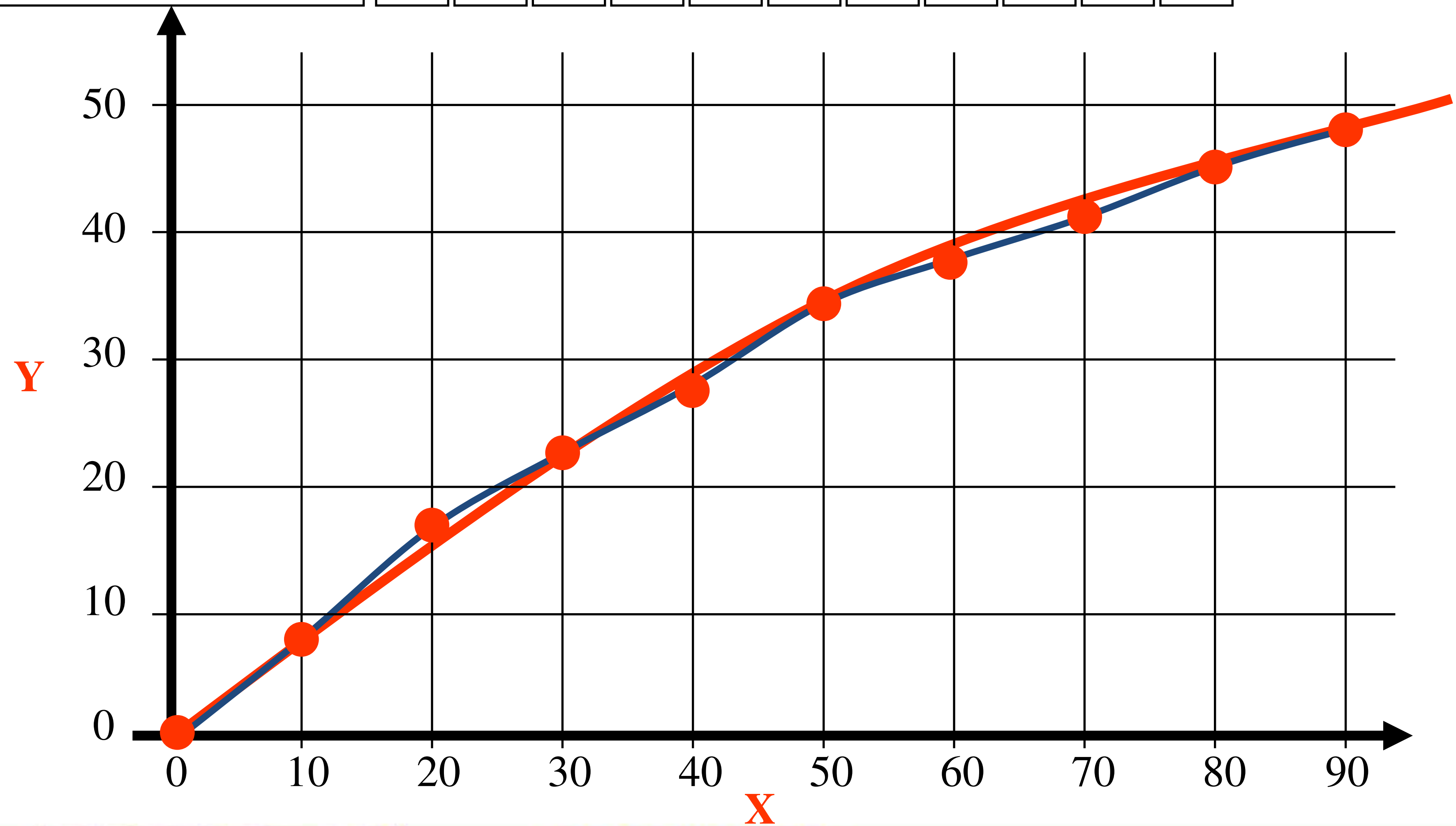
Independent Variable	X	0	10	20	30	40	50	60	70	80	90
Dependent Variable	Y	0	8	16	22	28	33	37	41	44	47



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$$y = 2x^2 - 4$$

Independent Variable

X	-3.0	-2.5	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0
Y	14	8.5	4.0	0.5	-2.0	-3.5	-4.0	-3.5	-2.0	0.5	4.0	8.5	14

Dependent Variable

$$y = 2(-3.0)^2 - 4 = 14$$
$$y = 2(3.0)^2 - 4 = 14$$
$$y = 2(-2.5)^2 - 4 = 8.5$$
$$y = 2(2.5)^2 - 4 = 8.5$$
$$y = 2(-2.0)^2 - 4 = 4.0$$
$$y = 2(2.0)^2 - 4 = 4.0$$
$$y = 2(-1.5)^2 - 4 = 0.5$$
$$y = 2(1.5)^2 - 4 = 0.5$$
$$y = 2(-1.0)^2 - 4 = -2.0$$
$$y = 2(1.0)^2 - 4 = -2.0$$
$$y = 2(-0.5)^2 - 4 = -3.5$$
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$$y = 2(-0.0)^2 - 4 = -4.0$$

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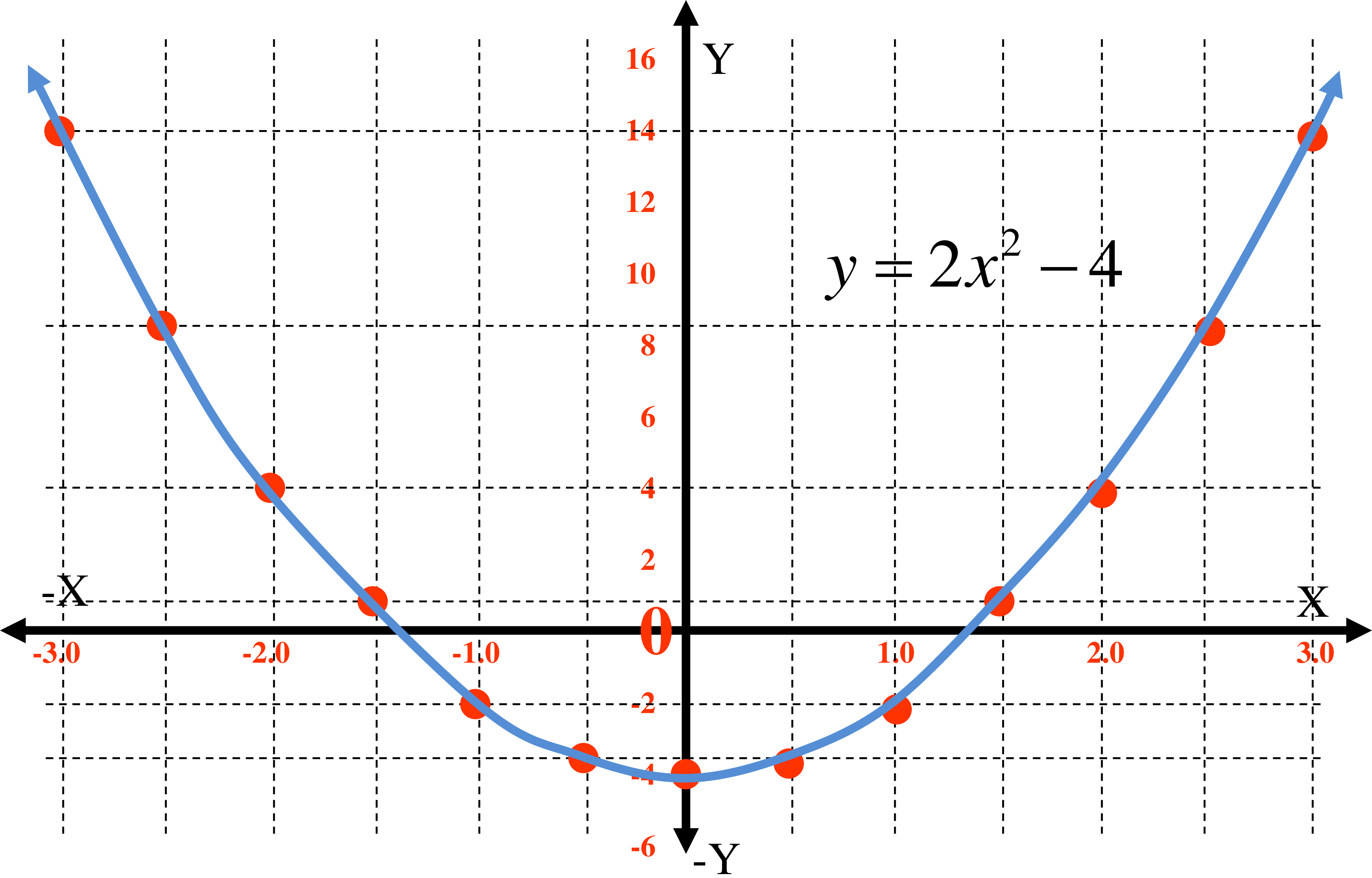

ELECTRICAL PRINCIPLES

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Multiples, Submultiples And Scientific Notation

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Multiples & Submultiples

Term	Symbol	Multiple
Terra	T	1 000 000 000 000
Giga	G	1 000 000 000
Mega	M	1 000 000
kilo	k	1 000
Units	Eg. meters	1
milli	m	1 / 1 000
micro	μ	1 / 1 000 000
nano	n	1 / 1 000 000 000
pico	p	1 / 1000 000 000 000

Scientific Notation

Term	Symbol	Multiple	Sci Not^n
Terra	T	1 000 000 000 000	x 10^{12}
Giga	G	1 000 000 000	x 10^{9}
Mega	M	1 000 000	x 10^{6}
kilo	k	1 000 $= 1 \times 10^3$	x 10^{3}
Units	Eg. meters	1 $= 1 \times 10^0$	x 10^{0}
milli	m	1 / 1 000 $= 1 \times 10^{-3}$	x 10^{-3}
micro	μ	1 / 1 000 000	x 10^{-6}
nano	n	1 / 1 000 000 000	x 10^{-9}
pico	p	1 / 1000 000 000 000	x 10^{-12}

Move DP LEFT

Move DP RIGHT

Break Time

20 Minutes

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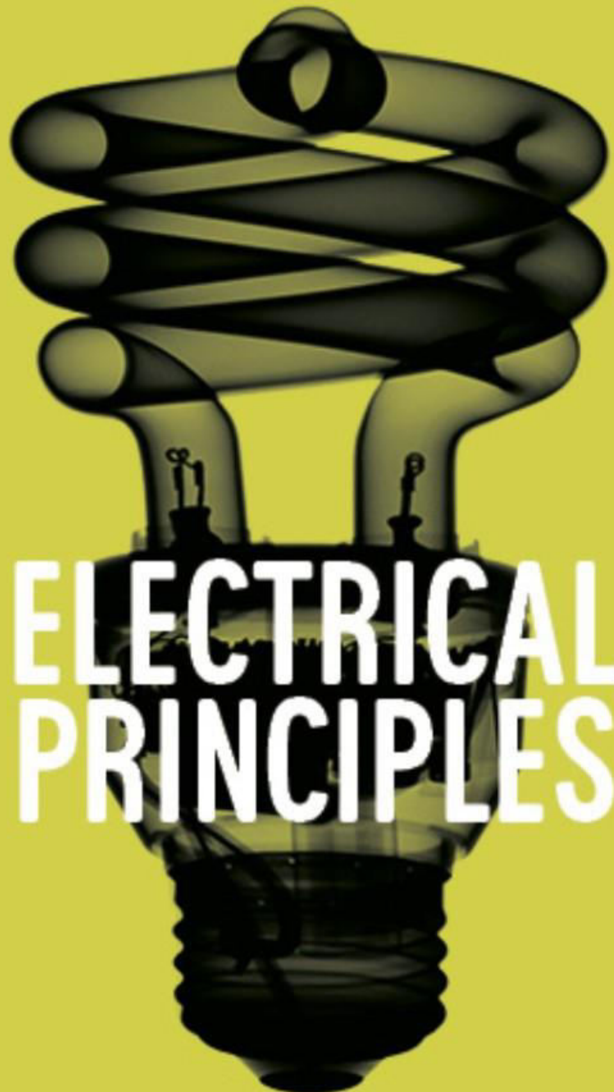

ELECTRICAL PRINCIPLES

PETER PHILLIPS

3RD EDITION

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Chapter 1

The electric circuit

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About this chapter

This chapter:

- introduces the electrotechnology industry
- looks at legislation about WHS and environmental issues
- introduces the terms voltage, current and resistance
- discusses the difference between a conductor and an insulator
- introduces the terms open-circuit, closed-circuit and short-circuit
- explores the electric circuit and its component symbols.

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Contents

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Contents (2)

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1.1 The electrotechnology industry

- The industry can be roughly divided into two groups, electrical and electronics.
- Those working in any area of the electrotechnology industry need to know the principles of electricity.
- Electricity is provided by electrical generating sources and is supplied by way of overhead and underground cables.

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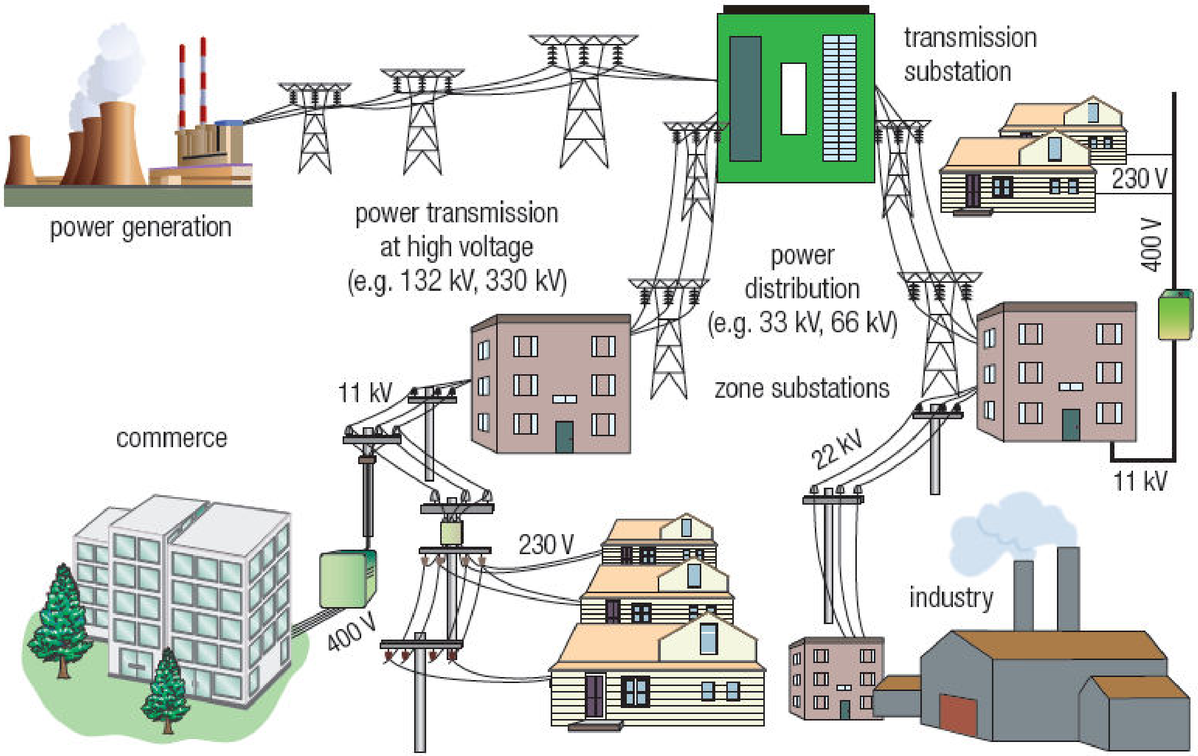
Electrical power distribution



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Electrical industry

The electrical industry includes:

- electrical supply – covering power generation, transmission and distribution
- industrial – installing and maintaining electrical machinery and electrical wiring in factories and industrial complexes
- commercial and domestic – installation of wiring (lighting, power, data) and appliances.

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Electronics industry

The electronics industry includes:

- data and voice communications – telecommunications, radio and TV transmission, communication systems
- consumer electronics – maintenance of domestic electronic appliances
- commercial electronics – repairing and servicing electronic equipment used by commerce.

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Electronics industry (2)

The electronics industry includes:

- computer system installation, repair and servicing
- industrial – electronic systems used in industry
- security – installation of security systems.

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Electronics industry (3)

domestic appliances

computers

security

telecommunications

industrial

appliances servicing
domestic and commercial

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Chapter 1
The electric circuit

1.2 Workplace safety laws

1.3 Sustainable energy principles

1.4 Voltage

1.5 Current

1.6 Resistance

1.7 Basic electric circuit

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Chapter 1
The electric circuit

1.8 Circuit diagrams

1.9 Open-circuit and closed-circuit

1.10 Measuring voltage

1.11 Measuring current

1.12 Meter connections

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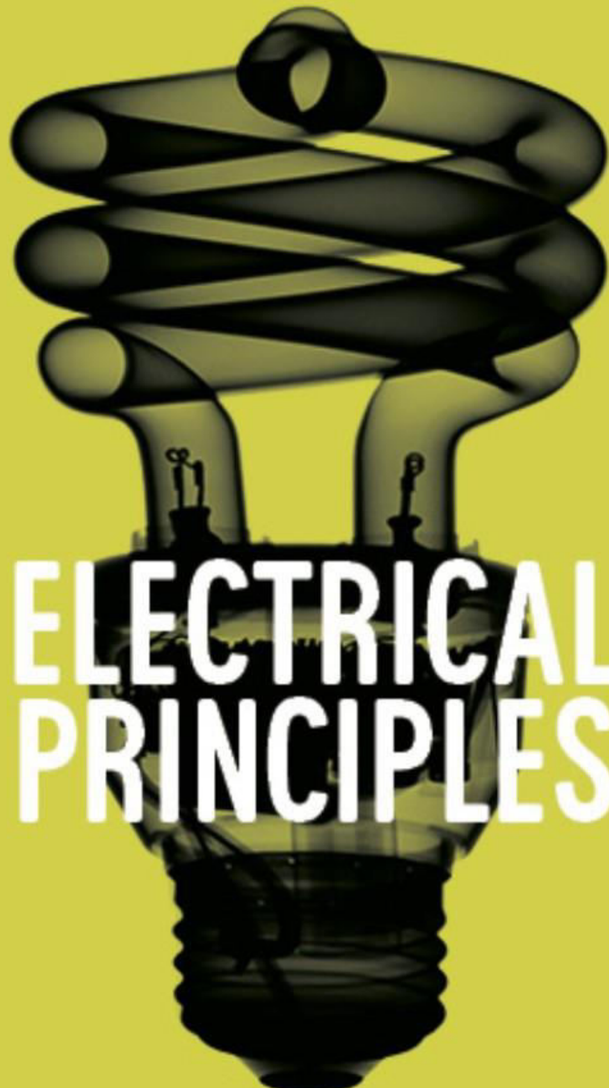

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1.2 Workplace safety laws

- Workplace WHS legislation requires every person in a workplace to ensure their own health and safety.
- Working with electricity has its own special hazards, including risk of electric shock.
- Before starting any electrical work:
  - identify all hazards
  - assess the risk associated with each hazard
  - determine methods of dealing with all identified risks.

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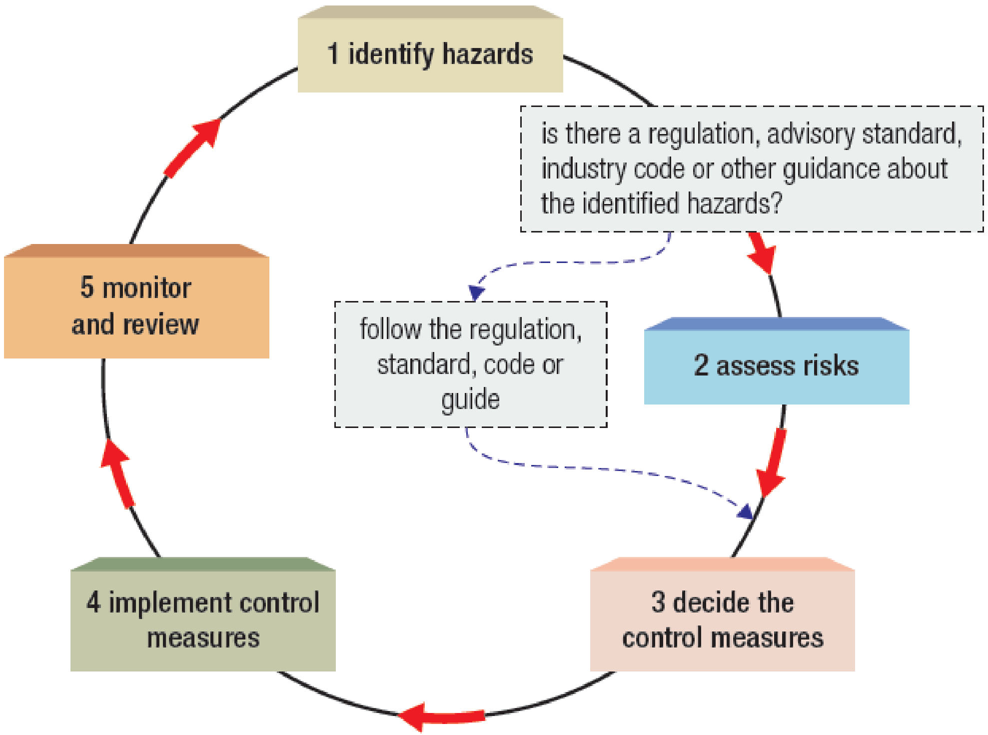
Risk management



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1.3 Sustainable energy principles

- Applying sustainable energy principles means minimising damage to the environment.
- Sustainable energy principles include anything that affects the ability of future generations to meet their own needs.
- Sustainable energy is made up of two parts: renewable energy and energy efficiency.
- Environmental laws require many industries to have an environmental management plan.

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Environmental incidents

Fallen power pole with transformer leaking oil

Pad mount transformer on fire

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RN
Video
Part 1

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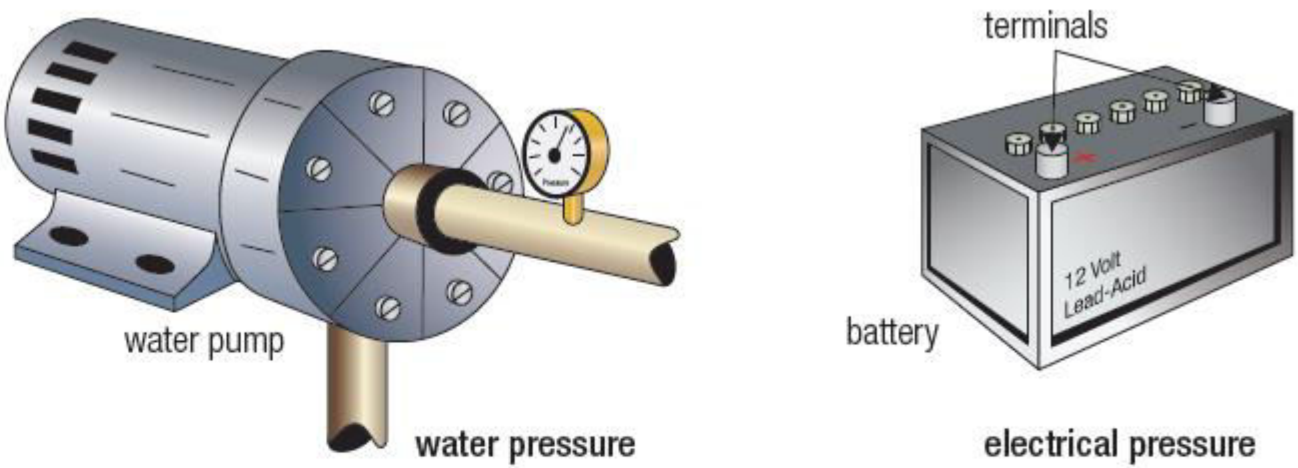
1.4 Voltage



A voltage is electrical pressure and occurs between two points if one point has more or less electrons than the other

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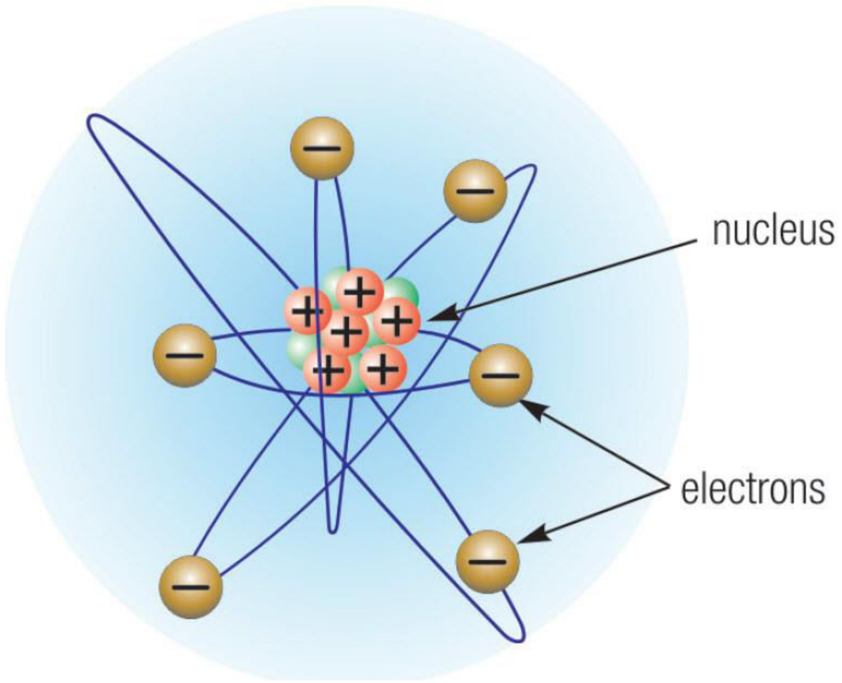
Electrons



Electrons have a negative charge and orbit the nucleus of an atom

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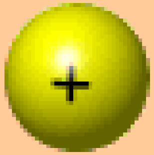
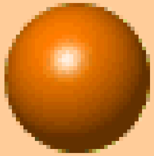
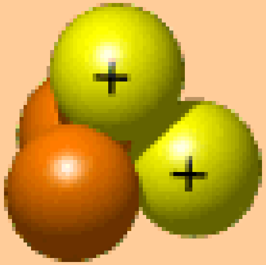
Atoms are made out of three basic particles:



Protons - carry a positive charge



Neutrons - carry no charge



Protons and Neutrons join together to form the Nucleus - the central part of the atom

Electrons - carry a negative charge and circle the nucleus

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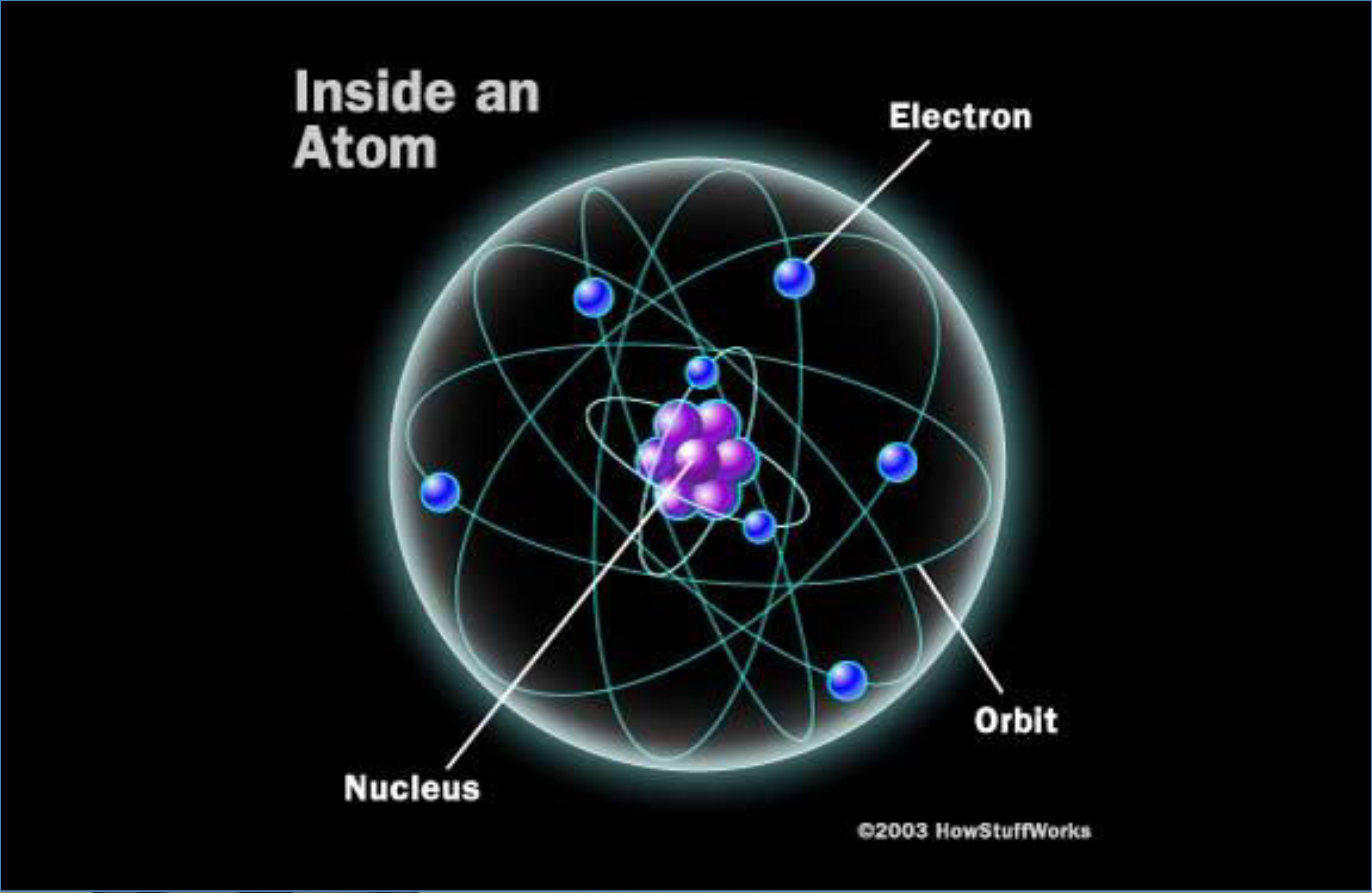

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Materials that have   Are called

Lots of Free Electrons — Good Conductors OR Poor Insulators

Eg. Steel, Copper, Aluminium, Silver, Gold
(Metals)

Few Free Electrons — Good Insulators OR Poor Conductors

Eg. Rubber, Plastics, Mica, Wood
(Non-Metals)

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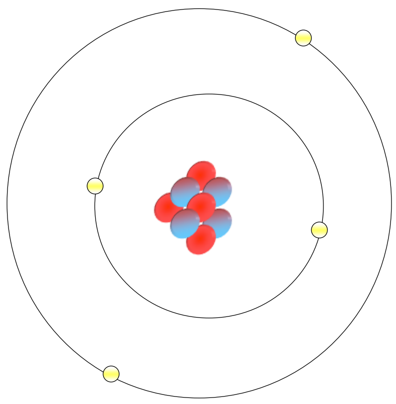
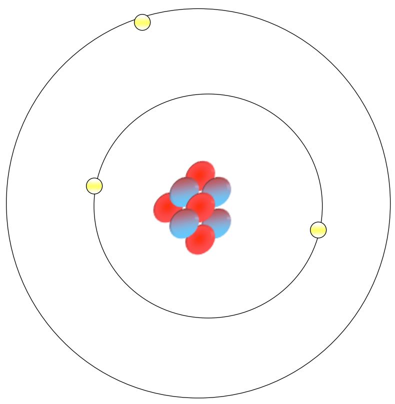


Atom

(Neutral Ion)

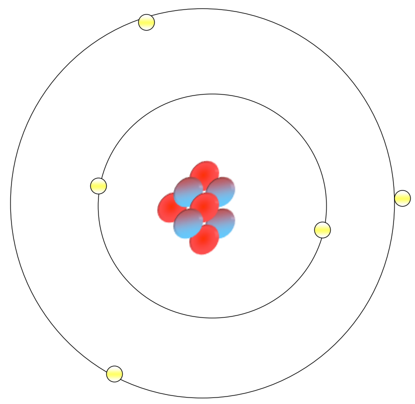
4 Protons (+)
&
4 Electrons (-)
{No Charge}



Pos Ion

(Deficient e^-)

4 Protons (+)
&
3 Electrons (-)
{Positive Charge}



Neg Ion

(Excess e^-)

4 Protons (+)
&
5 Electrons (-)
{Negative Charge)

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Charges react with each other

Unlike Charges → ATTRACT

Like Charges → REPEL

(Just like magnets)

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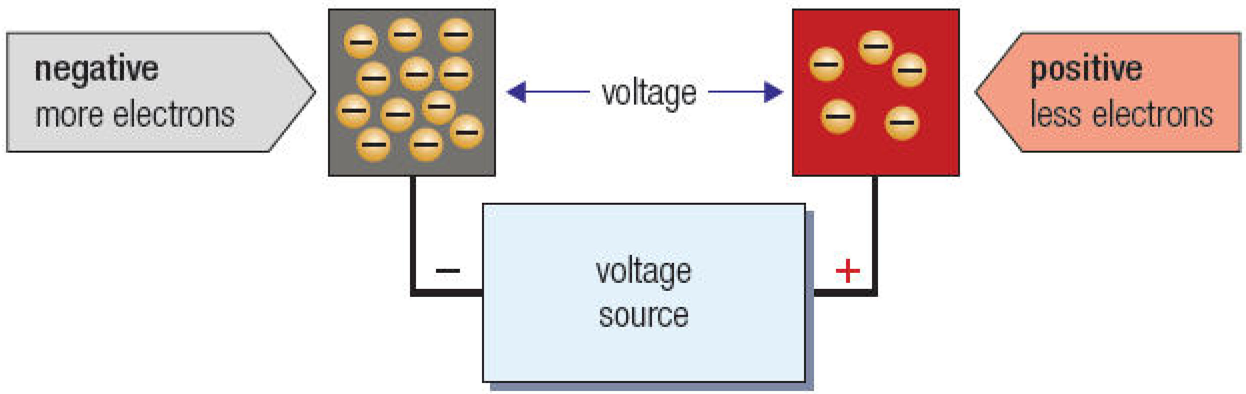
Voltage between two points



There is a voltage when one point has more electrons than another

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Voltage and EMF

- Voltage is measured in volts.
- The symbol for voltage (and for volts) is V.
- The voltage from a voltage source (such as a battery) is also called its electromotive force (EMF).
- The symbol for EMF is the letter E.

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Pressure = Voltage

Quantity	*Term*	*Letter*	*Unit*
Electrical Pressure	Electro Motive Force	E	Volt (V)
	Terminal Voltage or Potential Difference	V	

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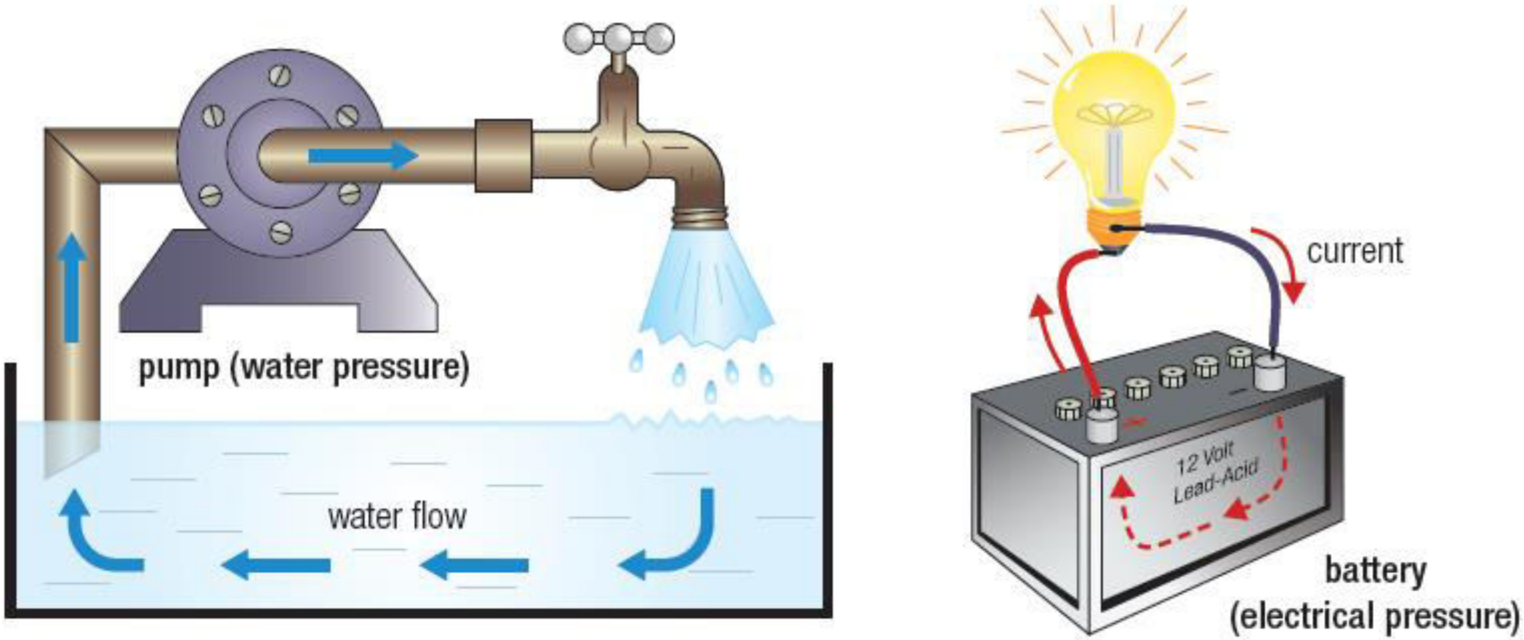
1.5 Current



Current is a flow of electrons

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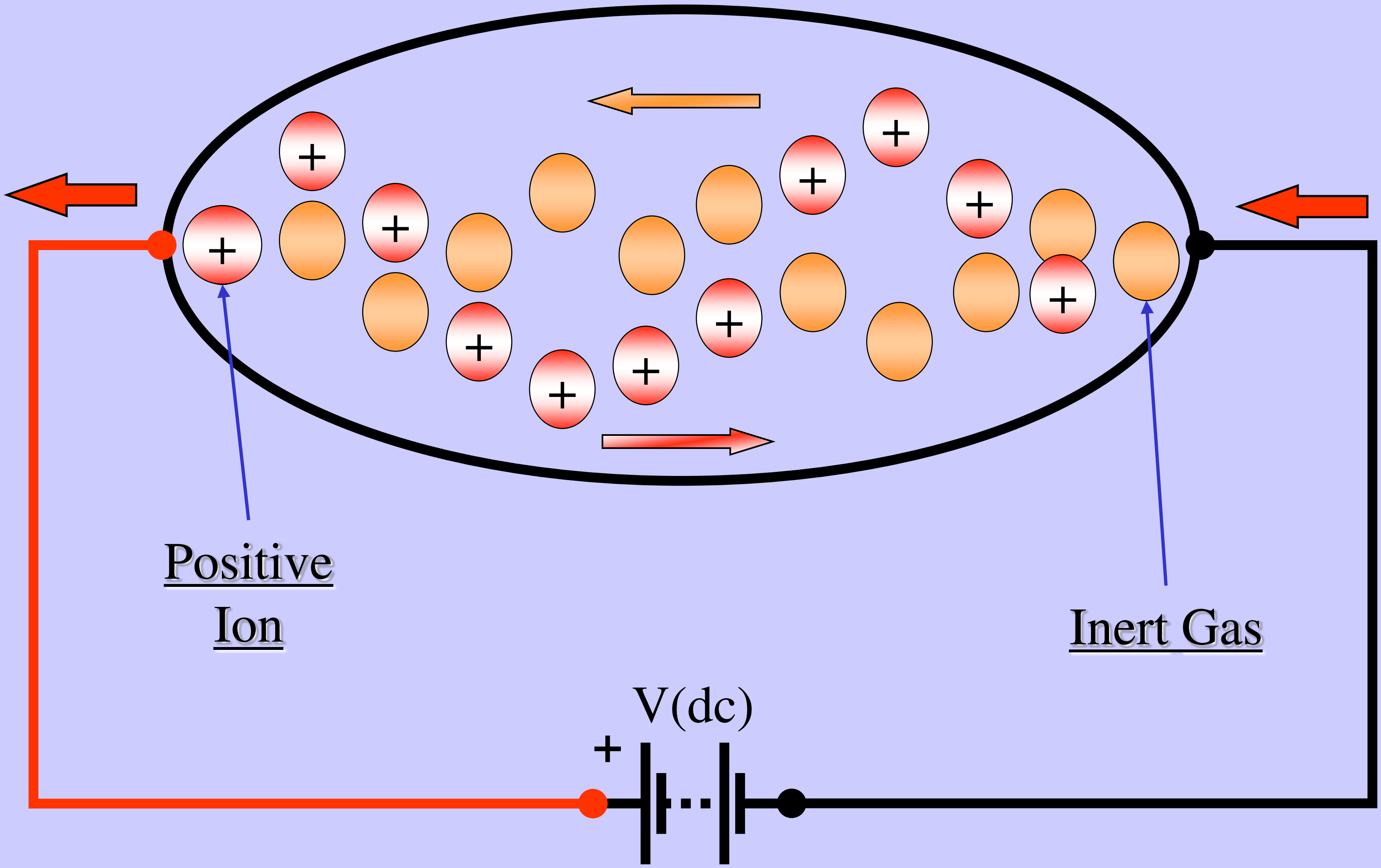
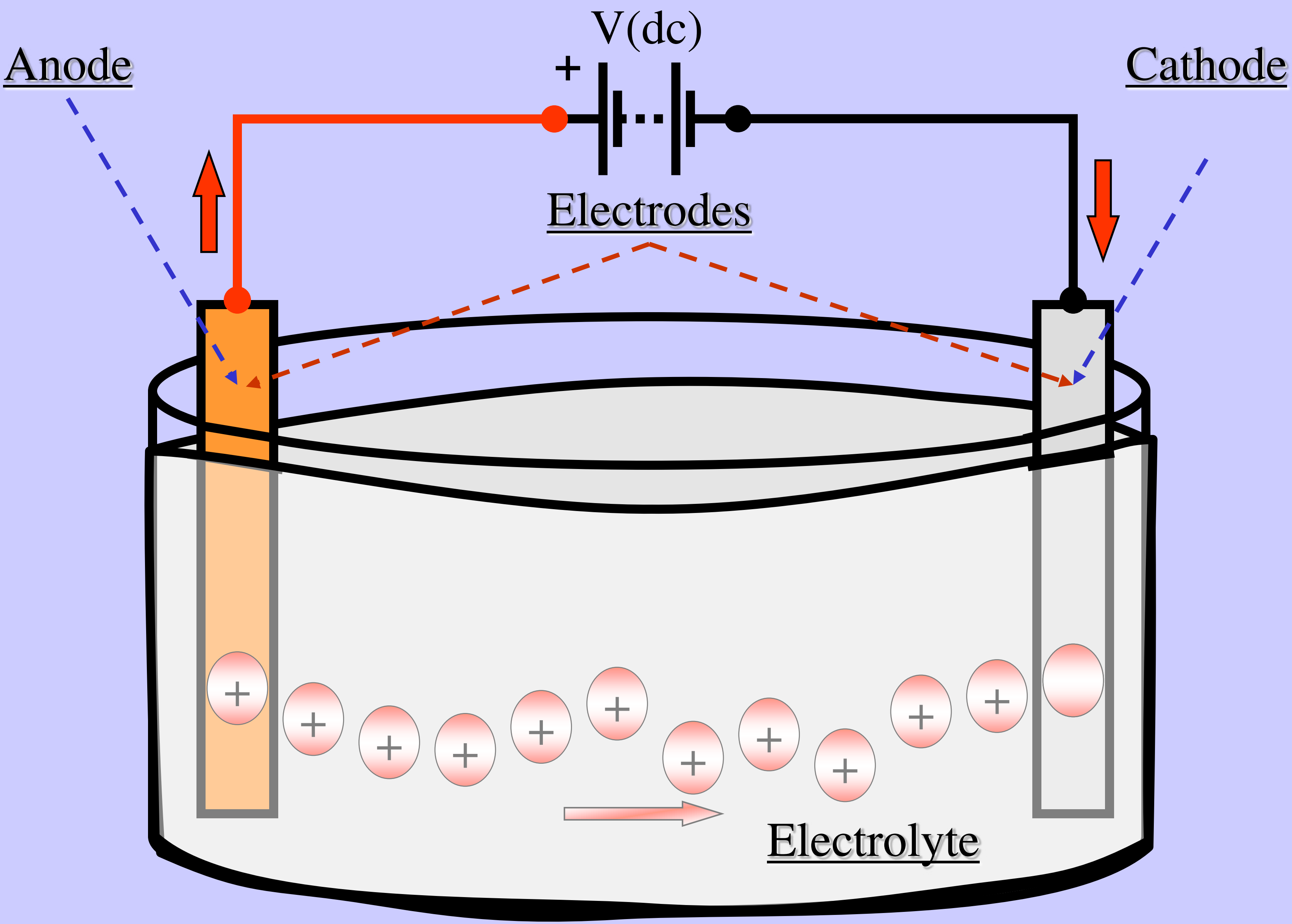
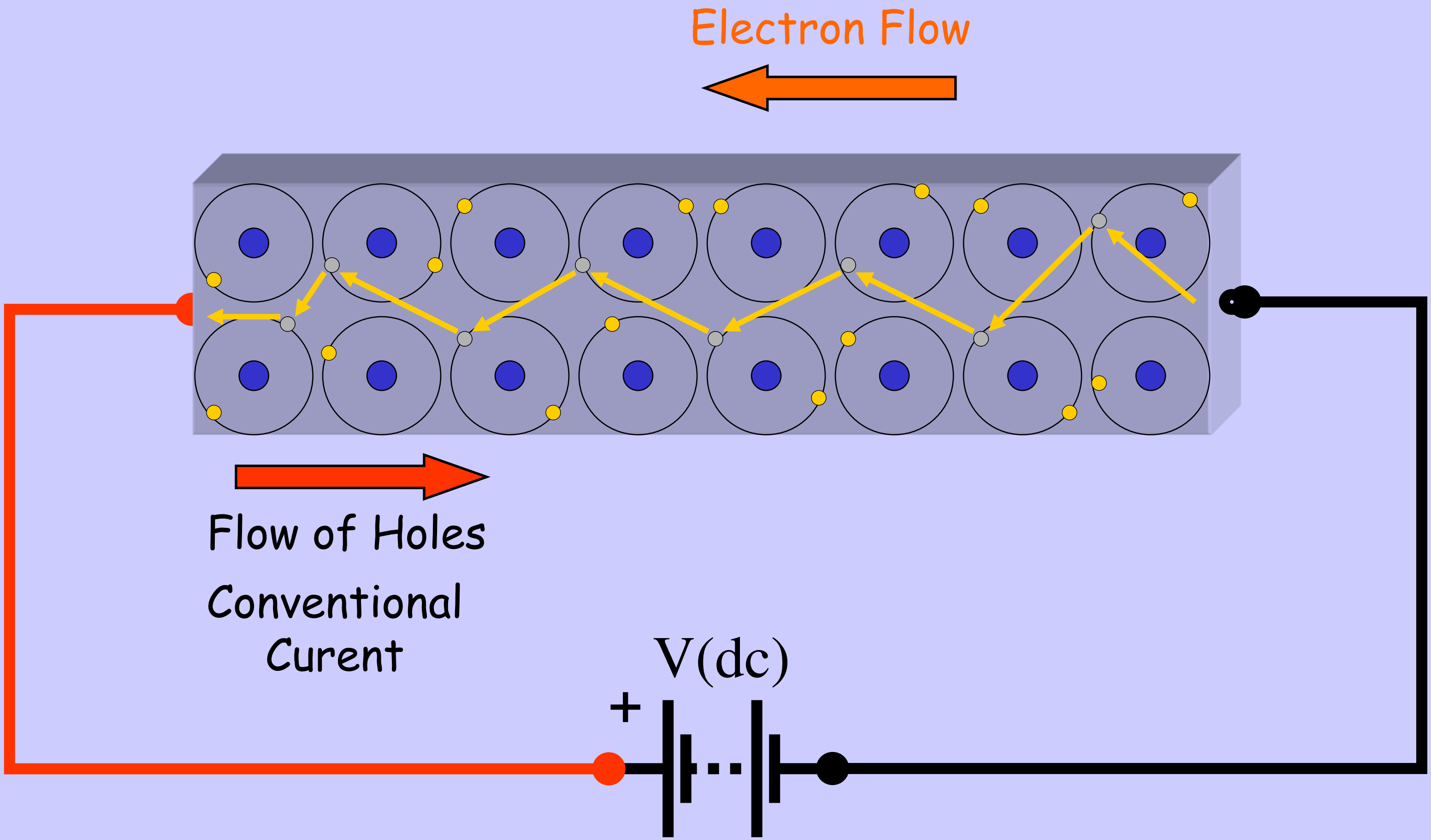
Conduction in a ***Gas*** is by the movement of IONs



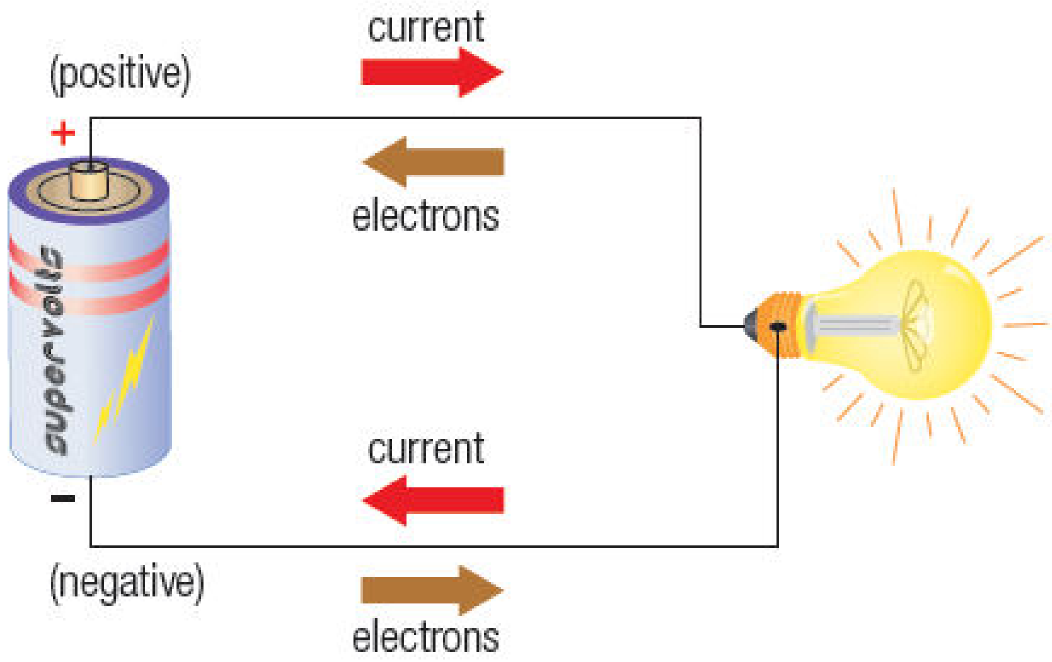
Conduction in a **Liquid** is also by the movement of IONs



Conduction in **Solids** is by the movement of Electrons



Current flow



‘conventional’ current flows the opposite way to the electron flow

Current is assumed to flow from positive to negative

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Current and coulombs

- Current is measured in amperes.
- The symbol for current is the letter I.
- The symbol for amperes is the letter A.
- One ampere of current equals one coulomb of charge flowing per second.
- A coulomb equals 6 240 000 000 000 000 electrons.
- The symbol for charge is the letter Q.

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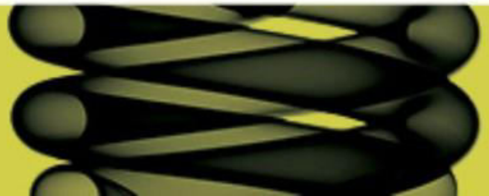
Charge ⇒ Coulombs

Quantity	Term	Letter	Unit
Charge	Charge	Q	Coulombs C

1 Coulomb = 6 240 000 000 000 000 electrons

$$1C = 6.24 \times 10^{15}e$$



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Flow = Current

Quantity	Term	Letter	Unit
Electric Flow	Current	I	Ampere (Amp) A

1 Amp = 1 Coulomb/second

$$1A = 6.24 \times 10^{15} e/S$$

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1.6 Resistance

- For current to flow, there must be a path for the electrons.
- All materials can be classified as conductors, insulators or semiconductors.
- A conductor is a material that lets electrons flow fairly easily because of its atomic structure.

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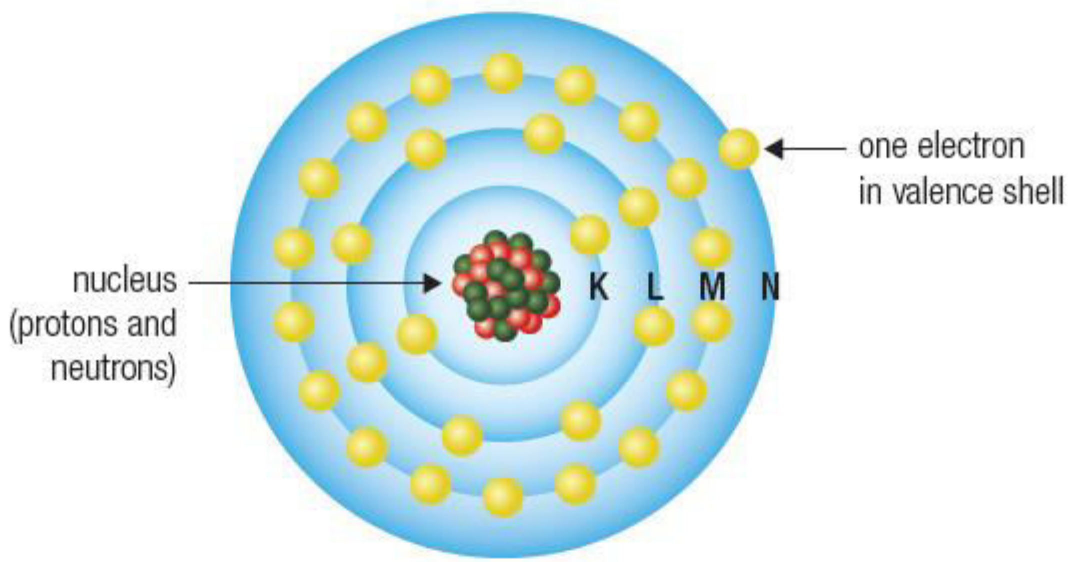
Atomic structure



Copper atom with 29 electrons orbiting the nucleus in four shells K, L, M and N. Copper has a valency of one.

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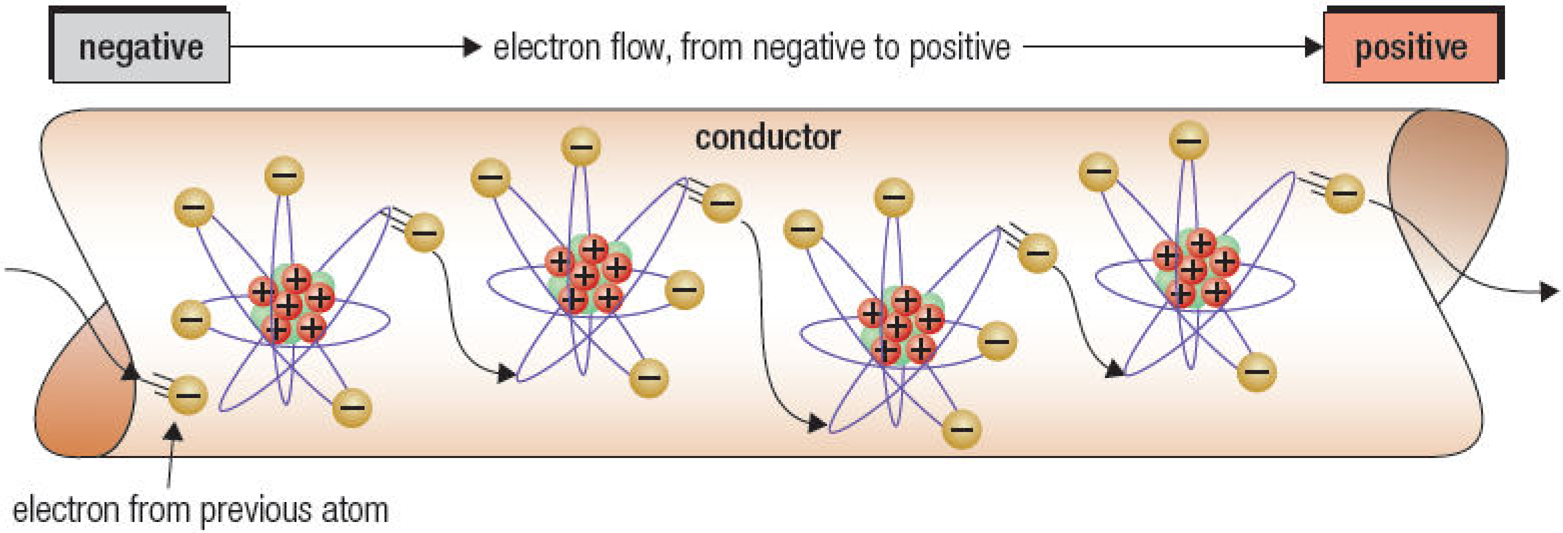
Electron flow in a conductor



In a conductor, electrons can easily move from one atom to the next because of its low valency

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Conductors

- Conductors include most metals.
- Silver is the best conductor.
- Copper is the next best conductor and is widely used in the electrical field.
- Gold has less conductivity than copper, but does not corrode.
- Aluminium is a poorer conductor than copper, but being lighter, is used in high voltage power transmission lines.

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Insulators

- An insulator does not conduct electricity.
- If the voltage is high enough an insulator can break down and conduct electricity.
- Air is a good insulator.
- Lightning is an example of air breaking down and becoming a conductor.
- Most insulating materials are destroyed when they break down.

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Semiconductors

- A semiconductor is neither a conductor nor an insulator.
- The most common semiconductor material is silicon. Germanium is another.
- When these two semiconductors are 'doped' they can be used to make solid-state components such as transistors and diodes.

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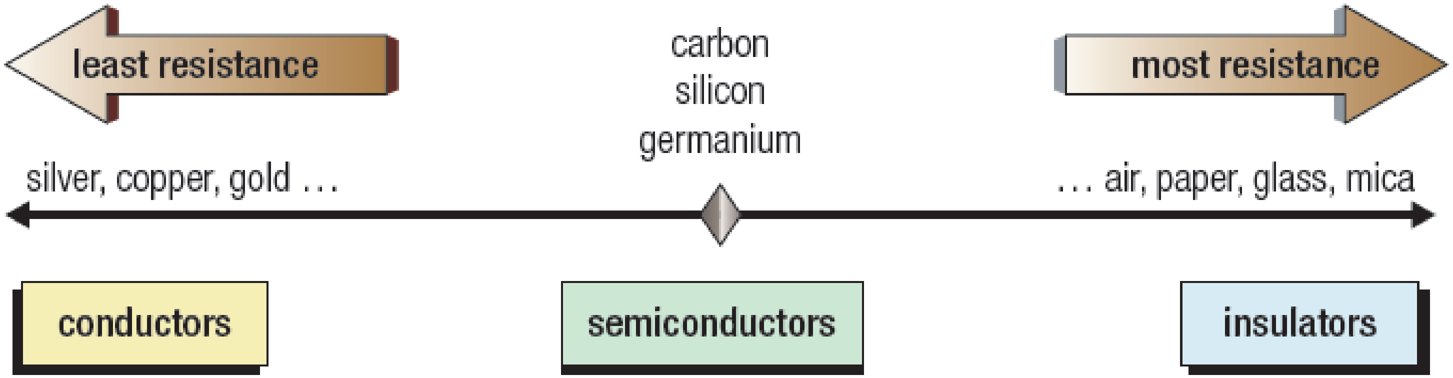
Comparing resistance



Conductors have much less resistance to electron flow than insulators or semiconductors

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Resistance

- Resistance is opposition to current flow.
- Resistance is measured in ohms and has the symbol R.
- The term ohm is often replaced with the Greek letter Ω (omega). A resistance of two ohms is written as R = 2 Ω.
- If voltage doesn't change, the higher the resistance the less the current.

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Opposition to Flow = Resistance

Quantity	*Term*	*Letter*	*Unit*
Opposition to Current Flow	Resistance	R	Ohm (Ω)
Ease of Current Flow	Conductance	G	Siemens (S)

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SUMMARY

Quantity	Term	Letter	Unit
Electrical Pressure	Electromotive Force (EMF)	E	Volt (V)
	Potential Difference (PD)	V	
Charge	Charge	Q	Coulombs (C)
Electric Flow	Current	I	Amp (A)
Opposition to Flow	Resistance	R	Ohm (Ω)
Ease of Flow	Conductance	G	Siemens (S)

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1.8 Circuit diagrams

- A circuit diagram shows how components in a circuit are connected.
- The diagram is drawn using symbols for each component in the circuit.
- All electrical components have their own symbol.
- Australian Standard symbols are used in the electrical trades.

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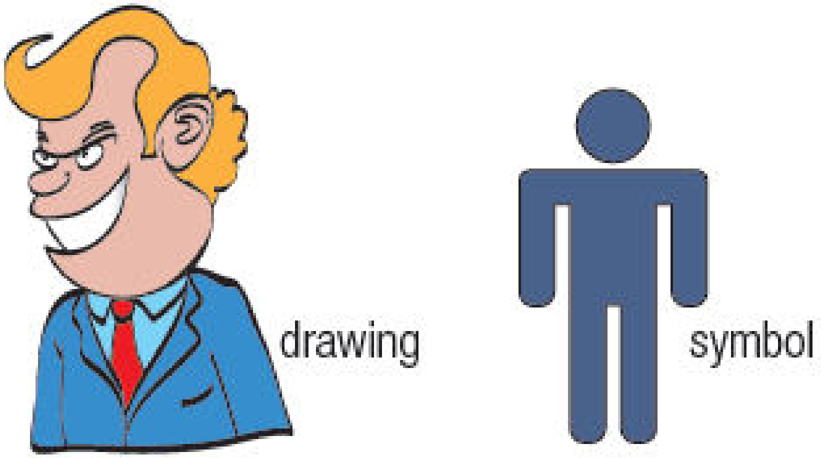
1.8 Circuit diagrams (2)



Symbols are used to represent something

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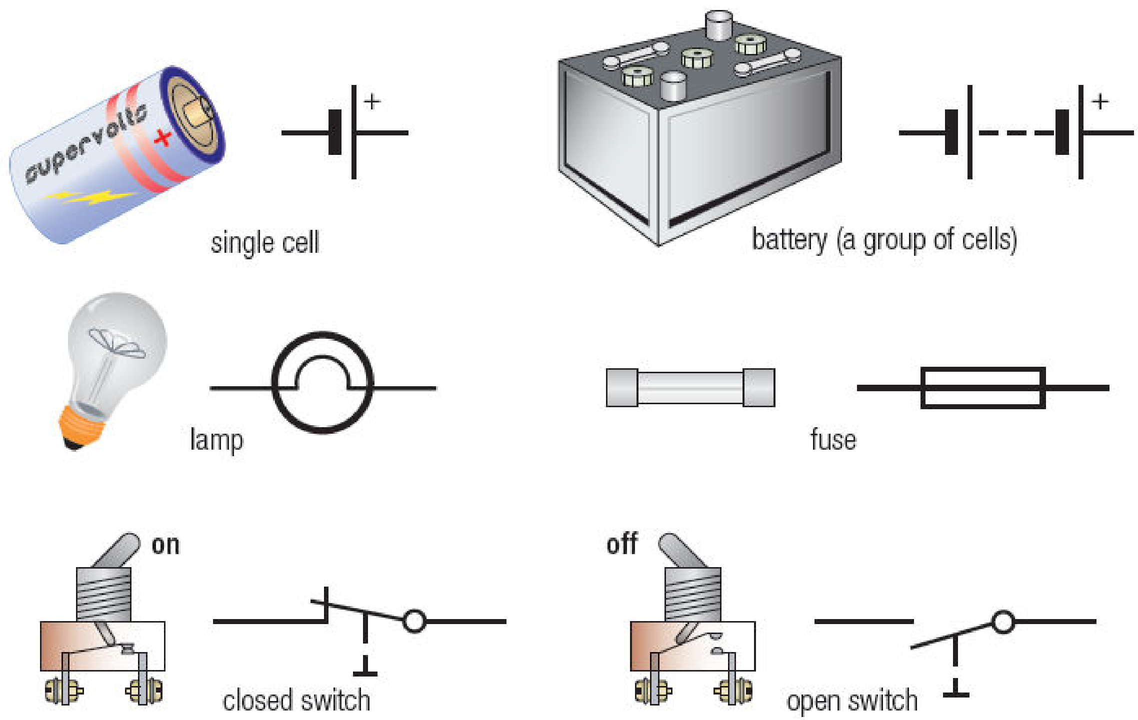
Component symbols



Each component in a circuit has its own symbol

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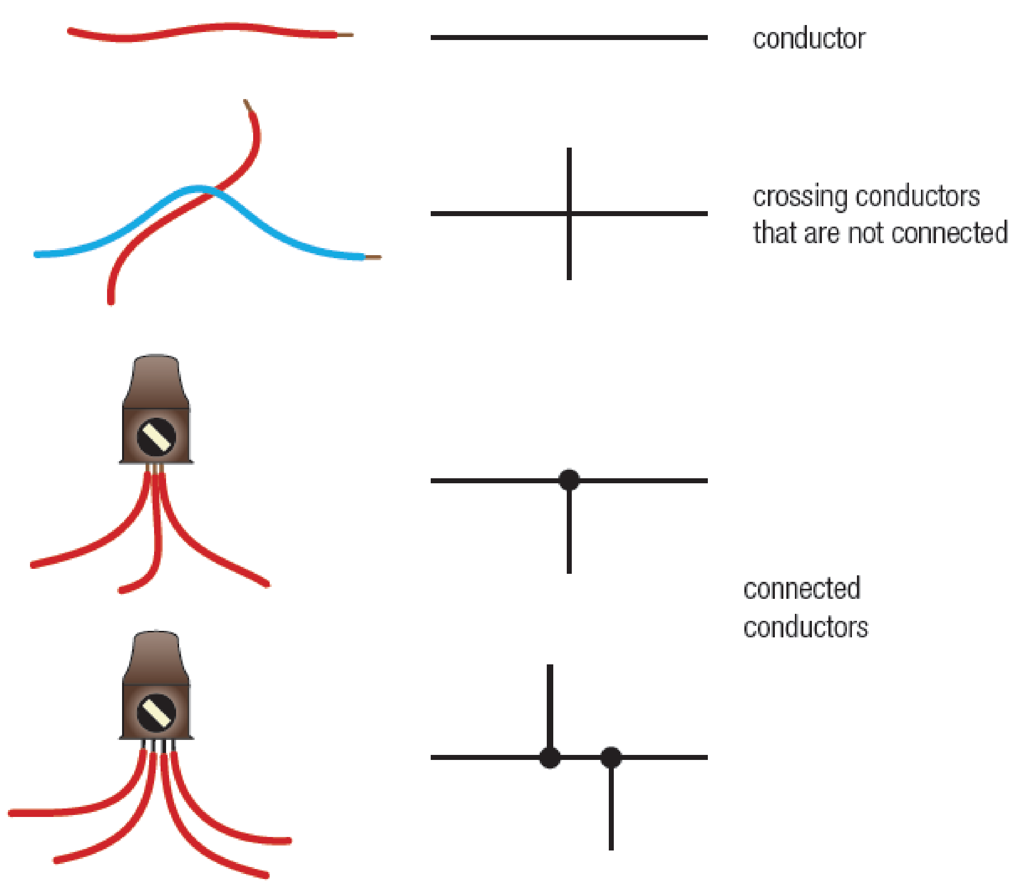
Conductor connections



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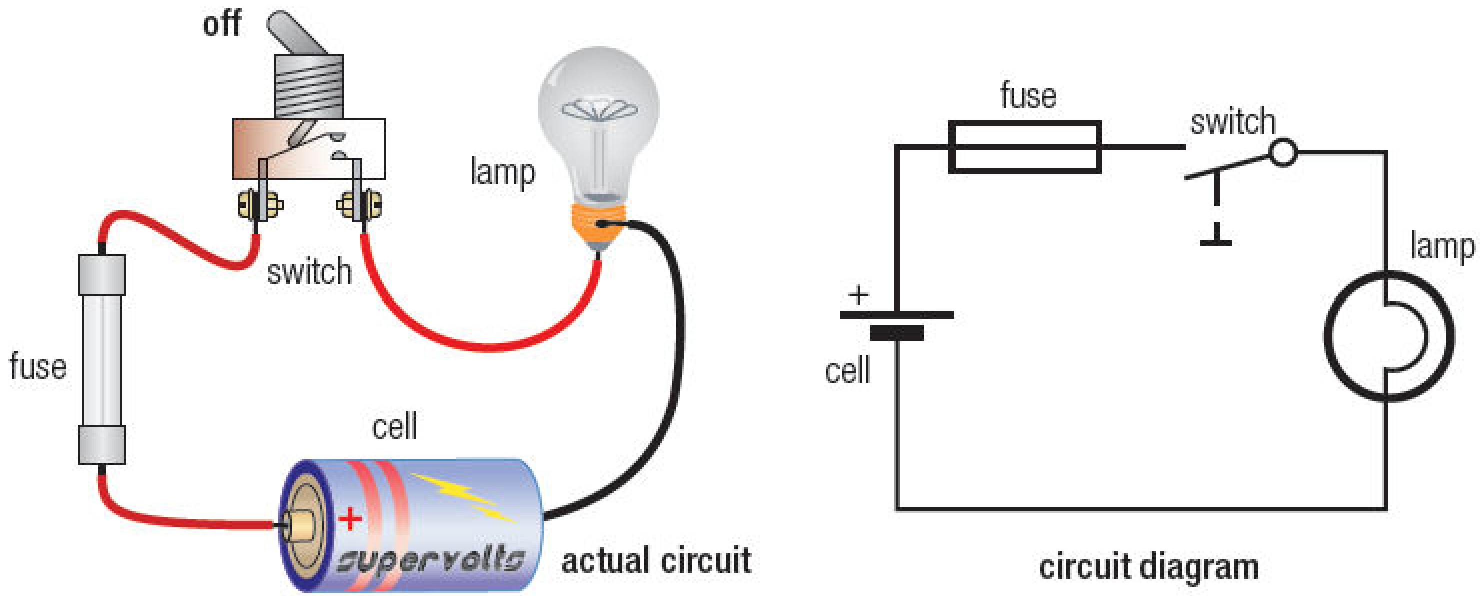
Drawing and its circuit diagram



Circuit diagrams use symbols and show how the circuit is connected

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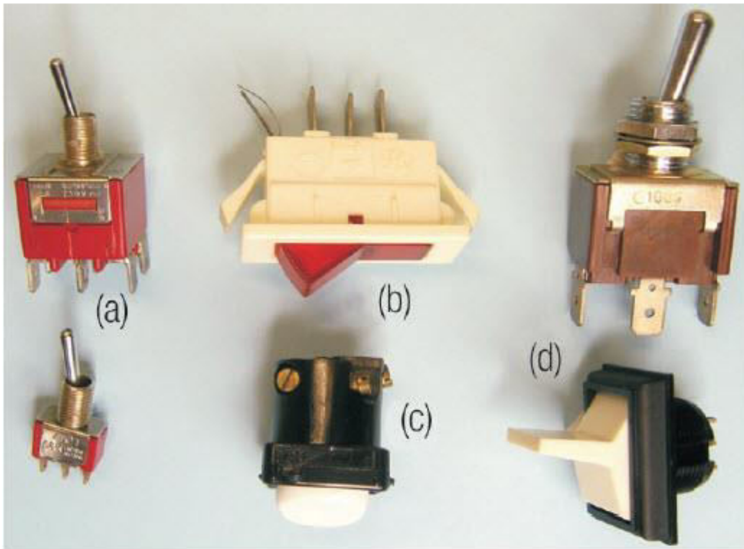
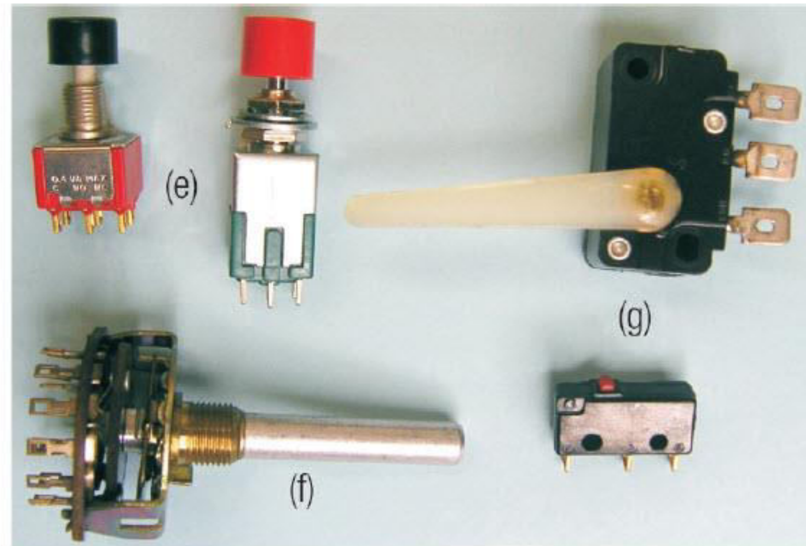
Example switches





(a) miniature toggle
(b) rocker
(c) mechanism from a light switch
(d) toggle

(e) pushbutton,
(f) rotary or wafer switch,
(g) limit switch which is operated mechanically

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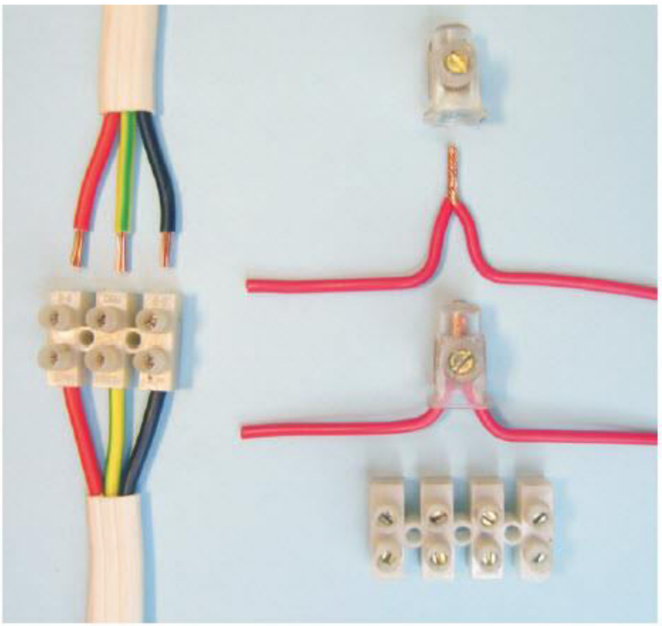
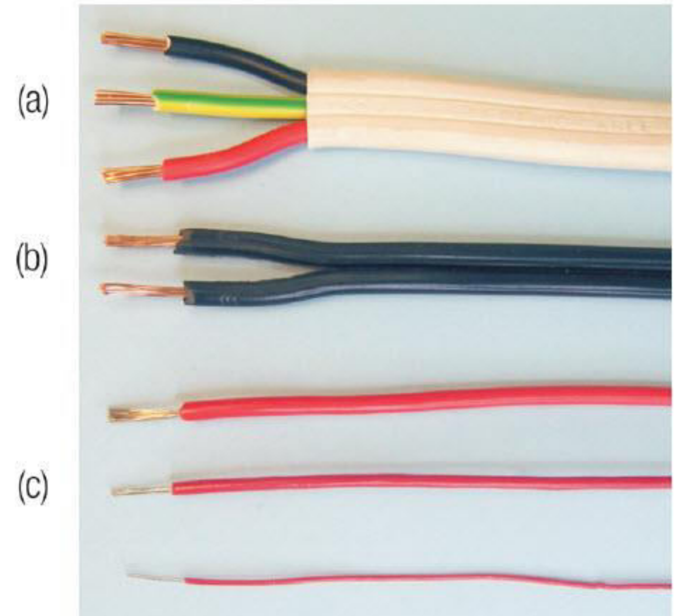
Cables and connectors





(a) mains power wiring
(b) 12 V garden lighting wiring
(c) different types of conductors

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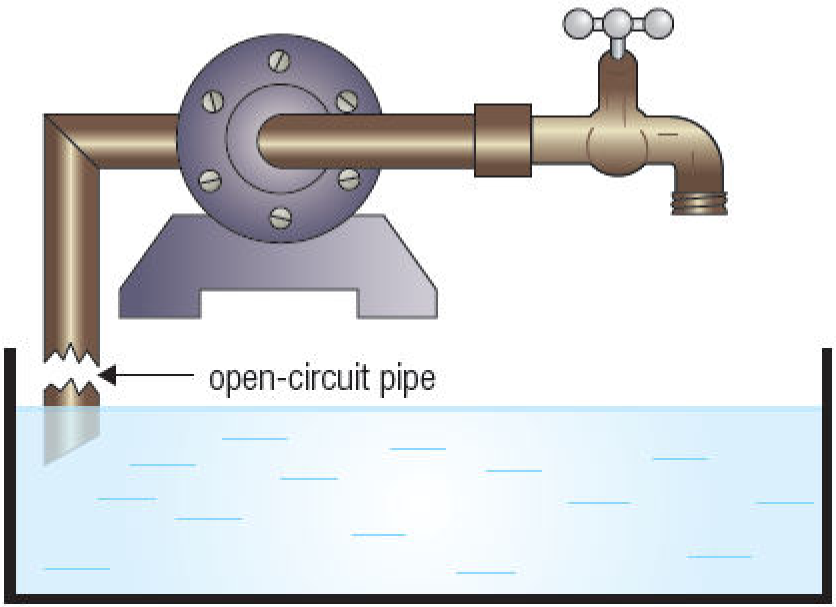
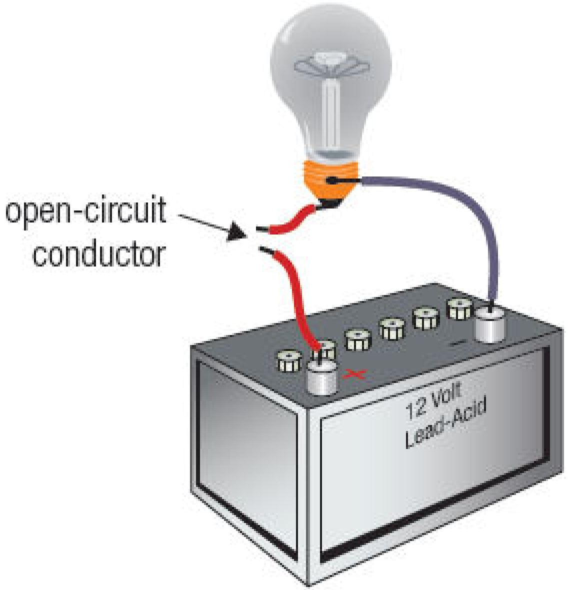
1.9 Open-circuit and closed-circuit





An open-circuit is caused when the path is broken

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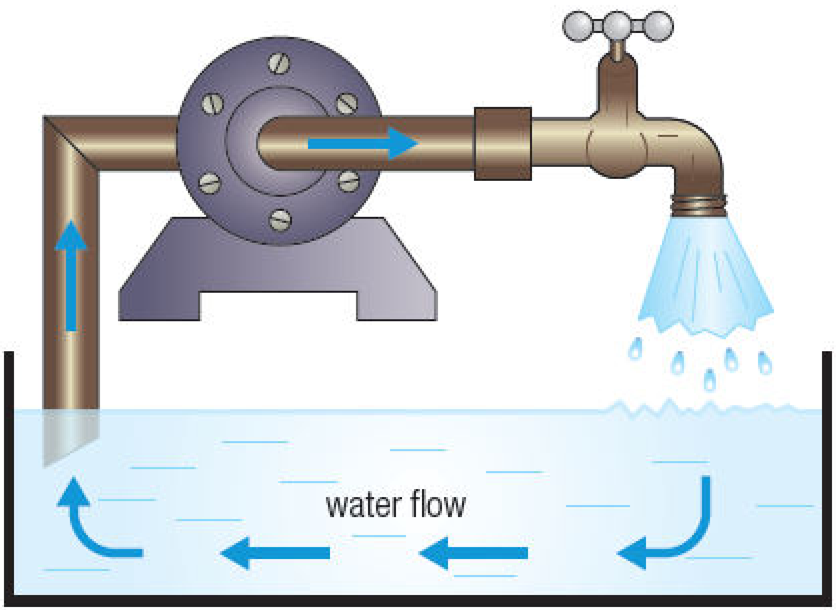
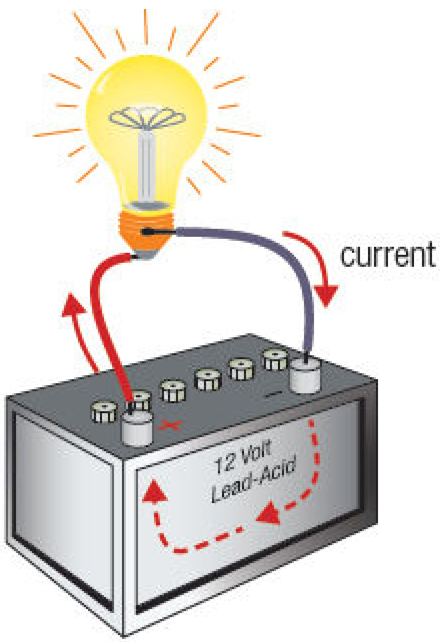
1.9 Open-circuit and closed-circuit (2)





A circuit is closed when normal current is flowing in the circuit

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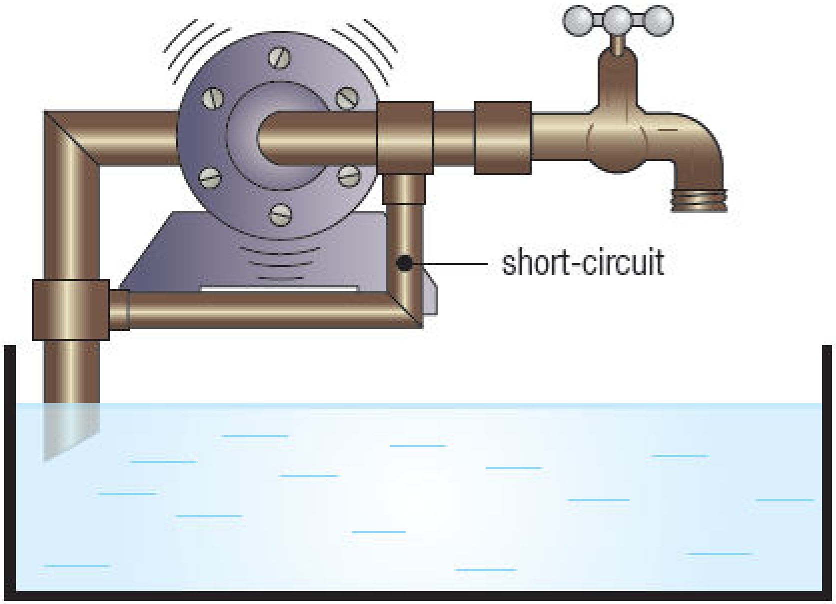
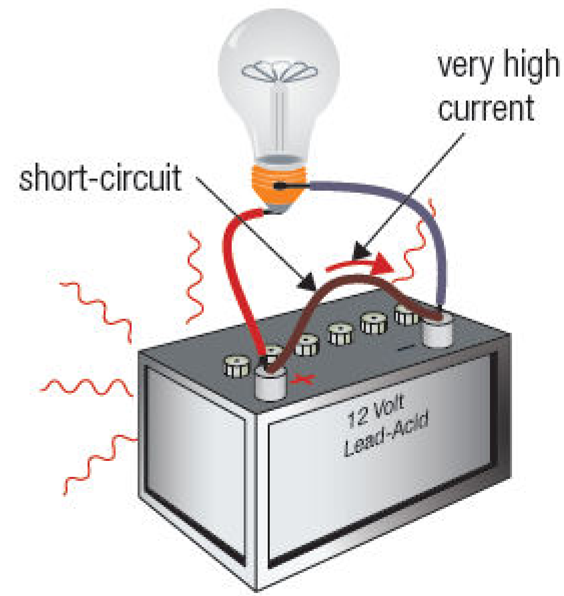
Short-circuit





A short-circuit is an accidental connection across the terminals of an electrical supply source

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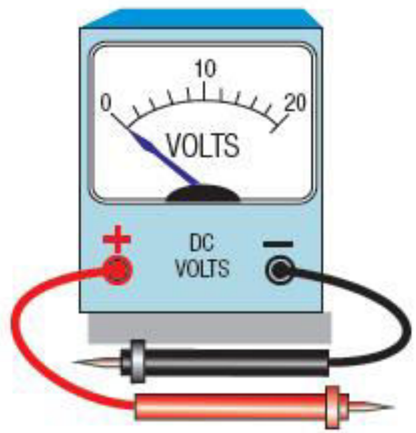
1.10 Measuring voltage

analog multimeter
set to read voltage

voltmeter symbol



voltmeter drawing
as used in this book

digital multimeter
set to read voltage

A voltmeter, used to measure voltage, can be analog and digital

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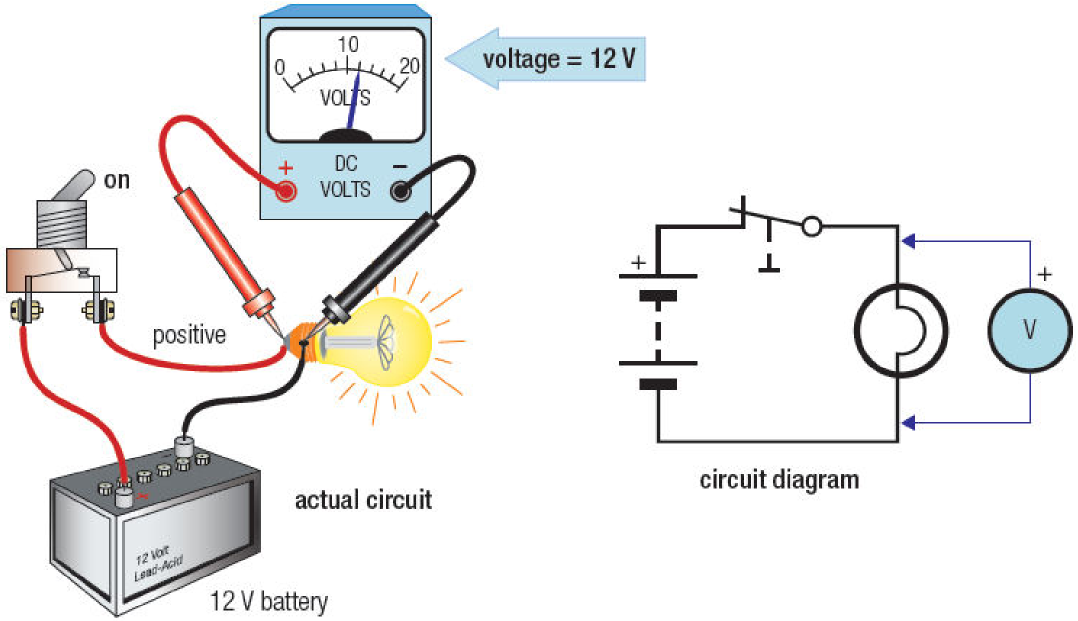
Connecting a voltmeter



A voltmeter is connected across the lamp to measure the voltage applied to the lamp

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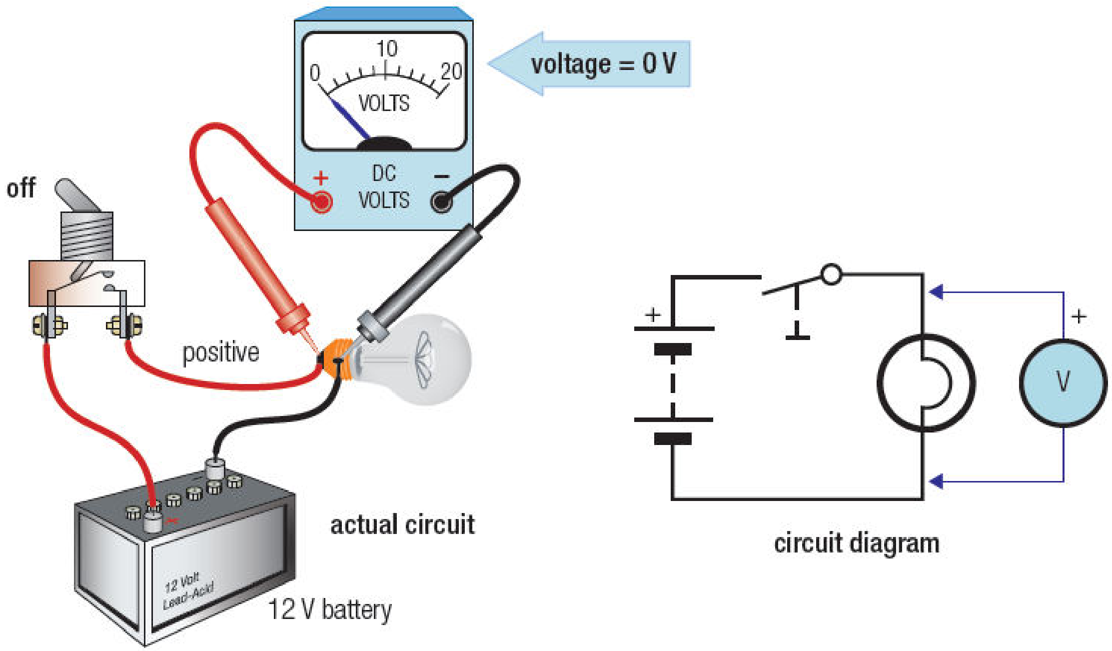
Effect of an open-circuit



Voltmeter shows 0 V when it's connected across the lamp and the switch is off (an open-circuit)

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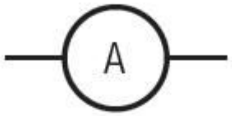
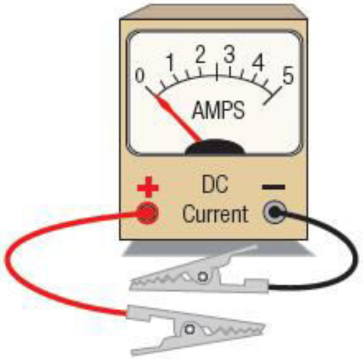
1.11 Measuring current

analog multimeter set to read current



ammeter symbol



ammeter drawing as used in this book

digital multimeter set to read current

Ammeters, like voltmeters, are either analog or digital

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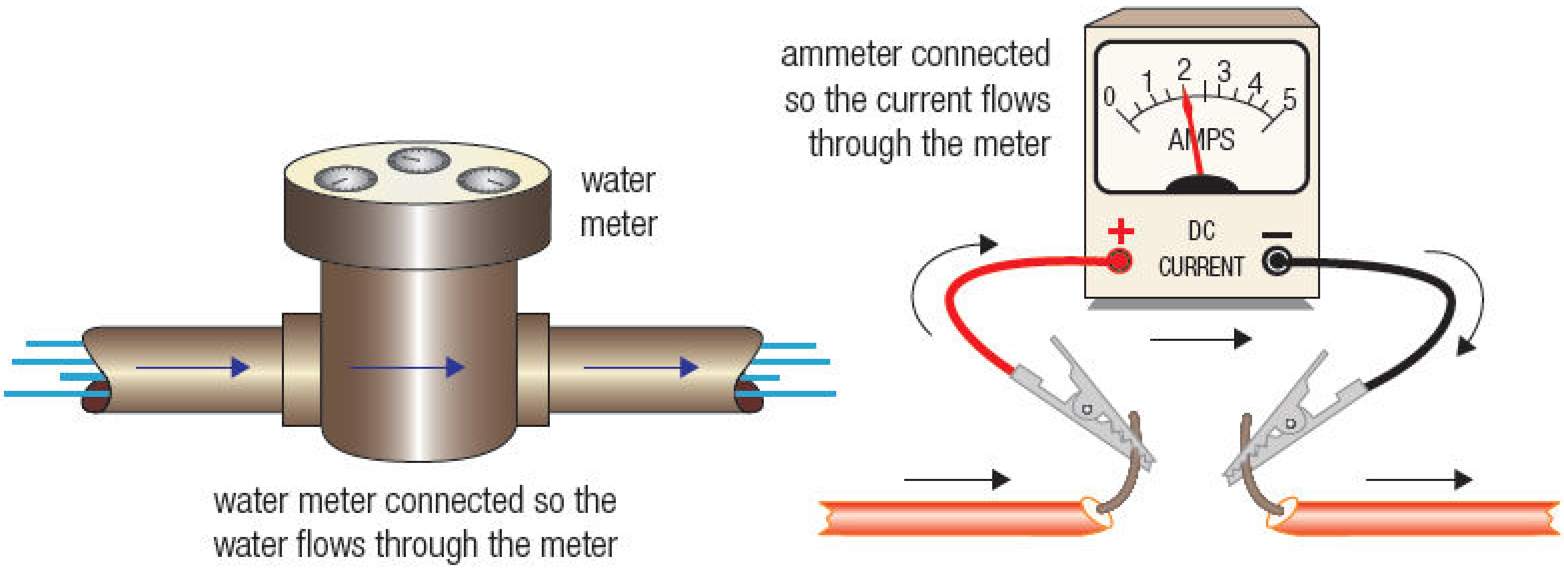
Connecting an ammeter



Measuring current is like measuring water flow – the current has to pass through the meter

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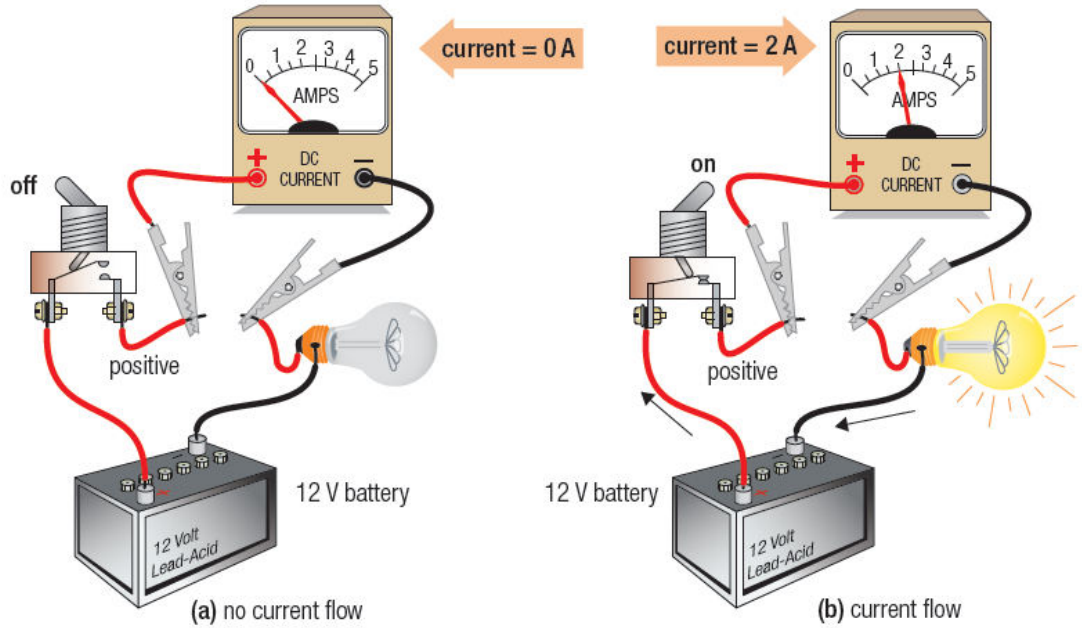
Ammeter in a circuit



When the switch is closed, current flows in the circuit and through the ammeter, which shows the value of the current

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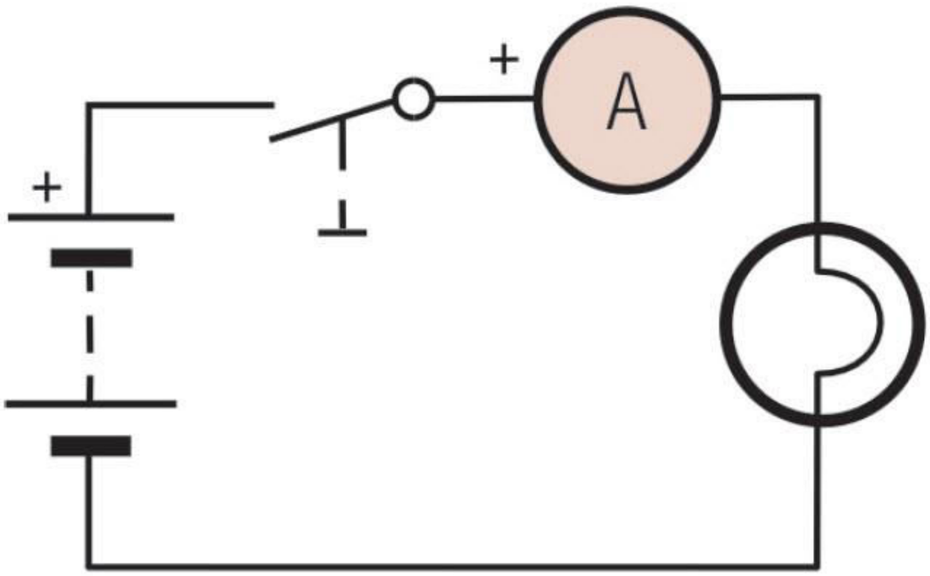
Circuits of previous drawings



Open-circuit, no current

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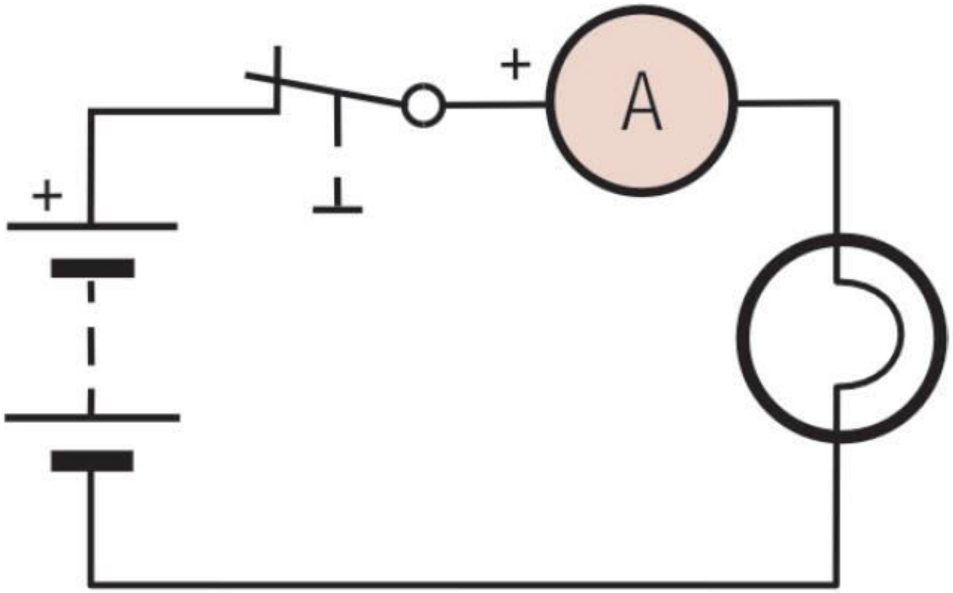
Circuits of previous drawings (2)



Closed-circuit, normal current

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1.12 Meter connections

Using meters in a DC circuit:

- polarity – the positive lead of a meter should connect to the positive voltage. The polarity of a meter only applies to a DC voltage or current.
- range – normally start with the highest range.

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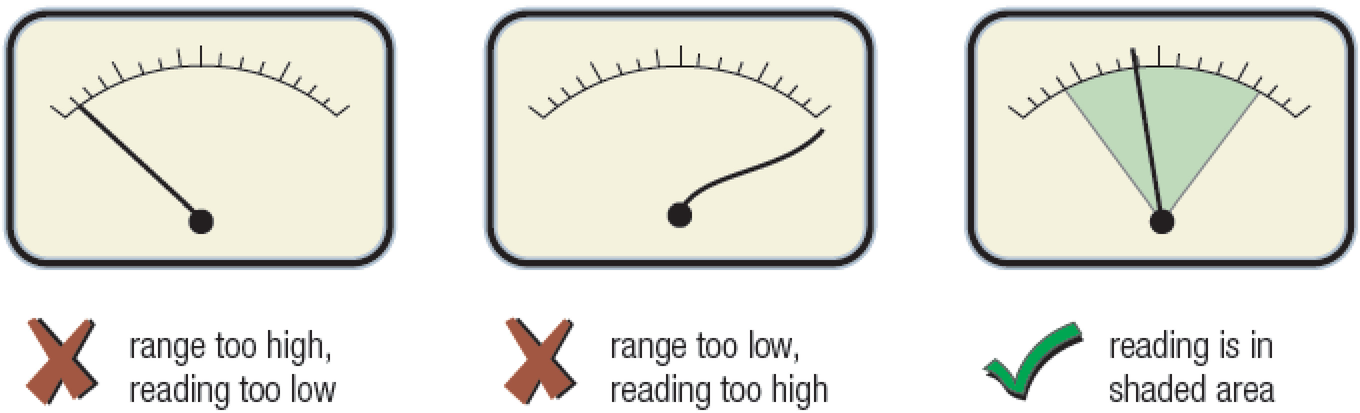
1.12 Meter connections (2)



Choose the correct meter range to avoid damaging the meter

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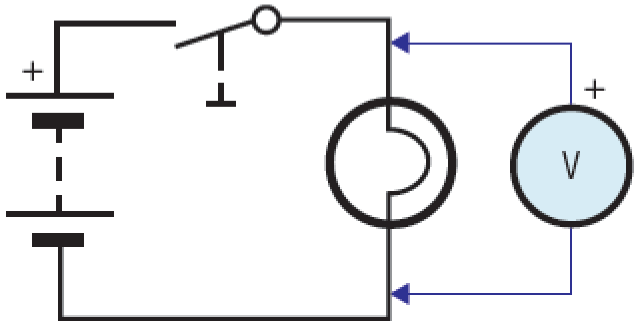
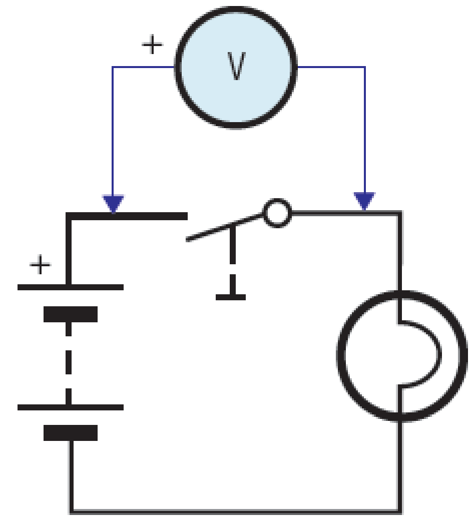
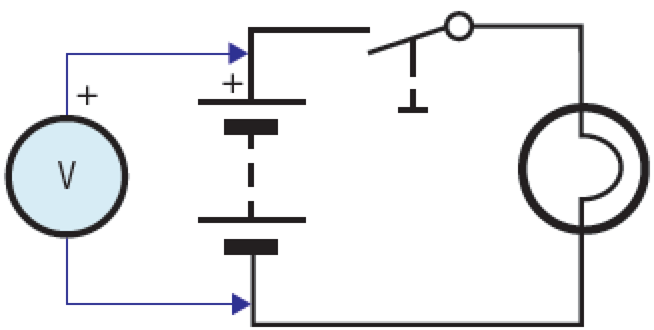
Voltmeter connection



measuring voltage
across the lamp



measuring voltage
across the switch



measuring the battery voltage

voltmeters are connected in parallel

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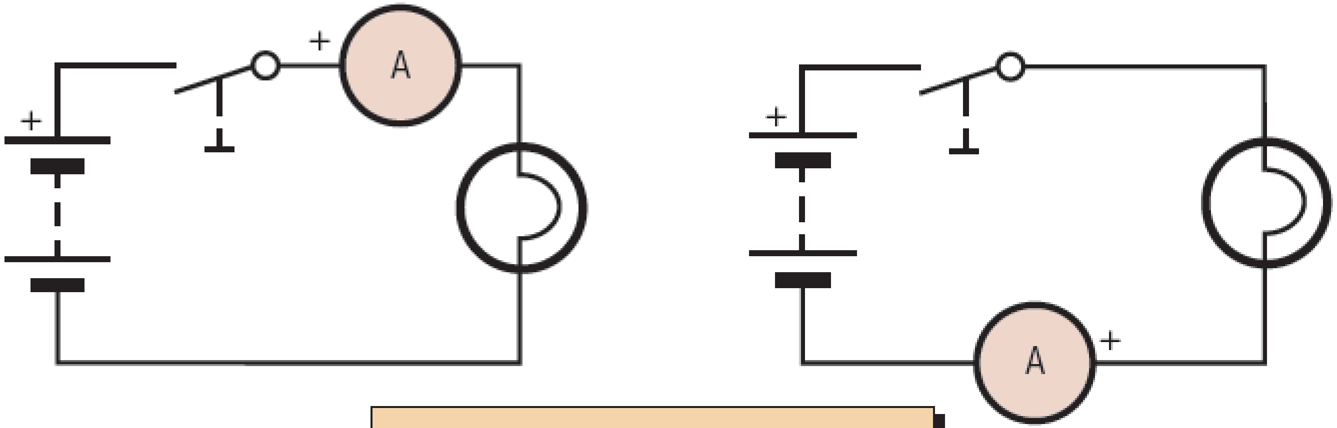
Ammeter connection



ammeters are connected in series

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Chapter summary

- Electrical power is transmitted over high voltage transmission lines and distributed over lower voltage power lines.
- The electrotechnology industry has over 20 qualification areas, each requiring a knowledge of electrical principles.
- You should be aware of the applicable WHS Act and Environmental Protection Acts, as they have legal obligations.

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Chapter summary (2)

- Sustainable energy is made up of two parts: renewable energy and energy efficiency.
- Voltage is electrical pressure between two points, it is measured in volts and is given the symbol V.
- Voltage is measured by connecting a voltmeter across (in parallel with) a component in the circuit.
- Current is a flow of electrons that flows only if there's a voltage and a conducting path.

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Chapter summary (3)

- Current is measured in amperes (A), its symbol is I and is measured with an ammeter by breaking the circuit and inserting the meter in series with the circuit.
- One ampere is one coulomb (Q) flowing per second.
- Resistance (R) is opposition to current flow and is measured in ohms (Ω).
- A conductor has a low resistance and an insulator has a high resistance.

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Chapter summary (4)

- A basic electric circuit has a voltage source, switch, conductors and a load. A circuit diagram shows how the components are connected.
- An open-circuit prevents current flow, a closed-circuit allows current flow, and a short-circuit is a fault that can cause too much current to flow.
- Voltmeters and ammeters can be analog or digital, and are either standalone or part of a multimeter.

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Chapter summary (5)

- The polarity of a meter is important when measuring a DC value.
- When measuring an unknown voltage or current, select the meter's highest range and then work down through the ranges to give a clear reading.

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Chapter 2

Voltage sources and effects of an electric current

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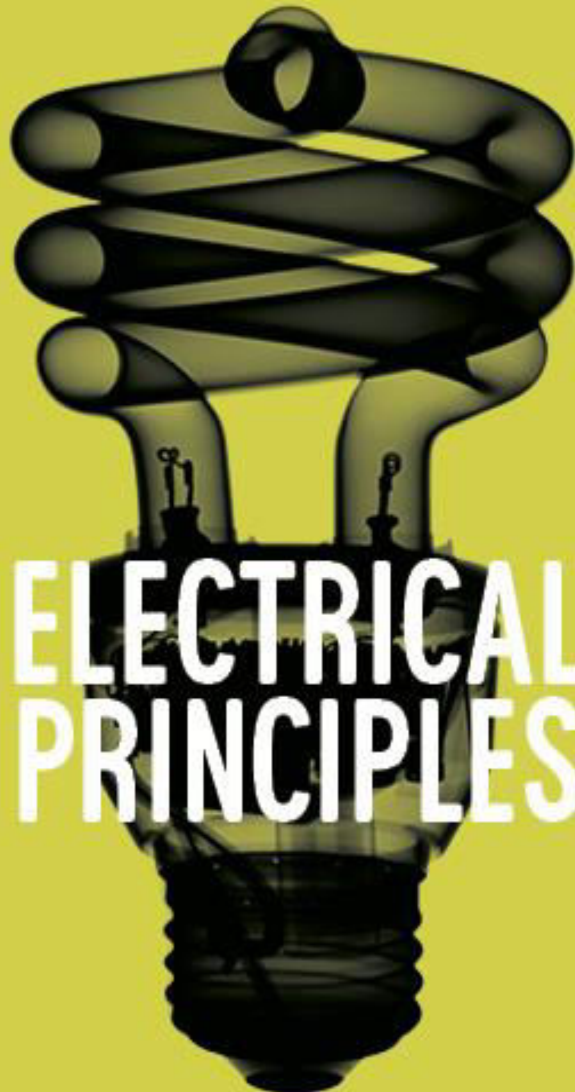

ELECTRICAL PRINCIPLES

PETER PHILLIPS
3RD EDITION

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About this chapter

This chapter:

- discusses how electrical energy is produced from other sources of energy
- outlines the effects of an electric current and the uses for each effect
- looks at the effect of an electric current on the human body and ways of protecting against unwanted effects.

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Contents

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2.1 Producing a voltage

Electrical energy is produced by converting other forms of energy.

Energy sources are:

- mechanical
- chemical
- heat
- light.

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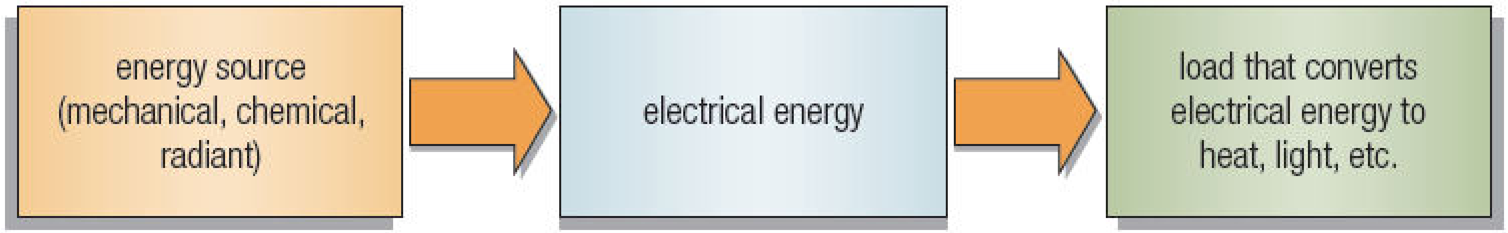
2.1 Producing a voltage (2)



Electrical energy is produced by converting other forms of energy

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Mechanical to electrical

There are three ways to convert mechanical movement into electrical energy:

- friction between two materials
- mechanical stress applied to a piezo-electric element
- moving a conductor in a magnetic field.

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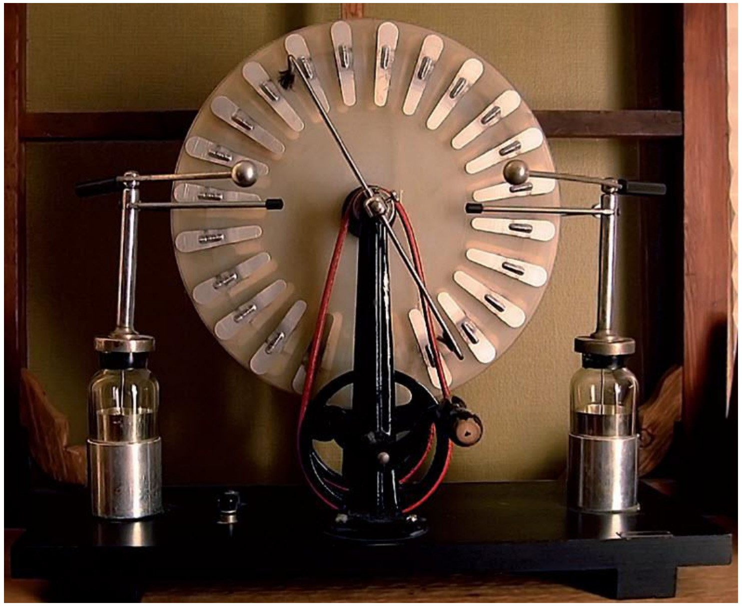
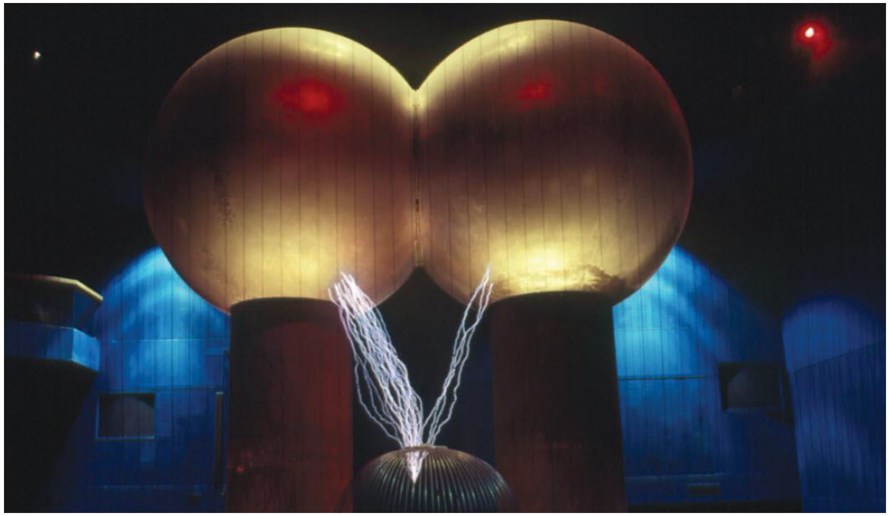
Friction

Friction between two materials can produce a very high voltage.



Wimshurst machine



Van de Graaff generator

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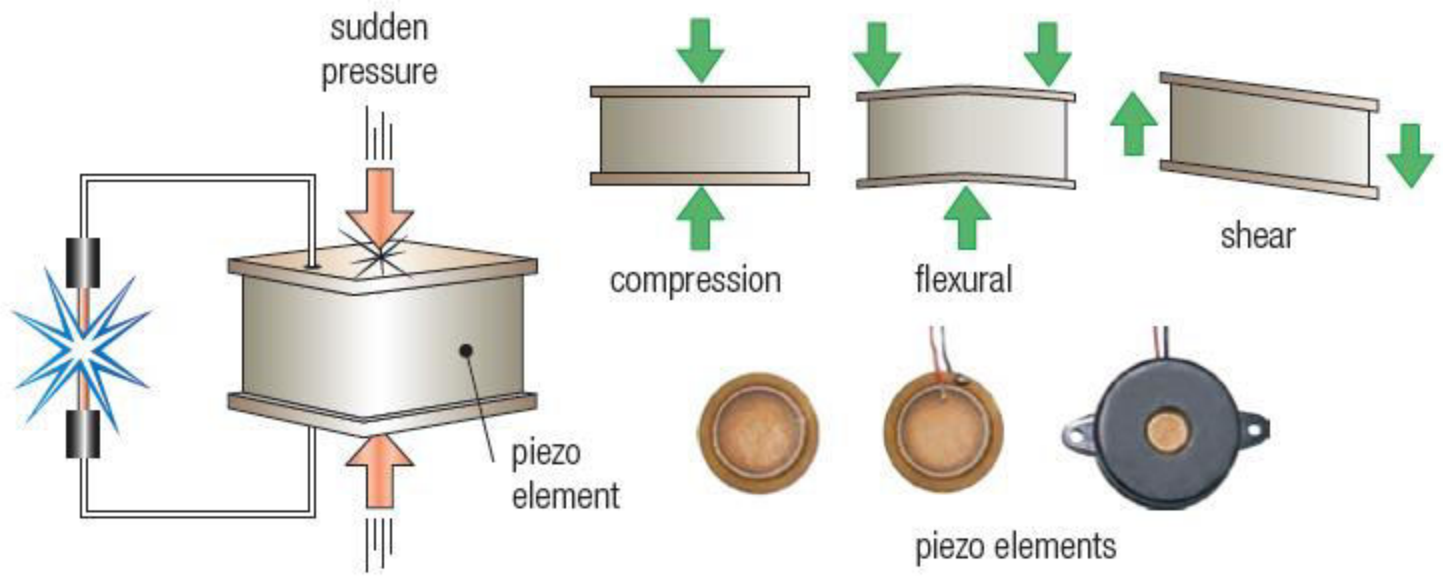
Piezo-electric crystal



Piezo-electric effect, where pressure is applied to opposite faces of various types of crystal to produce a voltage

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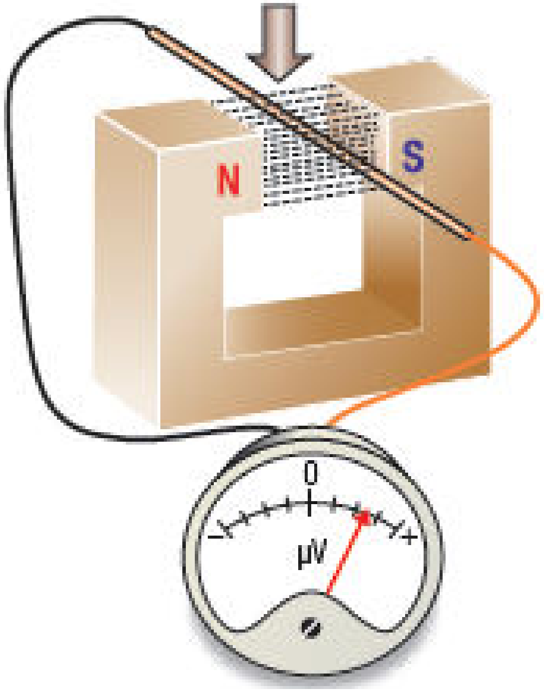
Magnetism



Producing a voltage by using mechanical energy to move a conductor in a magnetic field

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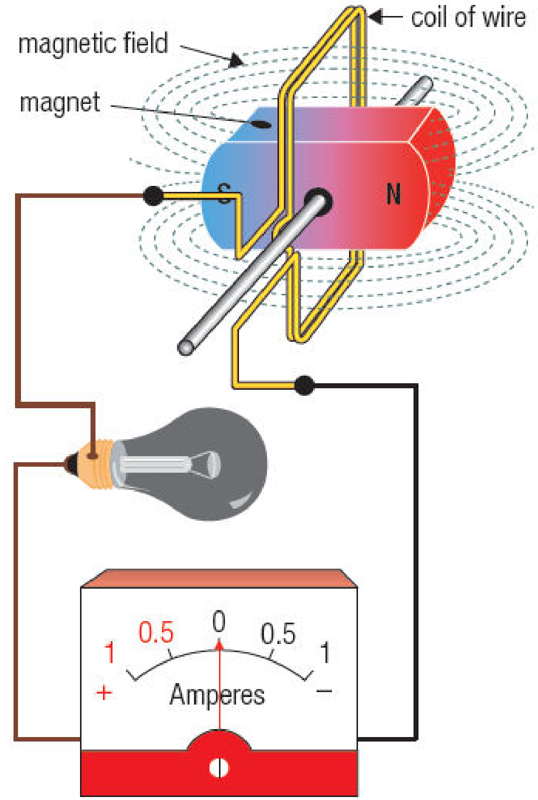
Simple alternator

A simple alternator has a magnet that rotates inside a coil. When the magnet is rotated, its magnetic field intersects with the coil, producing a voltage.



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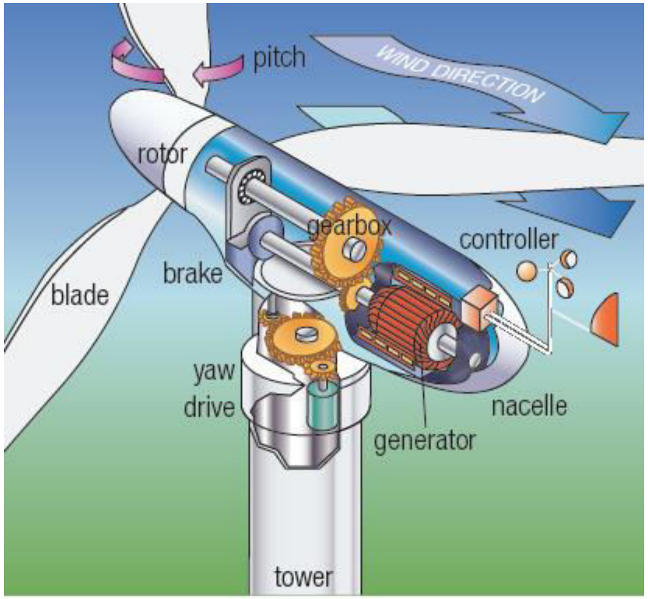
Practical alternator



(a) wind generator components

(b) wind generator under construction

In a practical alternator, rotation is provided by a prime mover, such as a diesel or petrol engine, flowing water, wind power, or high pressure steam that turns a turbine.

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Renewable energy sources

Renewable energy sources used to rotate an alternator include:

- geothermal – heat from within the Earth that produces steam to drive a turbine
- solar – heat from the sun is focused onto pipes to heat water flowing through the pipes, producing steam to drive a turbine.

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Renewable energy sources (2)

Renewable energy sources used to rotate an alternator include:

- hydro-electric – in which flowing water from a dam or river turns the alternators
- wind power
- biogas.

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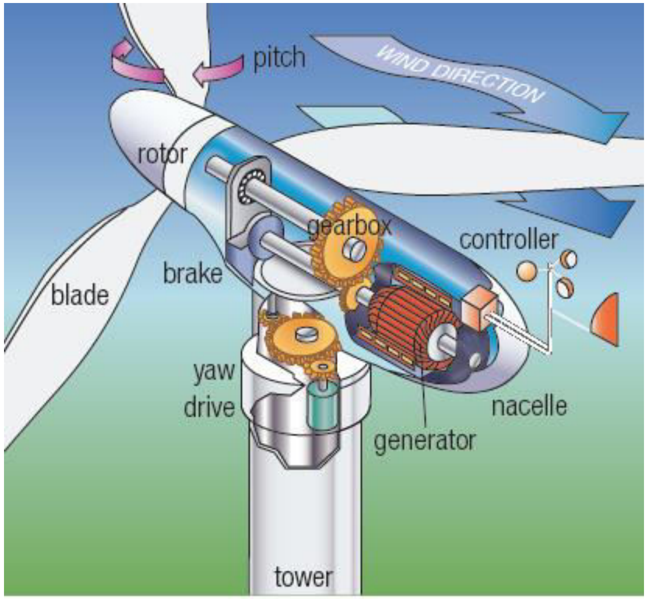
Wind power



(a) wind generator components


(b) wind generator under construction

Main components are the rotor (usually three blades), a tower and the nacelle which houses a gearbox, alternator and yaw motors

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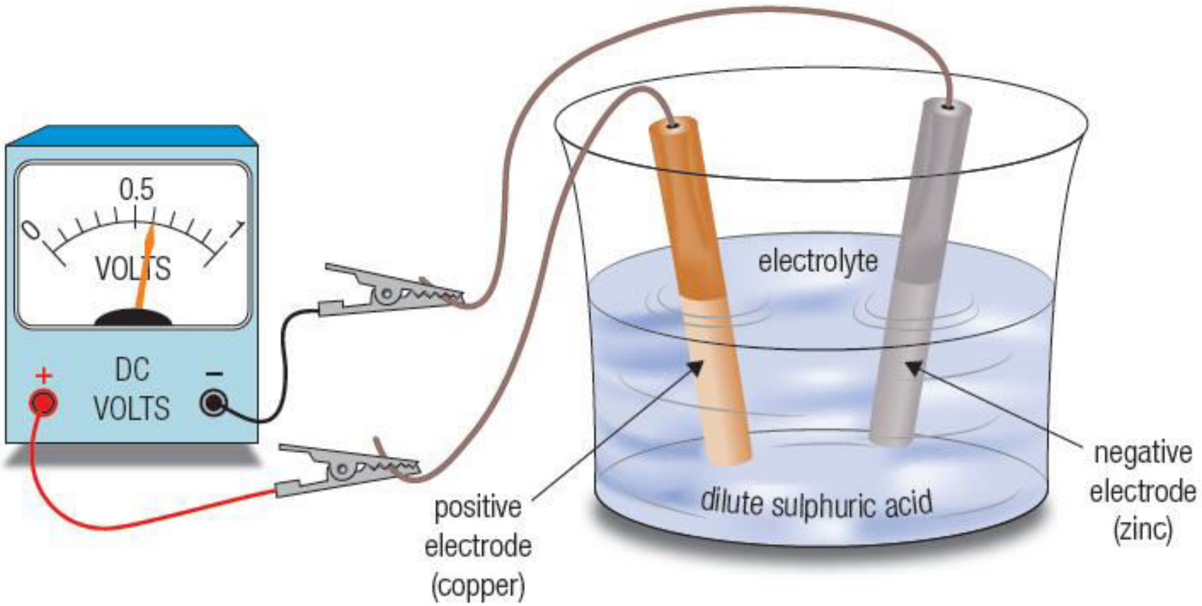
Chemical to electrical



The basic electric cell has three components:
the positive electrode, the negative electrode and an electrolyte

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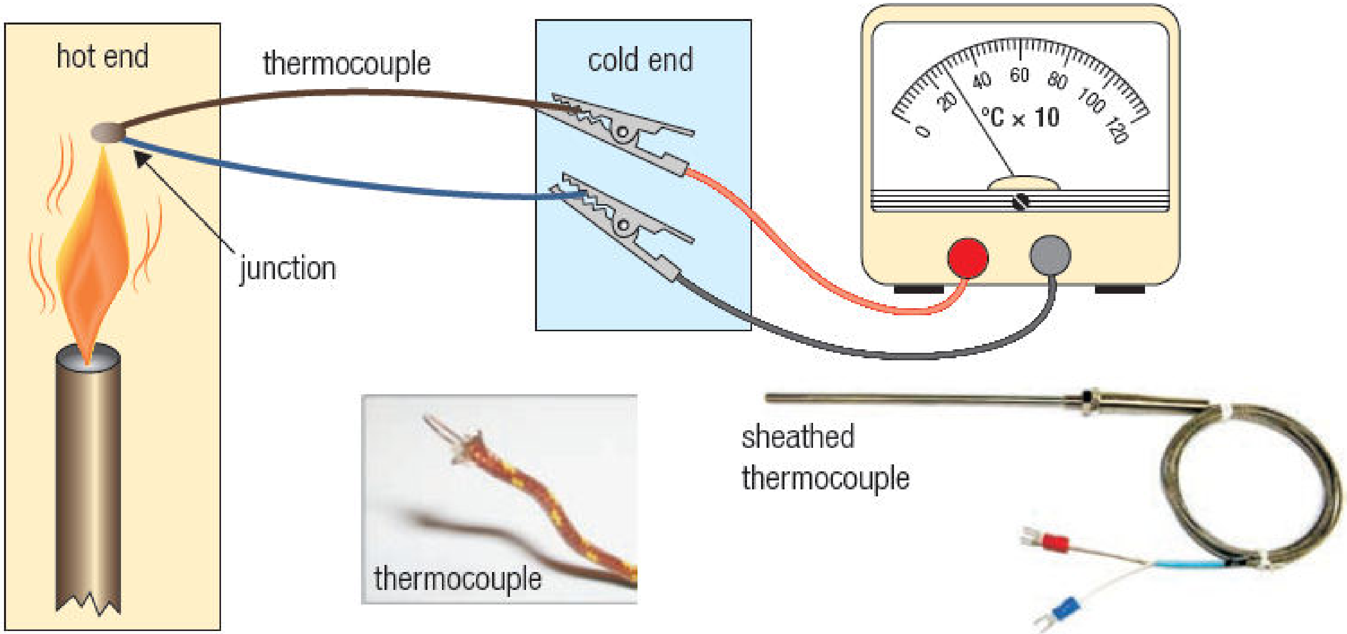
Heat to electrical



The thermocouple is formed by two different metals joined at one point

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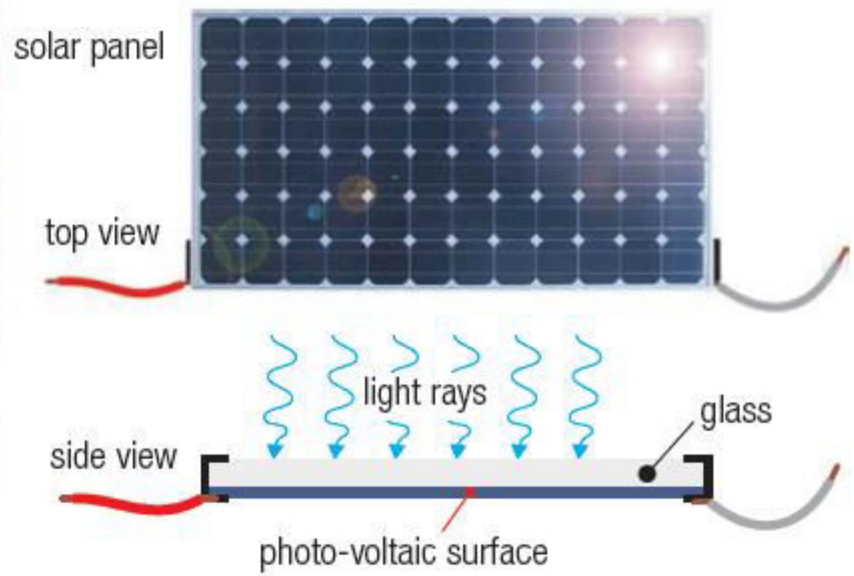
Light to electrical

1500 W domestic solar panel installation



Solar cells convert the sun’s light energy to electrical energy

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Summing up

- Electrical energy is produced by converting other sources of energy.
- Most electrical power is produced by alternators driven by mechanical energy.
- High voltages can be produced with friction between two materials, or by applying force to a piezo-electric material.

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Summing up (2)

- Batteries produce electricity by converting chemical energy to electrical energy.
- Photo-voltaic devices such as the solar cell produce electricity when exposed to light.
- Renewable energy sources include geothermal, solar, hydro, biogas and wind power.

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2.2 Effects of an electric current

Effects caused by an electric current include:

- heating
- magnetism
- chemical
- luminous
- physiological.

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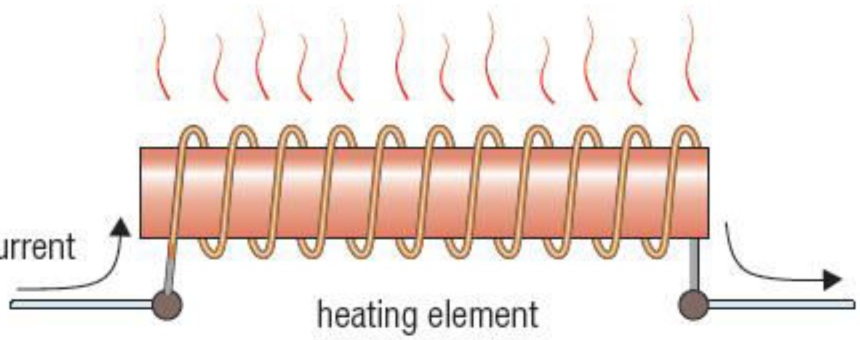
Heating



Heat is developed when current flows through a resistance

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Magnetism

- A basic application of the magnetic effect is the electromagnet, which has a coil of wire wound around a soft iron core.
- When current flows in the coil, the iron core becomes magnetised.
- A common use for the electromagnet is in a device called a relay.

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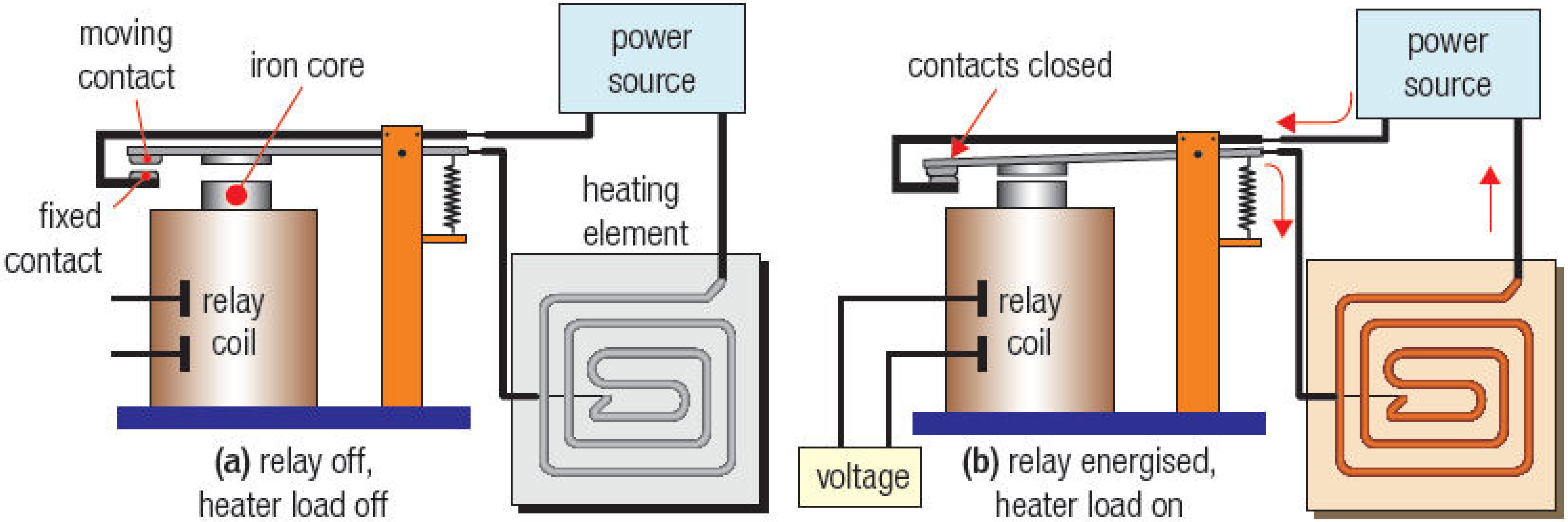
Relay



A relay is used to switch loads such as motors, heating elements and lights. Low power is needed to operate the relay coil, but the relay contacts can switch large amounts of power.

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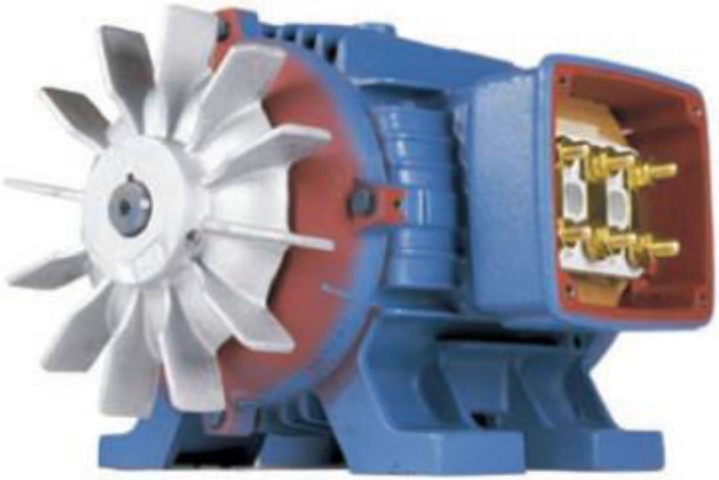
Applications of magnetic effect

power distribution transformer in a substation



electric motors come in a wide range of types and sizes

Motors and transformers are common applications of the magnetic effect of an electrical current

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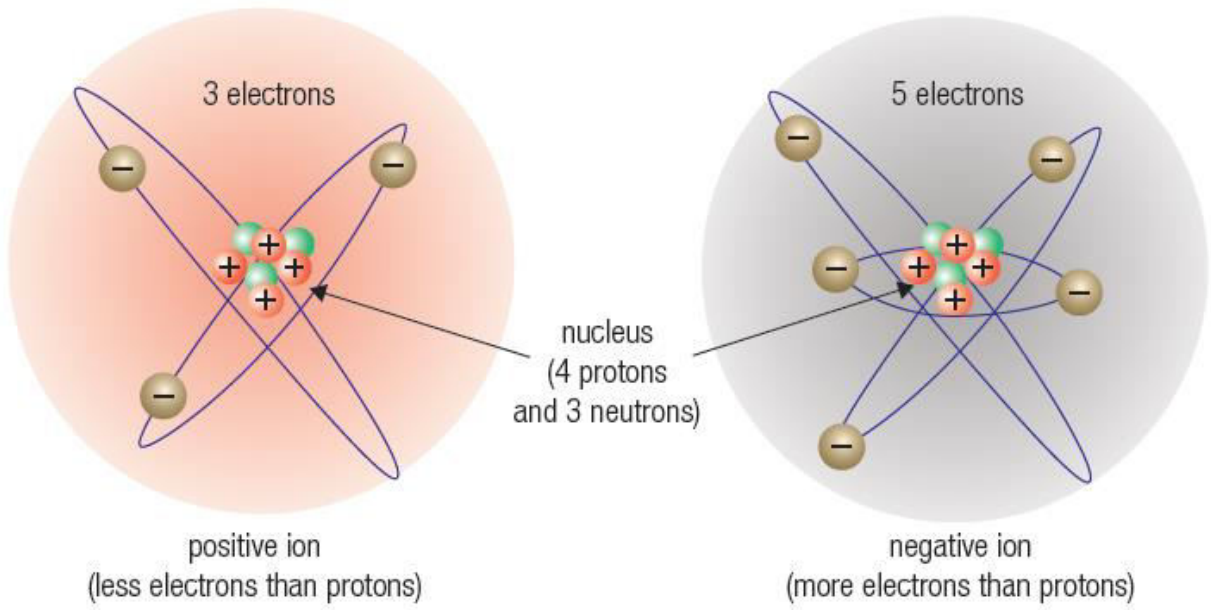
Chemical effect



Current can flow in liquids called electrolytes because an electrolyte contains ions, which are atoms with a positive or a negative charge

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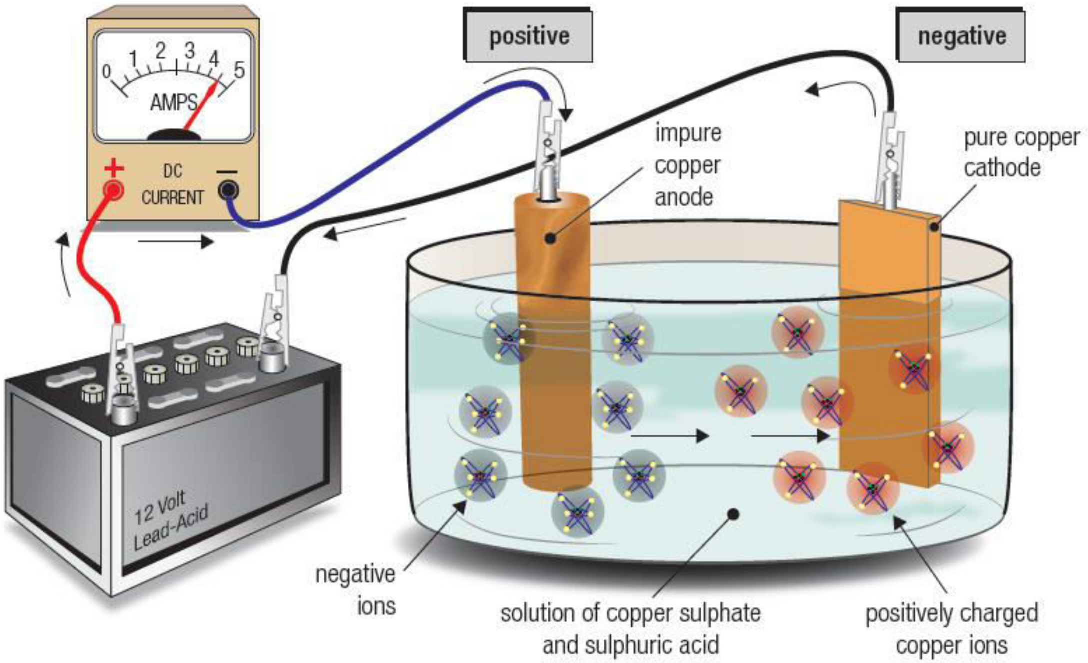
Electrolysis



Positive ions move to the cathode and negative ions move towards the anode in this drawing, to produce purified copper

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Electroplating

- The main use of electroplating is to protect metals against corrosion.
- The part to be plated is connected to a negative potential (cathode).
- The anode is made of the metal to be plated onto the part.
- Both components are immersed in an electrolyte.
- Current flowing in the electrolyte causes ions to flow from the anode to the cathode.

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Galvanic corrosion

- Corrosion occurs because of the voltaic effect in which two dissimilar metals and the electrolyte form an electric cell.
- The current produced by the cell causes the metals to corrode, with one metal corroding before the other.
- To limit the corrosion, a sacrificial anode is placed in contact with the metal being protected.

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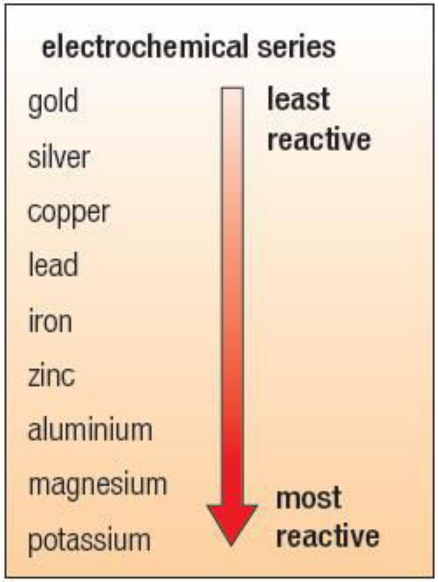
Sacrificial anodes

sacrificial zinc anodes on a steel structure

sacrificial anode



Zinc is more reactive than iron which is why zinc sacrificial anodes are used to protect a steel structure

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Luminous effect

- Light is produced by passing an electric current through certain types of gas, which ionises creating a plasma.
- An example is a fluorescent lamp (also called a gas-discharge lamp).
- A light emitting diode (LED) produces light by way of the effect called electroluminescence, which is caused by electrons releasing energy in the form of photons (light).

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Light emitting diode

LEDs operate from a low DC voltage,
they have a long life and maintain a consistent light output

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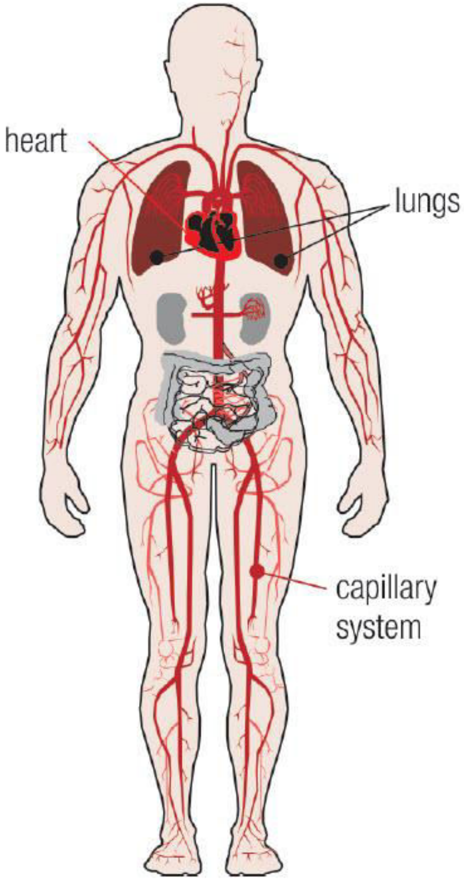
Physiological effect

- The effect is caused by passing a current through a living organism.
- Blood is a good conductor.
- Current flowing through a human interferes with the body's nervous system.
- The effect on a human depends on how much current flows and the path it takes through the body.



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Current and the human body

EFFECTS OF AN ELECTRIC CURRENT PASSING THROUGH THE BODY	
Current	**Effect**
up to 2 mA	barely perceptible
2 mA to 8 mA	sensation becomes obvious and more painful
8 mA to 12 mA	muscle spasms and greater pain
12 mA to 20 mA	unable to let go the conductor, can't control muscles
20 mA to 50 mA	if passing through the chest, breathing might stop
50 mA to 100 mA	if near the heart, causes ventricular fibrillation
100 mA to 200 mA	heart stops beating
above 200 mA	severe burns as well!

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2.3 Protection against effects of an electric current

AS/NZS 3000 specifies ways of minimising the risk of an electric shock:

- protection against direct contact, through a combination of insulation, barriers or enclosures and placing exposed electrical contacts out of reach
- protection against indirect contact due to a fault condition through the use of devices that automatically disconnect the power (e.g. safety switch or RCD).

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Direct contact

Direct contact with a live conductor can cause current to flow through your body to ground

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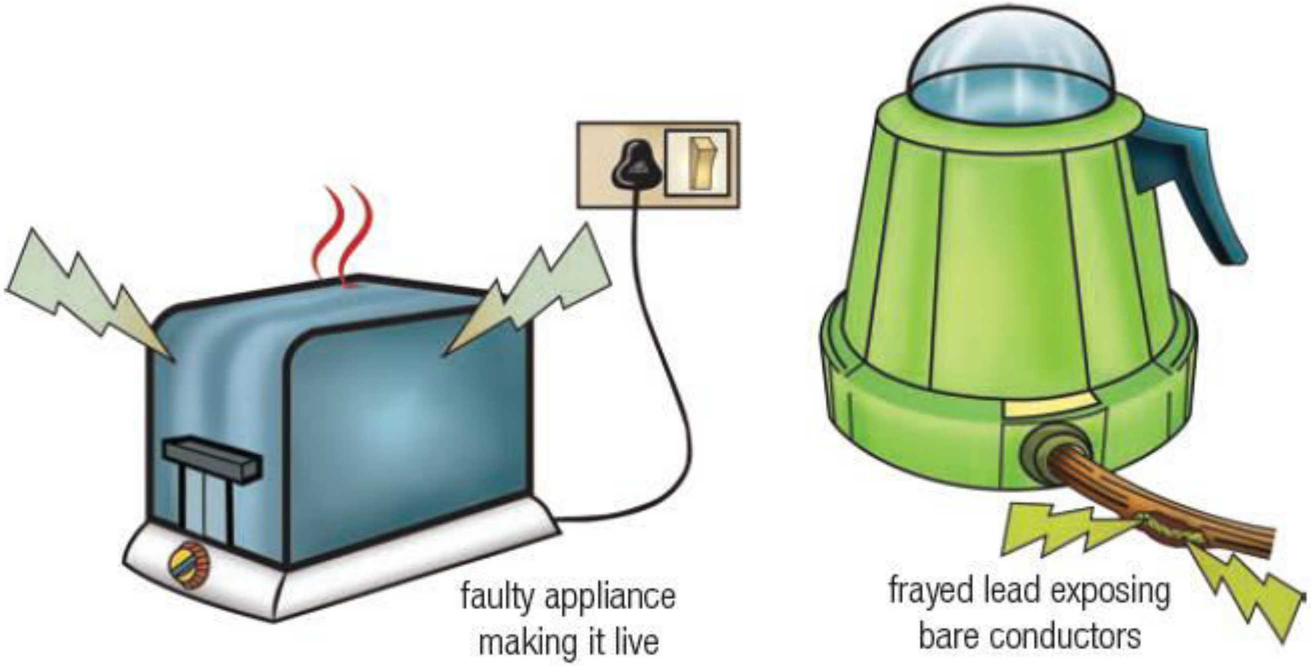
Indirect contact due to faults



Faults that can cause an electric shock include touching a live appliance or exposed live conductors

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Chapter summary

- Electrical energy is produced by converting other forms of energy (mechanical, chemical, heat and light).
- Electrical energy is converted to other forms of energy by the electric load.
- Large alternators driven by steam turbines (mechanical energy) generate most of Australia's electrical energy.
- An alternator has coils of wire arranged so they intersect with a moving magnetic field, thereby producing electricity.

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Chapter summary (2)

- Renewable energy sources that can drive an alternator include geothermal, solar, hydro, biogas and wind power.
- Solar panels are photo-voltaic devices that convert light energy to electrical energy.
- Friction can be used to produce high voltages. Examples are the Wimshurst machine and the Van de Graaff generator.
- The electric cell produces electricity by converting chemical energy to electrical energy.

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Chapter summary (3)

- Charging a battery reverses the chemical action that occurred when the battery was being discharged.
- Electric motors, transformers and electromagnets work by way of the magnetic effect of an electric current.
- Electrolysis is the process of passing current through an electrolyte from one electrode to another.
  (e.g. electroplating).

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Chapter summary (4)

- Discharge lamps are filled with a gas that produces light energy when an electric current passes through the gas. In a fluorescent lamp, UV light is produced which excites phosphors inside the tube.
- Physiological effects of an electric current are an unwanted by-product, and pose dangers to all forms of biological life, including muscle contraction, ventricular fibrillation, burns and death.

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Chapter summary (5)

- Effects caused by an electric current include heating, magnetism, chemical, luminous and physiological.
- Heat is produced in a conductor because of its resistance.
- Current flowing in a conductor creates a magnetic field around the conductor. Coiling the conductor makes an electromagnet.
- Chemical effects of an electric current include electrolysis and voltaic effect (electric cell).

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Chapter summary (6)

- Galvanic corrosion is caused when two different metals are in electrical contact, creating an electric cell.
- A metal surface can be protected from corrosion with sacrificial anodes that corrode instead of the metal being protected.
- Fluorescent lamps are an example of the luminous effect on an electric current.
- LED lighting is an example of electroluminescence.

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Chapter 3

Ohm’s law

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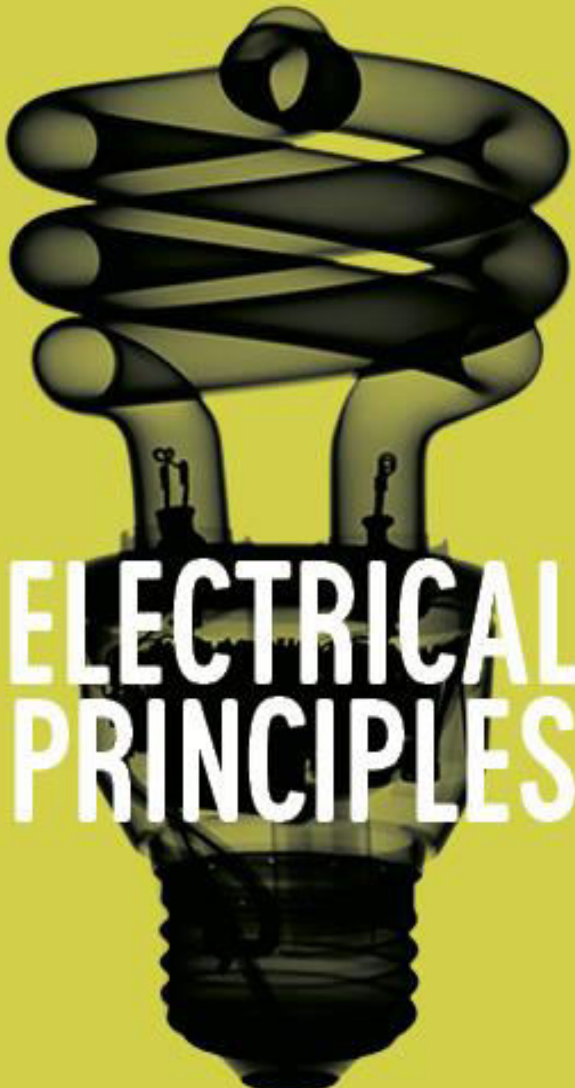

ELECTRICAL PRINCIPLES

PETER PHILLIPS
3RD EDITION

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About this chapter

This chapter:

- explains resistance and its effect in a circuit
- explains Ohm's law
- discusses engineering notation and the role of metric prefixes when dealing with very large or small numbers.

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Contents

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3.1 Resistance and conductance

Resistance:

- is opposition to the flow of current
- is measured in ohms (Ω)
- has the symbol R.

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3.1 Resistance and conductance (2)

Conductance:

- is a measure of the ability of a conductor to carry an electric current
- is measured in Siemens (S)
- has the symbol G
- is the reciprocal of resistance.

i.e. $R = \frac{1}{G}$ & $G = \frac{1}{R}$

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Opposition to Flow = Resistance

Quantity	*Term*	*Letter*	*Unit*
Opposition to Current Flow	Resistance	R	Ohm (Ω)
Ease of Current Flow	Conductance	G	Siemens (S)

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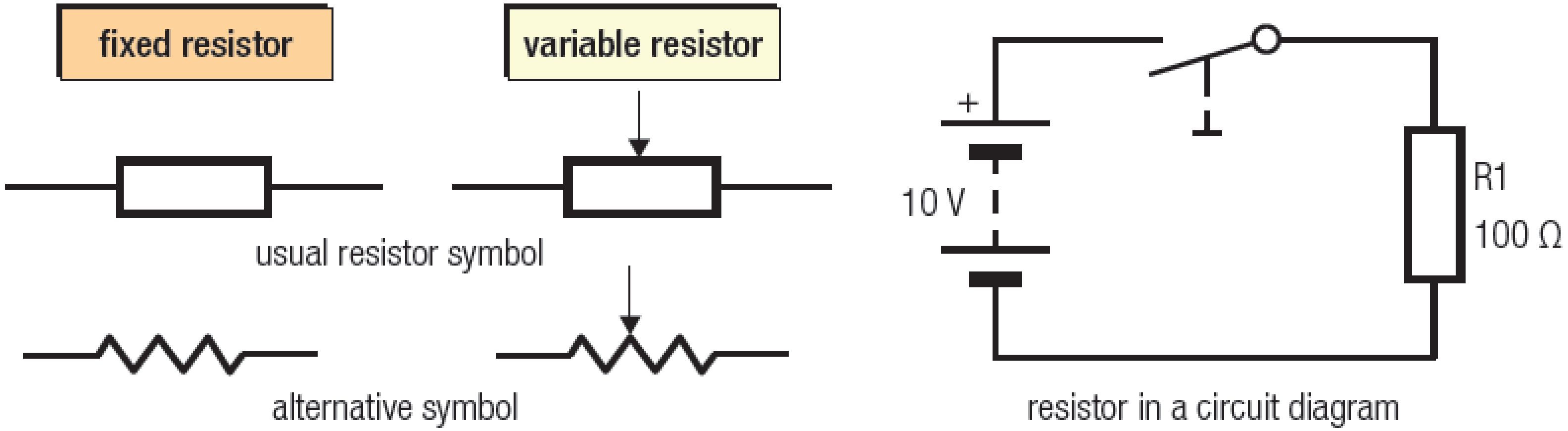
Resistor symbols



Resistor symbols, and how a resistor is depicted in a circuit

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RN Video

Part 5

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3.2 Ohm's law

Ohm's law combines the three fundamental electrical quantities of voltage, current and resistance, where:

- voltage has the symbol V and is measured in volts (V)
- current has the symbol I and is measured in amperes (A)
- resistance has the symbol R and is measured in ohms (Ω).

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Ohm's Law States

'… Provided that the temperature of a given conductor remains unchanged, the ratio of the Potential Difference between its ends and the steady Current in it is a constant quantity. …'

$$\frac{V}{I} = K$$

We call this constant:

Resistance

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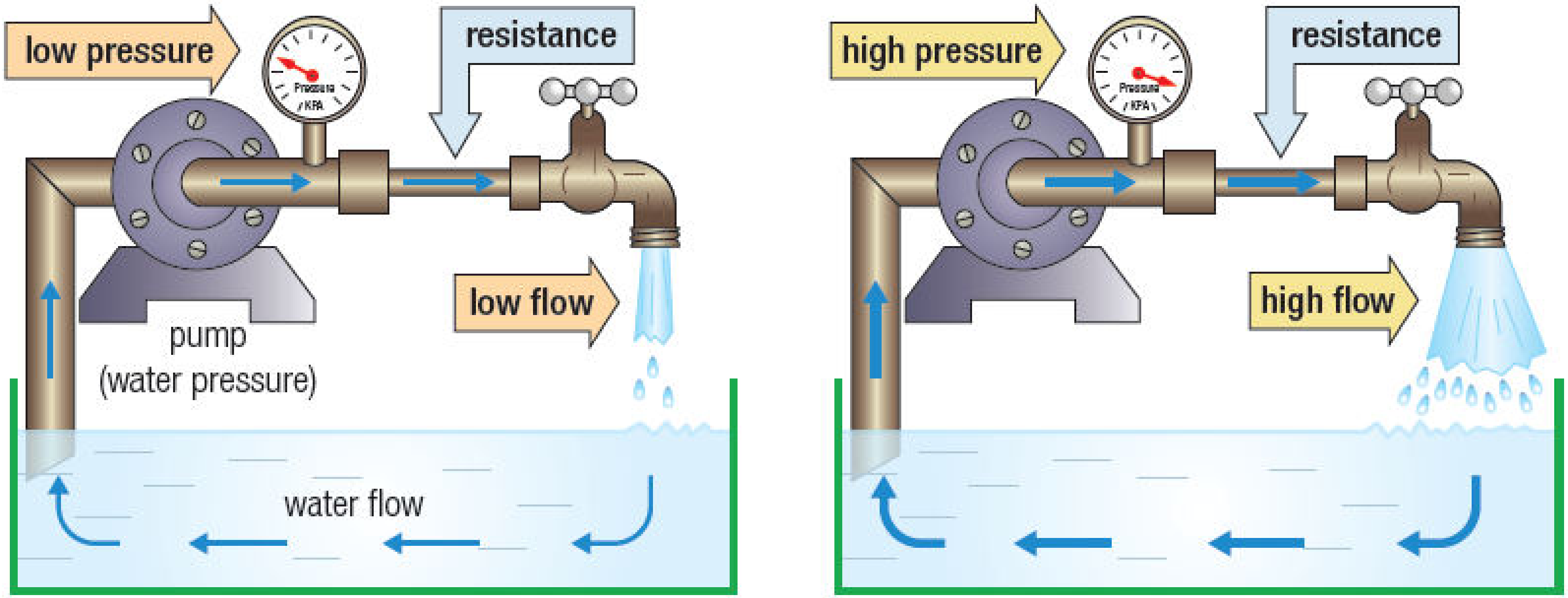
Pressure and flow



(a) low pressure gives low water flow

(b) high pressure gives high water flow

Water flow is directly proportional to the water pressure

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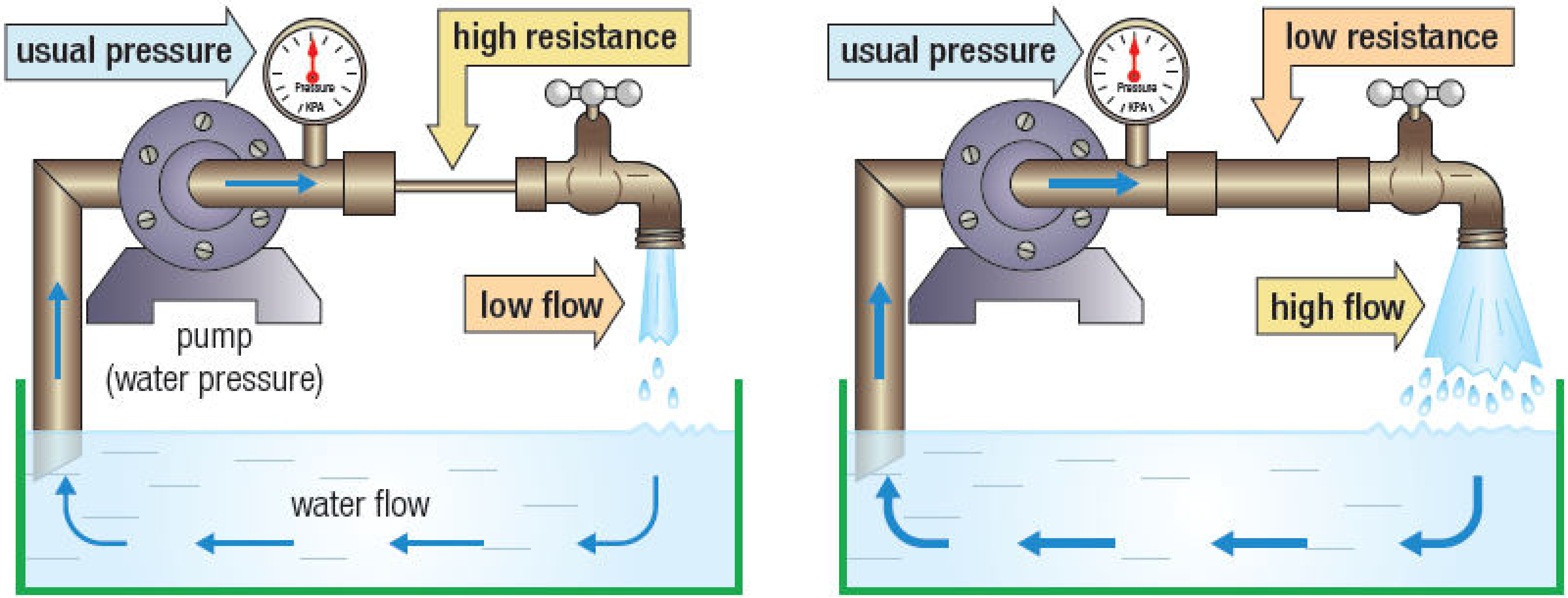
Flow and resistance



(a) high resistance gives low water flow

(b) low resistance gives high water flow

Water flow is inversely proportional to resistance of the pipe

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Accordingly …

Because water pressure is comparable to voltage, and water flow is comparable to current:

- current is directly proportional to voltage

$$I \propto V$$

- current is inversely proportional to resistance

$$I \propto \frac{1}{R}$$

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Ohm's law for current

Ohm's law takes away the 'proportional to' (∝) sign:

$$I = \frac{V}{R}$$

where:

I = current in amperes

V = voltage in volts

R = resistance in ohms.

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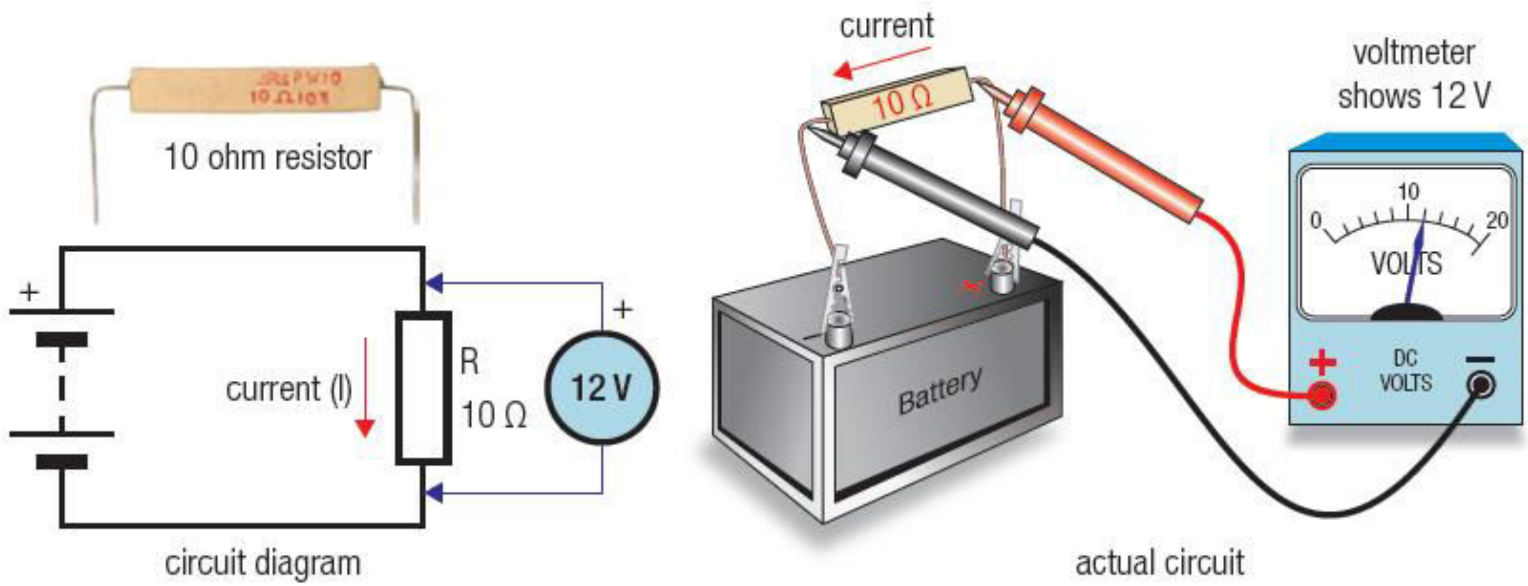
Ohm's law to find current



Values in the circuit: R = 10 Ω and V = 12 V. Therefore, to find current with Ohm's law:

$$I = \frac{V}{R} = \frac{12}{10} = 1.2 \text{ amperes}$$

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Using ohm's law to find voltage

Transpose the previous equation:

(1) write the equation

$$I = \frac{V}{R}$$

(2) multiply both sides by R

$$I \times R = \frac{V}{R} \times R$$

(3) cancel out the R's on the right-hand side

$$I \times R = \frac{V}{\cancel{R}} \times \cancel{R}$$

$$I \times R = V$$

(4) rewrite the equation with V on the left-hand side (V is now the subject)

$$V = I \times R$$

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Ohm's law for voltage

$$V = IR$$

where:

V = voltage in volts

I = current in amperes

R = resistance in ohms.

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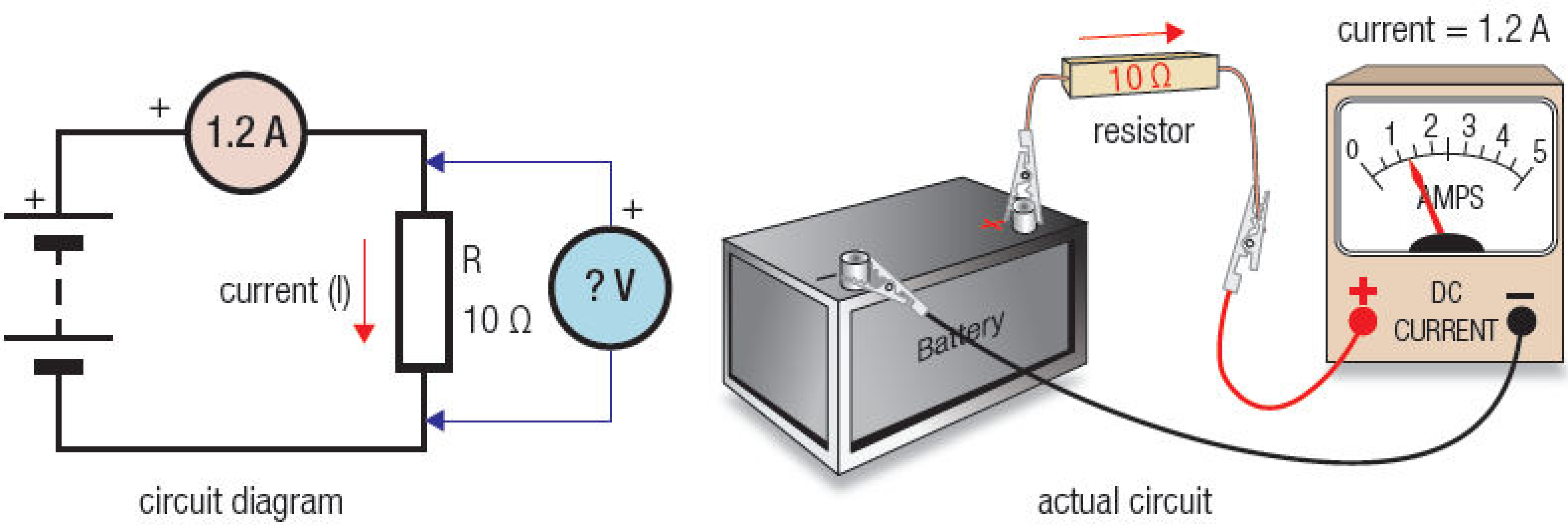
Ohm’s law to find voltage



Values in the circuit: R = 10 Ω and 1 = 1.2 A. Therefore, to find voltage with Ohm’s law: V = I × R = 10 × 1.2 = 12 volts.

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Using ohm's law to find resistance

Transpose the previous equation:

(1) write the equation

$$V = I \times R$$

(2) divide both sides by I

$$\frac{V}{I} = \frac{I \times R}{I}$$

(3) cancel out the I's on the right-hand side

$$\frac{V}{I} = \frac{\cancel{I} \times R}{\cancel{I}}$$

$$\frac{V}{I} = R$$

(4) rewrite the equation with R on the left-hand side (R is now the subject)

$$R = \frac{V}{I}$$

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Ohm's law for resistance

$$R = \frac{V}{I}$$

where:

- I = current in amperes
- V = voltage in volts
- R = resistance in ohms.

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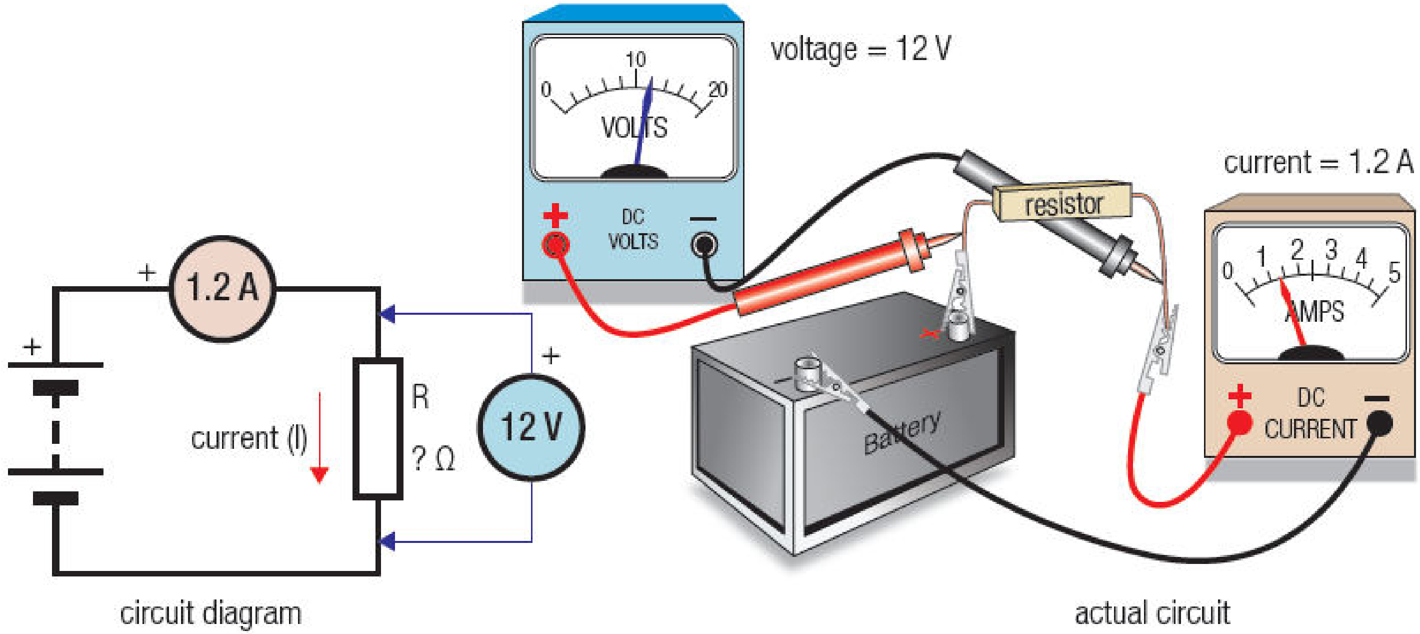
Ohm's law to find resistance



Values in the circuit: V = 12 V and 1 = 1.2 A. Therefore, to find resistance with Ohm's law: $R = \dfrac{V}{I} = \dfrac{12}{1.2} = 10 \text{ ohms}$

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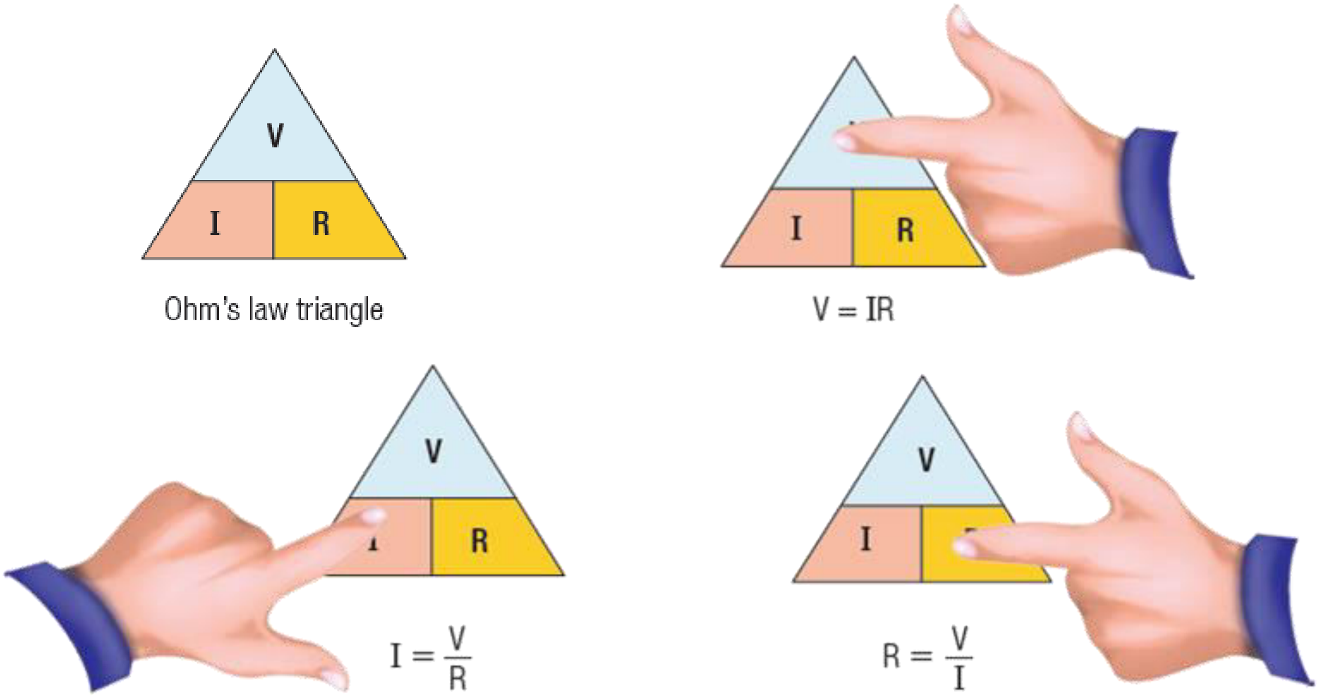
Ohm's law triangle



Cover the term you want to find: the equation is the other two terms.

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3.3 Metric prefixes

A metric prefix (multiplier) makes large or small numbers easier to handle.

For example, 800 kilometres (800 km) is easier than writing 800 000 metres.

The letter k (for kilo) is the metric prefix in the above example.

A metric prefix replaces groups of zeros that are always in multiples of 3.

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Metric prefixes used in electrotechnology

METRIC PREFIXES			
Term	**Symbol**	**Multiply by**	**Example**
tera	T	1 000 000 000 000	2 THz = 2 000 000 000 000 hertz
giga	G	1 000 000 000	2 GW = 2 000 000 000 watt
mega	M	1 000 000	39 MΩ = 39 000 000 ohm
kilo	k	1000	33 kV = 33 000 volts
milli	m	0.001	2 mA = 0.002 amperes
micro	μ	0.000 001	4 μF = 0.000 004 farads
nano	n	0.000 000 001	9 nA = 0.000 000 009 amperes
pico	p	0.000 000 000 001	3 pA = 0.000 000 000 003 amperes

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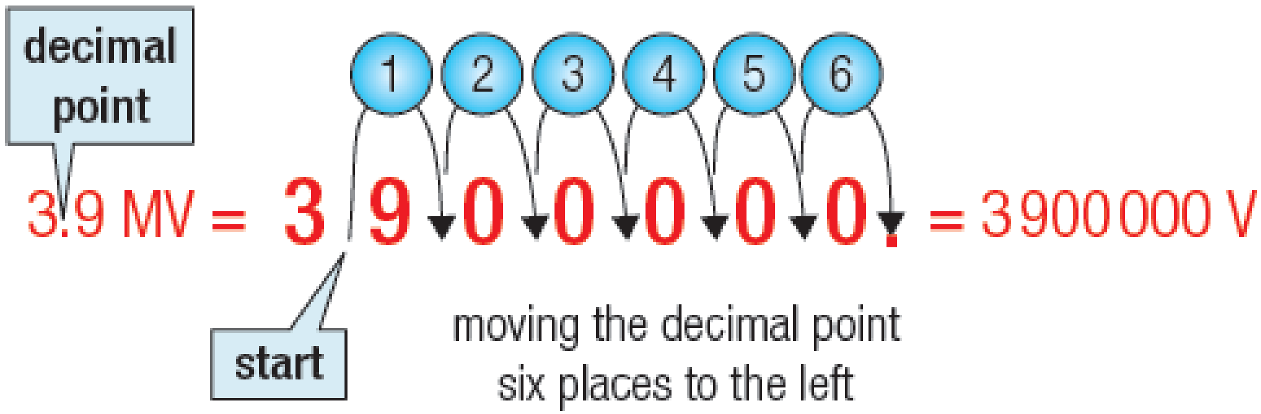
Converting 3.9 MV to volts



Decimal point is moved six places to the right

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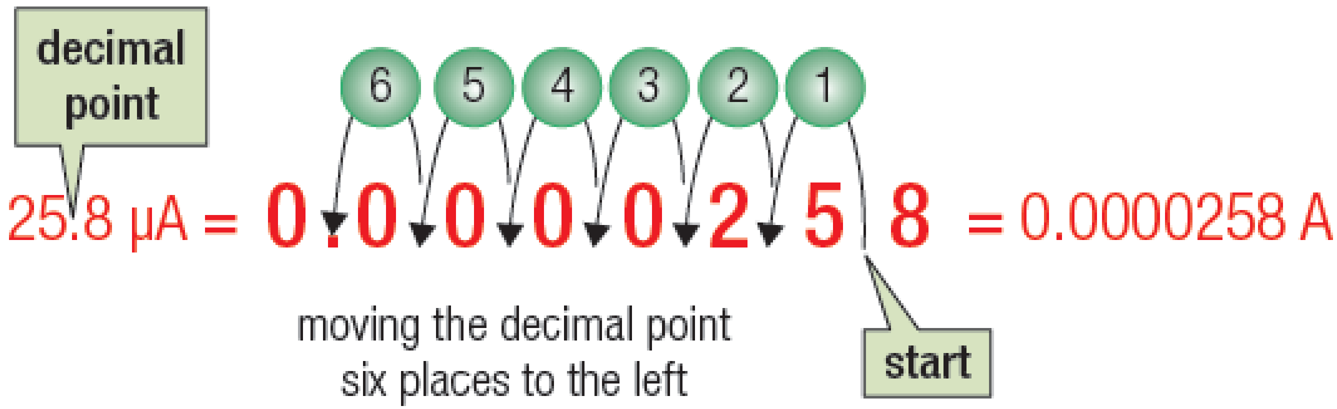
Converting 26.8 µA to amps



Decimal point is moved six places to the left

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3.4 Scientific and engineering notation

Scientific notation is an easier way of dealing with large and small values.

For example:

- the number 250 000 has four zeros
- in scientific notation, the four zeros can be written as 10^4 (10 multiplied by 10 four times)
- answer is 25×10^4
- 4 is a power of 10, and any power of 10 (plus or minus) can be used.

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Engineering notation

Engineering notation uses powers of 10 that are multiples of 3. It replaces a metric prefix with a power of 10. For example, to express 250 000 volts in engineering notation:

- metric prefix k (kilo) equals 1000
- 1000 equals 10^3
- answer is 250×10^3 V
- 250 000 V equals 250 kV

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Chapter summary

- Resistance is opposition to current flow.
- Resistance has the symbol R, and is measured in ohms, which has the Greek symbol Ω.
- Conductance is the reciprocal (inverse) of resistance, and is a measure of how well a conductor can carry an electric current.
- Conductance has the symbol G, and is measured in Siemens, symbol S.

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Chapter summary (2)

- Ohm's law mathematically relates the three fundamental electrical quantities of voltage (V), current (I) and resistance (R).
- Ohm's law says that the current flowing between any two points in an electric circuit is directly proportional to the voltage between the two points, and is inversely proportional to the resistance between the two points.

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Chapter summary (3)

The three Ohm's law equations are:

1) $R = \frac{V}{I}$ 2) $I = \frac{V}{R}$ 3) $V = IR$

where:

V = voltage in volts

I = current in amperes

R = resistance in ohms.

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Chapter summary (4)

- Metric prefixes are used to abbreviate the written form of large or small numbers.
- Commonly used prefixes are kilo (k), mega (M), milli (m) and micro (μ). Others include giga (G), pico (p) and nano (n).
- A metric prefix symbol is sometimes used to replace the decimal point in a value.
- Scientific notation expresses a metric prefix in mathematical form, in which each prefix is treated as a power of 10.

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Chapter summary (5)

- Engineering notation uses only powers of 10 that are multiples of 3.
- Problems involving values expressed in scientific (engineering) notation can be solved with a scientific calculator.
- Each entered value has a coefficient (a number) and an exponent (power of 10).

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Chapter summary (6)

- Multiplication:
  Multiply the coefficients and algebraically add the exponents.
- Division:
  Divide the coefficients, then algebraically subtract the exponent of the divisor from the exponent of the dividend.
- Addition & Subtraction:
  The exponents must be same.

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Chapter 4

Electrical power

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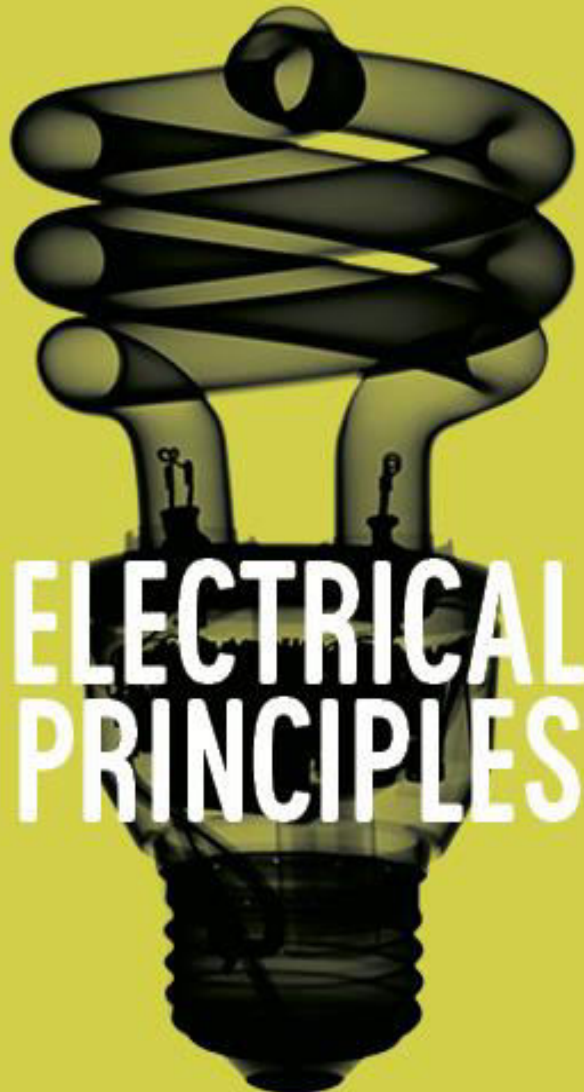

ELECTRICAL PRINCIPLES

PETER PHILLIPS
3RD EDITION

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About this chapter

This chapter:

- introduces power, energy and work
- looks at mechanical energy
- explains electrical power and ways of finding the power taken by an electrical load
- examines the effect on power if the voltage or current changes
- examines how the efficiency of an electrical load affects the amount of power required to achieve a certain task.

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Contents

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4.1 Energy and Work

Energy:

- is the ability to do work
- can only exist in a form, such as heat or light
- cannot be created or destroyed
- can only be transformed from one form to another
- is measured in joules (J).

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Work

- Work is done when energy is transformed from one form to another.
- The amount of work done equals the amount of energy transformed.
- Work, like energy, is therefore measured in joules.

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Mechanical energy

- Work is done when a force applied to an object causes it to move by a certain distance.
- Work is always against resistance such as gravity, friction or other opposing forces.
- Work done = force × distance $(\mathcal{W} = Fs)$

  where:

  - Work (W) done is measured in joules (J)
  - Force (F) is measured in newtons (N)
  - Distance (s) is measured in metres (m).

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The Joule

One joule of work is done when a force of one newton is moved through a distance of one metre in the direction of the force.

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Force

Force equals mass times acceleration.

That is:

$$F = ma$$

where:

force (F) is in newtons

mass (m) in kilograms

acceleration (a) is in metres per second per second (written as m/s^2).

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The Newton

One newton is defined as the force required to accelerate a one kilogram mass by a rate of one metre per second per second (or m/s^2).

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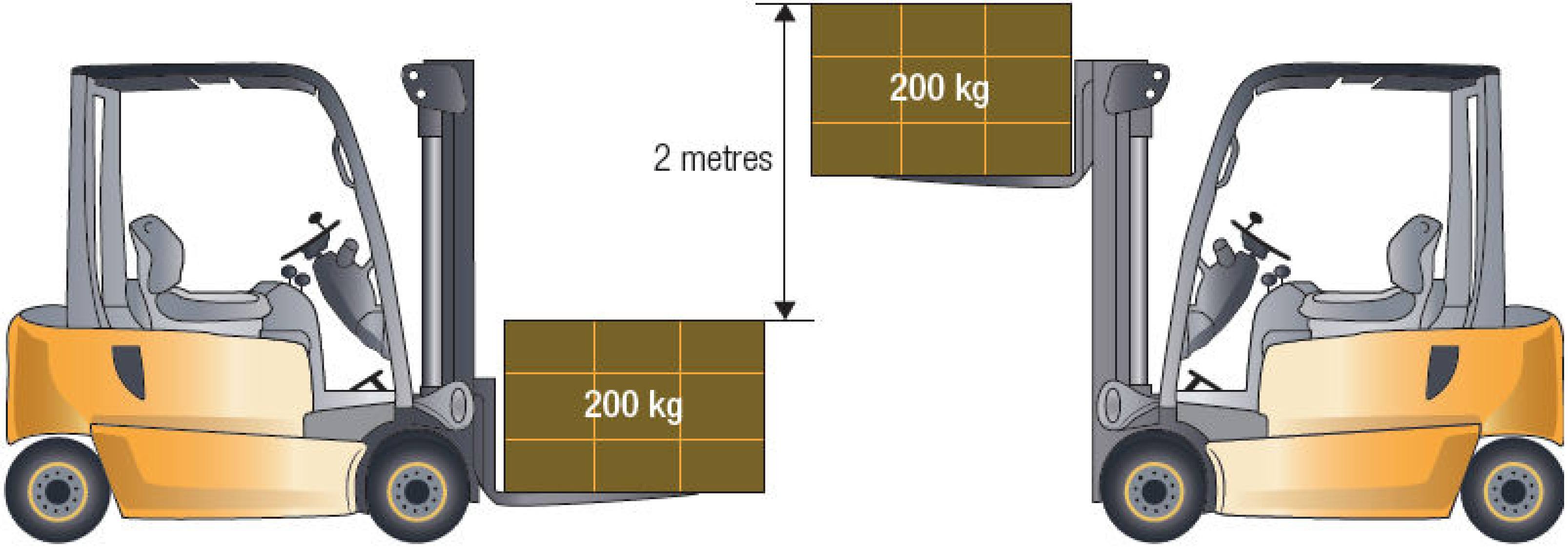
Example…



Electric forklift raising a 200 kg load through a distance of 2 metres against the force of gravity ($9.8\ m/s^2$)

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- Page 65 Example 4.1

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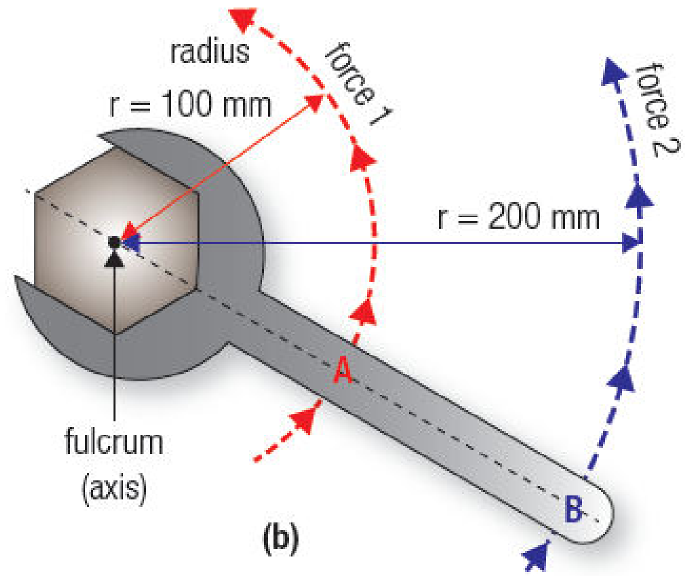
Rotational energy

(a) torque wrench with scale indicating the torque being applied to the bolt



(b)

Rotational force is called torque

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Torque

If the force is applied at right angles:

$$T = Fr$$

where:

T = torque in newton-metres (Nm)

r = distance in metres (m) between the fulcrum and the applied force

F = applied force in newtons (N).

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- Page 66 Example 4.2

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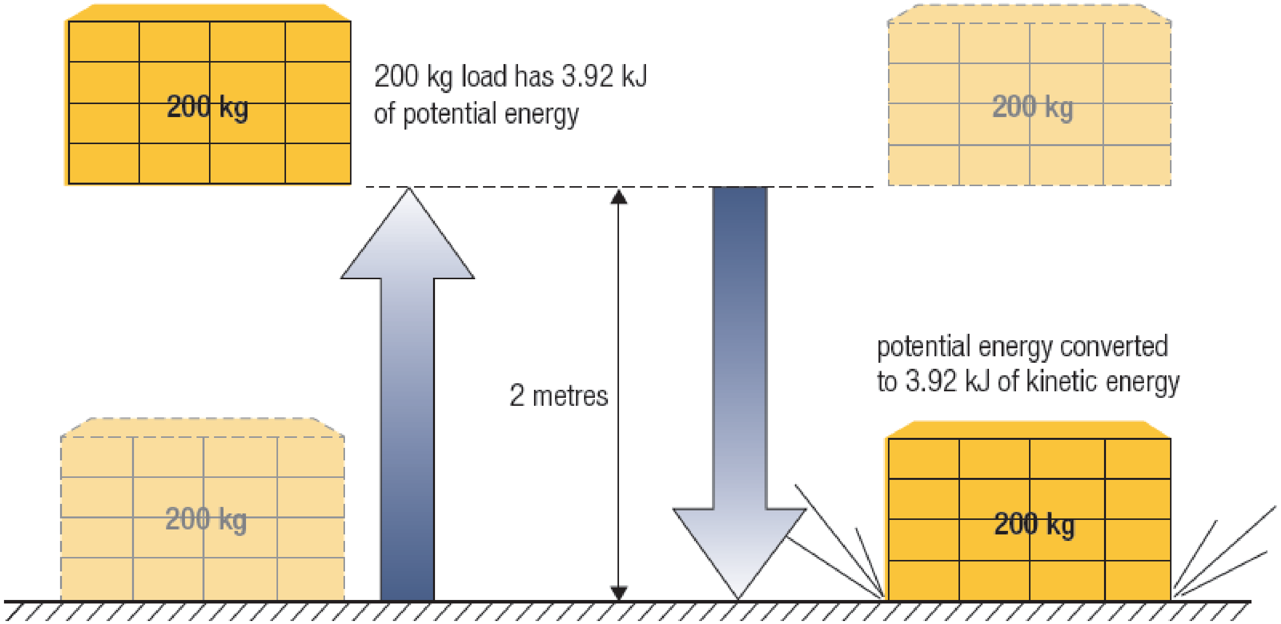
Potential and kinetic energy



Potential energy

Kinetic energy

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Kinetic energy

kinetic energy = ½ mv^2 joules

where:

m = mass in kilograms

v = velocity in metres per second.

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Forms of potential energy

All forms of energy can be classified as either potential or kinetic. Potential energy is stored energy, waiting to be used.

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Forms of potential energy (2)

Forms include:

- Chemical
  Energy stored in the bonds of atoms and molecules. Examples are biomass, petroleum, natural gas and coal
- Gravitational
  Energy stored due to height, such as falling water driving a turbine
- Nuclear
  Energy stored in the nucleus of an atom that holds the nucleus together.

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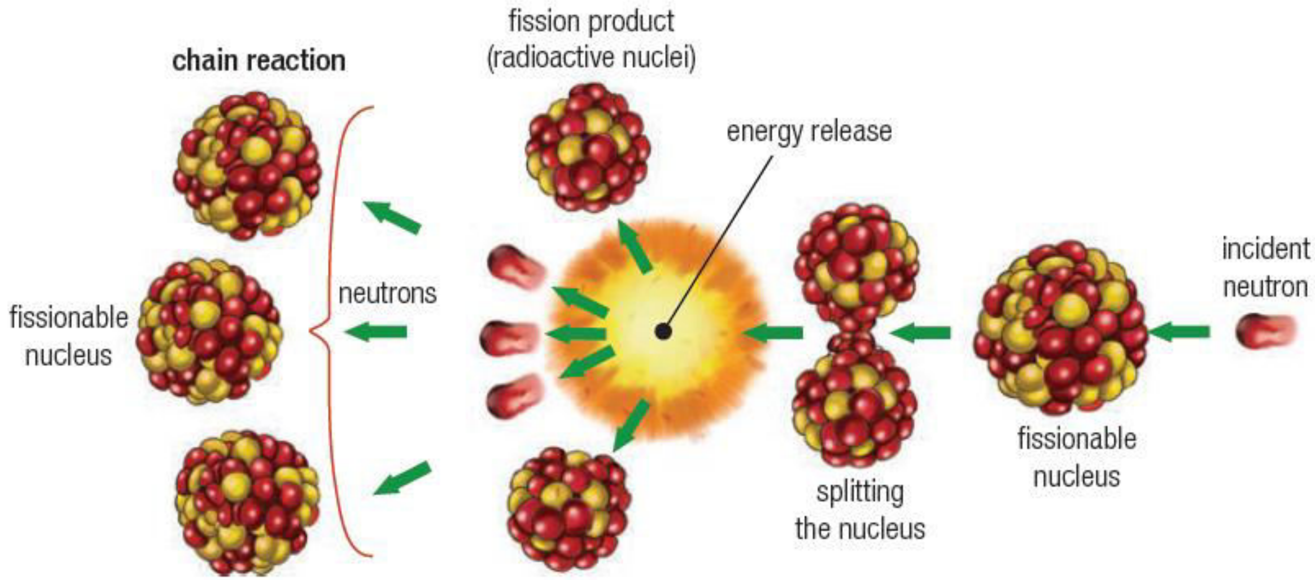
Nuclear energy



Nuclear power plants generate electricity by using heat obtained from a fission reaction, which releases large amounts of heat energy

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Forms of kinetic energy

Forms of kinetic energy used to generate electricity include:

- Radiant energy
  Electromagnetic energy such as visible light, which can be converted to electricity using solar panels
- Thermal energy (heat)
  Vibration and movement of atoms and molecules due to being heated by a potential energy source
- Motion energy
  Movement, such as wind power, hydro-power from falling water, rotational energy from a turbine.

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4.2 Power

- Power is the rate at which energy is transfromed, or the rate at which work is done.
- The unit of Power (P) is the Watt (W).
- By definition, a Power of one Watt is used if one Joule of energy is transformed in one second.
- Power is given the symbol P.

Quantity	*Term*	*Letter*	*Unit*
Power	Power	P	Watts (W)

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Rate of doing work

Both men have used the same amount of energy and have done the same amount of work. The runner has taken less time to do so and has therefore applied more power.

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Power, work and time

$$\text{power} = \frac{\text{work}}{\text{time}}$$

where:

power is in watts

work is in joules

time is in seconds.

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- Page 70 Example 4.3

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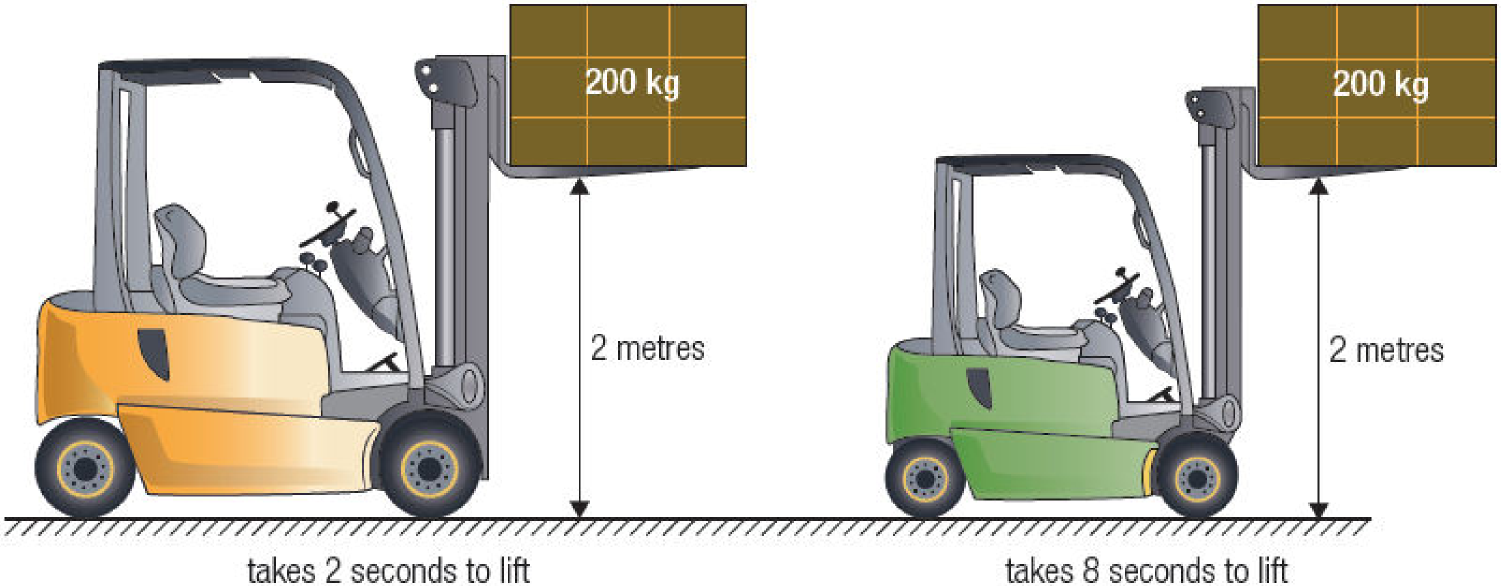
Example of power



More power
(does job more quickly)

Less power
(does job more slowly)

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Mechanical power

- Mechanical power is a rating of how much work a machine such as a motor can do in a certain time.
- The mechanical power produced by a motor depends on its speed of rotation and the torque it is delivering at that speed.

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Equation for mechanical power

$$P = \frac{2\pi nT}{60}$$

where:

P = mechanical power in watts

2π is a circular reference equal to 6.28 (approx.)

n = revolutions per minute (RPM)

T = torque in newton-metres.

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- Page 71 Example 4.4

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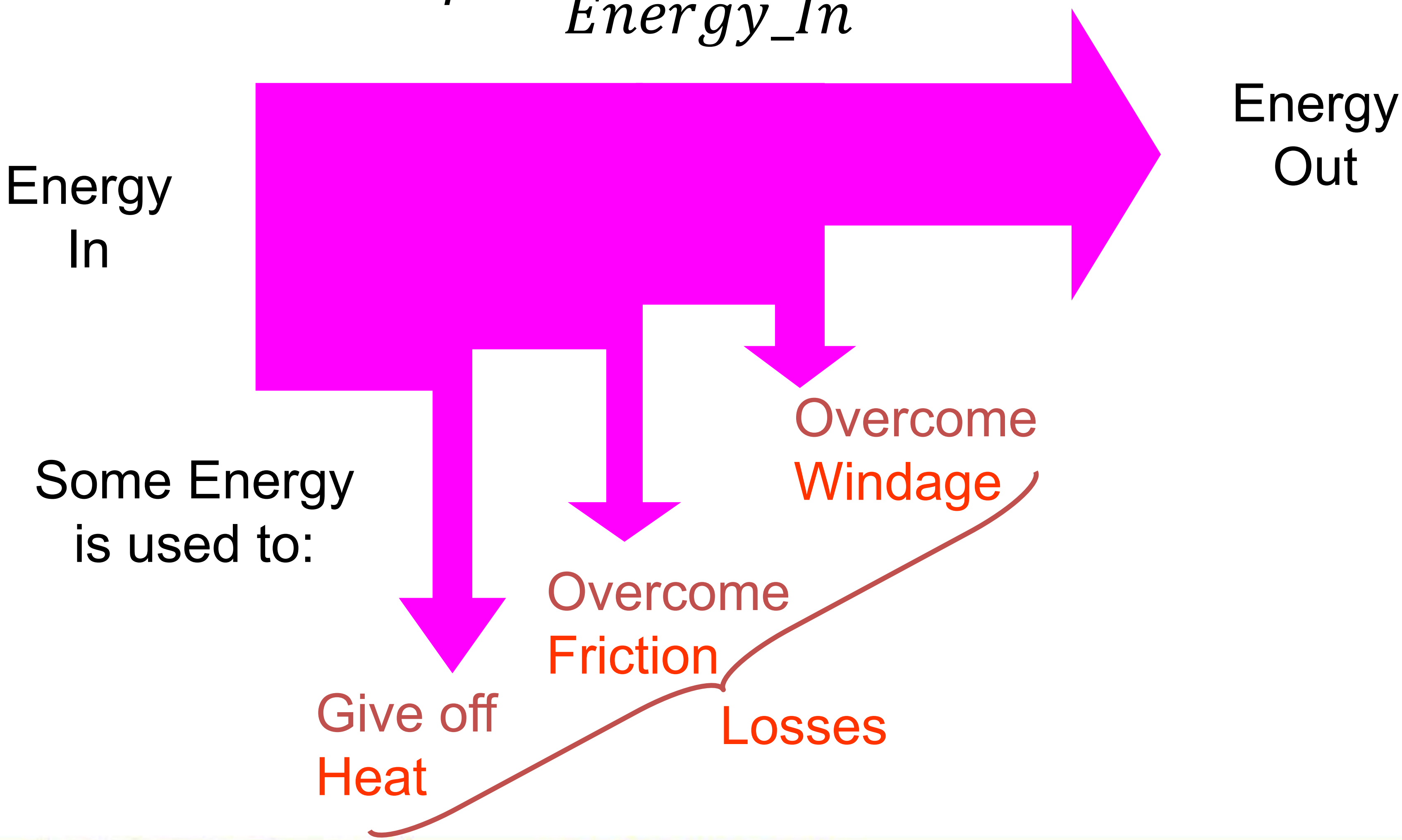
$$\eta = \frac{Energy\_Out}{Energy\_In}$$



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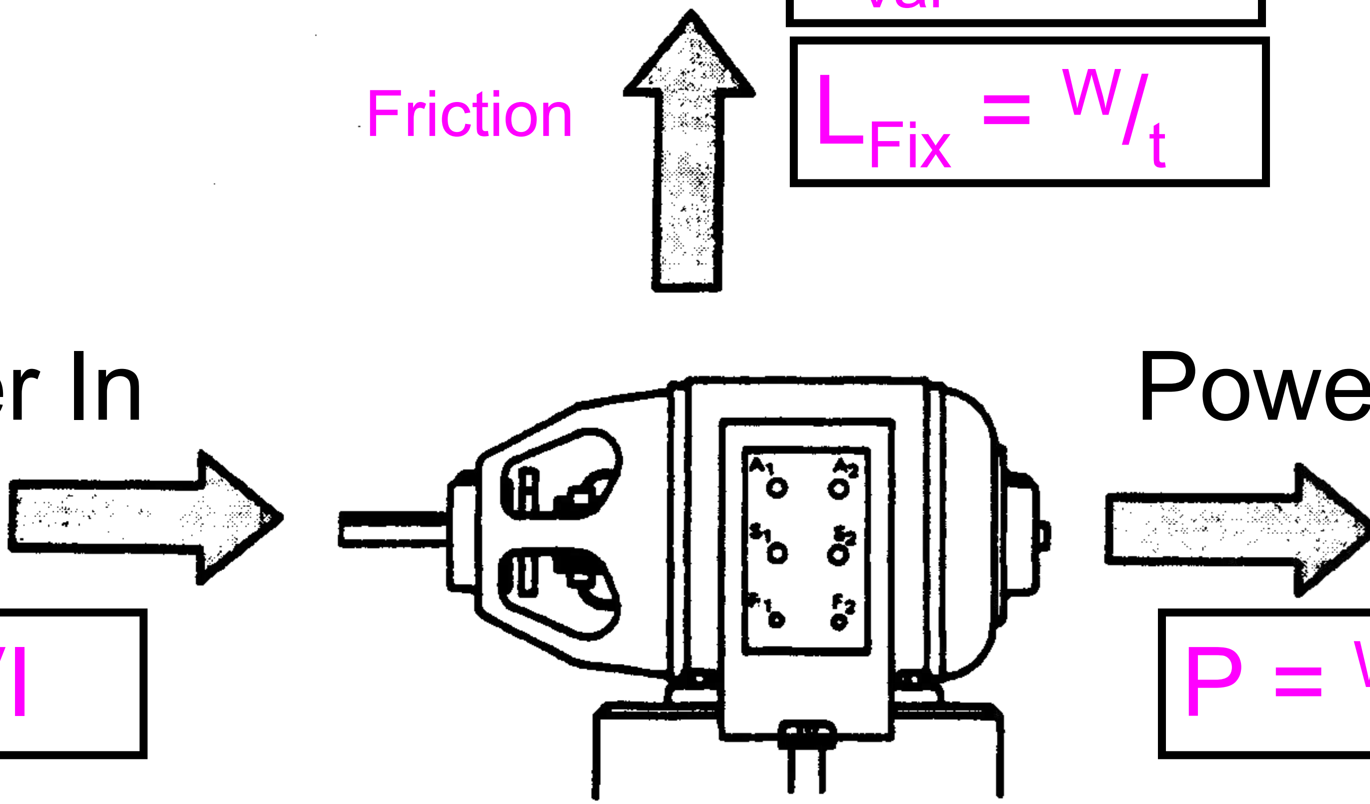
Losses

Copper Losses - Heat

$L_{Var} = I^2R$

Friction

$L_{Fix} = {}^{W}/_{t}$



Power In

$P = VI$

Power Out

$P = {}^{W}/_{t}$

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Efficiency

Efficiency is a measure of how much input power is required for a certain output power.

$$\eta = \frac{\text{power out}}{\text{power in}} \times 100\%$$

where:

η = efficiency

power in and power out are in watts.

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- Page 71 Example 4.5
- Pg 72 Ex 4.1

3^{RD}	4^{TH}
1	1
2	2
5	3
8	4
10	5

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4.3 Electrical power

- Electrical power is measured in watts.
- One watt of electrical power is dissipated in a resistor when a voltage of one volt causes a current of one ampere to flow through the resistor.
- By Ohm's law, the resistance of the circuit is one ohm.

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Equation for electrical power

power = voltage x current

or

$$P = VI$$

where:

- P = power in watts
- V = voltage in volts
- I = current in amperes.

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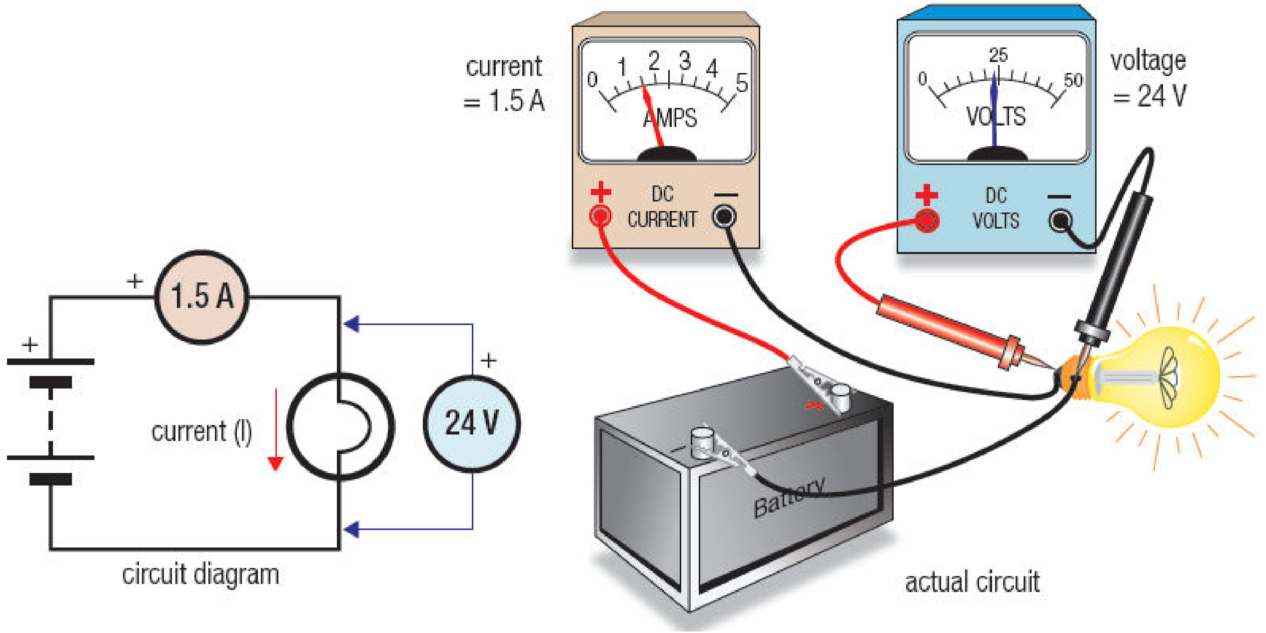
Example 4.6



V = 24 V

I = 1.5 A

P = 24 × 1.5 = 36 watts

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4.4 Transposing the power equation

Transposing gives three equations that relate power (P), voltage (V) and current (I):

1. $P = VI$

2. $V = \frac{P}{I}$

3. $I = \frac{P}{V}$

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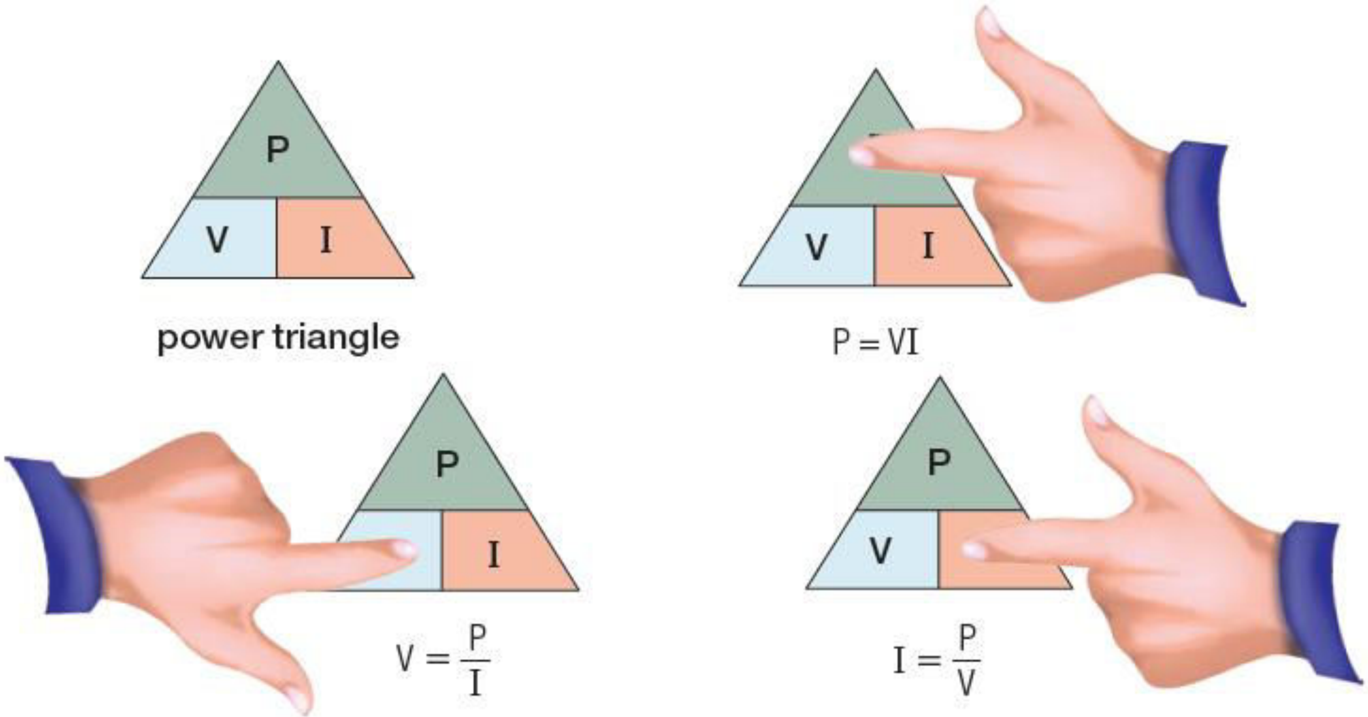
Power triangle



Cover the term you want to find: the equation is the other two terms

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- Page 74 Examples 4.7 & 4.8

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Power and metric prefixes

POWER WITH METRIC PREFIXES			
Term	**Symbol**	**Equals**	**Engineering notation**
gigawatt	GW	1 000 000 000	1 GW = 1×10^9 W
megawatt	MW	1 000 000 watts	1 MW = 1×10^6 W
kilowatt	kW	1000 watts	1 kW = 1×10^3 W
milliwatt	mW	0.001 watts	1 mW = 1×10^{-3} W
microwatt	µW	0.000 001 watts	1 µW = 1×10^{-6} W

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- Page 75 Examples 4.9 & 4.10

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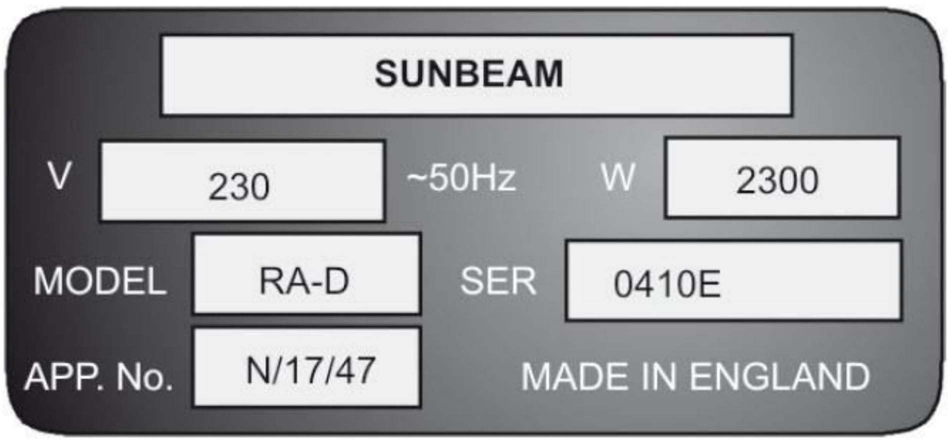
Power and energy rating

$$\text{energy (joules)} = \text{power} \times \text{time}$$

or

$$\text{energy (kWh)} = \text{kW} \times \text{hours}$$



After one hour, this heater will have used 2.3 kWh of energy

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- Page 76 Example 4.11
- Page 77 Exercise 4.2 Problems 1 - 10

3RD	4TH
1	1
2	2
5	3
6	4
7	5

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4.5 Power and Ohm's law

- The three Ohm's law equations are:

  1. $V = IR$ 2. $I = \frac{V}{R}$ 3. $R = \frac{V}{I}$

- The three Power equations are:

  1. $P = VI$ 2. $V = \frac{P}{I}$ 3. $I = \frac{P}{V}$

These six equations can be combined to give a set of equations that relate to the four quantities of power, voltage, current and resistance.

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Power from resistance and current

(1) Write the power equation $P = V \times I$

(2) Write Ohm's law for V $V = I \times R = IR$

(3) Replace V in equation 1 with IR $P = IR \times I$

(4) Multiply $I \times IR$ to give I^2R $P = I^2R$

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- Page 78 & 79 Examples 4.12 & 4.13

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Current from power and resistance

Start with $P = I^2R$

Transpose the equation in terms of current I.

This gives:

$$I = \sqrt{\frac{P}{R}}$$

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- Page 79 Example 4.14

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Resistance from power and current

Start with $P = I^2R$

Transpose the equation in terms of resistance R.

This gives:

$$R = \frac{P}{I^2}$$

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- Page 80 Example 4.15

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Power from resistance and voltage

(1) Write the power equation $P = V \times I$

(2) Write Ohm's law for I $I = \dfrac{V}{R}$

(3) Replace I in equation 1 with $\frac{V}{R}$ $P = V \times \dfrac{V}{R}$

(4) Multiply $V \times \frac{V}{R}$ to give $\frac{V^2}{R}$ $P = \dfrac{V^2}{R}$

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- Page 81 Example 4.16

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Resistance from voltage and power

Transpose $P = \frac{V^2}{R}$ in terms of R:

$$R = \frac{V^2}{P}$$

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- Page 81 Example 4.17

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Voltage from power and resistance

Transpose $P = \frac{V^2}{R}$ in terms of V:

$$V = \sqrt{PR}$$

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- Page 82 Example 4.18
- Page 82 Exercise 4.3 Problems 1 - 10

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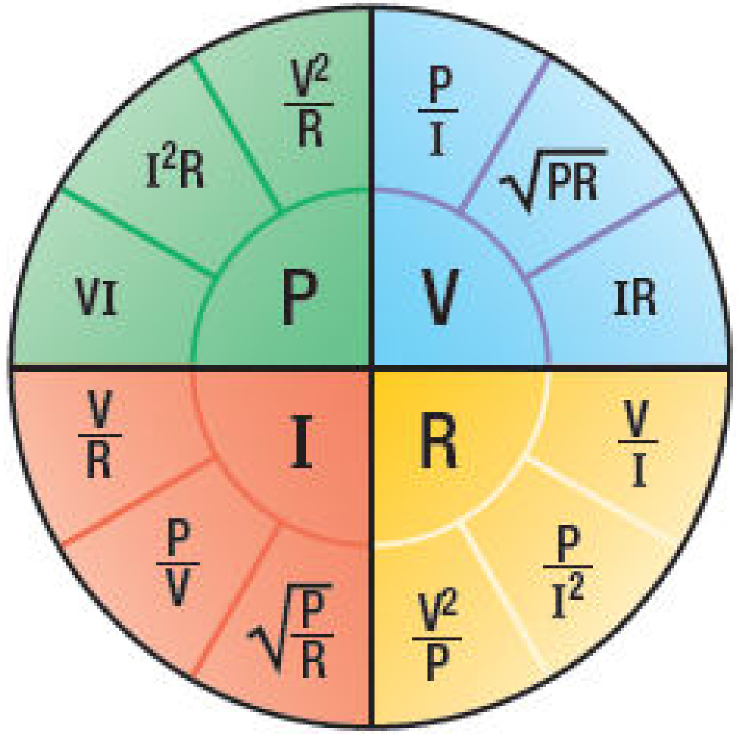
Equation wheel



The four quantities V, I, R and P in the centre section near their three related equations, giving 12 equations

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4.6 Power change with I, V or R changes

If the voltage to a circuit changes, the current will change. Therefore the power taken by the circuit will also change.

The next set of slides explain by how much the power changes.

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Effect on power if the voltage changes

Because $P = \frac{V^2}{R}$, the power taken by the circuit will

change by the square of the voltage.

That is:

- if voltage changes to twice its normal value, power taken increases four times, because 2 squared equals 4
- if voltage falls to half its normal value, power will fall by four times.

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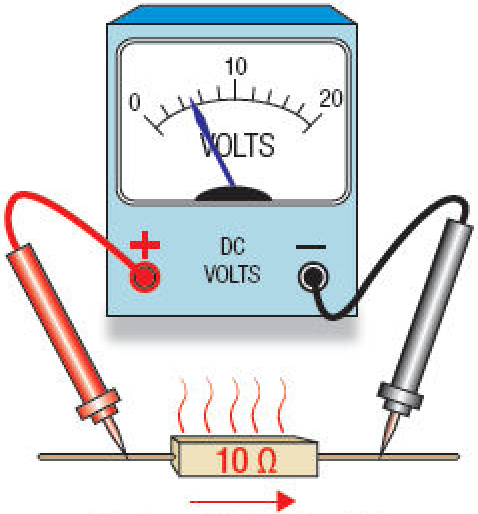
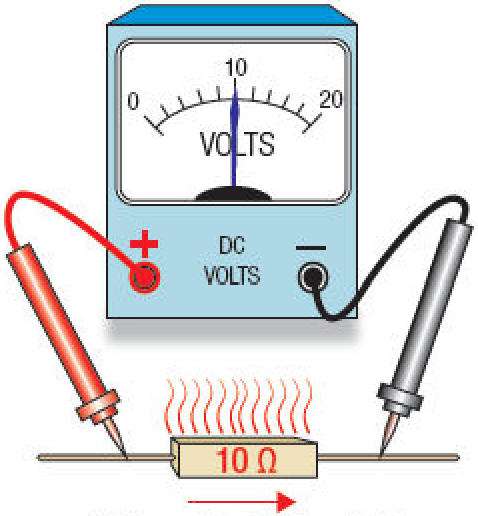
Example – effect on P if V changes

Changing the applied voltage from 5 V to 10 V in a 10 ohm circuit:



(a) R = 10 Ω, V = 5 V

P = 2.5 W



(b) R = 10 Ω, V = 10 V

P = 10 W

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Effect on power if the current changes

Because $P = I^2R$, power taken will change by the square of the current.

That is:

- if current changes to twice its normal value, the power taken will increase to four times its initial value.
- if current falls to half its normal value, the power will fall by a factor of four.

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Effect on power if resistance changes

- If the voltage to a circuit is constant and the circuit resistance falls by half, the current doubles in value.
- Because P = VI, the power taken by the circuit also doubles.

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Chapter summary

- Energy and Work are both measured in Joules.
  Energy is the ability to do work, and
  Work is done when energy is transformed.
- Force is measured in Newtons.
  One newton of force is needed to accelerate a
  one kilogram mass by one metre per second per second.
- Motors are rated by their power and torque, where torque is measured in newton-metres (Nm) and power is measured in watts.

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Chapter summary (2)

- Energy is either kinetic (moving) or potential (stored).
- Potential energy becomes kinetic energy when used.
- Power is the rate of doing work. That is:

$$\text{power} = \frac{\text{work}}{\text{time}}$$

where:

power is in watts
work is in joules
time is in seconds.

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Chapter summary (3)

- Power is one watt when one joule of energy is transformed in one second.
- Mechanical power is given by:

$$P = \frac{2\pi n T}{60}$$

where:

N = RPM

T = torque (Nm).

- Efficiency: $$\eta = \frac{\text{power out}}{\text{power in}} \times 100\%$$

Efficiency gives a measure of power and energy losses.

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Chapter summary (4)

- Electrical power (P) to a load equals the product of the current in the load and the voltage across the load, i.e. ($P = VI$).
- $P = VI$ is transposed to make either V or I the subject, and is combined with Ohm's law to give nine equations relating to circuit power, resistance, current and voltage.

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Chapter summary (5)

- $P = \frac{V^2}{R}$ means power changes by the square of the voltage change.
- It also means that power changes inversely with resistance (when the voltage is constant).
- $P = I^2R$ means power changes by the square of the current change.
- 'I squared R losses' (I^2R) refer to the losses generated as heat in a conductor or connection.

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Chapter 5

Resistance and resistors

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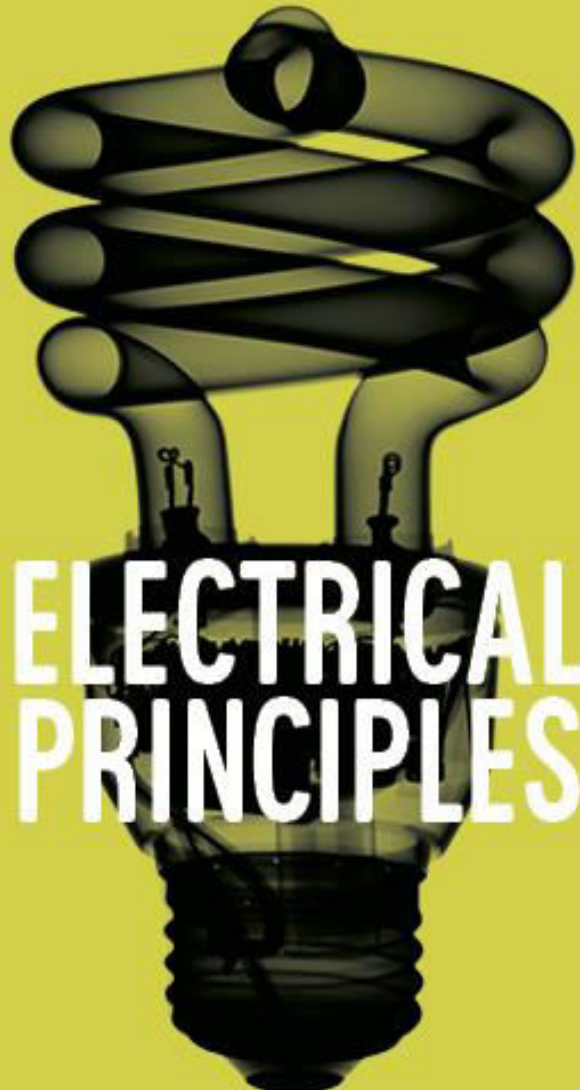

ELECTRICAL PRINCIPLES

PETER PHILLIPS
3RD EDITION

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About this chapter

This chapter:

- explains the factors that determine the resistance of a conductor
- introduces the resistor
- describes other components whose resistance varies with external influence, such as light or heat
- explains the resistor colour code
- explains how to measure resistance with an ohmmeter.

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Contents

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5.1 Factors that determine resistance

Four factors that determine resistance of a conductor are:

- the material it is made of
- its length
- its cross-sectional area
- its temperature.

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Material the conductor is made of

- All conducting materials have a certain value of resistivity.
- Resistivity is defined as the resistance the material offers between opposite faces of a cube of one metre dimensions.
- A resistivity value is expressed in ohm-metres (Ωm).
- The symbol for resistivity is the Greek letter ρ (pronounced rho).

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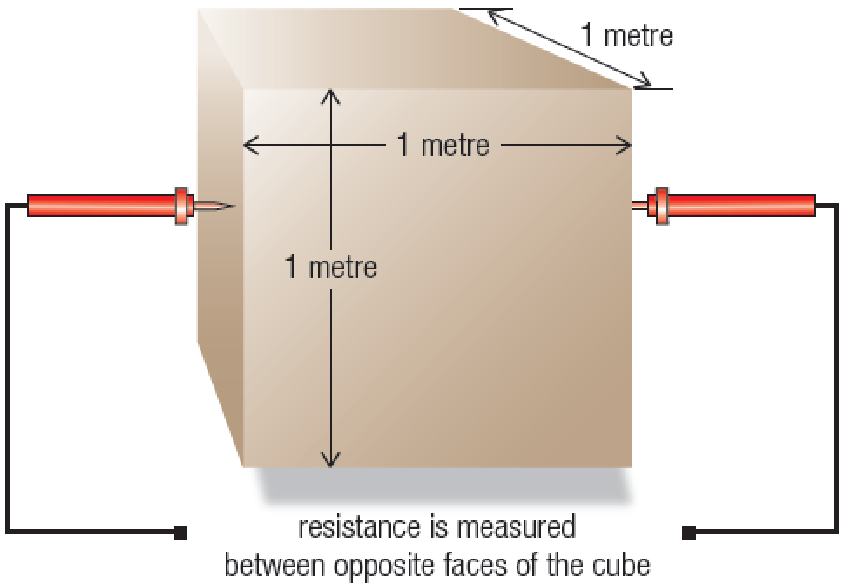
Measuring resistivity



Resistivity of a material is its resistance measured at a specified temperature between opposite faces of a cube of the material

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Table of resistivity values

RESISTIVITY OF CONDUCTORS AT 20 °C		
Material	Resistivity in ohm-metre (ρ)	
silver	1.63×10^{-8}	Note: Expressed without scientific notation, silver has a resistivity of 0.0000000163 ohm-metre
copper	1.72×10^{-8}	
gold	2.44×10^{-8}	
aluminium	2.83×10^{-8}	
tungsten	5.3×10^{-8}	
nichrome	112×10^{-8}	
carbon	3.5×10^{-3}	

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Conductor resistance

COMPARISON OF CONDUCTOR RESISTANCE	
Material	**Resistance in ohms (1 km by 1 mm dia. wire at 20 °C)**
silver	20.4
copper	21.7
gold	28.0
aluminium	34.4
tungsten	67.5
nichrome	1426
carbon	4 456 327

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Length of the conductor

- Resistance is proportional to the length of a conductor.
- If a 1 mm diameter copper conductor has a length of 2 km, its resistance will be twice that shown in the previous table.

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Cross-sectional area

- Resistance is inversely proportional to the cross-sectional area (csa) of a conductor.
- That is, the smaller the csa the higher the resistance of the conductor.

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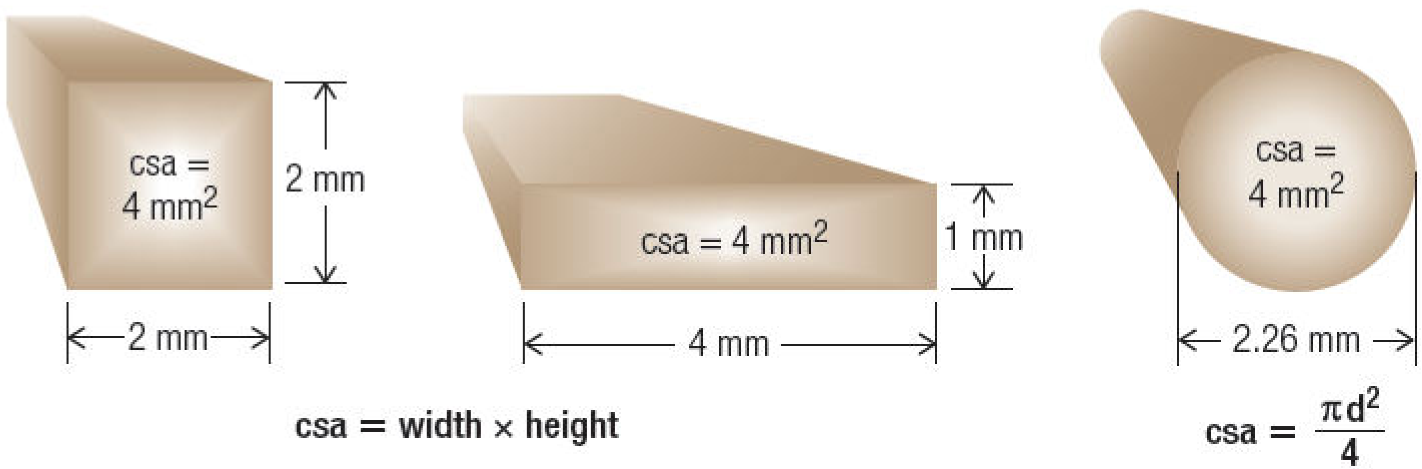
Calculating csa



Cross-sectional area of a conductor is the area of the face of the conductor

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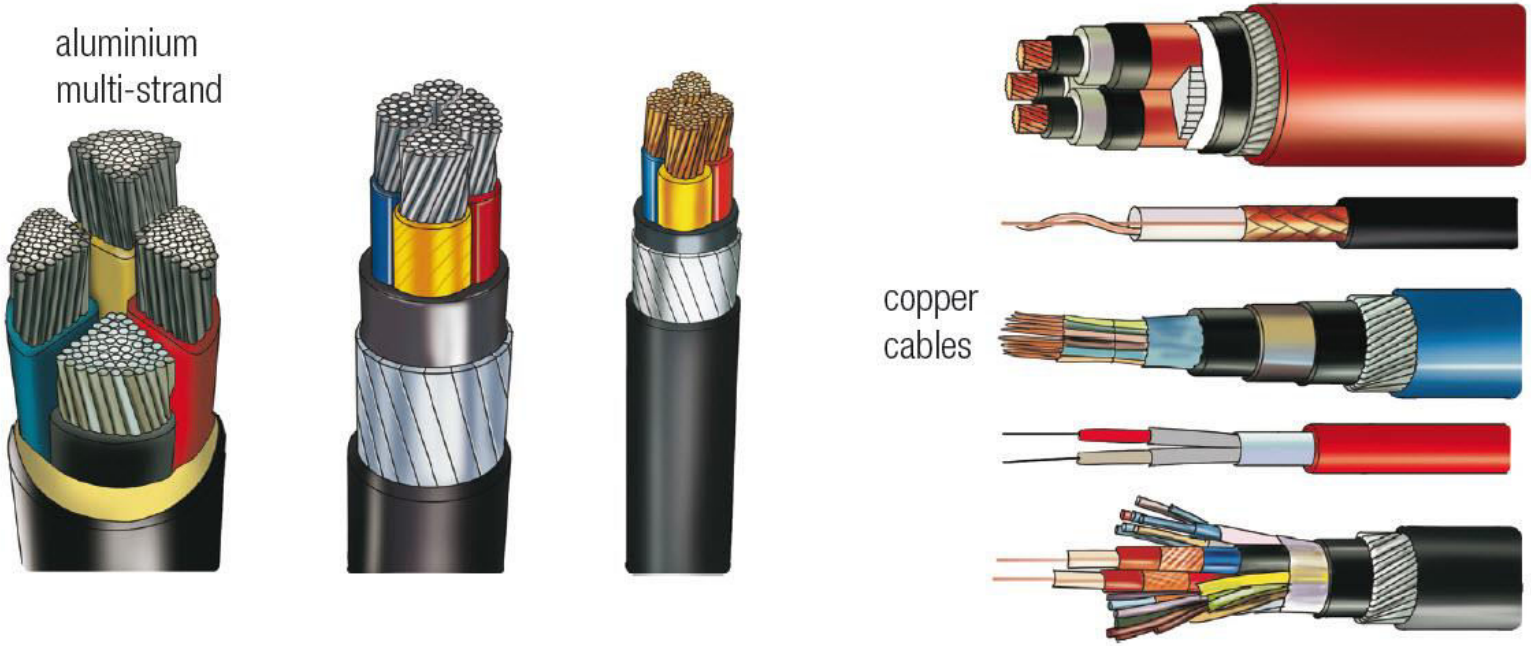
Example cables



Cables are typically made from aluminium or copper

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Calculating cable resistance

Conductor resistance is found with this equation:

$$R = \frac{\rho l}{A}$$

where:

- R = resistance in ohms
- ρ = resistivity in ohm-metres
- l = length in metres
- A = csa in square metres (m^2).

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Temperature

- The resistance of all conductors varies with temperature.
- For pure metals, an increase in temperature will give an increase in resistance.
- How much the resistance changes depends on the type of metal.

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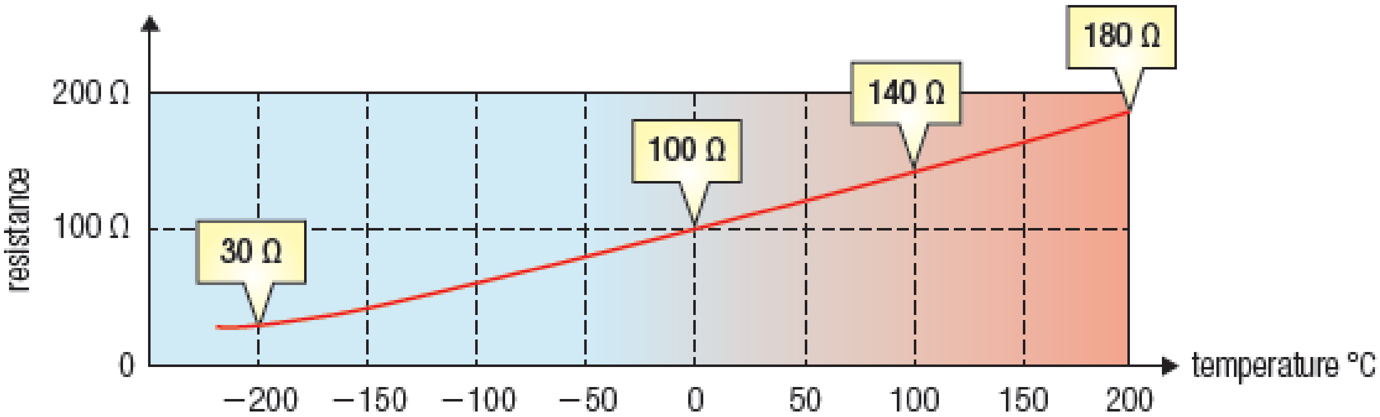
Graph of temperature and resistance



Graph of resistance of a coil of copper wire versus temperature change. If the resistance at 0 ºC is 100 Ω, it will be 180 Ω at 200 ºC. If the temperature drops to –200 ºC, the resistance will drop to about 30 Ω.

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Temperature coefficient

- Most conductors have a positive temperature coefficient.
- This means their resistance increases with temperature.
- Carbon has a negative temperature coefficient, so its resistance drops with an increase in temperature.

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Table of temperature coefficients

TEMPERATURE COEFFICIENTS	
Material	**Temperature coefficient per degree C at 20 °C (α_{20})**
silver	0.004
copper	0.00392
gold	0.0034
aluminium	0.0039
tungsten	0.0045
nichrome	0.0017
carbon	−0.0005

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5.2 Resistors

- A resistor is an electrical component with a fixed value of resistance.
- Resistor values range from less than one ohm up to many millions of ohms.
- Resistors are given a power rating because they get hot when current is passed through them.
- The power rating of a resistor determines the maximum current the resistor can pass without overheating.

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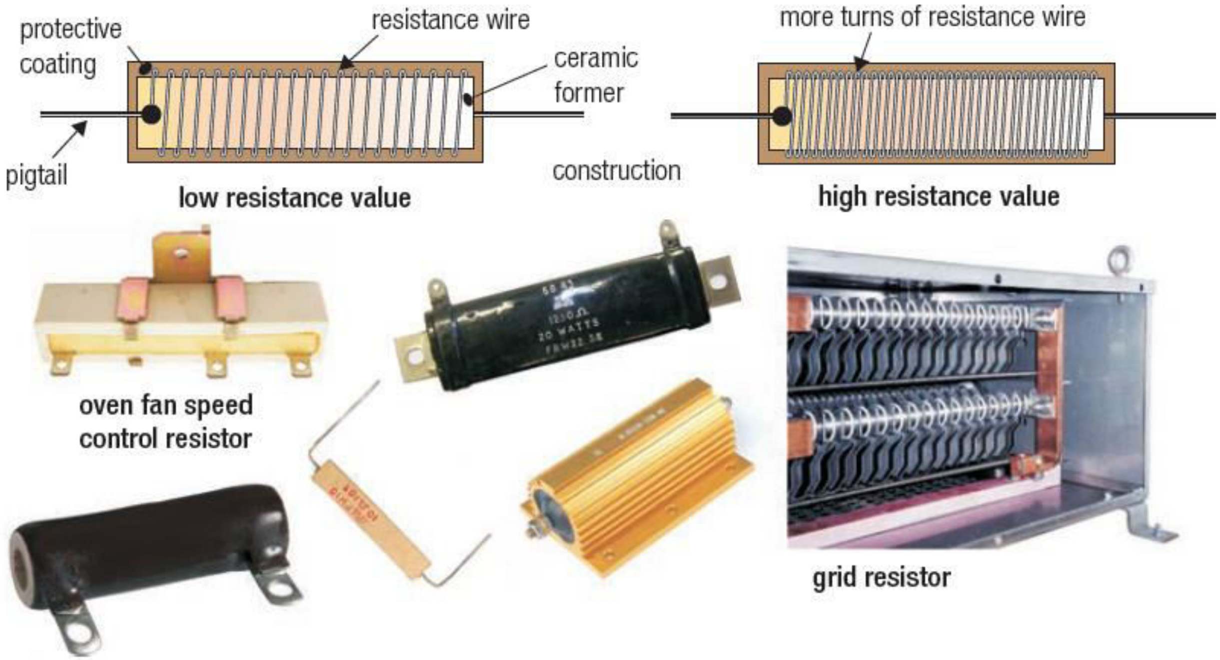
Power resistors



Power resistors, showing typical construction and types

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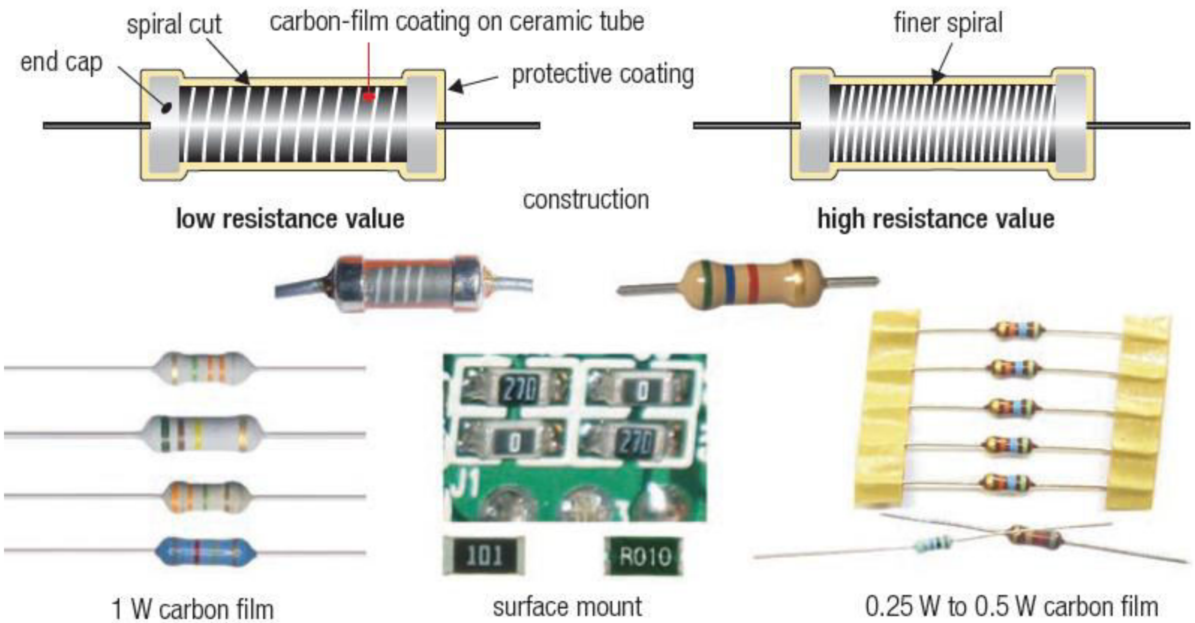
Low power resistors



Carbon-film resistors are for low power use. They range in power from ¼ W to 5 W

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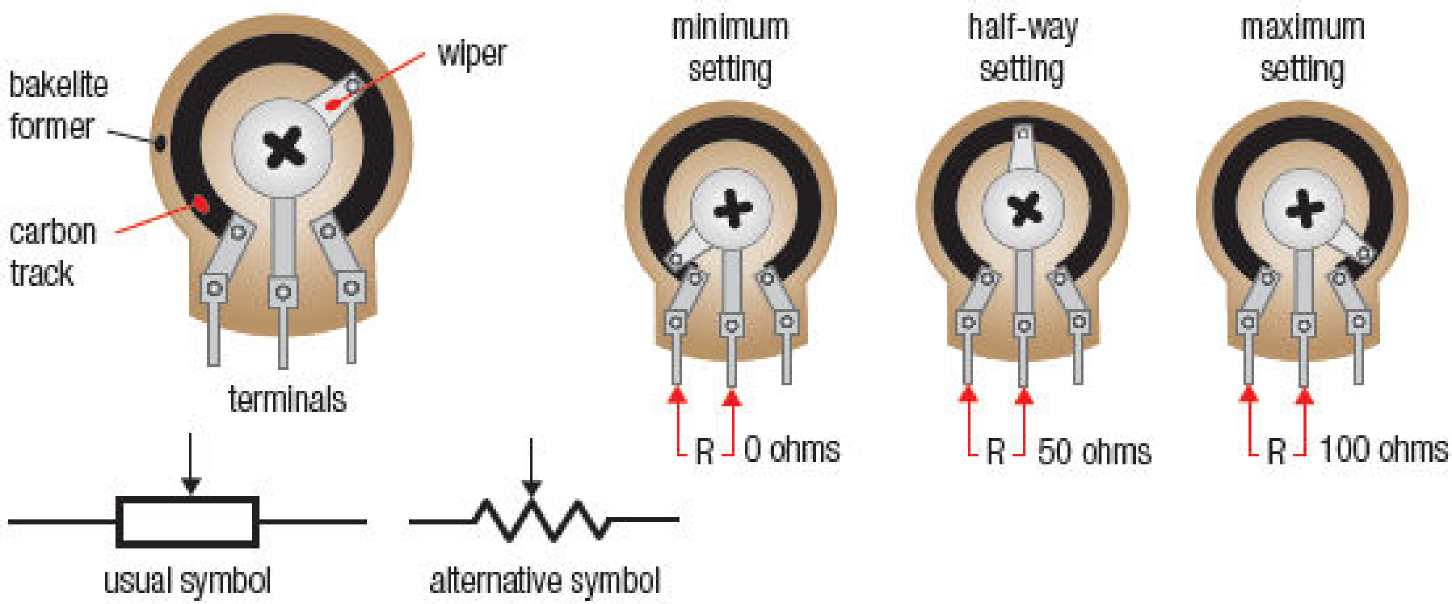
Variable resistor



A variable resistor (potentiometer) has three terminals, the centre one connected to a moving wiper. As the wiper is moved along the carbon track, the resistance between it and the outside terminals changes.

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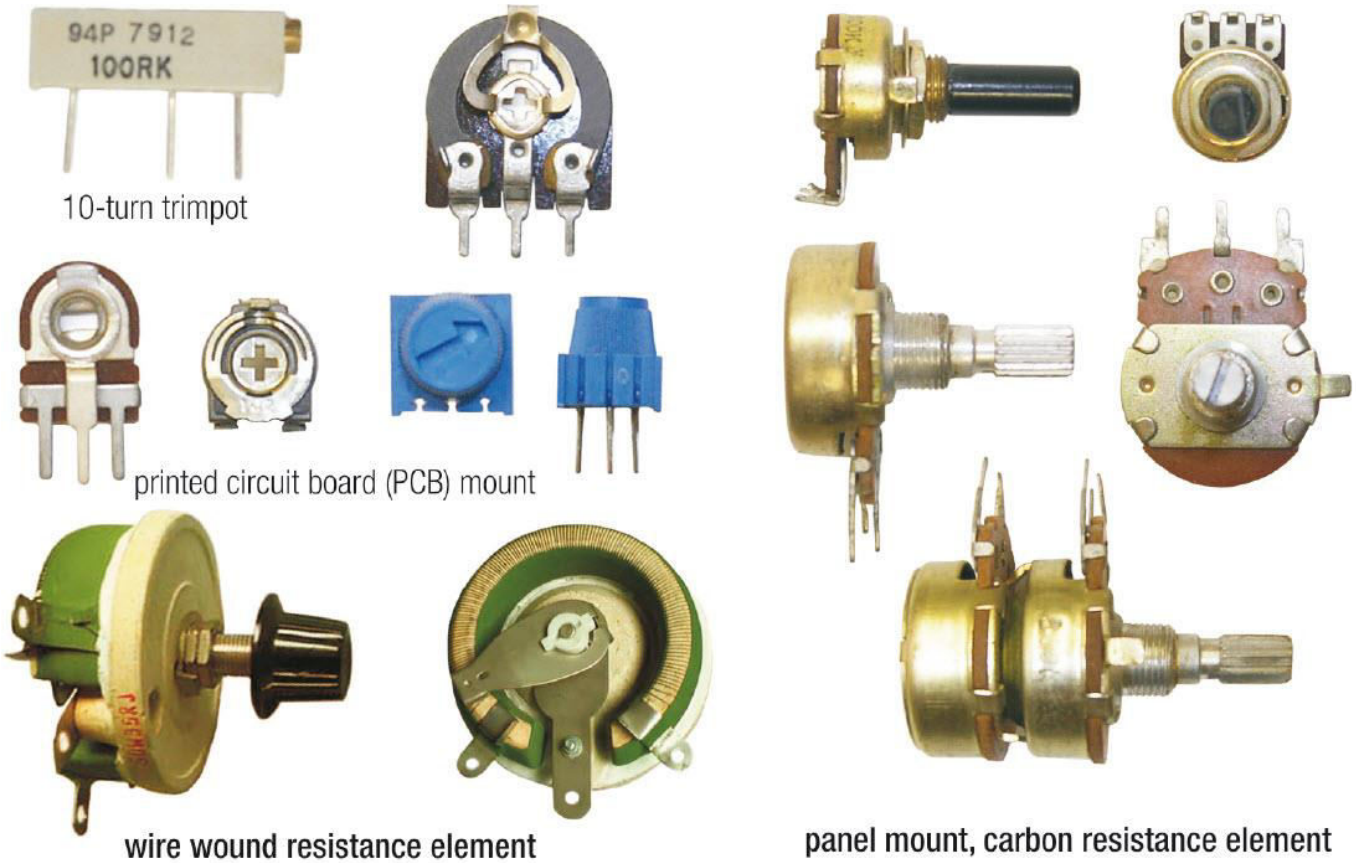
Example variable resistors



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Temperature-dependent resistors

Temperature-dependent resistors:

- change resistance with a change in temperature
- are used to measure temperature, and also as a sensor in temperature control or protection systems
- have two main types, wire-wound and thermistor.

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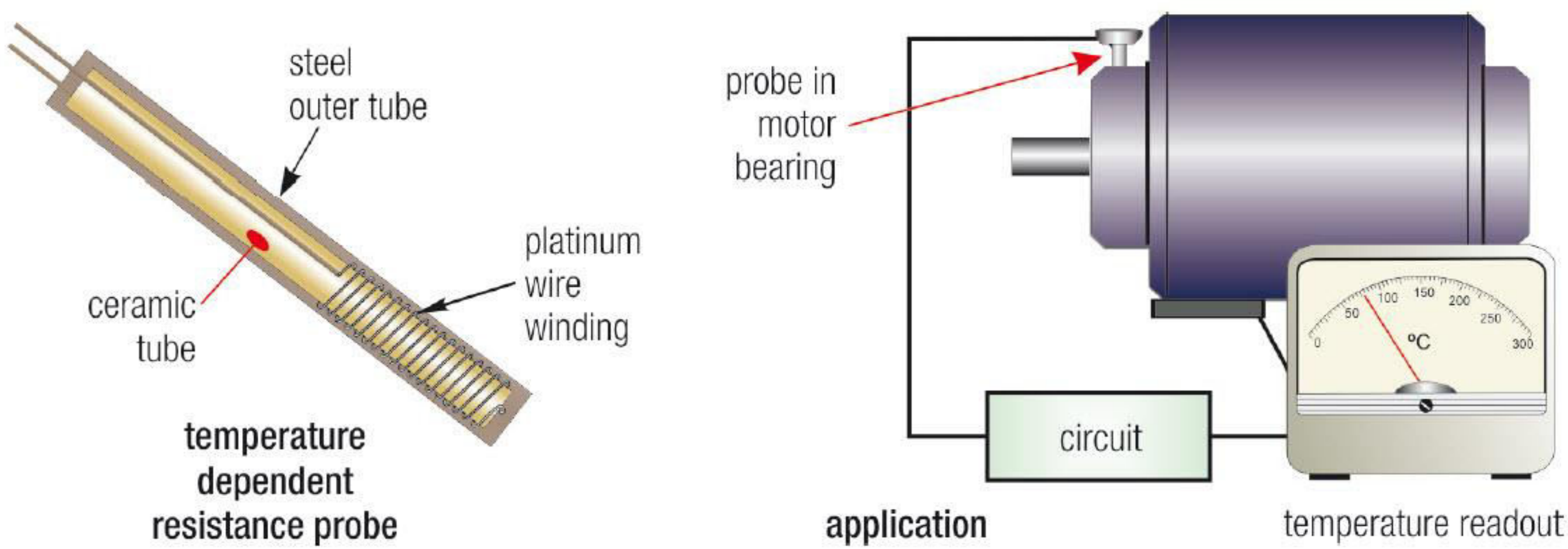
Wire-wound TDR



A temperature-dependent resistor can be made by winding copper, nickel or platinum wire around a ceramic former

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Thermistors

Thermistors (thermal resistors):

- are made with a semiconductor material
- can have a positive (PTC) or a negative temperature coefficient (NTC)
- are often used to detect overheating, such as in a motor.

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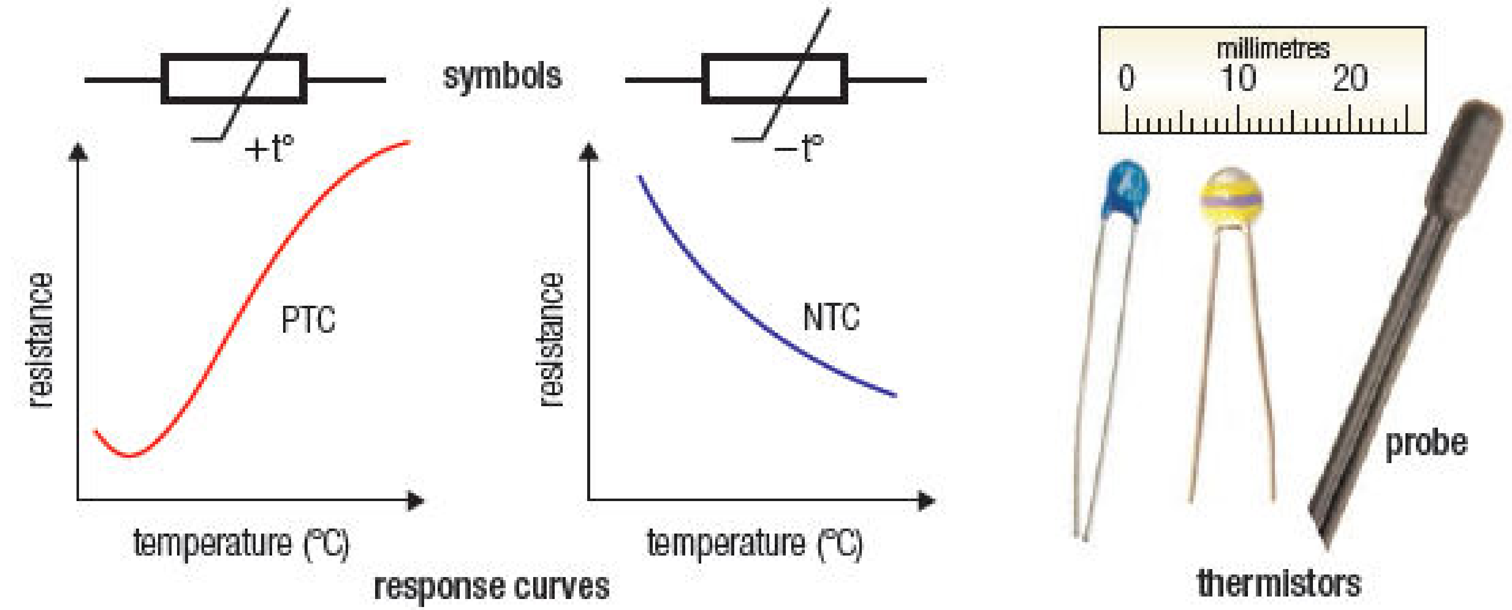
Thermistor response curves



Thermistors have many applications, and are either NTC or PTC devices packaged in disc or rectangular form

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Light-dependent resistors

Light-dependent resistors (LDR):

- change resistance with a change in light level
- are made from cadmium-sulphide, which is a photo-conductive material
- are used to control lighting installations, including street lights.

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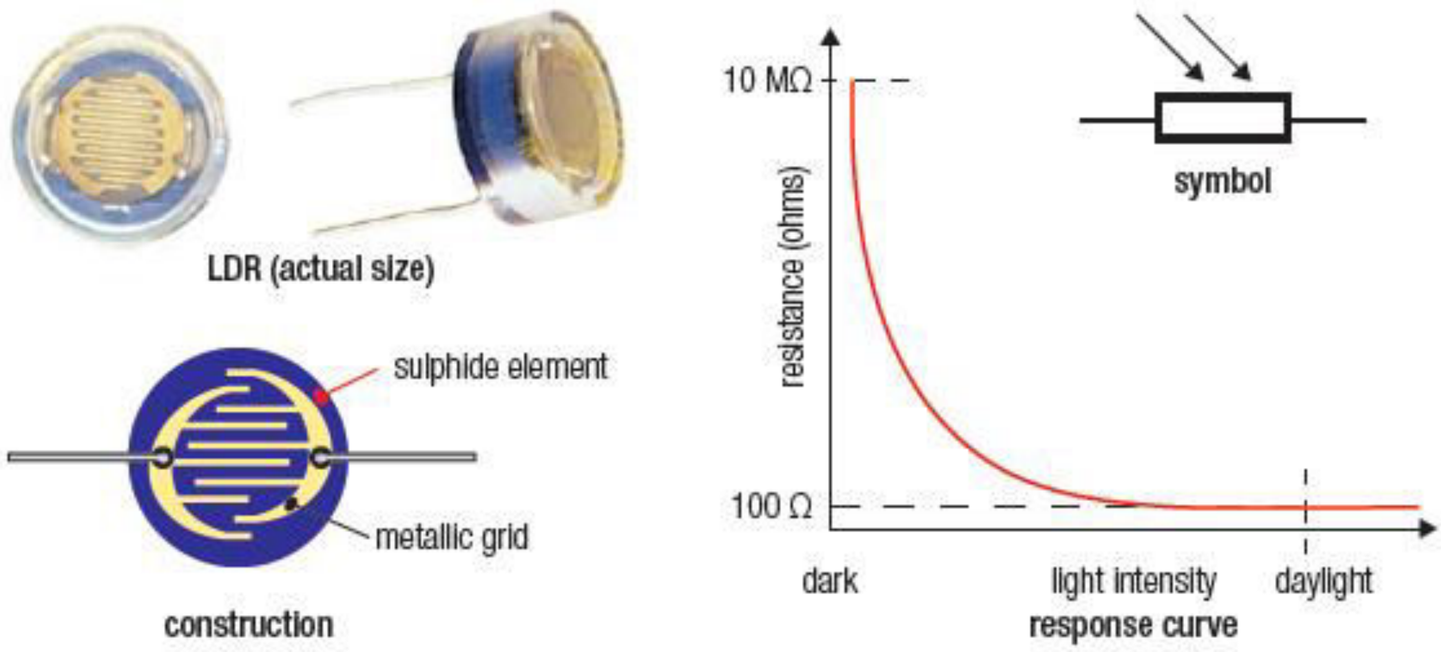
Typical LDR



The LDR symbol, construction and response curve

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Voltage-dependent resistors

Voltage-dependent resistors:

- are components that change resistance by a large amount when the voltage across the component exceeds its rated value
- have low power types known as VDRs or varistors which are used in surge protection circuits
- have high power types called surge arrestors and are used in lightning protection systems, in particular in substations.

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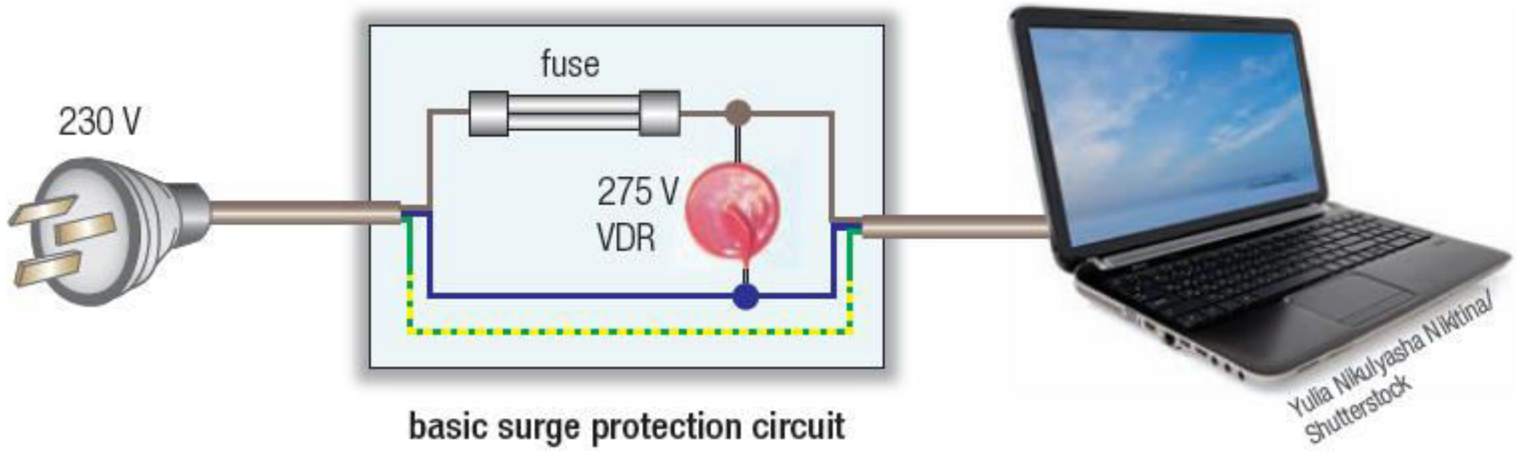
VDR protection circuit



The VDR is connected so a surge in the 230 V supply voltage causes a high current to flow, which ruptures the fuse

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Surge arrestors

Surge arrestors (diverters):

- are used to protect equipment against lightning strikes
- are used in electrical power generation and distribution, connected between power lines and a metal stake driven into the ground
- are similar in construction to a VDR except they are much larger and can absorb high amounts of energy.

ELECTRICAL PRINCIPLES

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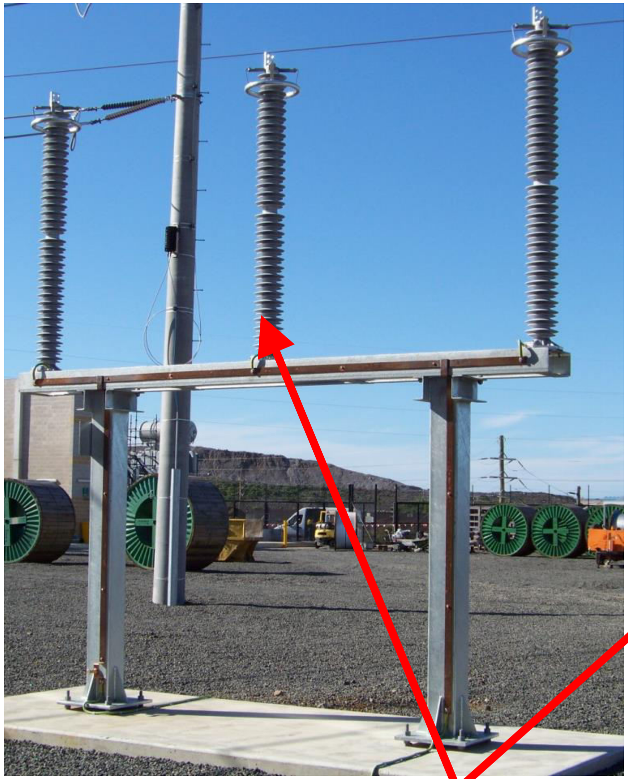
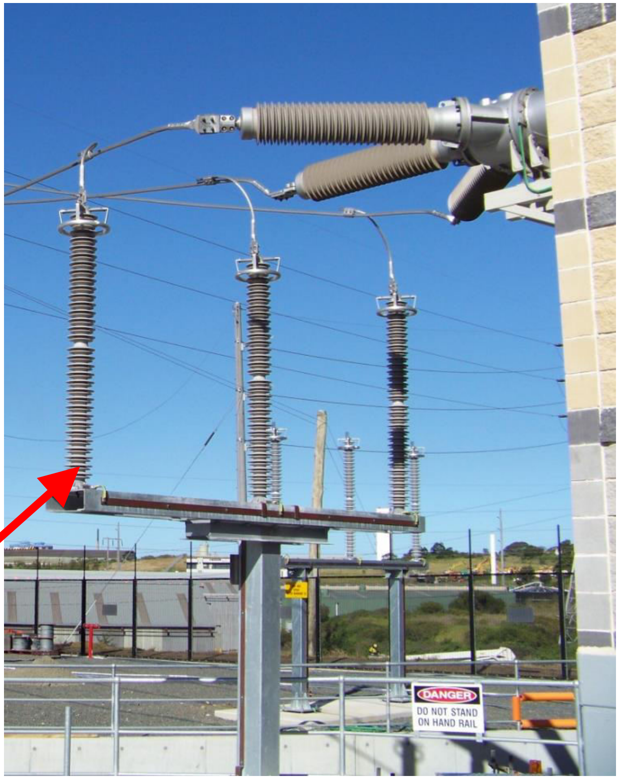
Surge arrestors in use





Surge arrestors are connected across incoming and outgoing high voltage lines

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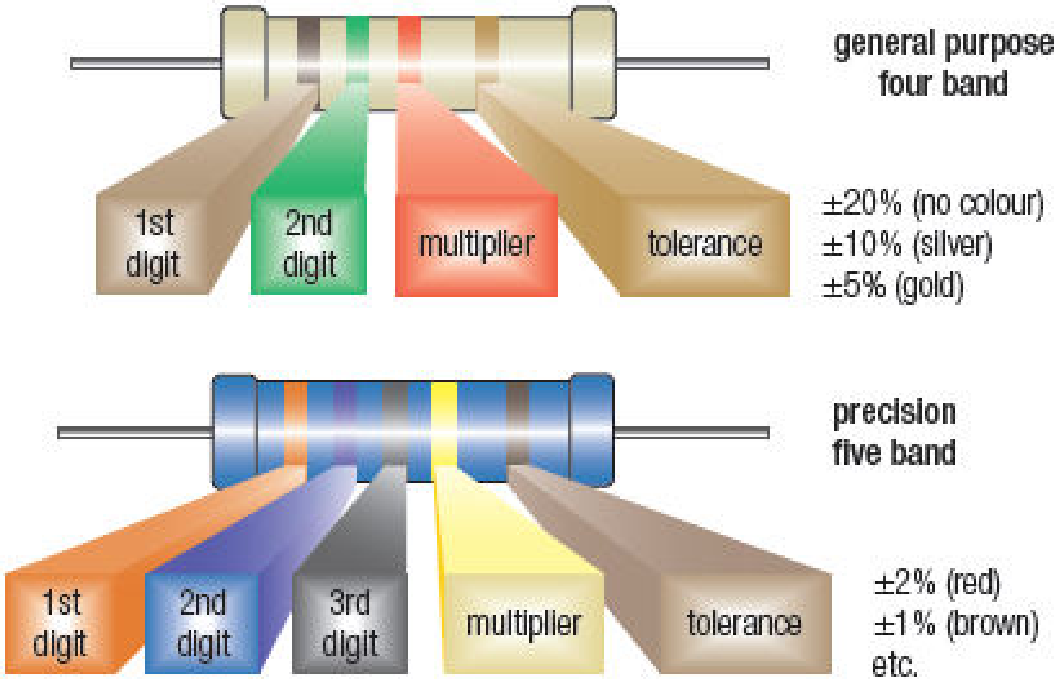
5.3 Resistor colour code



The resistance of small resistors is shown with four (or five) coloured bands

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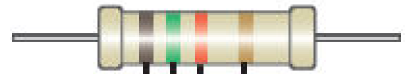
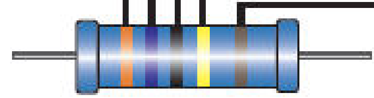
Colour code chart



colour	1st digit	2nd digit	3rd digit	multiplier	tolerance
black	0	0	0	× 1	
brown	1	1	1	× 10	± 1%
red	2	2	2	× 100	± 2%
orange	3	3	3	× 1 k	
yellow	4	4	4	× 10 k	
green	5	5	5	× 100 k	± 0.5%
blue	6	6	6	× 1 M	± 0.25%
violet	7	7	7	× 10 M	± 0.1%
grey	8	8	8		± 0.05%
white	9	9	9		
gold				× 0.1	± 5%
silver				× 0.01	± 10%



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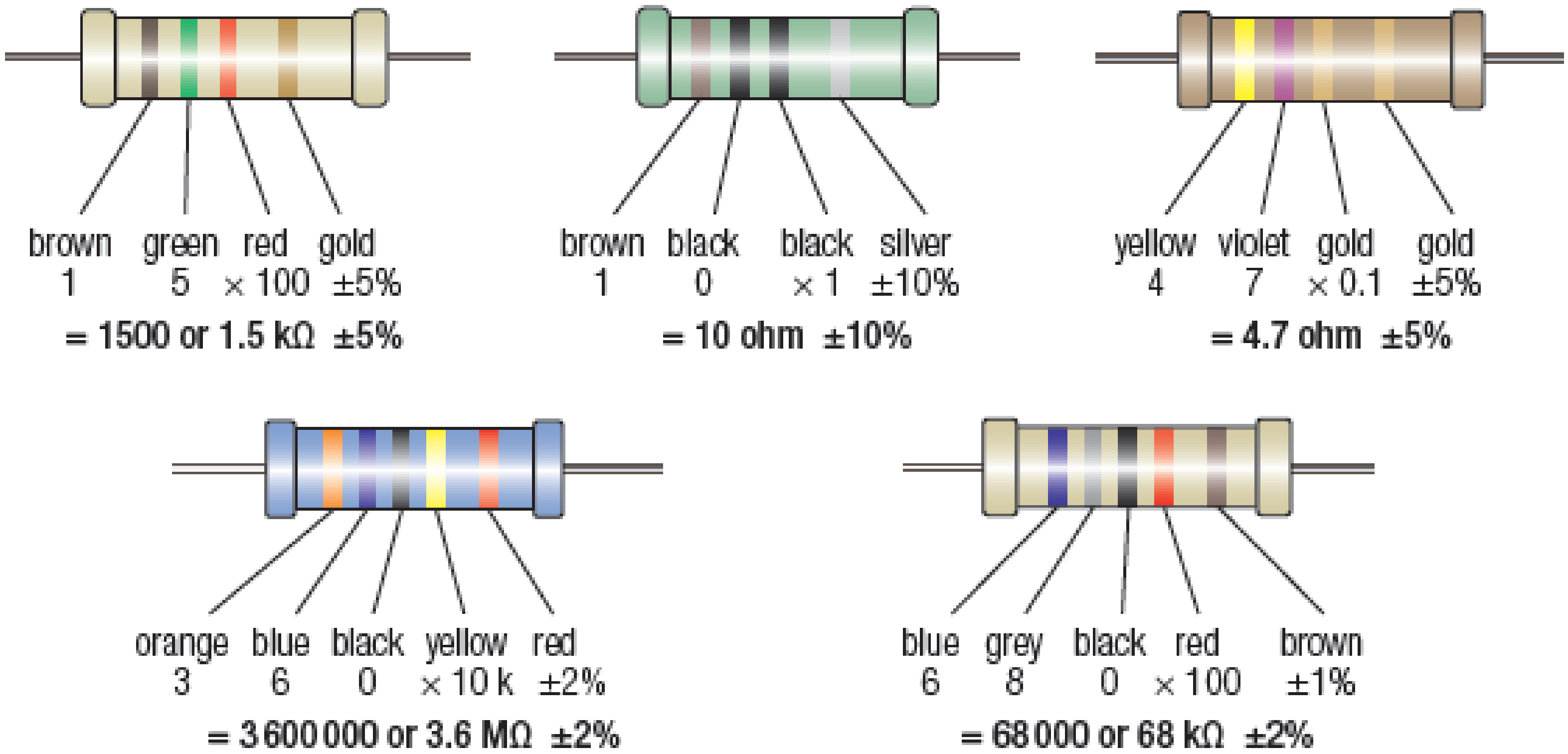
Example colour code values



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E12 preferred resistor values

E12 PREFERRED RESISTOR VALUES												
Decade	**Range of preferred values**											
× 0.01	0.01	0.012	0.015	0.018	0.02	0.027	0.033	0.039	0.047	0.056	0.068	0.082
× 0.1	0.1	0.12	0.15	0.18	0.22	0.27	0.33	0.39	0.47	0.56	0.68	0.82
× **1**	**1**	**1.2**	**1.5**	**1.8**	**2.2**	**2.7**	**3.3**	**3.9**	**4.7**	**5.6**	**6.8**	**8.2**
× 10	10	12	15	18	22	27	33	39	47	56	68	82
× 100	100	120	150	180	220	270	330	390	470	560	680	820
× 1 k	1 k	1.2 k	1.5 k	1.8 k	2.2 k	2.7 k	3.3 k	3.9 k	4.7 k	5.6 k	6.8 k	8.2 k
× 10 k	10 k	12 k	15 k	18 k	22 k	27 k	33 k	39 k	47 k	56 k	68 k	82 k
× 100 k	100 k	120 k	150 k	180 k	220 k	270 k	330 k	390 k	470 k	560 k	680 k	820 k
× 1 M	1 M	1.2 M	1.5 M	1.8 M	2.2 M	2.7 M	3.3 M	3.9 M	4.7 M	5.6 M	6.8 M	8.2 M
× 10 M	10 M	12 M	15 M	18 M	22 M	27 M	33 M	39 M	47 M	56 M	68 M	82 M

Commonly available range of resistors

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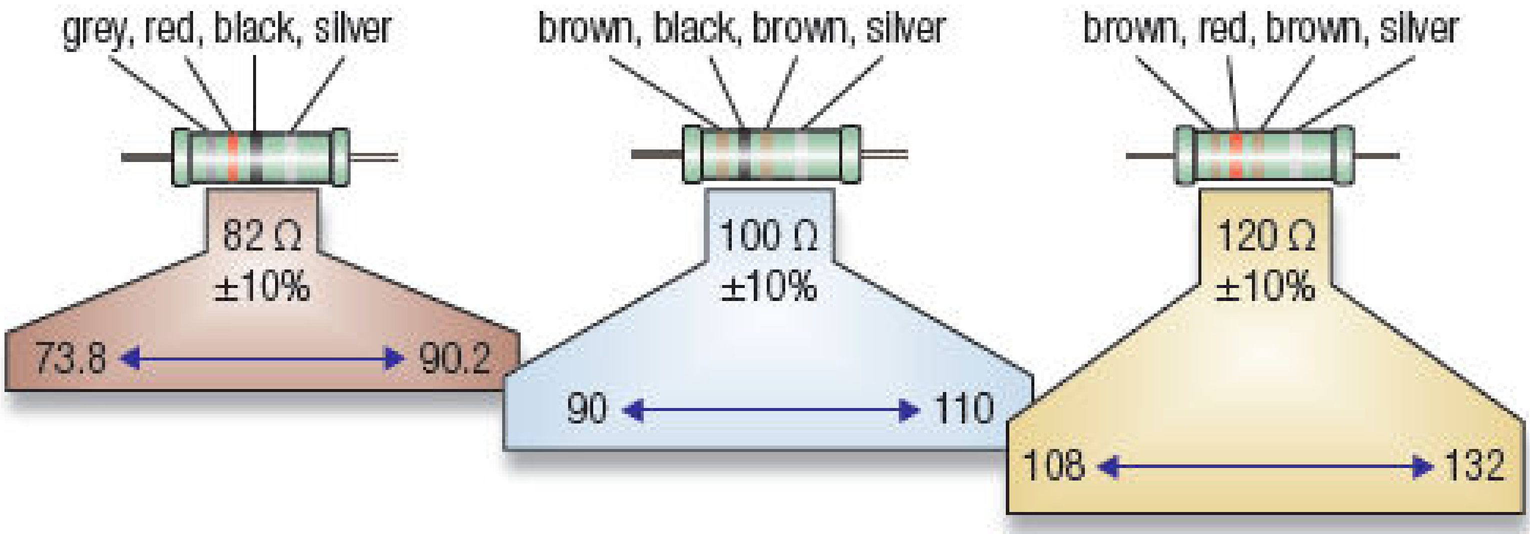
How the E12 range covers all values



The E12 resistor range is based on resistors with an accuracy of ±10%. These 10% tolerance resistors give all values from 73.8 ohm to 132 ohm.

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5.4 Measuring resistance

Resistance is measured with an ohmmeter, which is usually a function on a multimeter.

When measuring resistance:

- make sure there is no voltage present at the measurement points
- avoid touching either probe but particularly both probes.

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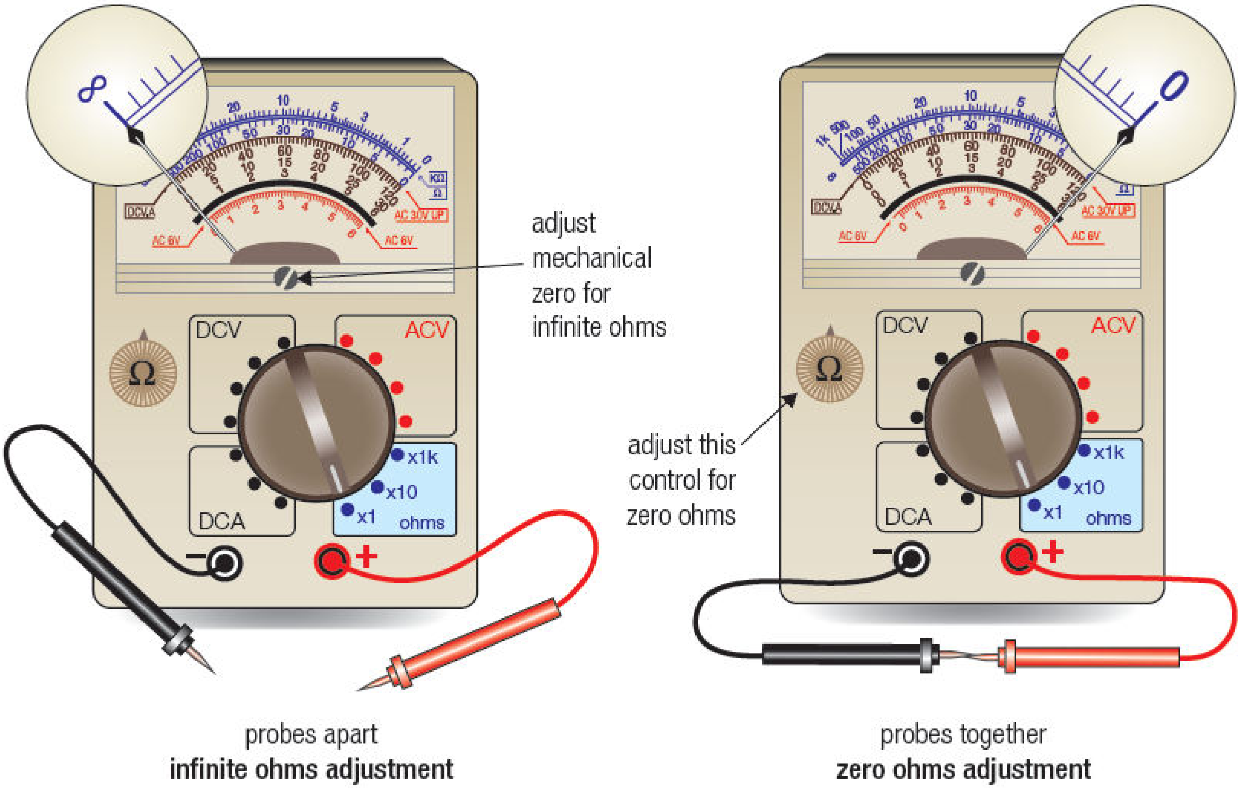
Analog ohmmeter



Adjusting mechanical zero

Adjusting for zero on scale

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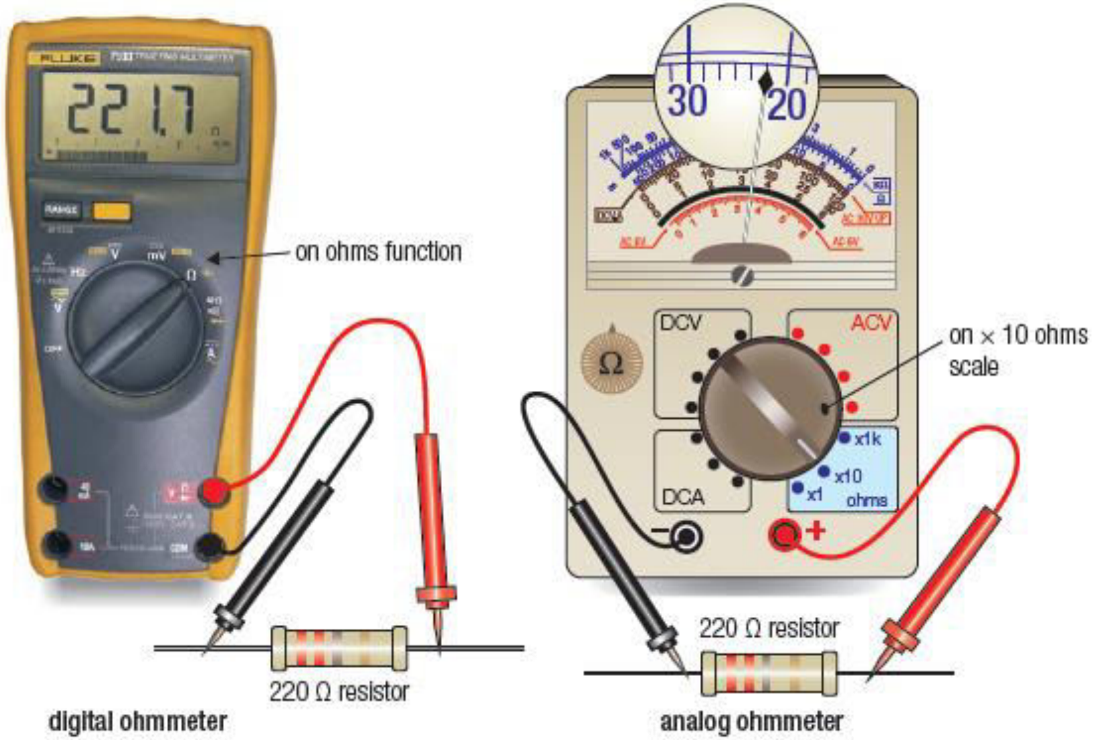
Using an ohmmeter



Analog and digital multimeters measuring the resistance of a 220 Ω resistor

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Chapter summary

Resistance of a conductor can be found with:

$$R = \frac{\rho l}{A}$$

where:

- R = resistance in ohms
- ρ = resistivity in ohm-metres
- l = length in metres
- A = cross-sectional area in square metres.

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Chapter summary (2)

- Conductors such as copper and aluminium have a positive temperature coefficient of 0.004, which means their resistance increases by 0.4 per cent per 1 ºC.
- Resistors are electrical components that range from large, metal grid units to surface mount devices. They are rated by their power and resistance values.

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Chapter summary (3)

- Low power resistors have their resistance identified with a colour code. The resistor colour code is based on the colour spectrum, but starting at black and ending at white.
- The tolerance of a resistor indicates the range of resistance values a resistor might actually have.
- Low power resistors are made in either the E12 or E24 ranges.

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Chapter summary (4)

- Components that change resistance due to an external influence include the variable resistor (mechanical force), LDR (light), thermistor (temperature) and the varistor (voltage).
- When using an ohmmeter, ensure the circuit is 'dead' and only touch one metal probe at a time.

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