8.Electromagnetism

Introduction

Magnets exist in two forms; 'permanent magnets' and 'electromagnets'.

Permanent magnets are manufactured from magnetic materials, which retain their magnetic properties for a long time after they are initially magnetised. Electromagnets are temporary magnets which are created when current flows through a coil of wire.

This topic will help you develop your understanding of magnetism and the properties of permanent magnets, magnetic field patterns and the laws of magnetism. You will learn about common magnetic and non-magnetic materials and the applications for permanent magnets.

Permanent Magnets

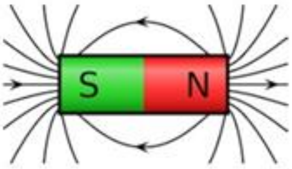
A magnet is any object which has the property of attracting magnetic substances to itself. This property of attracting in this way is called 'magnetism'.

A 'permanent magnet' is a magnet that retains its magnetism for a long period of time after having first been magnetised. By contrast a 'temporary magnet' loses practically all of its magnetism when the magnetising influence is removed.

Magnetic Flux

Magnetism creates a force of attraction or repulsion between magnetic materials. The magnetic force is carried by invisible magnetic field lines called magnetic 'flux' that surrounds all magnets.

All practical magnets have a 'north pole' and a 'south pole'. The magnetic lines of force extend outwards from the north pole and pass back into the south pole. Magnetic lines of force can be distorted by other magnetic fields, but they can never cross one another.



Magnetic Lines of Force

Properties of Magnetic Lines of Force – 'Flux'	
Magnetic lines of force – 'flux'	• they are completely closed curves • they have a definite direction – North to South • they may be distorted or bent to any shape (by other magnetic fields), but they never cross each other • they are perfectly elastic • they can extend to any length, or contract and vanish when the magnetising force is removed • they pass unaffected through any non-magnetic substance

Magnetic Field Patterns

The 'poles' are points near the ends of the magnet where the magnetic lines of force are concentrated. The magnetic field lines extend out from the 'north pole' and into the 'south pole'.

The magnetic field pattern is determined by the shape of the magnet.

Introduction

Many electrical machines and components operate through the principles of electromagnetism. This includes motors, generators, transformers, relays, contactors and electromagnetic brakes. When current flows through a conductor a magnetic field is created. This magnetic field creates a force which can attract and repel magnetic materials.

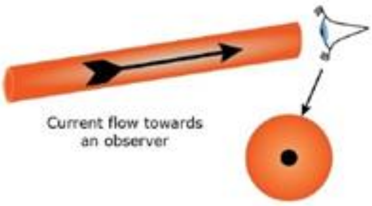
This topic will help you develop your understanding of electromagnetism, the magnetic field patterns surrounding current carrying conductors, the 'right hand rule', electromagnetic forces and applications for electromagnets.

Current Flow in a Conductor

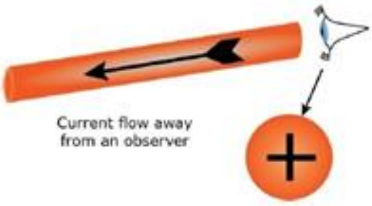
Current flow in a conductor creates a magnetic field around the conductor. The direction of the magnetic field is dependent on the direction of current through the conductor. By convention, we use an arrow to indicate the direction of current flow.

To determine the direction of the magnetic field around the conductor, you look along the conductor to see if the current is flowing towards or away from you.

Current flowing towards you will look like a 'dot', i.e. you see the point of the arrow coming towards you.

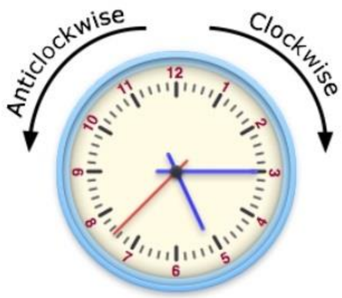


Current flowing away from you will look like a 'cross', i.e. you see the feathers of the arrow flying away from you.

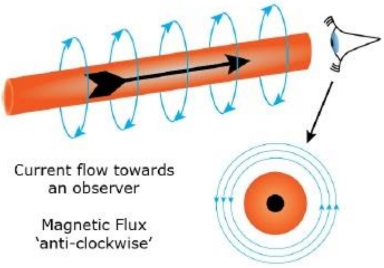


Magnetic Field Surrounding a Conductor

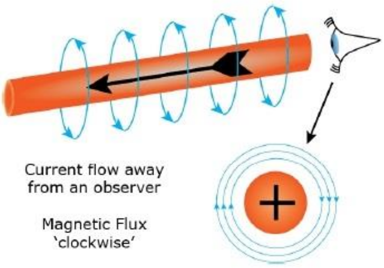
The magnetic field lines surrounding a conductor exist as an infinite number of concentric 'rings' around the conductor. These field lines either point in a 'clockwise' or 'anti-clockwise' direction depending on the direction of current.



The magnetic field lines surrounding a conductor with current flow towards an observer, will point in an anti-clockwise direction, as seen in this diagram.



The magnetic field lines surrounding a conductor with current flow away from an observer, will point in a clockwise direction, as seen in this diagram.



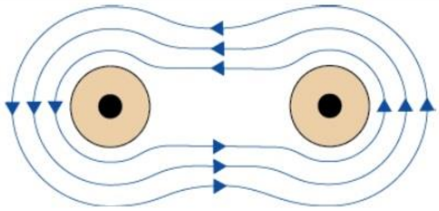
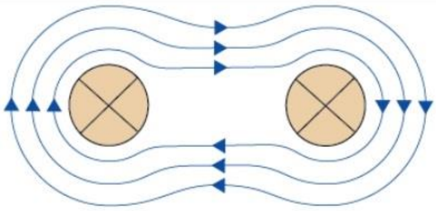
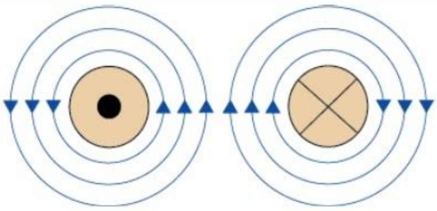
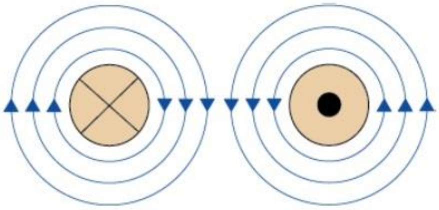
Right Hand Rule for Conductors

An easy way to determine the direction of the magnetic field is to use the 'right hand rule' for conductors.

1. Grasp the conductor in your right hand
2. Your thumb points in the direction of the current in the conductor
3. Your fingers point in the direction of the magnetic field surrounding the conductor

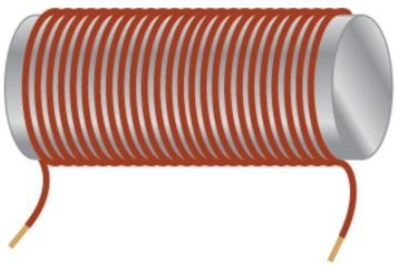
Magnetic Field Around Adjacent Conductors

When two adjacent conductors carry current, the magnetic fields around each conductor interact. When the magnetic fields are in the same direction, the field lines link up to form a stronger magnetic field. When the magnetic fields are in the opposite direction, the field lines do not link up.

Magnetic Fields Around Adjacent Conductors	
Currents in the same direction **Magnetic field lines link up**	
	
Current in the opposite direction **Magnetic field lines DO NOT link up**	
	

Solenoid

A solenoid is created when several turns of insulated conductor are wound around a 'former' into a coil.



Solenoid

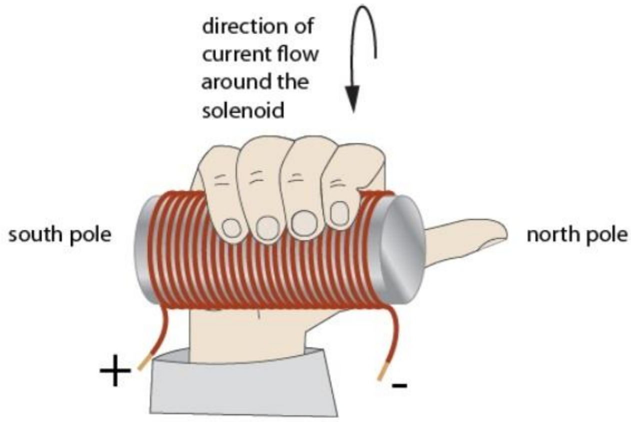
Right Hand Rule for a Solenoid

When current flows through the solenoid, a magnetic field is set up around each individual 'turn' of the coil. These individual magnetic fields join together to create one 'strong' electromagnet.

The direction of the magnetic field surrounding the solenoid is determined by applying the 'right hand rule' for solenoids.

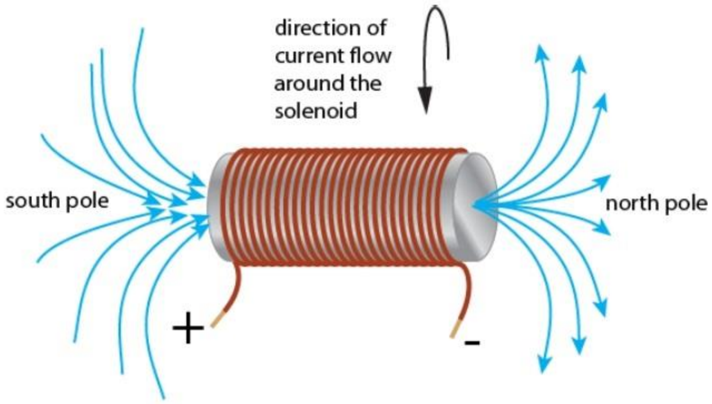
1. Grasp the solenoid in your right hand

2. Your fingers point in the direction of the current around the solenoid
3. Your thumb points in the direction of the north pole of the solenoid

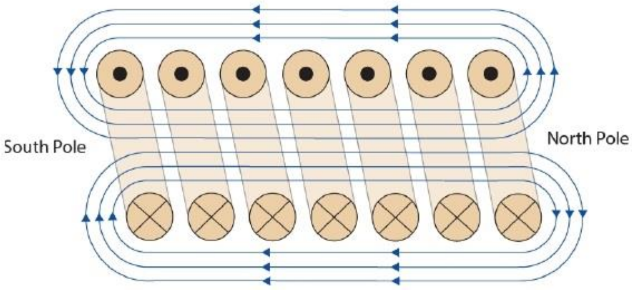


Magnetic Field Surrounding a Solenoid

The magnetic field pattern around a solenoid carrying current is the same as that around a bar magnet. The magnetic flux extends out from the north pole and into the south pole.



To illustrate why this occurs, consider the cross-section of a solenoid, as shown below, as well as what you have learnt about magnetic fields around current carrying conductors.



Magnetomotive Force (Fm)

When current flows in a solenoid a magnetomotive force (Fm) is created. The magnetomotive force is the magnetising force (magnetic pressure) that causes the magnetic flux to flow out of the north pole of the electromagnet and into the south pole.

Fm is the product of the current (I), in amperes, and the number of turns (N) of the coil. The unit of magnetomotive force is the ampere-turn (At).

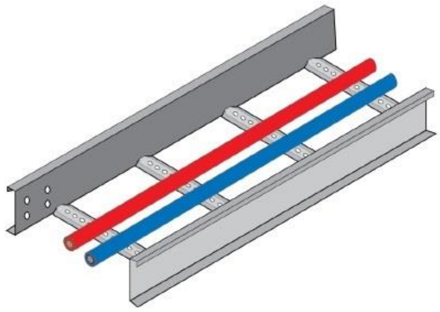
$$\text{m.m.f.} = IN$$

Where:

Electromagnetic Forces

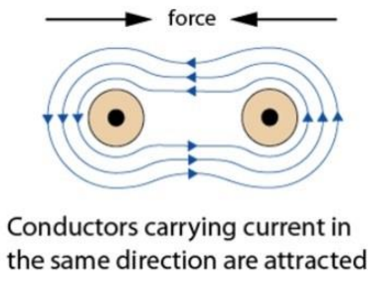
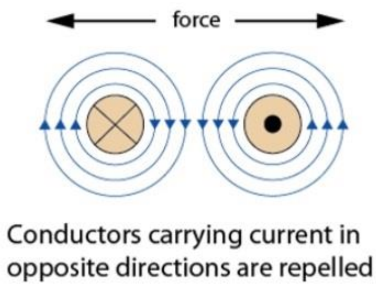
Electromagnetic forces exist between any two current carrying conductors installed in close proximity. Conductors laid together on cable trays, inside switchboards and clipped to walls must be securely fixed to ensure they do not move when energised. The higher the current the greater the force between the conductors.

Under normal conditions, bus bars installed inside a large switchboard can carry hundreds of amperes. Under fault conditions, such as a short circuit, thousands of amperes can flow, creating extremely large electromagnetic forces which can severely distort the bus bars, and cause a great deal of damage to a switchboard. To prevent movement and distortion, the bus bars must be securely bolted in position.



Direction of Force Between Current Carrying Conductors

The direction of the force between two conductors is dependent on the direction of current in each conductor. The conductors are either attracted to or repelled from each other. Either way, the conductors can move if they are not securely fixed.

<table>
<tr><th colspan="3">Direction of Force Between Current Carrying Conductors</th></tr>
<tr><td>Current in the same direction
'Attracted'</td><td>
</td><td>• Magnetic lines of force link up to encircle the two conductors
• Conductors are **attracted** to each other</td></tr>
<tr><td>Current in the opposite direction
'Repelled'</td><td>
</td><td>• Magnetic lines of force between conductors do not link up
• Conductors are **repelled** from each other</td></tr>
</table>

Calculating Force

The force between current carrying conductors is directly proportional to the current in each conductor and inversely proportional to the distance between them. The force is calculated from the following equation.

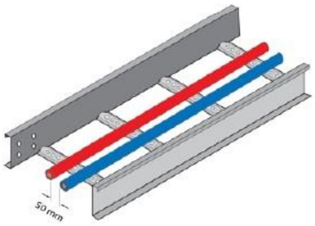
$$F = \frac{(2 \times 10^{-7})\, I_1 I_2}{d}$$

Where:

- F = force between two conductors (newtons per metre length)
- I_1 = current in conductor 1 (A)
- I_2 = current in conductor 2 (A)
- d = distance between the two conductors (m)

Worked Example – Calculating force on current carrying conductors 1

Calculate the force acting between two conductors separated by a distance of 50 mm. The current in each conductor is 100 amperes.



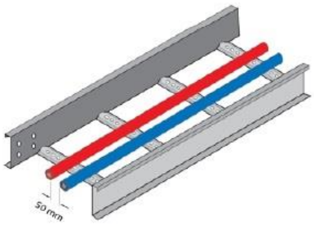
$$F = \frac{(2 \times 10^{-7})\, I_1\, I_2}{d}$$

$$F = \frac{(2 \times 10^{-7}) \times 100 \times 100}{0.05}$$

$$\underline{F = 0.04\ N/m}$$

Worked Example – Calculating force on current carrying conductors 2

What is the force acting on the two conductors, in newtons per metre, when the current in conductor 1 is 850 amperes and the current in conductor 2 is 625 amperes in the opposite direction?



$$F = \frac{(2 \times 10^{-7})\, I_1\, I_2}{d}$$

$$F = \frac{(2 \times 10^{-7}) \times 850 \times 625}{0.05}$$

$$\underline{F = 2.13\ N/m}$$

Introduction

Electromagnetic devices are designed for efficient and reliable operation. Their operation depends in part on the quality of the magnetic materials used in their manufacture.

High quality materials and good design of the magnetic circuit reduces electrical and magnetic 'losses', therefore reducing energy usage.

This topic will help you develop your understanding of the magnetic terms used to describe the properties of magnetic materials, magnetic and electrical losses and the common magnetic circuit types.

Magnetic and Electric Circuits

A magnetic circuit can be compared to an electric circuit.

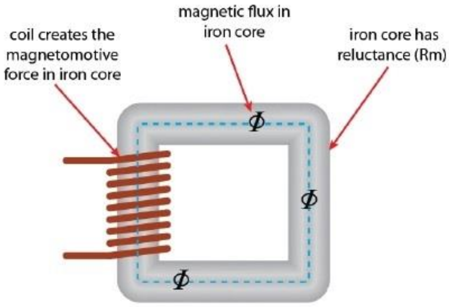
In an electric circuit an electromotive force (e.m.f.) causes current (I) to flow in the circuit. The opposition to current is called resistance (R).

In a magnetic circuit, a magnetomotive force (Fm) causes magnetic flux (Φ) to be established in the magnetic circuit. The opposition to the magnetic flux is called 'reluctance' (Rm).

The comparison is shown in this table.

Comparison between Magnetic and Electric Circuits		
Term	**Magnetic Circuit**	**Electric Circuit**
Pressure/Force	Magnetomotive Force (Fm)	Electromotive Force (e.m.f.)
Flow	Magnetic Flux (Φ)	Current (I)
Opposition	Reluctance (Rm)	Resistance (R)

In the iron cored magnetic circuit the coil creates the magnetomotive force (Fm) that causes the flux (Φ) to be established in the iron core. The iron core has some reluctance (Rm), which opposes the magnetic flux.



Magnetic Flux

Magnetic flux is the invisible lines of magnetic force that pass through all materials.

Magnetic flux can be calculated if the magnetomotive force and the reluctance of the magnetic circuit are known.

The unit of magnetic flux is the weber (Wb). The symbol is Φ (the Greek letter phi).

$$\Phi = \frac{Fm}{Rm}$$

Where:

- Φ = magnetic flux in weber (Wb)
- Fm = magnetomotive force in ampere-turns (At)
- Rm = reluctance in ampere-turns per weber (At/Wb)

Worked Example – Calculating magnetic flux

Calculate the flux established in a magnetic circuit when the magnetomotive force is 900 At and the reluctance is 18,500 At/Wb.

$$\Phi = \frac{Fm}{Rm}$$

$$\Phi = \frac{900}{18500}$$

$$\underline{\Phi = 48.65 \text{ mWb}}$$

Worked Example – Calculating reluctance

What is the reluctance of a magnetic circuit, if a magnetic flux of 85 mWb is established when a magnetomotive force of 1200 At is applied?

$$Rm = \frac{Fm}{\Phi}$$

$$Rm = \frac{1200}{(85\ x\ 10^{-3})}$$

$$\underline{Rm = 14{,}118\ At/Wb}$$

Worked Example – Calculating magnetomotive force

What magnetomotive force is needed to establish a magnetic flux of 54 mWb if the reluctance of the magnetic circuit is 12,600 At/Wb?

$$Fm = \Phi\ x\ Rm$$

$$Fm = (54\ x\ 10^{-3})\ x\ 12600$$

$$\underline{Fm = 680.4\ At}$$

Reluctance

Reluctance (Rm) is the opposition to the establishment of magnetic flux in a magnetic circuit. Reluctance is a property of the material in the magnetic circuit, which may consist of both magnetic and non-magnetic materials.

Low reluctance magnetic circuits, such as alloys of ferromagnetic materials are good 'conductors' of magnetic flux.

High reluctance magnetic circuits, such as paramagnetic and diamagnetic materials are poor conductors of magnetic flux.

The unit of reluctance is the ampere-turns per weber (At/Wb). The symbol for reluctance is Rm.

Permeability

The 'Permeability' of a material is the ease with which it allows magnetic flux to be established. Materials with a high permeability have a low reluctance, and vice versa.

Ferromagnetic materials have higher permeability than non-magnetic (paramagnetic/diamagnetic) materials. Generally electromagnetic machines and devices are manufactured from high permeability ferromagnetic materials.

The unit of permeability is henrys per metre (Hm^{-1}). The symbol is μ (Greek letter mu).

The symbol μ represents the 'actual permeability', which can be calculated from the 'relative permeability' (μ_r) of a material and the permeability of 'free space' (μ_O).

We use the permeability of free space (effectively the vacuum of space) as a reference point for permeability. The relative permeability of a material indicates how permeable it is *compared to free space*. For example, if silicon steel has a relative permeability of 40,000, it means silicon steel is 40,000 times as permeable as free space.

Permeability		
Actual Permeability	μ	The actual permeability of a magnetic circuit depends on • Type of material in the magnetic circuit
Relative Permeability	μ_r	The permeability of the material compared to free space Examples: • Air = 1 • Carbon steel = 100 • Silicon steel = 40,000 • Iron = 200,000 (all non-magnetic materials have a relative permeability of approximately 1)
Permeability of Free Space (absolute permeability)	μ_O	S.I. unit of the permeability of free space, $4\pi \times 10^{-7}$ in henrys per metre (Hm^{-1})

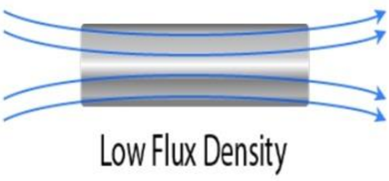
$$\mu = \mu_r \mu_o$$

Where:

- μ = actual permeability of a material in henrys per metre (Hm^{-1})
- μ_r = relative permeability of the material
- μ_O = permeability of free space ($4\pi \times 10^{-7}$)

Flux Density

Flux density represents the amount of flux concentrated within the cross-sectional area of a magnetic circuit.



Flux density can be calculated if the flux and the cross-sectional area of the magnetic circuit are known.

The unit of flux density is the tesla (T). The symbol is B.

$$B = \frac{\Phi}{A}$$

Where:

- B = flux density in tesla (T)
- Φ = magnetic flux in weber (Wb)
- A = cross-sectional area in metres squared (m^2)

Worked Example – Calculating flux density 1

Calculate the flux density in a magnetic circuit having a cross-sectional area of 850 mm^2, if the total flux is 1.5 mWb.

$$B = \frac{\Phi}{A}$$

$$B = \frac{(1.5 \; x \; 10^{-3})}{(850 \; x \; 10^{-6})}$$

$$\underline{B = 1.76\,T}$$

Worked Example – Calculating flux density 2

What is the flux density in an iron circuit with a cross-sectional area of 1,650 mm^2 and a flux of 350 mWb?

$$B = \frac{\Phi}{A}$$

$$B = \frac{(350 \; x \; 10^{-3})}{(1650 \; x \; 10^{-6})}$$

$$\underline{B = 212.12\,T}$$

Magnetising Force

The magnetising force (H) in a magnetic circuit is the magnetomotive force per unit length of the magnetic circuit. The magnetising force is an important parameter in the design of electromagnetic machines.

The magnetising force can be calculated if the magnetomotive force and the length of the magnetic circuit are known.

The unit of magnetising force is the ampere-turn per metre (At/m). The symbol is H.

$$H = \frac{Fm}{l}$$

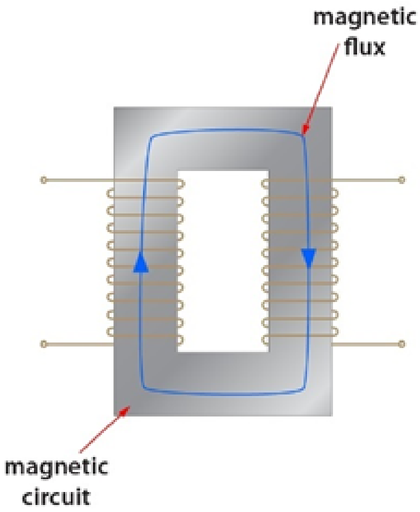
Where:

- H = magnetising force in ampere-turns per metre (At/m)
- Fm = magnetomotive force in ampere-turns (At)
- l = length of magnetic circuit in metres (m)

Magnetic Circuit Types

Magnetic circuits are constructed in a variety of configurations. They may be a type that does not produce any motion, such as a transformer, or they may produce a linear motion or rotary motion when the coil is energised.

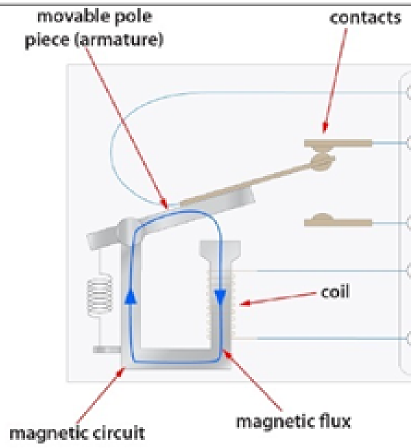
Transformer Type



Linear Motion Type

Two examples of a magnetic circuit that creates linear type motion are relays and contactors.

Both operate when a coil is energised to attract a movable magnetic piece attached to electrical contacts.

Linear Motion Type	
Relay	

Introduction

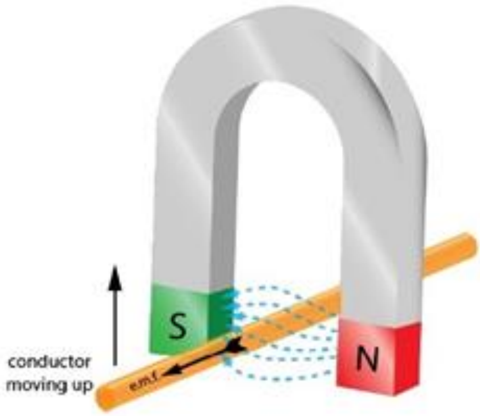
Coal and gas fired power stations, wind generators and transformers rely on electromagnetic induction for the generation, transmission and distribution of electricity. Several other devices operate through the same principles, which is that when relative motion exists between a conductor and a magnetic field, a voltage will be induced into the conductor.

This topic will help you develop your understanding of electromagnetic induction principles, Faraday's law of electromagnetic induction, Fleming's right hand rule, Lenz's law and the applications for electromagnetic induction.

Electromagnetic Induction

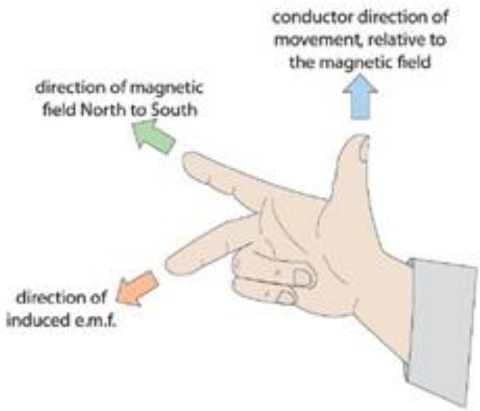
When a conductor moves through magnetic lines of force, a voltage is induced into the conductor. This is called 'electromagnetic induction'. The direction of the induced e.m.f. depends on the direction of the magnetic field, and the direction of relative movement between the conductor and the magnetic field.

In this diagram the conductor is moving up, and the direction of the induced e.m.f. is towards you.



Fleming's Right Hand Rule

Use 'Fleming's right hand rule' to determine the direction of the induced e.m.f.



Fleming's Right Hand Rule	
Thumb	• Points in the direction of the conductor moving relative to the magnetic field
First Finger	• Points in the direction of the magnetic field from north to south
Middle Finger	• Points in the direction of the induced e.m.f. in the conductor*

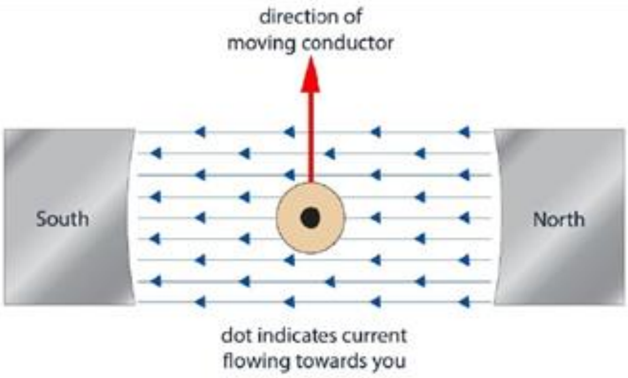
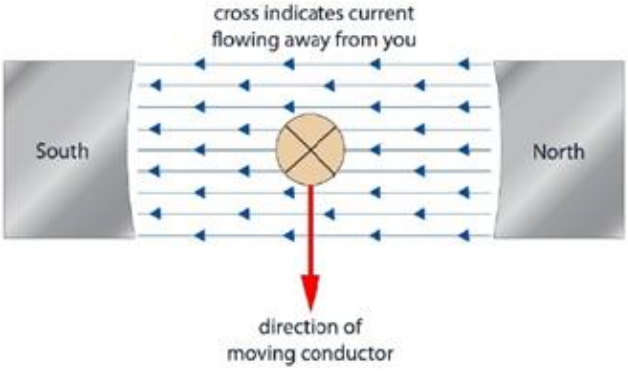
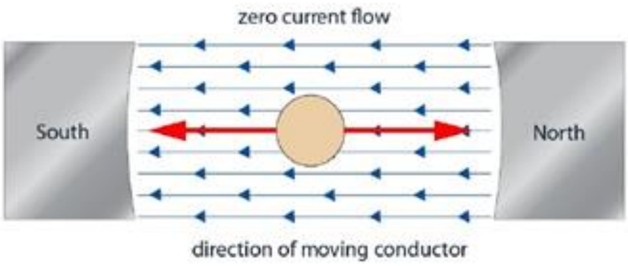
**Note: If the conductor is connected into a circuit, then the middle finger will also indicate the direction of the current flow.*

Faraday's Law of Electromagnetic Induction

Faraday's Law states:

"When relative motion exists between a conductor and a magnetic field, such that flux-linkages occur between them, an e.m.f. is induced which is proportional to the rate of change of flux linkages."

Conductors moving at *right angles* to a magnetic field will have the maximum induced e.m.f. Conductors moving *parallel* with a magnetic field will have zero induced e.m.f.

Conductors Moving Through Magnetic Fields	
Moving at right angles **Maximum e.m.f. induced**	
	
Moving parallel **Zero e.m.f. induced**	

$$F = BlI$$

Where:

- F = force on the conductor in newtons (N)
- B = flux density in tesla (T)
- l = length of conductor in the magnetic field in metres (m)
- I = current in the conductor in amperes (A)

Worked Example – calculating force on a current carrying conductor

Calculate the force acting on a 300 mm length of conductor carrying 5.2 A in a magnetic field with flux density of 1.4 T.

$$F = BlI$$

$$F = 1.4 \times 300 \times 10^{-3} \times 5.2$$

$$\underline{F = 2.18\ newtons}$$

Check your understanding of the content by clicking on the link below then undertaking the activity.

Load the Activity

Lenz's Law

Lenz's law states:

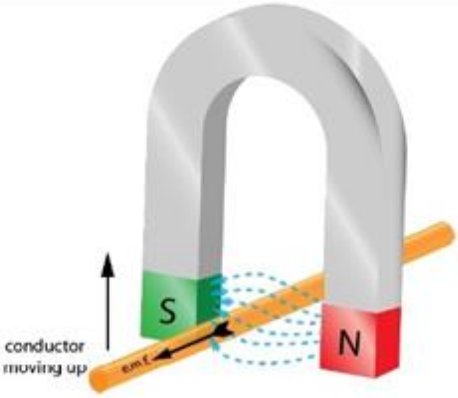
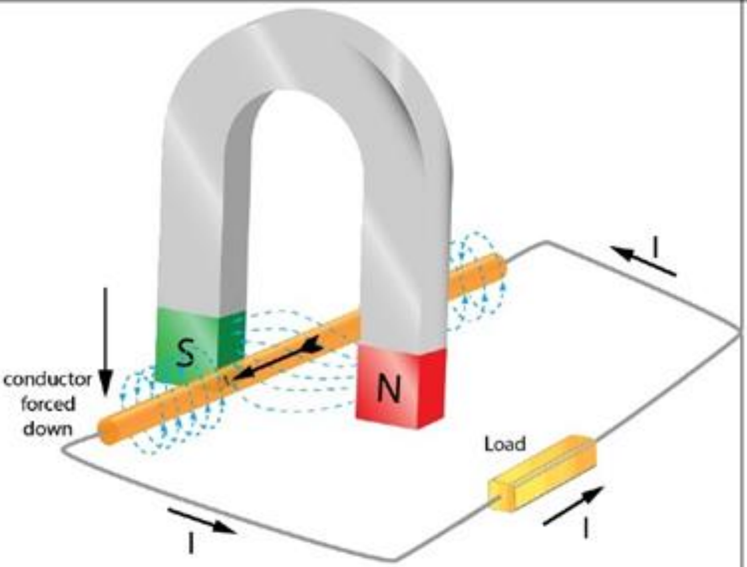
"The current due to an induced e.m.f. is in such a direction that its reaction tends to stop the motion or change which causes the induced E.M.F."

Lenz's law is evident in generators. Consider that a generator consists of a coil of wire being physically rotated in a magnetic field – we will call this field the 'main field'. Due to the relative movement between the coil and the main field, an e.m.f. is induced into the coil of wire.

When current starts flowing through the coil and out to the load, an interesting thing happens – the current flow in the coil creates a magnetic field of its own which is opposite in polarity to the main field!

The result is that when the generator is operating and supplying current, the generator tends to slow down.

You will explore the subject of d.c motors and generators in greater depth in the unit UEEEL0019.

Lenz's Law	
	• An e.m.f. is induced into the conductor as it is pushed up through the magnetic field • The direction of the e.m.f. in the conductor is determined by Fleming's right hand rule
	• When the conductor is connected into a circuit, current flows • The direction of the current in the conductor creates a magnetic field with an anti-clockwise rotation surrounding the conductor (right hand conductor rule) • The interaction between the two magnetic fields creates a downwards force on the conductor • The downwards force opposes the upwards force creating the e.m.f. in the first place • This is Lenz's law

Introduction

Inductance is one of the three (3) fundamental properties of electric circuits, along with resistance and capacitance. Some electrical machines and devices rely on inductance for their operation. Others are designed with as little inductance as possible. Inductance is present to some degree in every current carrying conductor.

This topic will help you develop your understanding of the property of inductance, inductors, self- and mutual-inductance and L-R time constants.

Inductors

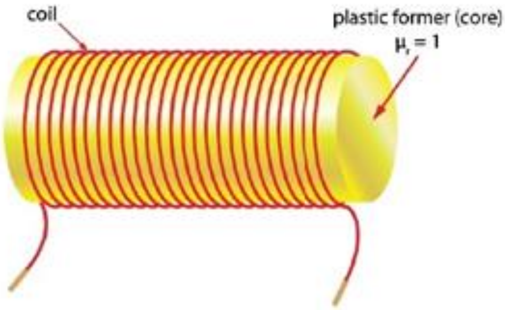
An 'inductor' is a device or component that has the property of 'inductance'. Inductance is the property of a conductor that opposes a change in current flow.

Inductors are made by winding a conductor around a core or former to create a coil.

Air cored Inductor

An 'air cored' inductor has several turns of conductor wound around a plastic former or other non-magnetic material. It is called an air cored inductor because the core has a relative permeability, $\mu_r = 1$, which is the same as air.

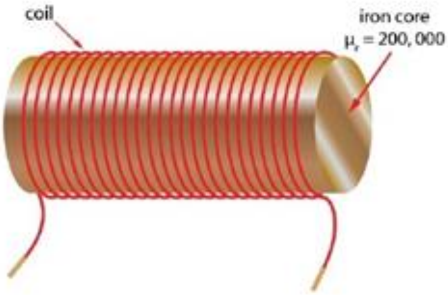
Its inductance is relatively low.



Iron cored Inductor

When the former is replaced with an iron core, the inductance is greatly increased due to the increased permeability of the ferromagnetic material. Iron has a relative permeability, $\mu_r = 200{,}000$.

An iron cored inductor has a relatively high value of inductance.



Australian Standard Inductor Symbols

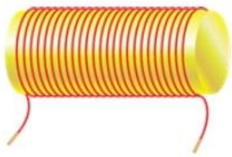
There are five (5) basic types of inductors used in electric circuits, each having an Australian Standard symbol for use in electrical drawings.

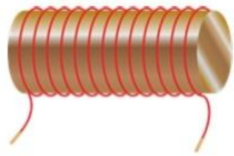
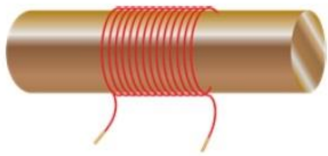
	Australian Standard Inductor Symbols		
Type	**Symbol**	**Construction**	**Applications**
Air cored inductor		• Non-magnetic core • Permeability same as air • Very low inductance • Used where high speed and low inductance required	• Used where high speed and low inductance required
Iron cored inductor		• Ferromagnetic core • Very high inductance • Used where low speed, high inductance required	• Used where low speed, high inductance required
Variable iron cored inductor		• Ferromagnetic core • Inductance can be varied	
Ferrite cored inductor		• Ferrite core - manufactured from iron powder mixed from bonding material • Can be molded into specific shapes • High Inductance • Used where moderate to high speed operation required • Such as radio tuning circuits and radio transmitters	• Used where moderate to high speed operation required • Such as radio tuning circuits and radio transmitters
Variable ferrite cored inductor		• Ferrite core • Inductance can be varied	

Physical Parameters Affecting Inductance

The inductance of an inductor is determined by its physical dimensions and the permeability of the core material.

This table shows the parameters that affect the inductance of an inductor.

Factors Affecting Inductance		
Parameter	**High Inductance**	**Low Inductance**
Permeability of core material	 Iron Core	 Air Core
Cross sectional area of the core	 Large CSA	 Small CSA

Number of Turns in the coil	 Many turns	 Few turns
Length of core	 Short core	 Long core

Calculating Inductance

Based on its physical parameters, the inductance of a coil can be calculated using this equation.

The unit for inductance is the henry (H). The symbol is L.

$$L = \frac{N^2 \mu_r \mu_O A}{l}$$

Where:

- L = inductance in henrys (H)
- N = number of turns on the coil
- μ_r = relative permeability of the core material
- μ_O = absolute permeability ($4\pi \times 10^{-7}$)
- A = cross-sectional area of the of the core in square metres (m^2)
- *l* = length of core in meters (m)

Note: this equation is for explanatory purposes only. You will not be required to calculate inductance using this equation in this Unit.

Applications for Inductors

This table provides some examples of the typical applications for inductors.

Applications For Inductors	
Ballast	• Found in some discharge lighting control circuits, such as fluorescent lighting
Choke	• An inductor used to present a relatively high opposition to a.c.
Line Reactor	• Air cored inductor of relatively low inductance • Used to limit short circuit currents to safe values • Found in power stations and sub stations
Transformer	• Used to transform voltage from one level to another level • Commonly found in electrical appliances, lighting circuits, and transmission and distribution networks
Low pass filter	• Filter for low frequencies in electronic circuits

Inductance

The effect of inductance is to induce a voltage into any nearby conductors when the current in a circuit changes.

When the current changes, the magnetic field around the conductors change, thereby inducing a voltage into adjacent conductors by electromagnetic induction.

The conductor can be in the same circuit or in another circuit.

By definition, an inductor is said to have an inductance of 1 henry, if 1 volt is induced when the current in it is changing at the rate of 1 ampere per second.

Voltage Induced into a Coil

The voltage induced into a coil can be calculated if the inductance of coil and the rate of change of current in the coil are known, as shown by this equation.

$$V = L\,\frac{\Delta I}{\Delta t}$$

Where:

- V = voltage induced into a coil (volts)
- L = inductance of the coil in henrys (H)
- ΔI = change in current in amperes (A)
- Δt = change in time in seconds (s)

Worked Example – Calculating voltage induced into a coil

Calculate the voltage induced into a coil with an inductance of 1.2 H when the current flowing in it is reduced from 4.5 A to 1 A in 450 ms.

$$V = L\,\frac{\Delta I}{\Delta t}$$

$$V = 1.2 \text{ x} \left(\frac{4.5 - 1.0}{0.45 - 0}\right)$$

$$V = 1.2 \text{ x} \left(\frac{3.5}{0.45}\right)$$

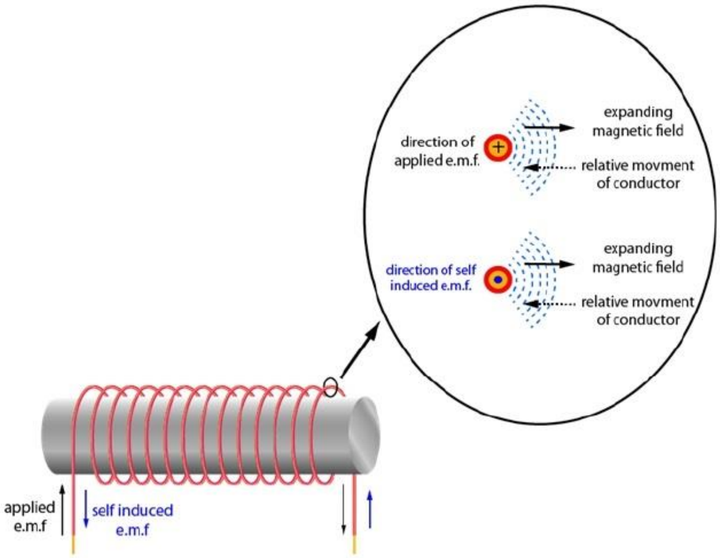
$$\underline{V = 9.33\ volts}$$

Self Induction

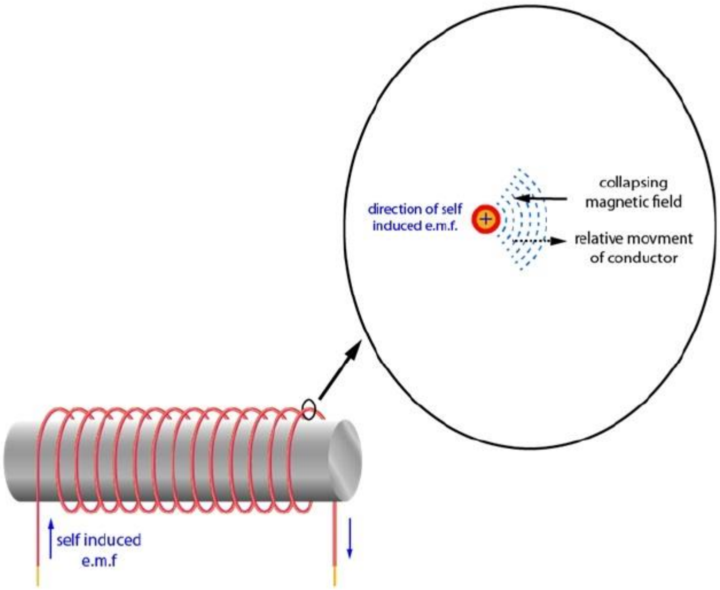
Self induction occurs when a conductor or coil has an e.m.f. induced into itself by its own changing magnetic field. The e.m.f. induced in the conductor or coil is called an e.m.f. of 'self induction'. This is sometimes referred to as the 'back e.m.f.' of a coil, because the self-induced e.m.f. opposes the applied e.m.f. that created it (in accordance with Lenz's Law).

This diagram shows the directions of the applied e.m.f. and the self induced e.m.f. in one turn of a coil.

When the e.m.f. is first applied, the direction of current through the coil creates an expanding magnetic field around each turn of the coil. This expanding field is 'moving' relative to the stationary conductors of the coil. Because it is expanding (moving) it induces an e.m.f. into its own coils in the opposite direction to the applied e.m.f.



When the applied e.m.f. is switched off, the magnetic field around each conductor collapses in on itself. This collapsing magnetic field is again moving relative to the stationary conductors of the coil, however, it is now in the opposite direction. The self induced e.m.f. is now in the same direction as the original applied e.m.f. that created the magnetic field in the first place.



Hazards of Self Induced E.M.F.

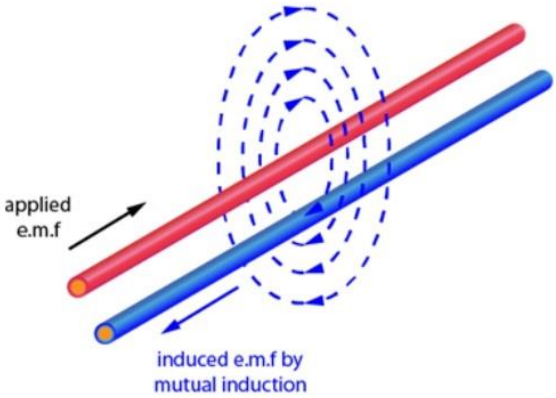
When large coils with high inductance are switched off, dangerously high voltages can be induced into the coil through self inductance. This has the potential to cause electric shocks.

This effect can be seen as an arc at the contacts of switches controlling large inductance coils such as electromagnetic brakes and d.c. motor field coils. This arc is caused by the back e.m.f. of the coils generated when the current is switched off.

Mutual Induction

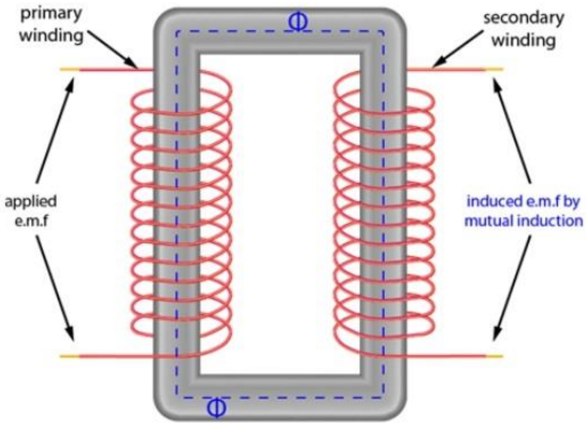
Mutual induction can occur between two conductors in close proximity, when a changing current in one conductor induces a voltage into an adjacent conductor.

In this diagram the red conductor is carrying current due to the applied e.m.f. This creates a changing magnetic field around both conductors. The blue conductor has an e.m.f. induced into it through the mutual inductance between the two conductors.



Mutual induction also occurs between two coils that are in close proximity, where the magnetic field created by one coil is coupled to a second coil, such as the two windings of a transformer.

In this diagram the applied voltage creates a magnetic field around the primary winding. The secondary winding has a voltage induced into it by mutual induction.



Hazards of Mutual Induction

When cables are laid together in a low voltage installation, mutual induction can cause hazardous voltages to be induced into adjacent cables. This is particularly dangerous when a circuit has been correctly isolated and locked out. The expectation is for the isolated circuit to have zero volts when tested to confirm that it is 'dead', however, the voltage tester may show hundreds of volts on the isolated circuit. This voltage is due to mutual induction, and can cause electric shocks.

The dangers of mutual induction are greatly increased on the high voltage transmission and distribution networks, where an isolated power line may have thousands of volts induced into it from other 'live' high voltage power lines nearby.

Before working on isolated lines, powerline workers must 'ground' the isolated lines, by bonding them to earth in two places and work on the equipment between the two earth bonds. This is to ensure that any mutually induced e.m.f. will immediately be reduced to earth potential.

Current and Voltage in an Inductive Circuit

This circuit shows an inductor connected to a d.c. voltage. When the switch is operated the current does not reach its maximum or zero values instantaneously. There is a time delay due to the self induced e.m.f. of the inductor opposing the change in current.

Electromagnetic effects

a. What is the main reason for **NOT** enclosing low voltage power cables and telecommunication cables in the same conduit?

____

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b. Following are schematic circuit symbols for an **iron-core** & **air-core** type inductors.

Label each inductor and circle which one would have the most concentration of magnetic flux in the core:

Type? ______________________

Type? ______________________

c. The following diagram represents a solenoid coil with the respective poles shown.

Connect the battery to the coil at A & B so that current flow produces the poles shown: