MAGNETISM

Magnet

A magnet is any material that is able to attract iron or steel. Materials that are attracted to magnets are called ferromagnetic. (e.g. iron, steel, cobalt)

When a piece of material is brought close to or stroked by a magnet, the material itself becomes magnetic.

If a material looses its magnetism when the magnet is removed then the magnetism is said to be temporary. Hence if the material keeps the magnetism when the magnet is removed, the magnetism is said to be permanent.

Soft iron can be easily magnetised but it does not retain its magnetism (temporary magnet). However, hard steel is more difficult to magnetised but retain their magnetism (permanent magnet).

All magnets have two (2) poles: a North Pole and South Pole. Experiments also show that:

1. unlike poles attract and like poles repel each other.
2. forces of attraction decreases as the poles get further apart.

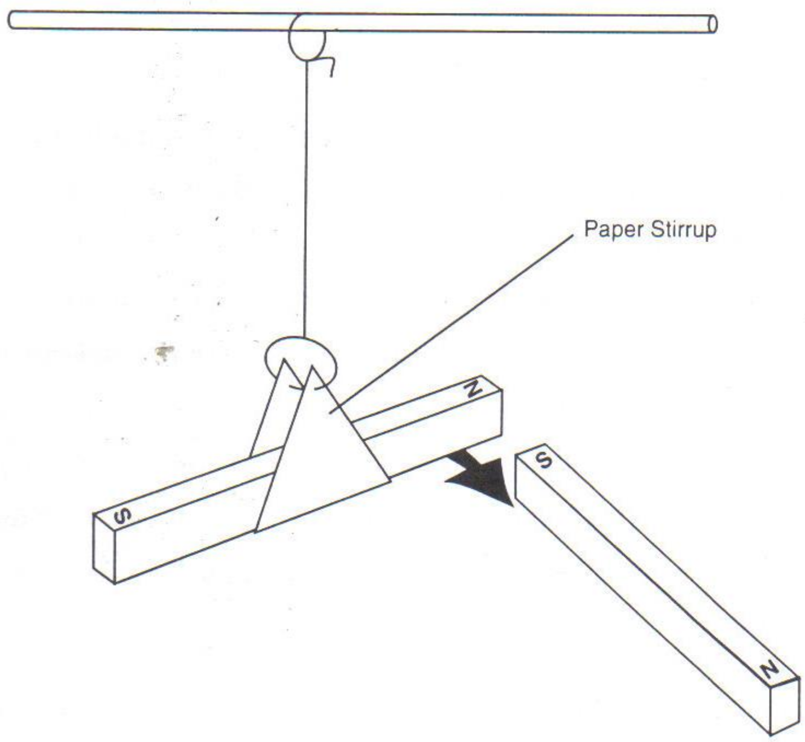

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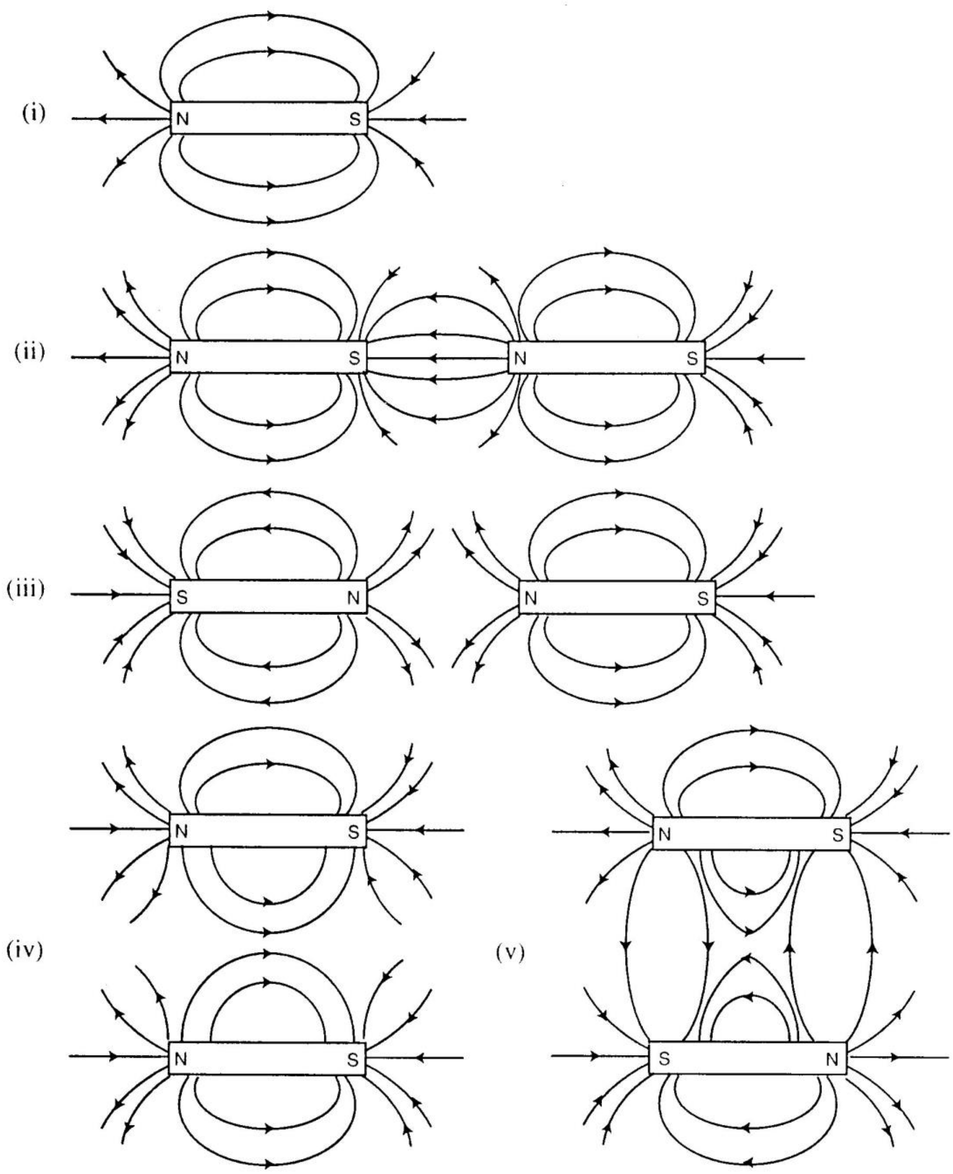
Fig. 12.2 Attraction between unlike poles

Magnetic Fields and Forces

A magnetic field is said to exist at a point if a force of magnetic origin is exerted on a moving charge at that point. A small North Pole placed at the point can also be used to determine the presence of a magnetic field. The direction of the magnetic field is the direction of motion of a moving charge on which no force is exerted or the direction a North Pole would take if placed at that point.
The lines used to represent the magnetic fields are usually closed loops. A magnetic field can be produced by a current carrying conductor or a permanent magnet.

Direction of a Magnetic Field
The direction of a magnetic field is the force produces on a magnetic north pole.
(North $\longrightarrow$ South)

The diagrams below show different arrangements of magnetic flux patterns.



Magnetic Field Flux Density (*B*)

The magnitude and the direction of a magnetic field are represented by its magnetic flux density or magnetic induction (***B***). The flux density is proportional to the magnetic field strength ***(H)***. The unit of the magnetic flux density is the **tesla (T).**

The direction of the flux density at a point is that of the tangent to the field lines at the point. The magnetic field flux density is high where the number of field lines per unit area is high.

We can use the equation to calculate the magnetic field flux density

$$\boldsymbol{B = \frac{F}{Vq}}$$

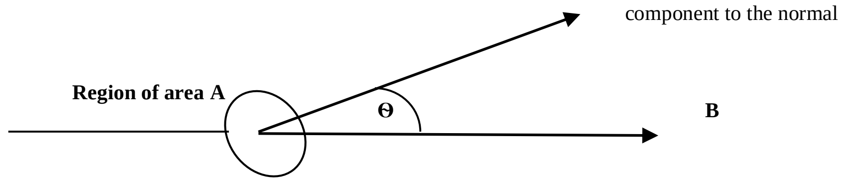
where $\boldsymbol{q}$ is the charge and $\boldsymbol{v}$ is the speed

Tesla (T) is defined as:

One tesla is the magnetic field flux density of a field in which a force of 1 newton acts on a 1 metre length of a conductor which is carrying a current of 1 ampere and is perpendicular to the field.

Magnetic Field Flux (ϕ)

The magnetic field flux measures the number of magnetic field line passing through the region.



We can calculate the flux by using: the region of area ***(A)***, the normal to which lies at an angle($\boldsymbol{\theta}$) , and field of flux density (***B)***, to get the equation

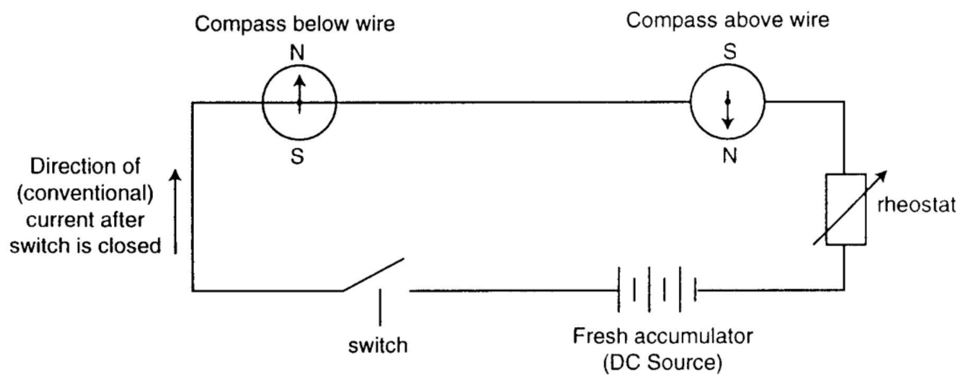
$$\boldsymbol{\phi = AB\cos\theta}$$

The unit of the magnetic flux is the **weber (Wb)**

(NB: 1 telsa = 1 weber per square meter, 1 T = 1 Wbm^{-2})

Magnetic Fields of Current Carrying Conductors

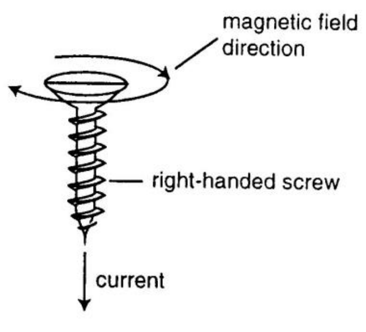
Oersted's Discovery
In 1819, Hans Christian Oersted discovered that where an electric current flowed through a wire, it was able to deflect a compass needle. His experiment demonstrated that a magnetic field existed everywhere around the wire and its direction depended on the direction of the current and the position around the wire. We can use either '***Maxwell's Corkscrew Rule***' or '***Right Hand Grip Rule***' to predict the direction of the field around the wire.



Oersted's Experiment.

Maxwell's Corkscrew Rule (Right-hand screw rule)

If a right-handed screw is turned so that it moves in the same direction as the convectional current, then the direction of the magnetic field is due to the direction of the current.



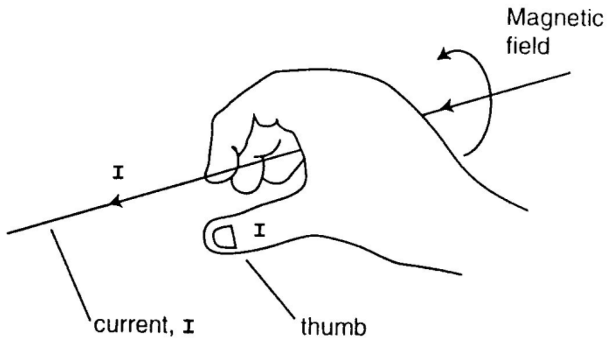
(a)

Fig. 12.10 (a) Maxwell's Screw Rule

Right-Hand Grip Rule

If a wire carrying a current is gripped with the right hand and the thumb is pointing along the wire in the direction of the current; then the fingers point in the direction of the magnetic field around the wire.

(N.B. Circular magnetic fields are formed when currents flow through a straight conductor)



(b)

(b) Right-hand Grip Rule

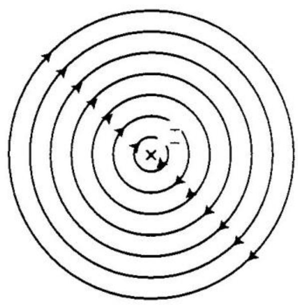


Fig. 12.13 Magnetic Field Pattern due to long straight current-carrying wire

Magnetic Field in Flat Circular Coil

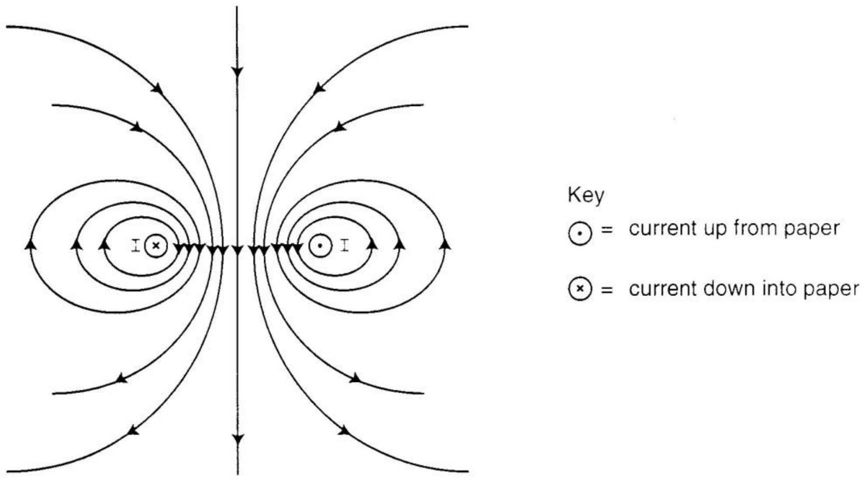


Fig. 12.15 Field pattern of a flat circular coil

Solenoid (Multiple Loops)

A solenoid is large number of circular insulated coil wounds close together. The magnetic field due to the solenoids is the vector sum of the fields all the coils. The magnetic field inside a solenoid is uniformed except at the edges and the field produce is exactly like the bar magnet.

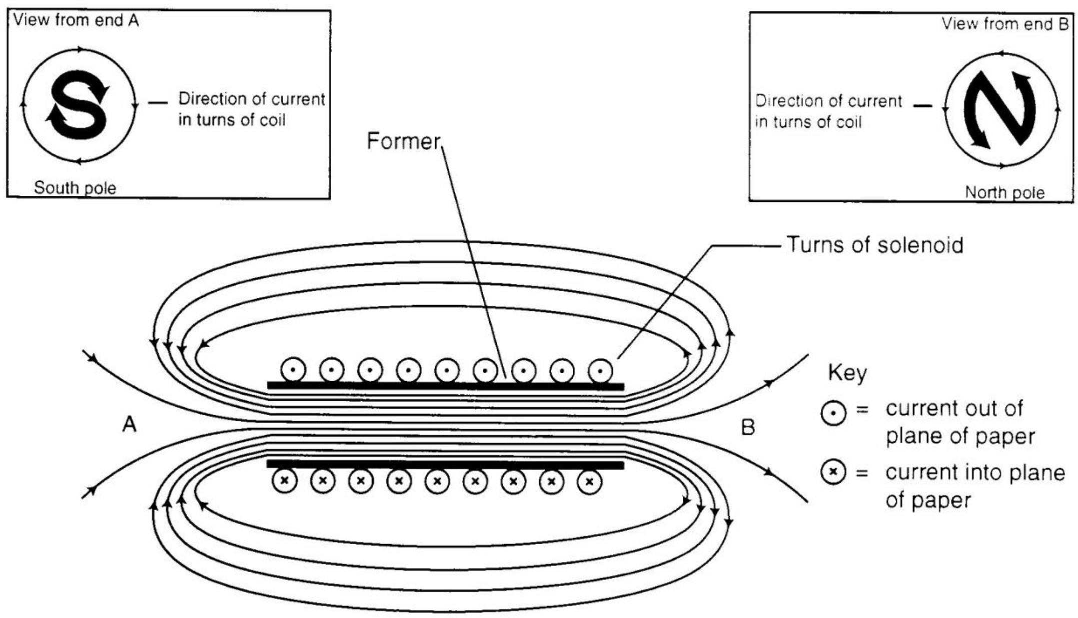
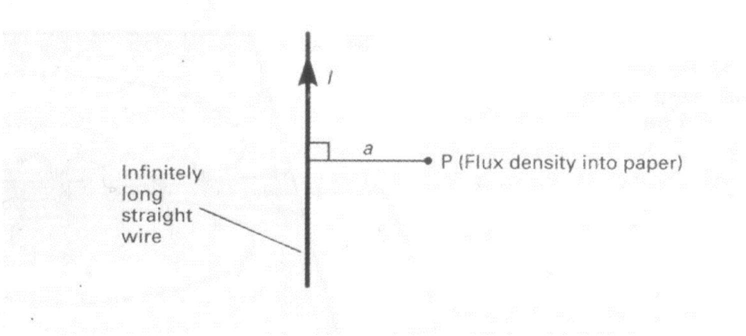


Fig. 12.14 Field pattern of Solenoid

<u>Flux Density Due to a Long Straight Wire</u>

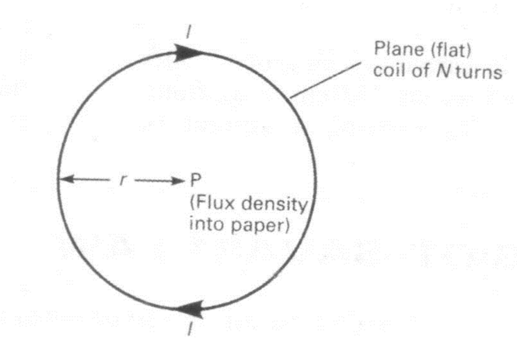


The magnetic flux density **(B)** at any point around a long straight wire is calculated by the equation:

$$\boldsymbol{B = \frac{\mu_0 I}{2\pi r}}$$

where $\boldsymbol{\mu_0}$ is the permeability of the free space (vacuum). **[Value: $4\pi\times10^{-7}$Hm^{-1}]**
$\boldsymbol{I}$ is the current in the wire **(A)**
$\boldsymbol{r}$ is the perpendicular distance from the wire **(m)**

<u>Flux Density Due to a Flat Circular Coil</u>

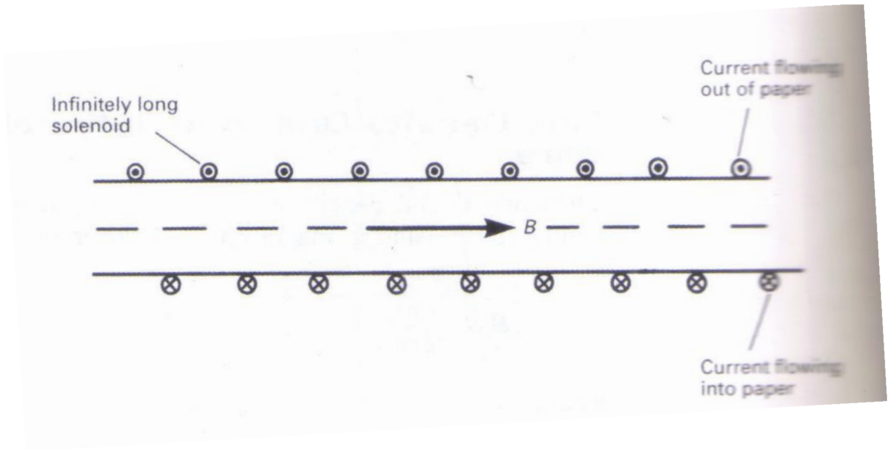


The magnetic flux density **(B)** at the centre of a flat coil is calculated by the equation:

$$\boldsymbol{B = \frac{\mu_0 N I}{2r}}$$

where $\boldsymbol{\mu_0}$ is the permeability of the free space (vacuum). **[Value: $4\pi\times10^{-7}$Hm^{-1}]**
$\boldsymbol{N}$ is the number of turns on the coil **(pure number)**
$\boldsymbol{I}$ is the current in the coil **(A)**
$\boldsymbol{r}$ is the radius of the coil **(m)**

Flux Density Due to a Long Solenoid



The magnetic flux density **(B)** on the axis of a long solenoid is calculated by the equation:

$$\boldsymbol{B = \mu_0 n I}$$

where $\boldsymbol{\mu_0}$ is the permeability of the free space (vacuum). **[Value: $4\pi\times10^{-7}$Hm^{-1}]**
$\boldsymbol{n}$ is the number of turns per unit length **(m^{-1})**
$\boldsymbol{I}$ is the current in the solenoid **(A)**

NB: nI is called the ampere- turns per metre. It is equal to the magnetic field strength **(H)** and hence we can say that $\boldsymbol{B = \mu_0 H}$**.**
The unit for magnetic field strength is **Am^{-1}.**

Example 1
A long straight wire carries a current of 2A. A charge of magnitude 2×10^{-6} C is moving at 20m/s in a plane at right angles to the wire at a distance of 10cm from the wire. Calculate the magnetic flux density at 10 cm from the wire.
(Take $\mu = 4\pi\times10^{-7}$ Hm^{-1})

Example 2
A long conductor passes vertically through the centre of a laboratory. The direction of the current is upward. The magnetic field at a point of 0.2 m from the wire is 5×10^{-4} T. What is the current in the conductor? (Take $\mu = 4\pi\times10^{-7}$ Hm^{-1})

Example 3
A long telephone cable contains 6 wires in which each is carrying a current of 0.5 A. The distance between the wires can be neglected.

a) If the current in all 6 wires are in the same direction, what is the magnitude of the magnetic field 10 cm from the wires?
b) If 4 wires carry current in the one direction and the other 2 wires in the opposite direction, what is the magnitude of the magnetic field 10 cm from the wire?

The Force on a Current-Carrying Conductor in a Magnetic Field

If a current carrying conductor is placed in a magnetic field experiences a force. This force will increase if:

- the strength of the magnetic field increases
- the magnitude of the current increases.

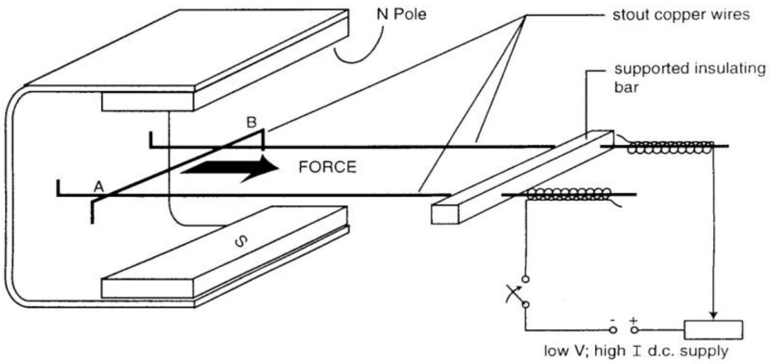
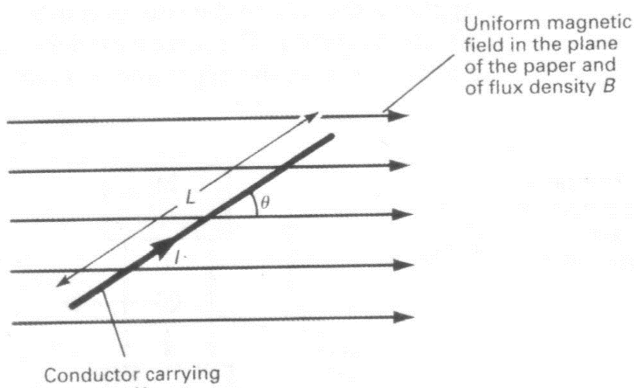


Fig. 12.20 Demonstrating an electromagnetic force

The diagram above demonstrates the existence of an electromagnetic force on a conductor.

The magnitude of a force on a current carrying conductor in a magnetic field can be calculated by using the formula:



$$\boldsymbol{F = BIL\ \sin\theta}$$

where
F is the force on the conductor (N)
B is the magnitude of the magnetic flux density of the field (T)
I is the current in the conductor (A)
L is the length of the conductor (m)

The Direction of the Force

When a current flows in the circuit the wire AB is thrown horizontally out of the magnetic field. If the current or the direction of the magnetic field is reversed, the direction of the movement of the wire AB is also reversed. We can determine the direction the wire moves by using Fleming's Left Hand Rule (Motor rule).

Fleming's Left Hand Rule

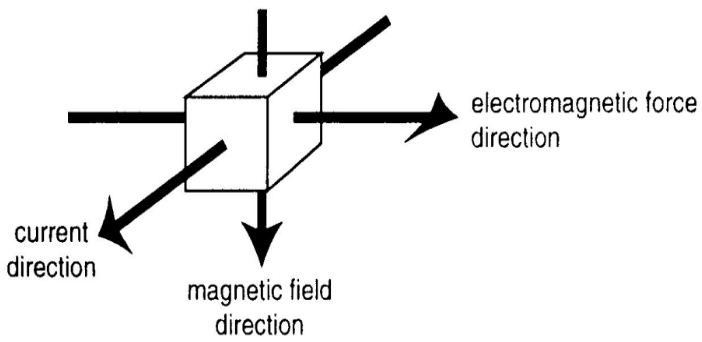


Fig. 12.21 The directional relationships

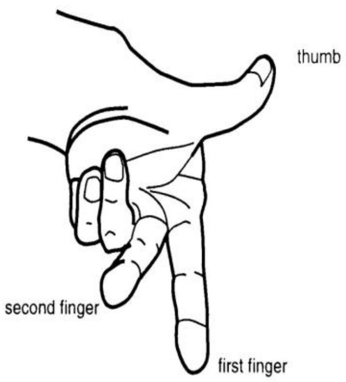
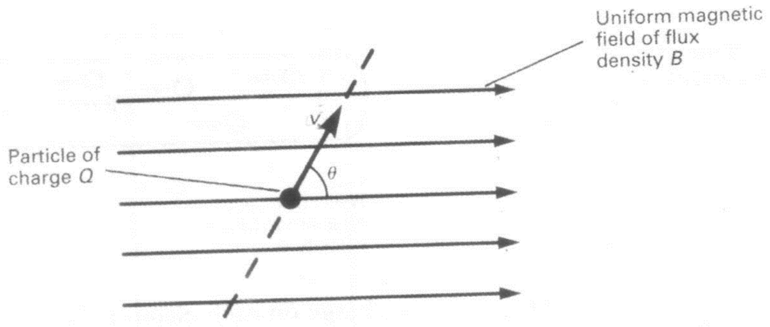


Fig. 12.22 Fleming's Left-hand Rule

Thumb	Thrust / Force
First Finger	Magnetic Field
Se**C**ond Finger	Current

Force on a Charged Particle in a Magnetic Field

Experiments have shown that the force (***F***) on a charge moving in a magnetic field is proportional to the charge (***Q***), the magnetic flux density (***B***), and the speed of the charge ***(v)***. The force also depends on the direction of motion of the charge and can be calculated by using the equation:



$$\boldsymbol{F = BQv\ \sin\theta}$$

where θ is the angle between the field and the direction of motion of the charge. The direction can be found by using Fleming's Left Hand Rule. This force is always at right angles to the plane containing $\boldsymbol{v}$ and $\boldsymbol{B}$.
(**NB:** a magnetic field cannot exert a force on a stationary charged particle)

The Direction of the Force

The force on a positively charged particle is in the same direction as that on a conductor which is carrying current in the same direction as that which the particle is moving. Hence the direction of the force can be found by using Fleming's Left Hand Rule. Hence in the diagram above, the positive charge experiences a force which is perpendicular to it and acting into the paper. Therefore a negative charge feels a force in the opposite direction.

Relationship between the Force on a Conductor and the Force on a Charged Particle

We know that current is the flow of charge. We can therefore assume that the force experienced by a current- carrying conductor in a magnetic field is simply the resultant of forces felt by the moving charges which makes up the current.

Consider a conductor of length ***l*** and area ***A*** lying at right angles to a magnetic field of strength ***B***. The force on the charge is given by the equation:

$$\boldsymbol{F = BQv\ \sin\theta}$$

If there are $\boldsymbol{n}$ charges per unit volume $\boldsymbol{V}$**,** and we also say that the volume $\boldsymbol{V}$ is area $\boldsymbol{A}$ multiplied by length $\boldsymbol{L}$**.** Then the force on the $\boldsymbol{n}$ charges is

$$\boldsymbol{F = (nV)(BQv\ \sin\theta)}$$

$$\therefore\ \ \boldsymbol{F = (nAL)(BQv\ \sin\theta)}$$

But we know that $\boldsymbol{I = nAvQ}$

Hence we can say that

$$\boldsymbol{F = BIL\ \sin\theta}$$

Example 1

A current of 5 A flows in a straight wire placed in a uniform magnetic field of flux density 2.0×10^{-2} T. Calculate the force per unit length (1m) on the wire if :

a) it is places at right angles to the field
b) it is placed at 30^{0} to the field

Example 2

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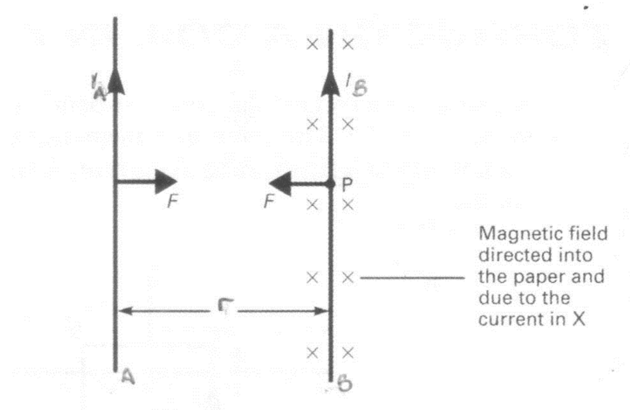
Forces Between Two Current Carrying Conductors

If two current carrying conductors are place close to each other and since a current carrying conductor has a magnet field associated with it, each will experience a force.



From the diagram above Conductor B sits in the field produced by Conductor A, therefore a force is exerted on Conductor B due to Conductor's A field.

The conductors are in a vacuum and their separation is given as r. Therefore we can calculate the magnetic flux density at any point on Conductor B due to current in conductor A by using

$$\boldsymbol{B = \frac{\mu_0 I_A}{2\pi r}} \qquad \dots \boldsymbol{eq\ i}$$

By using the Right Hand Grip Rule, we can determine that the field is directed into the paper.

We can therefore calculate the Force experienced by Conductor B by using the equation

$$\boldsymbol{F = BI_BL\ \sin\theta}$$

Where: $\boldsymbol{I_B}$ is the current in Conductor B and $\boldsymbol{L}$ is the length of Conductor B

Since the angle between the direction of $\boldsymbol{I_B}$ and the field along Conductor B is 90^0, we can rewrite the equation above as

$$\boldsymbol{F = BI_BL} \qquad \dots \boldsymbol{eq\ ii}$$

Substituting equation *i* into equation *ii* gives us that

$$\boldsymbol{F = \frac{\mu_0 I_A I_B L}{2\pi r}}$$

By using Fleming's Left Hand Rule we can establish that the force is directed towards Conductor A.

Similarly, Conductor A will experience a force due to conductor B's magnetic field and the equation used to express this force is the same as above. However the force acts in the opposite direction to that of Conductor B because the field along Conductor A is directed out of the paper.

Hence we can conclude that the forces between two parallel conductors carrying current in the same direction are attractive forces. And it can also be shown that when the currents are travelling in the opposite direction the forces are repulsive.

Therefore we can conclude that: ***like currents attract, while unlike currents repel***

Ferrous Materials and Magnetic Fields

The magnetic properties of a body arise from a multitude of tiny closed circuit loops within the body itself. These currents loop consist of electrons revolving around the nucleus and spinning about their axis. In some materials, especially ferrous material, these "tiny magnets" (spinning and revolving electrons) tend to become aligned with an external field. When this type of material is placed in a device, such as a solenoid, the magnetic field becomes many times larger than when the ferrous core was not there. Hence many applications of magnetic fields produced by currents have ferrous cores.

Electromagnets

This is made up of a coil of wire wound on a ferrous (soft iron) core (solenoid on a soft iron core). When the current is switched, on the iron core becomes magnetised and it easily loses its magnetism when the current is removed. Electromagnets are a very strong magnet and can be used to lift heavy objects in construction.
The strength of the electromagnet depends on the number of turns on the coil and the magnitude of the current flowing through it.

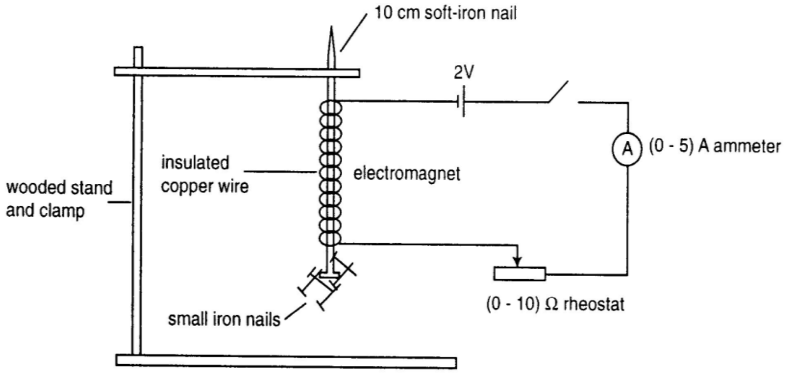


Fig. 12.16 A simple Electromagnet

Examples of Electromagnets

Electric Bell

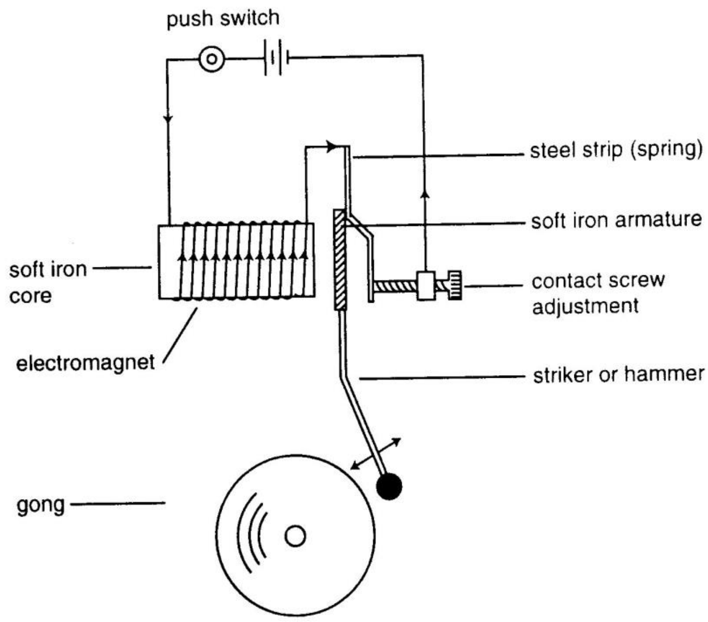


Fig. 12.17 Using an Electromagnet to make sound

The electric bell consists of a solenoid and a soft iron core (electromagnet). One end is connected to the battery while the other end is connected to a steel strip (spring) that supports the soft iron armature. The spring with the armature is pressed against a contact screw that has a wire that connects back to the battery. When the switch is pressed, the current flows through the circuit and the soft iron core becomes magnetised. The armature attracts to the soft iron core which results in the hammer striking the gong once. Simultaneously, the spring moves away from the contact screw, breaking the circuit and the stopping the current from flowing. The electromagnet is no longer magnetised and it releases the armature, which returns to its original position. The spring is once again touching the contact screw, the circuit is reformed and hence the current flows again and the process is repeated.

Magnetic Relay

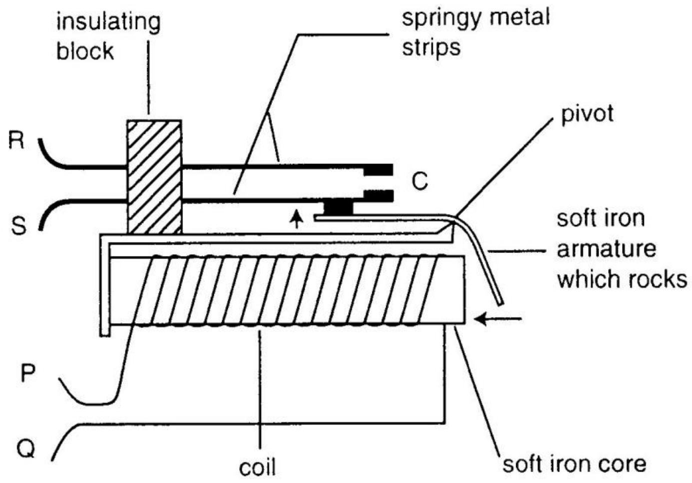


Fig. 12. 18 Simple magnetic Relay

The magnetic relay is a switching device, which uses an electromagnet. It has two or more completely separate circuits. (Input circuit at terminals P and Q. Output circuits at R and S). When the current flows in the coil from the input circuit the soft iron core becomes magnetised and attracts one end of the armature. The armature rocks at its pivot and closes the contact at C in the output circuit.

Vehicle Starting Motor Circuit

The starter motor has a difficult job of turning a stiff engine. Hence a large current is required to do this. As a result the starter motor is placed on a separate circuit and a relay is used to close the contacts in the starter motor circuit

When the ignition is turned on, a small current pass through the solenoid. The armature inside the solenoid pushes against the spring and closes the contacts of the starter motor circuit allowing a very large circuit to pass through the starter motor.

Advantages of the Magnetic Relay

1. One circuit can be used to control another circuit without any direct electrical connections between them.

2. The input circuit can work on a safe, low voltage supply and control another circuit with a dangerous high voltage supply.

3. a small current in the input circuit can switch on a larger current in an output circuit.

Electromagnetic Force

Applications of Motor Effect

Loud Speaker

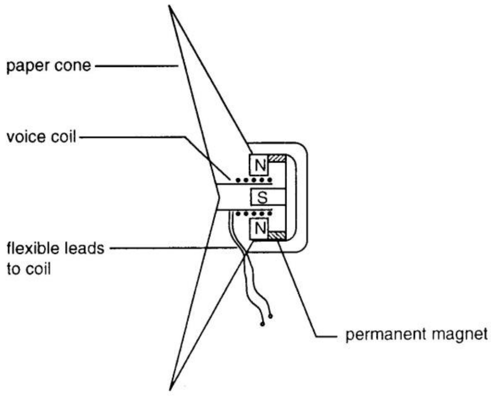


Fig. 12.27 (a) Moving Coil Loudspeaker: Overall structure

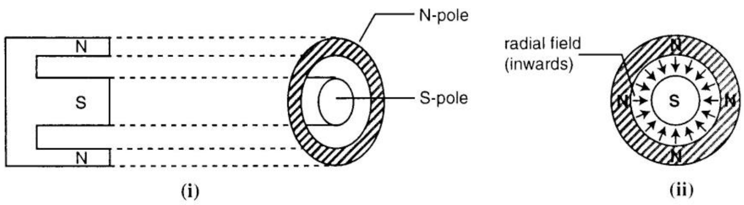


Fig. 12.27 (b) Moving Coil Loudspeaker: End-on Views of cylindrical magnet

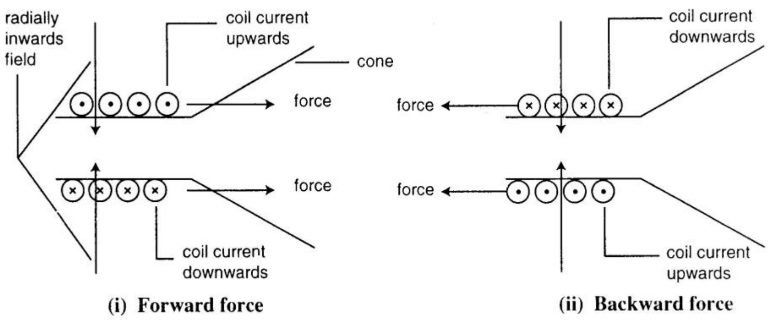


Fig. 12.27 (c) Moving Coil Loudspeaker: Longitudinal section of voice coil and cone

A loud speaker is a device that converts electrical energy into sound energy. (The complete energy change is electrical → kinetic → sound). ***Figure A*** above shows the parts of a moving coil loud speaker. The coil fits into a cylindrical magnet, which has a South Pole and is surrounded by the North Pole. This system creates a magnetic field, which is radial and hence cuts the coil at right angles as shown in ***Figure B***. The moving coil is also connected to a flexible paper cone, which moves the air molecules to produce sound. The loud speaker works on the principal that a force is exerted on the coil that is in the magnetic field causing it to move and hence moving the coil that produces sound waves. When varying electric currents pass through the coil and as the current directions reverse the movement of the coil changes direction. The direction of the cone can be determined by using Fleming's Left Hand Rule. (N.B. the loudspeaker can only work off of A.C. current.)

Electric Motor

A motor is a machine that converts electrical into mechanical / kinetic energy.

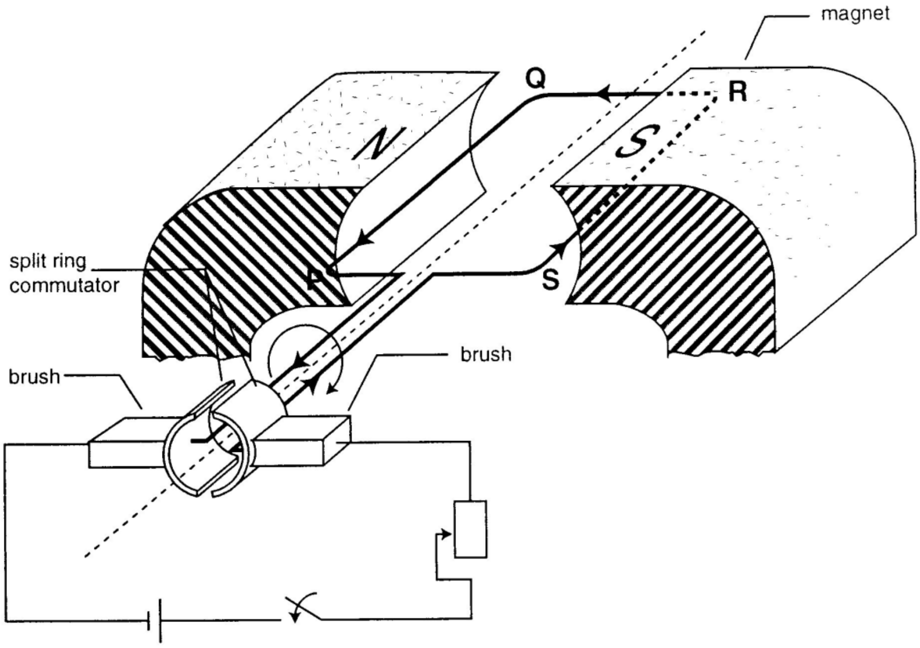


Fig. 12.24 Simple d.c. motor

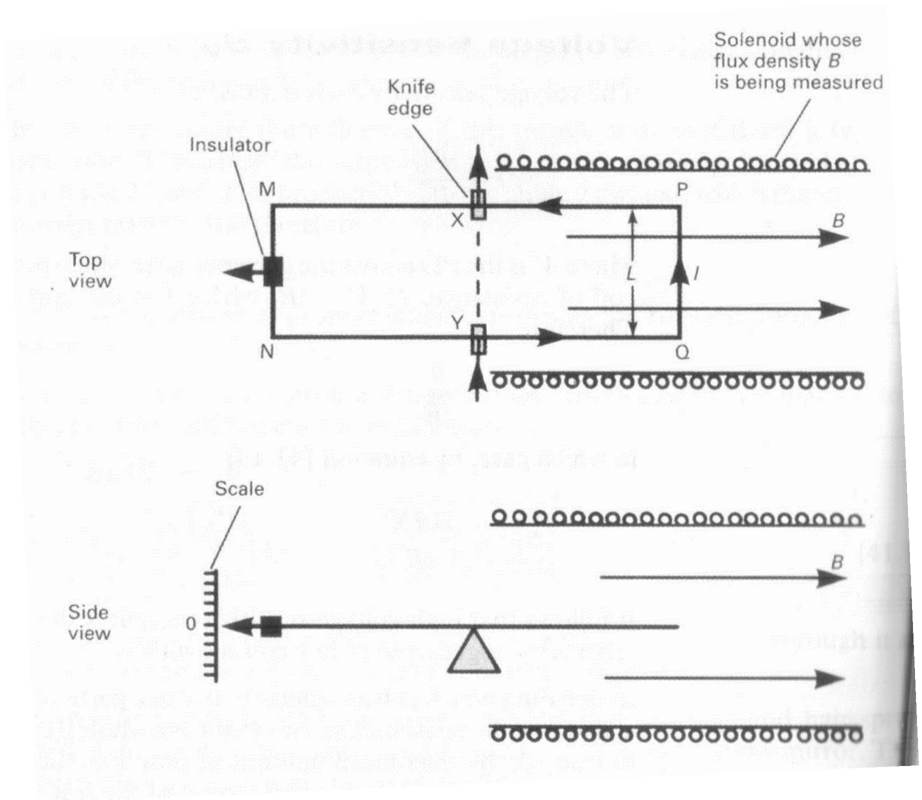
The diagram above is an example of a simple direct current (d.c.) electric motor. It consists of a rectangular coil of wire that is mounted on an axle so that it can rotate between the C shaped magnets. The ends of the coil are soldered onto two halves of a copper split ring commutator. The two carbon brushes shown in the diagram press against the commutators and are then connected to the electrical circuit. (Some electric motors have no brushes and are referred to as brushless induction motors.)

How the d.c. motor works?

Suppose the coil is in the horizontal position when the current is turned on, then the current will flow through the coil in the direction shown and the side PQ of the coil would experience an upward force and the side RS a downward force. We can determine these directions by using Fleming Left Hand Rule. These two forces form a couple that cause the coil to rotate in a clockwise direction until it reaches a vertical position. At this point the brushes are in the space between the commutator's halves and the current is cut off. Because of the momentum the coil does not come to a complete rest, but continues to move forward past the vertical position. The commutator halves automatically change contact from one brush to another, which reverses the direction of the forces on both sides of the coil. The side PQ which is now on the right hand side experiences a downward force while the side RS which is now on the left hand side experiences an upward force. Therefore, the coil continues to move in a clockwise direction.

Measuring Magnet Flux Density By Using A Current Balance

A current balance is used to measure current but can be adapted to measure the magnetic field flux density. A simple form consists of a wire frame which is pivoted about horizontal axis. The pivot is such that the current can be fed into the frame at one end of them and out the other (as shown in the diagram below)



If we want to measure the magnitude, B, of the flux density inside a solenoid, the solenoid is arranged such that its field is perpendicular to PQ as shown in the diagram. When no current is flowing, the frame is horizontal (pointer indicating zero), by adding riders to MN and PQ as necessary.

When a current I is passed through the frame, it produces a downwards force on PQ and the direction of the field is perpendicular to PQ. Hence

$$Force = BIL$$

(where L is the length of PQ)

The frame is restored to the horizontal by adding more riders of mass m and weight mg, to MN. If MN and PQ are equal then we can state that

$$Force\ due\ to\ riders = Force\ due\ to\ field$$

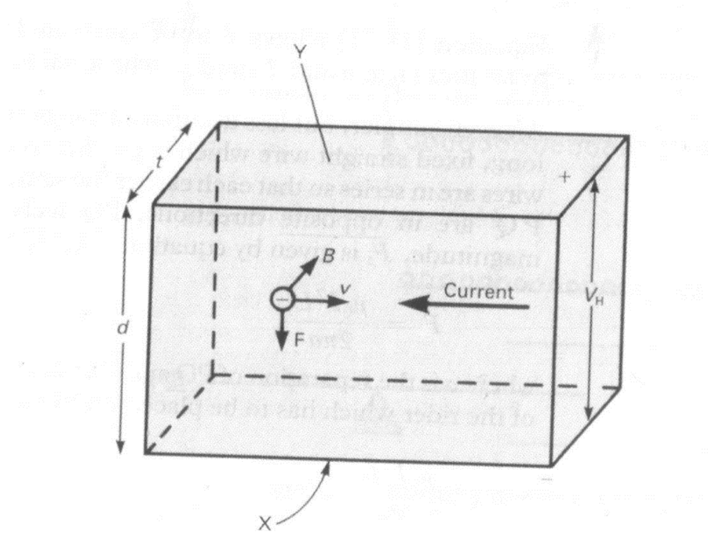
$$mg = BIL$$

$$\therefore \qquad B = \frac{mg}{IL}$$

Hall Effect

When a current flows through a conductor which is placed in magnetic field such that the charges move at right angles to the field, separation of the charges occur. The separation of charges caused by the magnetic field is called the Hall Effect.

Consider a conducting material in a magnetic field flux density B. If the field is directed into the paper, and current from left to right and the material is a metal, the current is carried by electrons from left to right.



Let us consider one electron and this electron has a velocity, v. The electron will experience a force, F, and according to Fleming's Left Hand Rule the force will be directed downwards. Hence electrons move away from face X to face Y and a negative charge builds up at X, leaving a positive charge at Y. Therefore a potential difference builds up between X and Y. There would be a point when the potential difference would be so large that it prevents further increase. We call this maximum potential Hall's Voltage.

We can calculate Hall's Voltage by using the equation:

$$V_H = \frac{BI}{net}$$

Where B is the magnitude of the magnetic flux density
n is the number of charge carriers per unit volume
e is the charge on each charge carrier
t is the time

Measuring Magnetic Flux Density Using The Hall Effect

The magnetic flux density, B, can be measured by using Hall probe. The device used consists of a small slice (wafer) of a semi conductor mounted on the end of a long handle so it can be probed into the magnetic field to be investigated.

A current, I, is passed between the two opposite faces of the semiconductor wafer. When the wafer is within the magnetic field then Hall's voltage is established across the other two faces. We can then determine the magnetic field flux by using the equation:

$$\boldsymbol{B = \frac{netV_H}{I}}$$

The manufactures usually provide the value of *net* in the equation and a voltmeter is used to determine V_H while an ammeter is used to determine *I*.

Electromagnetic Induction

In this case we are investigating electric currents that are induced in wires by magnetic fields.

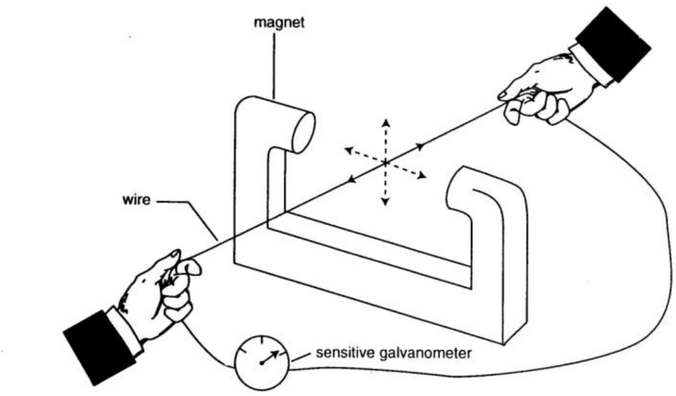


Fig. 12.29 E.M.F Induced in a straight wire

If we set up the experiment as shown above and move the wire in an upward and downward motion we would notice a flickering or movement of the sensitive galvanometer. This movement is due to an electric current, which was induced by the magnetic field since there was no other current source in the circuit itself.

As the wire moves through the magnetic field, a force acts on the electrons in the wire that produces the current. This effect is known as the dynamo or the generator affect. The direction of the induced current depends on both the direction of the motion of the wire and the direction of the magnetic field.

The wire however must move so that it is perpendicular or cuts the magnetic field. If the wire is parallel to the magnetic field, it does not cut the magnetic field so no current is induced. We can determine the magnitude of the electromotive force by Faraday's Law and the direction of the induced current maybe predicted by Lenz's Law.

An EMF is induced in a coil in a magnetic field whenever the flux (ϕ) through the coil changes.

Faraday's 2nd Law of Electromagnetic Induction

The magnitude of the induced EMF between the ends of the conductor is directly proportional to the rate of change of flux –linkage or to the rate of cutting the magnetic flux. (We can define flux-linkage as $N\phi$ where N is the number of turns)

We can increase the magnitude of the EMF by increasing:

1. the speed of the magnetic or conductor
2. the strength of the magnetic field.
3. the area of the conductor
4. the number of turns on the conductor.

Lenz's Law

The law states that the direction of the induced current is such as to oppose the change that is causing it. This law can be used to predict the direction of induced current. In the diagram below as the magnet approaches the magnet at end A of the coil with the North pole first, the induced current flows in the direction which makes the coil behaves like a magnet with end A acting as a North Pole. The inward motion of the magnet is opposed.

When the magnet is withdrawn, the end A of the coil becomes a South Pole and attracts the receding North Pole of the magnet, so hindering its removal. The induced current is therefore in the opposite direction to that when the magnet approaches. Lenz's Law is the law of conservation of energy expressed so that it apples to electromagnetism induction.

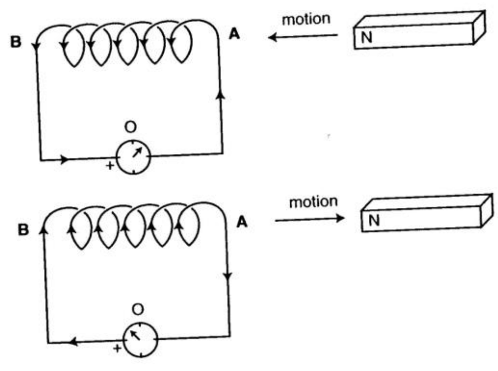


Fig. 12.30 E.M.F induced in a coil

These two laws can be expressed as a Neumann's equation:

$$E = -\frac{d}{dt}(N\phi)$$

Where E is EMF in volts

$\frac{d}{dt}(N\phi)$ is rate of change of flux-linkage in webers per second.

Remember

The magnitude of the EMF induced depends on a quantity called the magnetic flux. The magnetic flux is defined as the product of magnetic flux density, B, and the area which is normal to the magnetic field flux density. Hence we get that:

$$\phi = BA$$

The unit for the magnetic field flux is weber (Wb)

(NB: 1 telsa = 1 weber per square meter, 1 T = 1 Wbm^{-2})

Weber

The magnetic field flux for a surface is defined ad 1 Wb, when the magnetic field flux density normal to the surface is 1T and its area is 1m^2.

Fleming's Right Hand Rule

This rule enables us to predict the direction of the induced current for a straight conductor moving at right angles to a magnetic field.

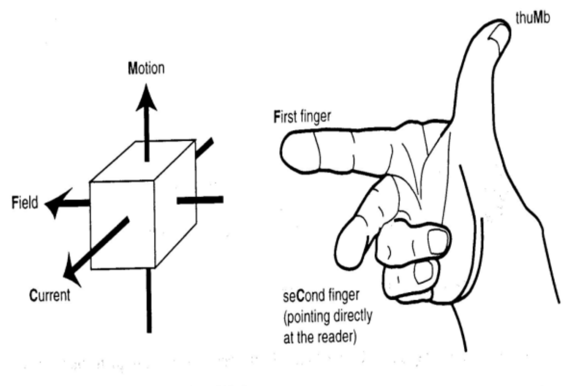


Fig. 12.28 Fleming's Right-hand Rule

Thu**M**b	Motion
First Finger	Magnetic Field
Se**C**ond Finger	Current

<u>EMF Induced In A Straight Conductor   (*E = BLv*)</u>

Consider a conductor of length, l, moving with a speed, v, at right angles to a magnetic field, B. Then each free charge will experience a force, F, defined as $F = Bvq$.

Positive charges therefore will accumulate at the top of the conductor and give rise to separation of charge; hence an EMF will be produced in the conductor.

We can derive the equation of this EMF, E:

$$work\ done\ on\ charge = F \times L$$

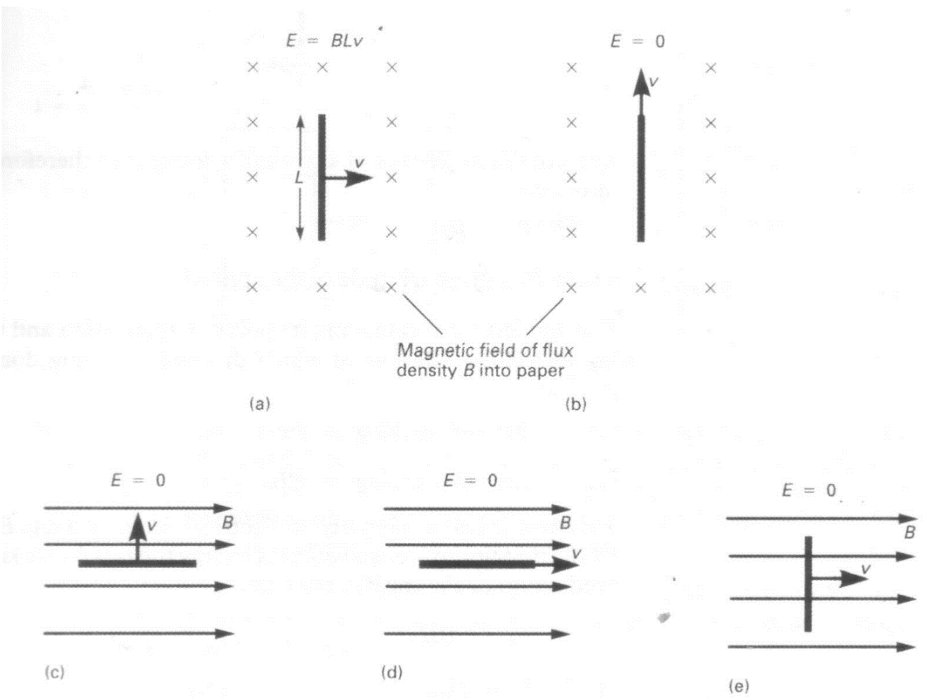
$$work\ done = (Bvq)L$$

Since $$voltage = \frac{work}{chrage}$$

We get that $$E = \frac{B\,vq\,L}{q}$$

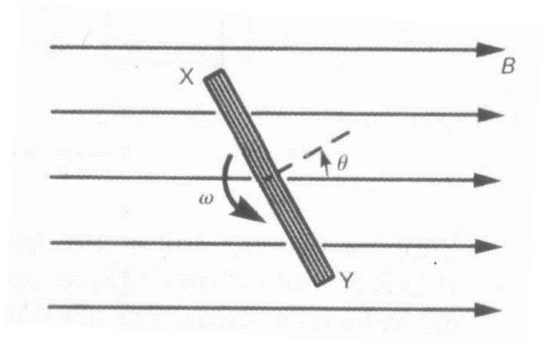
$$\therefore\ \ E = BLv$$

Examples of conductors moving in a magnetic field



EMF Induced In A Rotating Coil

Consider a rectangular coil of N turns each of area, A, rotating with a constant angular velocity, ω in a uniform magnetic field of flux density, B about an axis which is perpendicular to the paper as shown in the diagram below.



When the normal to the coil is at an angle, θ to the field; the flux, ϕ through each turn of the coil is given by

$$\boldsymbol{\phi = AB\cos\theta}$$

But $\theta = \omega t$

Therefore $\boldsymbol{\phi = AB\cos}\,\omega t$

The coil has N turns and therefore the flux-linkage $N\phi$ is given by

$$\boldsymbol{N\phi = NAB\cos\omega t}$$

Using the Neumann's Equation, we can calculate the induced EMF, E by

$$E = -\frac{d}{dt}(N\phi)$$

$$E = -\frac{d}{dt}(\boldsymbol{NAB\cos}\,\omega t)$$

\

$$E = -NAB\frac{d}{dt}\boldsymbol{\cos}\,\omega t$$

$$\therefore \quad \boldsymbol{E = NAB\omega\sin\omega t}$$

A.C. Generator

A generator is a machine used to convert mechanical energy into electrical energy. The diagram below shows a simple form of an alternating current generator. It consists of a rectangular coil between the poles of a C-shaped magnet. Each end of the coil is connected to a slip ring mounted on an axle against which carbon brushes press.

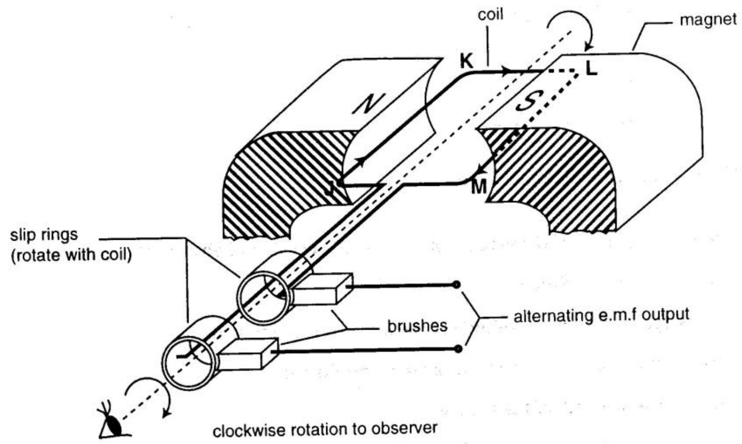


Fig. 12.31 (a) Simple A.C. Generator

When the coil rotates, it cuts the magnetic field lines and an EMF. is induced into it. We can use Fleming's Right Hand Rule to determine the induced current. Diagram A below shows how the EMF varies with time and Diagram B shows the position of the coil which corresponds to the points P, Q, R, S and T on Diagram A.

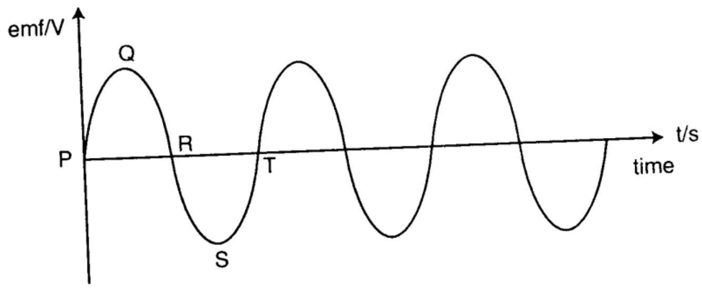


Fig. 12.32 (a) Graph of e.m.f against time

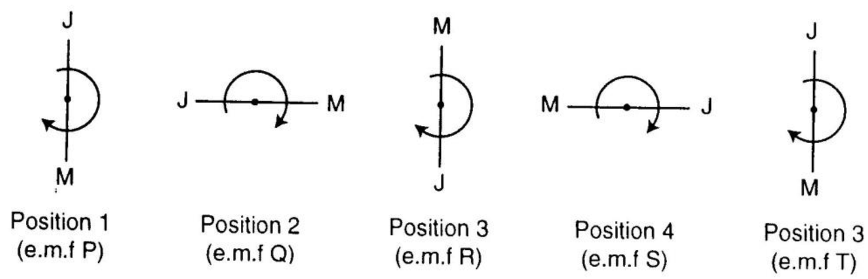


Fig. 12.32 (b) Some positions of the rotating coil

When the coil is moving through the vertical position, the line s of the magnetic fields are not cut, hence the EMF is zero. On the other hand when the coil is moving through the horizontal position, the rate at which the lines of magnetic field are being cut at the sides of the coil is at the greatest and hence the induced EMF is maximum.

Transformers

A transformer is a device that is used for changing the voltage of a supply of alternating current (A.C.) without changing the frequency.

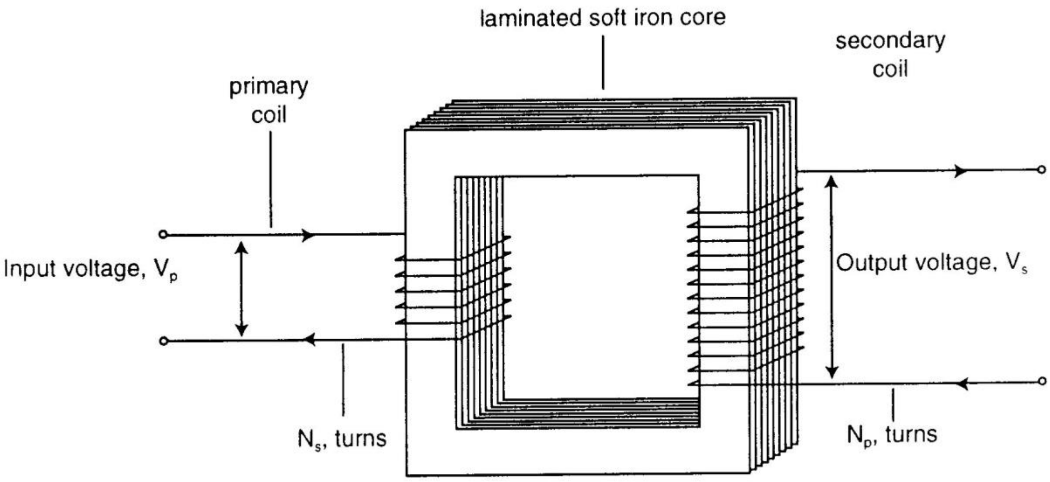


Fig. 12.33 Transformer

Structure of the Transformer
The transformer consists of two electrically separated coils, which are magnetically link, usually by being wound on a soft iron core. Thick insulated copper wires are usually used for making the coils. The iron core is usually constructed as a compact section of identical sections called laminations. These laminations are electrically insulated but not magnetically insulated from each other. (N.B. the transformer has no moving parts)

How does the transformer work?
The action of the transformer is based on a phenomenon called electromagnetic induction. When the alternation potential difference is passed through the primary coil the resulting current produces a large alternating magnetic field, which reaches the secondary coil and induces an EMF. in it. The magnitude of the induced EMF depends on the potential difference applied to the primary coil and the number of turns on both the primary and the secondary coils.

Efficiency of the Transformer

A well-designed transformer is a very efficient (99% efficient). This is due to the fact that the transformer has no moving parts hence energy is not lost to fictions. However there are electrical and magnetic factors that can affect the efficiency of transformers. The table below gives the causes of power loss as steps that can be taken in the design of the transformer to reduce them.

	SOME CAUSES OF POWER LOSS IN TRANSFORMERS	FEATURES IN DESIGN TO REDUCE POWER LOSS (OR INCREASE EFFICIENCY)
1	Heating effect of the current in the wires of the coils: power loss in each coil = I^2R where R = resistance of the wire in each coil; I = current in the coil.	Thick copper wire of low resistance is used.
2.	Heating effect of ("eddy") currents induced in the iron core: power loss = I^2R where R = resistance of a closed loop in the iron core where eddy currents flow.	The iron core is laminated, cutting across the path of any induced eddy current: the high resistance between the laminations greatly reduces the eddy currents and also the heat they would produce.
3	Energy is used in the process of magnetizing the iron core and reversing this magnetization every time the current reverses; this energy appears as heat.	The core is made of soft iron which is very easily magnetized and demagnetized by the magnetic field of the primary coil.
4	Some of the magnetic field lines produced by the primary coil do not link with the secondary coil, reducing the e.m.f in the secondary coil.	The core is designed for maximum linkage between the primary and secondary coils: the common method is to wind the secondary coil over the primary coil. The iron core must always be in the form of a closed loop.

The Ideal Transformer

No real transformer is 100% efficient, but many in everyday use have high efficiencies. In order to perform theoretical and practical calculations we need to develop a concept of an “ideal” transformer. An ideal transformer can therefore be defined as one for which the input and the output powers are equal.

$$\mathbf{P_{OUT} = P_{IN}}$$

Recall that the secondary circuit is the output circuit and the primary circuit is the input circuit of the transformer. Therefore we can write:

$$\mathbf{P_s = P_p}$$

Hence $\mathbf{I_S V_S = I_P V_P}$

Rearranging the equation we can state that for an ideal transformer

$$\frac{V_S}{V_P} = \frac{I_P}{I_S}$$

We can further state:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

where N_S and N_P are the number of turns which make up the secondary and primary coils respectively. (N_S/N_P is called the terms ratio and determines how large or how small the secondary voltage of the ideal transformer is in relation to the primary voltage)

Hence for the step up transformer where $V_S > V_P$. We can state that

$$\frac{V_S}{V_P} = \frac{I_P}{I_S} = \frac{N_S}{N_P} > 1$$

For the step down transformer where $V_S < V_P$. We can state that

$$\frac{V_S}{V_P} = \frac{I_P}{I_S} = \frac{N_S}{N_P} < 1$$