Effects Produced by Electric Current

An electric current can produce three important effects. These are :
(1) Heating effect,
(2) Magnetic effect,
(3) Chemical effect.

HEATING EFFECT OF CURRENT

When an electric current is passed through a high resistance wire,(like nichrome) the resistance wire becomes very hot and produces heat. This is called the heating effect of current.

when electric charge Q moves against a potential difference V, the amount of work done is given by :
$W = Q \times V$ ………... (1)

Current, $I = Q / t$
So, $Q = I \times t$
also
Potential difference, $V = I \times R$

putting in equation (1),
$W = I \times t \times I \times R$
So, Work done, $W = I^2 \times R \times t$

But all the electrical work done or all the electrical energy consumed is converted into heat energy

Heat produced, $H = I^2 \times R \times t$ joules
(This is known as Joule's law of heating)

the heat produced in a wire is directly proportional to :
(i) square of current (I^2)
(ii) resistance of wire (R)
(iii) time (t), for which current is passed

(a) Since the heat produced is directly proportional to the square of current :
$H \propto I^2$
so, if we double the current, then the heat produced will become four times. And if we halve the current, then heat generated will become one-fourth.

(b) Since the heat produced in a wire is directly proportional to the resistance :
$H \propto R$
so, if we double the resistance, then heat produced will also get doubled. And if we halve the resistance, then the heat produced will also be halved.

//Note - when two similar resistance wires are connected in series, then their combined resistance gets doubled but when they are connected in parallel then their combined resistance gets halved. So, a given current will produce more heat per unit time if the two resistances are connected in series than when they are connected in parallel.

(c) Since the heat produced in a wire is directly proportional to the time for which current flows :

$H \propto t$

so, if the current is passed through a wire for double the time, then the heat produced is doubled. And if the time is halved, the heat produced is also halved.

Sample Problem 1. A potential difference of 250 volts is applied across a resistance of 500 ohms in an electric iron. Calculate (i) current, and (ii) heat energy produced in joules in 10 seconds.

Sample Problem 2. Calculate the heat produced when 96,000 coulombs of charge is transferred in 1 hour through a potential difference of 50 volts.

Sample Problem 3. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in series and then in parallel in a circuit across the same potential difference. The ratio of heat produced in series and parallel combinations would be :

(a) 1 : 2 (b) 2 : 1 (c) 1 : 4 (d) 4 : 1

Applications of the Heating Effect of Current

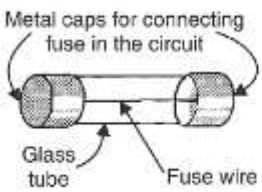
1. The heating effect of current is utilised in the working of electrical **heating appliances** such as electric iron, electric kettle, electric toaster, electric oven, room heaters, water heaters (geysers), etc.

2. The heating effect of electric current is utilised in electric bulbs (electric lamps) **for producing light.**

Note - (1) Tungsten metal is used for making the filaments of electric bulbs because it has a very high melting point (of 3380°C). Due to its very high melting point, the tungsten filament can be kept white-hot without melting away.

(2) the electric bulb is filled with a chemically unreactive gas like argon or nitrogen (or a mixture of both). The gases like argon and nitrogen do not react with the hot tungsten filament and hence prolong the life of the filament of the electric bulb.

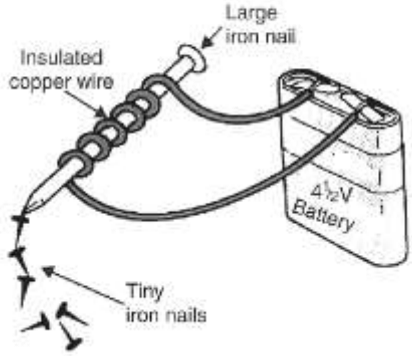
3. The heating effect of electric current is utilised **in electric fuse** for protecting household wiring and electrical appliances.



------ Chapter End------

Magnetic Effect of Electric Current

'an electric current flowing in a wire produces a magnetic field around it'.
In other words, electric current can produce magnetism.



Magnet

A magnet is an object which attracts pieces of iron, steel, nickel and cobalt.

Types - there are two types of magnet
1. U-type magnet 2. Bar magnet

A bar magnet is a long, rectangular bar of uniform cross-section which attracts pieces of iron, steel, nickel and cobalt.

A magnet has two poles near its ends : **north pole and south pole.**
//**story** // The end of a freely suspended magnet (or a freely pivoted magnet) which points towards the north direction is called the north pole of the magnet. And the end of a freely suspended magnet (or freely pivoted magnet) which points towards the south direction is called the south pole of the magnet.

Characteristics -
1. like magnetic poles repel each other
2. unlike magnetic poles attract each other.

Uses – Magnets are used in radio, television, and stereo speakers, in refrigerator doors, on audio and video cassette tapes, on hard discs and floppies for computers, and in children's toys.
Magnets are also used in making electric generators and electric motors.
The Magnetic Resonance Imaging (MRI) technique which is used to scan inner human body parts in hospitals also uses magnets for its working.

Magnetic Field

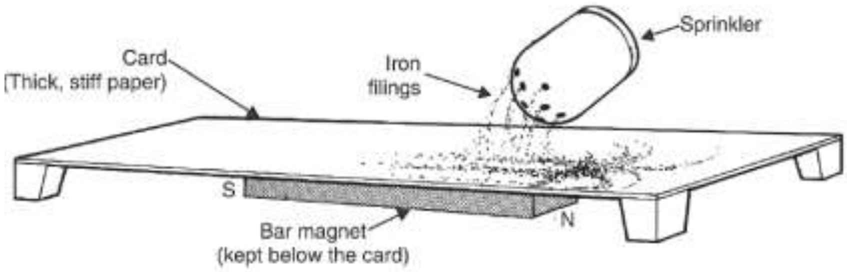
The space surrounding a magnet in which magnetic force is exerted, is called a magnetic field.

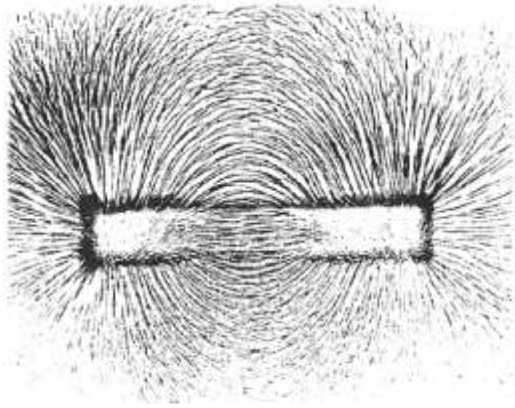
Magnetic Field Lines

A magnetic field is described by drawing the magnetic field lines.

//**story** // When a small north magnetic pole is placed in the magnetic field created by a magnet, it will experience a force. And if the north pole is free, it will move under the influence of magnetic field.

1. To Plot the Magnetic Field Pattern Due to a Bar Magnet by Using Iron Filings

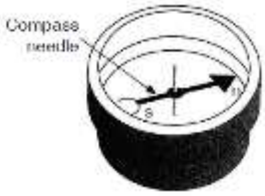


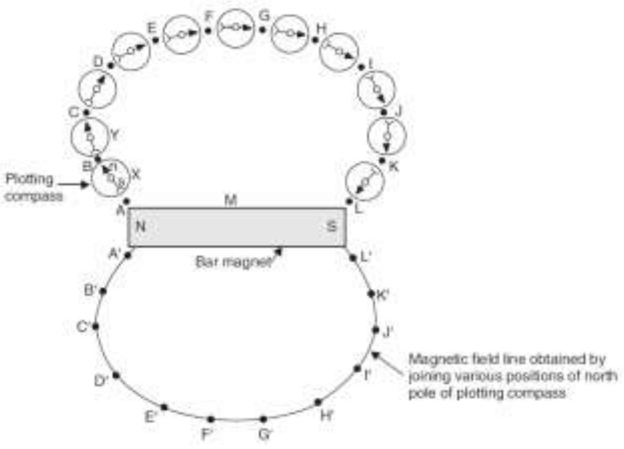


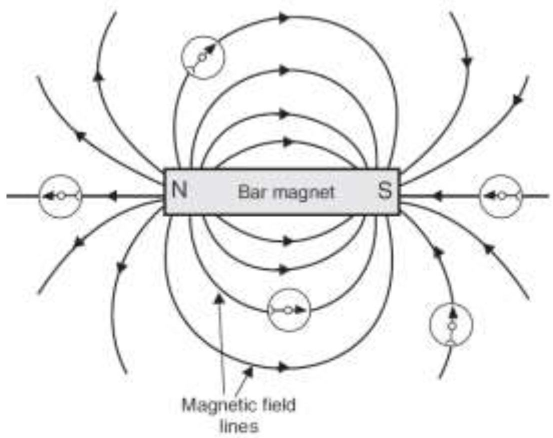
iron filings show the shape of magnetic field produced by a bar magnet by aligning themselves with the magnetic field lines.

2. To Plot the Magnetic Field Pattern Due to a Bar Magnet by Using a Compass

A compass (or plotting compass) consists of a tiny pivoted magnet usually in the form of a pointer which can turn freely in the horizontal plane.







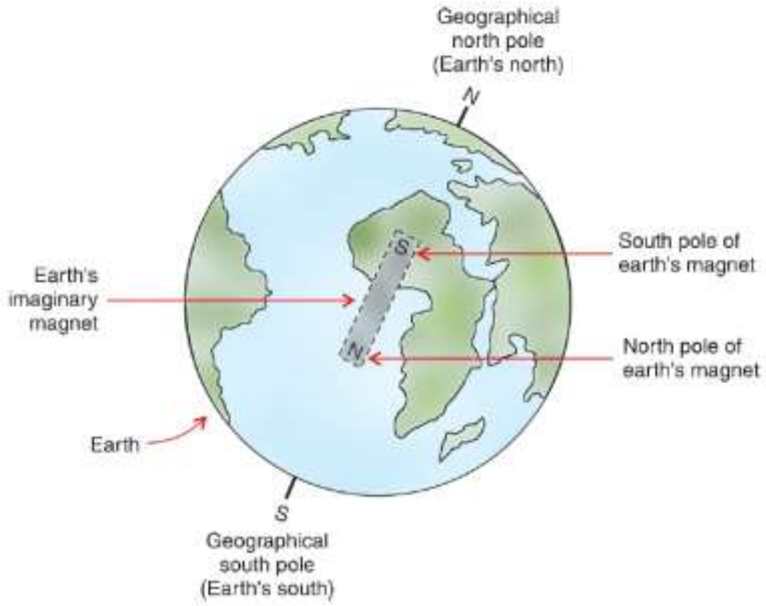
Properties (or Characteristics) of the Magnetic Field Lines

1. The magnetic field lines originate from the north pole of a magnet and end at its south pole.
2. The magnetic field lines come closer to one another near the poles of a magnet but they are widely separated at other places.
3. The magnetic field lines do not intersect (or cross) one another.

Magnetic Field of Earth

The earth itself behaves as a magnet. The shape of the earth's magnetic field resembles that of an imaginary bar magnet of length one-fifth of earth's diameter buried at its centre

The south pole of earth's magnet is in the geographical north because it attracts the north pole of the suspended magnet. Similarly, the north pole of earth's magnet is in the geographical south because it attracts the south pole of the suspended magnet.

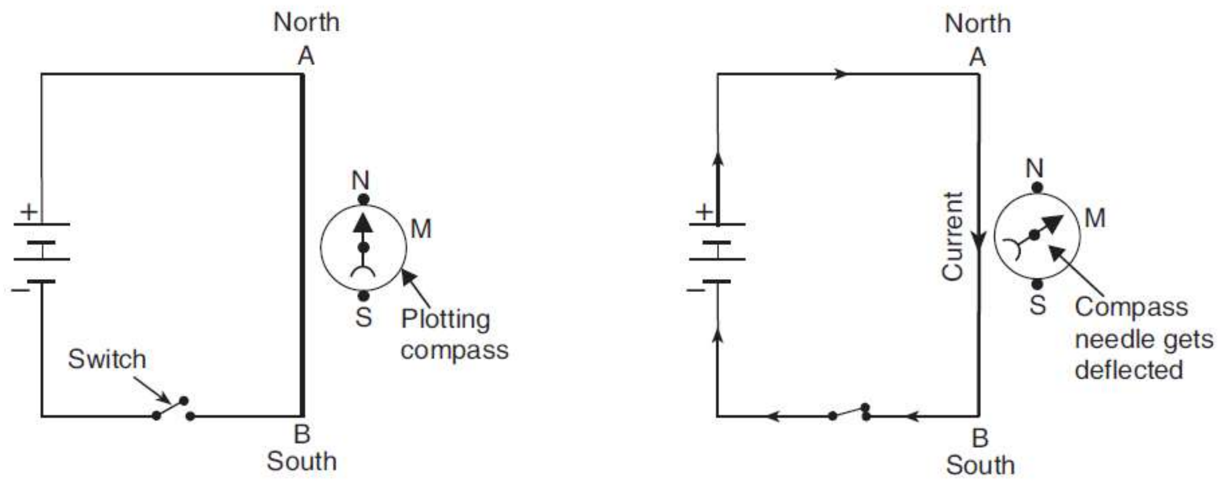


Note - The axis of earth's magnetic field is inclined at an angle of about 15° with the geographical axis.

MAGNETIC EFFECT OF CURRENT (OR ELECTROMAGNETISM)

The magnetic effect of current was discovered by Oersted in 1820.
A current flowing in a wire always gives rise to a magnetic field around it.

Experiment to Demonstrate the Magnetic Effect of Current

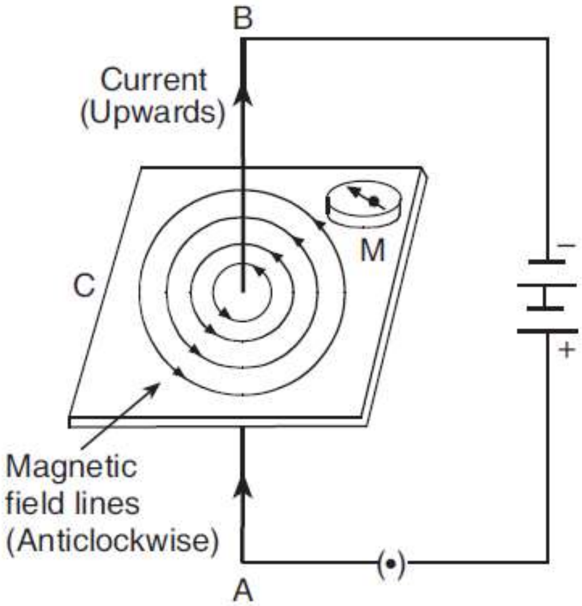


the deflection of compass needle by the current carrying wire in the above experiment shows that an electric current produces a magnetic field around it.

Magnetic Field Patterns Produced by Current-Carrying Conductors having Different Shapes

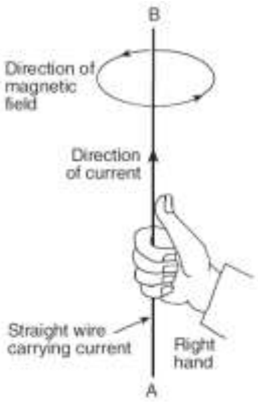
(i) a straight conductor (or straight wire) carrying current,
(ii) a circular loop (or circular wire) carrying current, and
(iii) a solenoid (long coil of wire) carrying current.

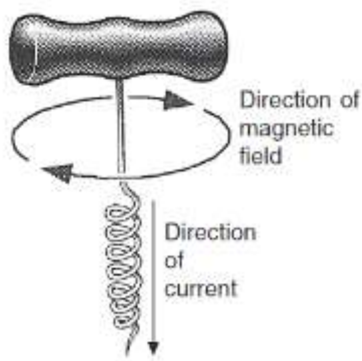
1. Magnetic Field Pattern due to Straight Current-Carrying Conductor(Straight Current-Carrying Wire)



Field - Circular

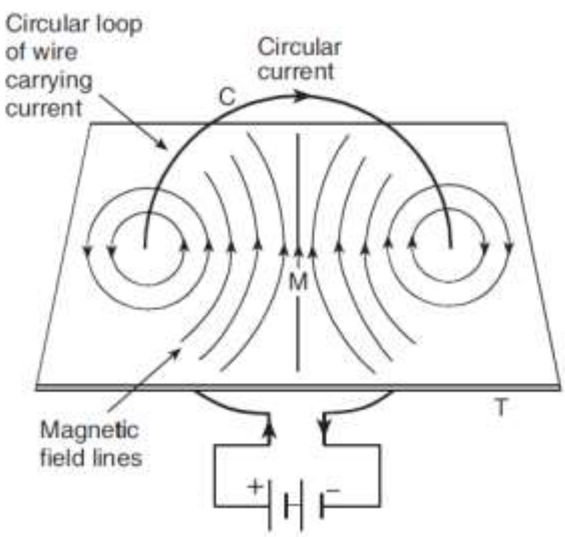
Direction of current - Right Hand Thumb Rule/ Maxwell's Corkcrew rule





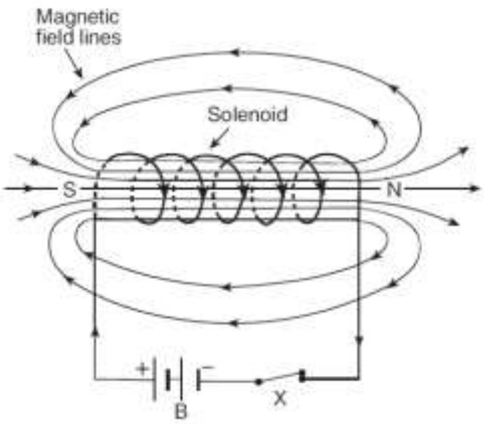
Magnitude of magnetic field - (i) directly proportional to the current ($\propto I$)
(ii) inversely proportional to the distance of that point from the wire. ($\propto 1/$ Distance)

2. Magnetic Field Pattern due to a Circular Loop (or Circular Wire) Carrying Current



Field – Circular
Direction of current - Right Hand Thumb Rule/ Maxwell's Corkcrew rule
upward - anticlock wise
downward - clock wise
Magnitude of magnetic field - (i) directly proportional to the current ($\propto I$)
(ii) inversely proportional to the radius of circular loop($\propto 1/$ Radius)

3. Magnetic Field due to a Solenoid
The solenoid is a long coil containing a large number of close turns of insulated copper wire.

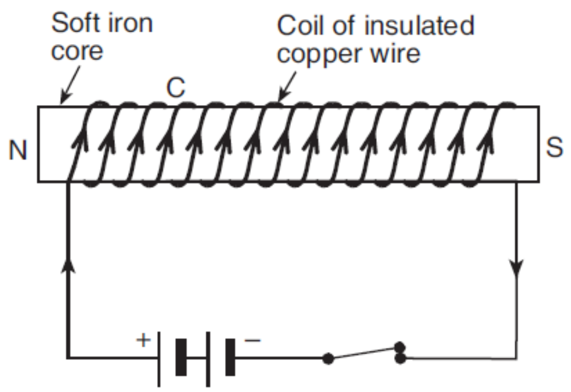


Field - similar to bar magnet
Direction of current - Clock Face Rule

The strength of magnetic field produced depends on :
(i) number of turns in the solenoid ($\propto n$)
(ii) current in the solenoid ($\propto I$)
(iii) The nature of "core material" used in making solenoid.
The use of soft iron rod as core in a solenoid produces the strongest magnetism.

Electromagnet

An electromagnet is a magnet consisting of a long coil of insulated copper wire wrapped around a soft iron core that is magnetised only when electric current is passed through the coil.



Factors Affecting the Strength of an Electromagnet

The strength of an electromagnet depends on :
(i) The number of turns in the coil
(ii) The current flowing in the coil
(iii) The length of air gap between its poles

Differences Between a Bar Magnet (or Permanent Magnet) and an Electromagnet

Bar magnet (or Permanent magnet)	Electromagnet
1. The bar magnet is a permanent magnet.	1. An electromagnet is a temporary magnet. Its magnetism is only for the duration of current passing through it. So, the magnetism of an electromagnet can be switched on or switched off as desired.
2. A permanent magnet produces a comparatively weak force of attraction.	2. An electromagnet can produce very strong Magnetic force.
3. The strength of a permanent magnet cannot be changed.	3. The strength of an electromagnet can be changed by changing the number of turns in its coil or by changing the current passing through it.
4. The (north-south) polarity of a permanent magnet is fixed and cannot be changed.	4. The polarity of an electromagnet can be changed By changing the direction of current in its coil.

MAGNETISM IN HUMAN BEINGS

when the weak ionic currents flow along the nerve cells, they produce magnetic field in our body. The two main organs of the human body where the magnetic field produced is quite significant are the heart and the brain.

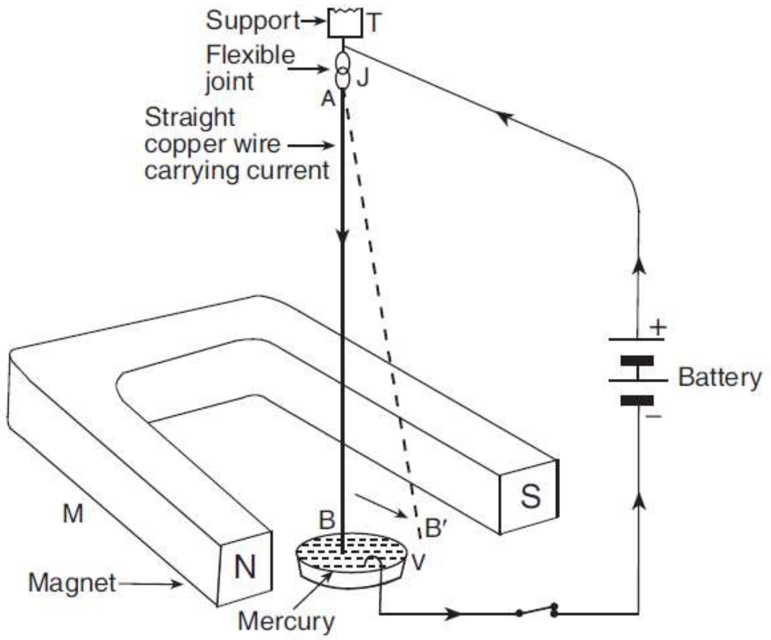
The magnetism produced inside the human body (by the flow of ionic currents) forms the basis of a technique called Magnetic Resonance Imaging (MRI) which is used to obtain images (or pictures) of the internal parts of our body.

---- End of Part 1 -----

FORCE ON CURRENT-CARRYING CONDUCTOR PLACED IN A MAGNETIC FIELD

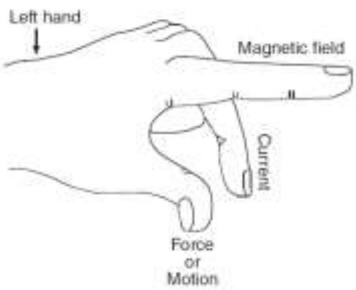
When a current-carrying conductor is placed in a magnetic field, a mechanical force is exerted on the conductor which can make the conductor move.

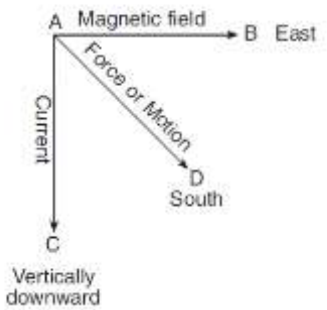
Experiment to Demonstrate the Force Acting on a Current-Carrying Conductor Placed in a Magnetic Field : **The Kicking Wire Experiment**



The direction of force acting on a current-carrying wire placed in a magnetic field is
(i) perpendicular to the direction of current, and (ii) perpendicular to the direction of magnetic field.
Note - the direction of force on a current-carrying conductor placed in a magnetic field can be reversed by reversing the direction of current flowing in the conductor.

Fleming's Left-Hand Rule for the Direction of Force





According to Fleming's left-hand rule : Hold the forefinger, the centre finger and the thumb of your left hand at right angles to one another. Adjust your hand in such a way that the forefinger points in the direction of magnetic field and the centre finger points in the direction of current, then the direction in which thumb points, gives the direction of force acting on the conductor.

Note - (i) By convention, the direction of flow of positive charges is taken to be the direction of flow of current. So, the direction in which the positively charged particles such as protons or alpha particles, etc., move will be the direction of electric current.

(ii) The direction of electric current is, however, taken to be opposite to the direction of flow of negative charges (such as electrons). So, if we are given the direction of flow of electrons, then the direction of electric current will be taken as opposite to the direction of flow of electrons.
(iii) The direction of deflection of a current-carrying conductor tells us the direction of force acting on it.

Sample Problem 1. A stream of positively charged particles (alpha particles) moving towards west is deflected towards north by a magnetic field. The direction of magnetic field is :
(a) towards south (b) towards east (c) downward (d) upward

Sample Problem 2. Think you are sitting in a chamber with your back to one wall. An electron beam moving horizontally from back wall towards the front wall is deflected by a strong magnetic field to your right side. What is the direction of magnetic field ?

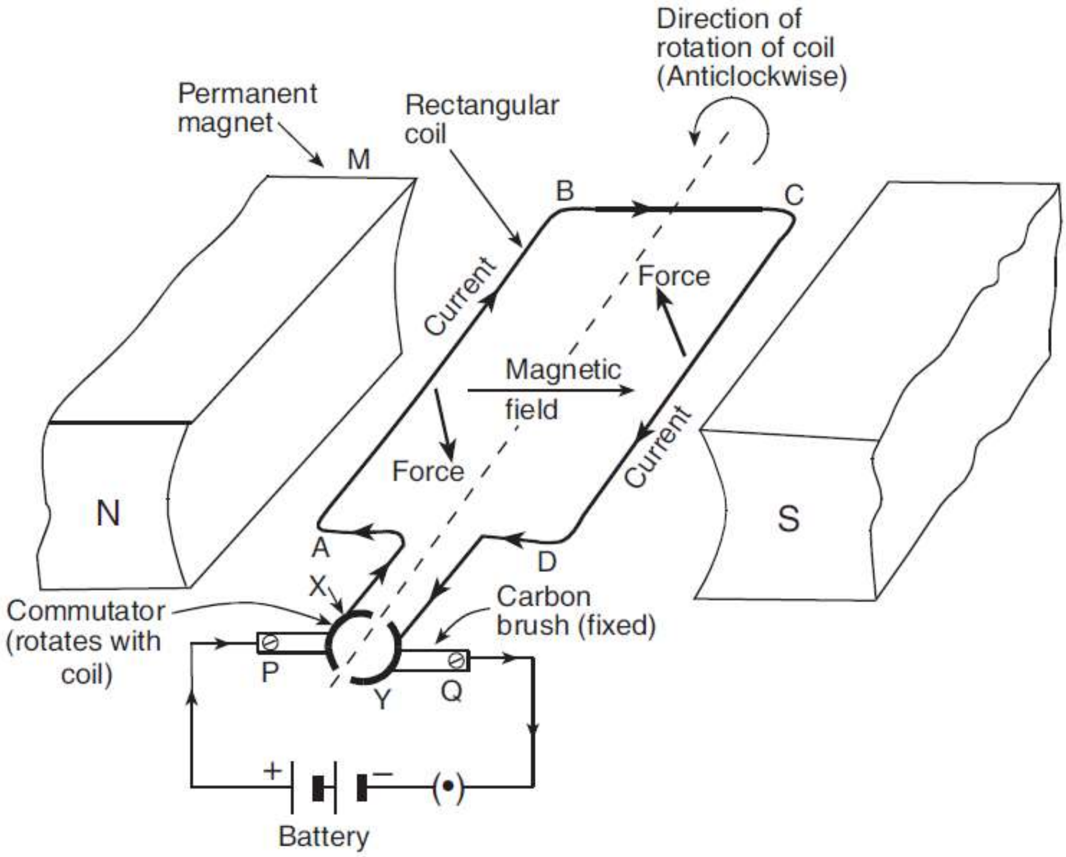
THE ELECTRIC MOTOR (DC motor)

Introduction A motor is a device which converts electrical energy into mechanical energy.
Uses - Electric motor is used in electric fans, washing machines, refrigerators, mixer and grinder, electric cars and many, many other appliances

Principle of a Motor

A motor works on the principle that when a rectangular coil is placed in a magnetic field and current is passed through it, a force acts on the coil which rotates it continuously.

Construction of a Motor



An electric motor consists of a rectangular coil ABCD of insulated copper wire, which is mounted between the curved poles of a horseshoe-type permanent magnet M in such a way that it can rotate freely between the poles N and S on a shaft. A device which reverses the direction of current through a circuit is called a commutator (or split ring). The two ends of the coil are soldered (or welded) permanently to the two half rings X and Y of a commutator.
The carbon brushes P and Q are fixed to the base of the motor and they press lightly against the two half rings of the commutator. The battery to supply current to the coil is connected to the two carbon brushes P and Q through a switch. The function of carbon brushes is to make contact with the rotating rings of the commutator and through them to supply current to the coil.

Working of a Motor
When an electric current is passed into the rectangular coil, this current produces a magnetic field around the coil. The magnetic field of the horseshoe-type magnet then interacts with the magnetic field of the current-carrying coil and causes the coil to rotate (or spin) continuously. The working of a motor will become more clear from 4 steps -
Suppose that initially the coil ABCD is in the horizontal position as shown in Figure. On pressing the switch, current from battery enters the coil through carbon brush P and commutator half ring X. The current flows in the direction ABCD and leaves via ring Y and brush Q.

(i) In the side AB of the rectangular coil ABCD, the direction of current is from A to B (see Figure). And in the side CD of the coil, the direction of current is from C to D (which is opposite to the direction of current in side AB). The direction of magnetic field is from N pole of the magnet to its S pole. By applying Fleming's left-hand rule to sides AB and CD of the coil we find that the force on side AB of the coil is in the downward direction whereas the force on side CD of the coil is in the upward direction. Due to this the side AB of the coil is pushed down and side CD of the coil is pushed up. This makes the coil ABCD rotate in the anticlockwise direction (see Figure).

(ii) While rotating, when the coil reaches vertical position, then the brushes P and Q will touch the gap between the two commutator rings and current to the coil is cut off. Though the current to the coil is cut off when it is in the exact vertical position, the coil does not stop rotating because it has already gained momentum due to which it goes beyond the vertical position.

(iii) After half rotation, when the coil goes beyond vertical position, the side CD of the coil comes on the left side whereas side AB of the coil comes to the right side, and the two commutator half rings automatically change contact from one brush to the other. So, after half rotation of the coil, the commutator half ring Y makes contact with brush P whereas the commutator half ring X makes contact with brush Q (see Figure). This reverses the direction of current in the coil. The reversal of direction of current reverses the direction of forces acting on the sides AB and CD of the coil. The side CD of the coil is now on the left side with a downward force on it whereas the side AB is now on the right side with an upward force on it. Due to this the side CD of the coil is pushed down and the side AB of coil is pushed up. This makes the coil rotate anticlockwise by another half rotation.

(iv) The reversing of current in the coil is repeated after every half rotation due to which the coil (and its shaft) continue to rotate as long as current from the battery is passed through it. The rotating shaft of electric motor can drive a large number of machines which are connected to it.

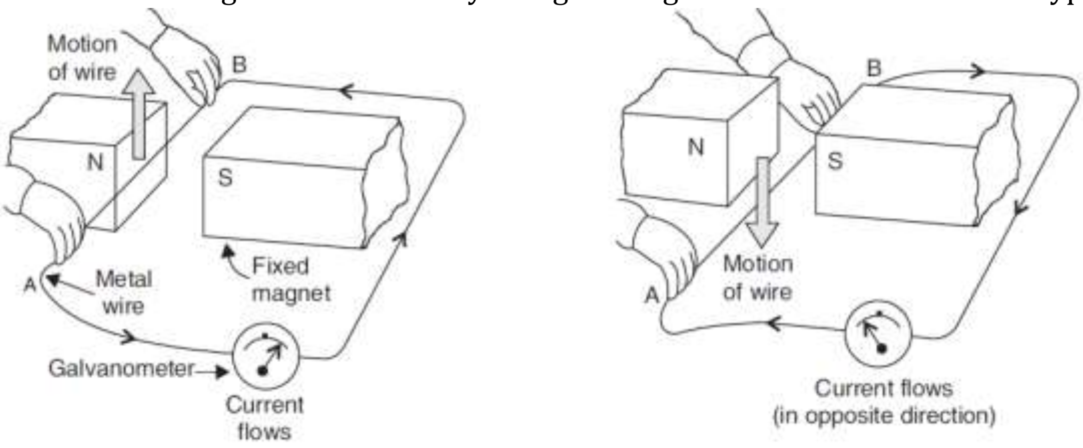
ELECTROMAGNETIC INDUCTION : ELECTRICITY FROM MAGNETISM

The production of electricity from magnetism is called electromagnetic induction.

A galvanometer is an instrument which can detect the presence of electric current in a circuit.

Experiment - 1

To Demonstrate Electromagnetic Induction by Using a Straight Wire and a Horseshoe–Type Magnet



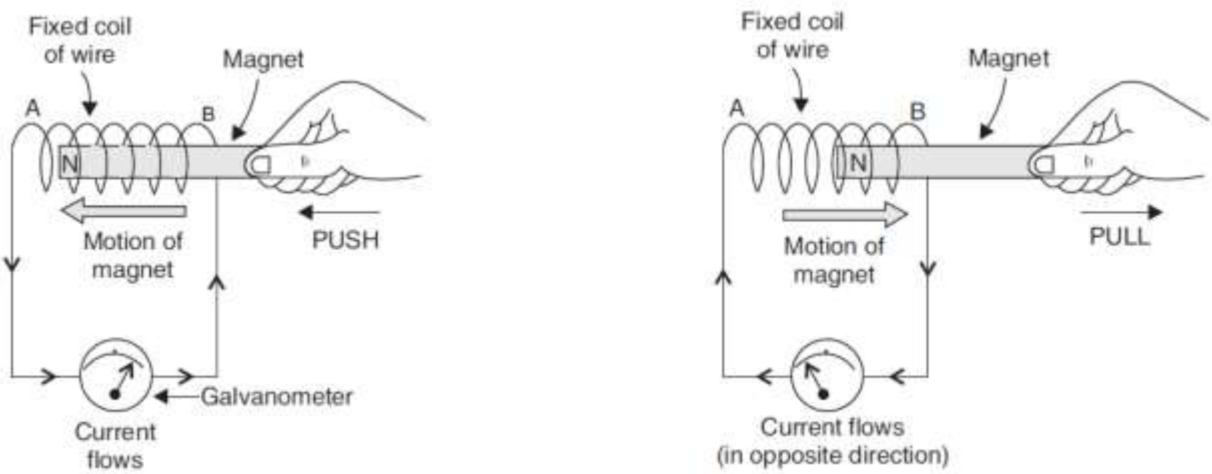
1. Let us move the wire AB upwards rapidly between the poles of the horseshoe magnet. When the wire is moved up, there is a deflection in the galvanometer pointer showing that a current is produced in the wire AB momentarily which causes the deflection in galvanometer. The deflection lasts only while the wire is in motion. Thus, as the wire is moved up through the magnetic field, an electric current is produced in it.

2. We now move the wire AB downwards rapidly between the poles of the horseshoe magnet. When the wire is moved down, the galvanometer pointer again shows a deflection, but in the opposite direction (to the left side). This means that when the wire is moved down in the magnetic field, even then an electric current is produced in it. But when the direction of movement of wire is reversed (from up to down), then the direction of current produced in the wire is also reversed.

If we move the wire AB up and down continuously between the poles of the horse-shoe magnet, then a continuous electric current will be produced in the wire. But the direction of this electric current will change rapidly as the direction of movement of the wire changes.

Experiment - 2

To Demonstrate Electromagnetic Induction by Using a Coil and a Bar Magnet



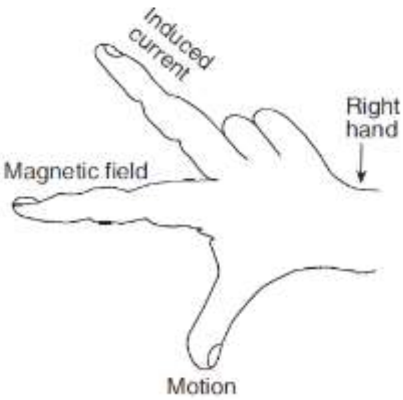
When a bar magnet is moved quickly into a fixed coil of wire AB, then a current is produced in the coil. This current causes a deflection in the galvanometer pointer. Similarly, when the magnet is moved out quickly from inside the coil, even then a current is produced in the coil.

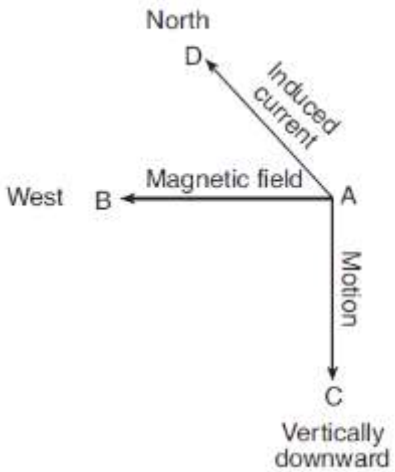
// the condition necessary for the production of electric current by electromagnetic induction is that there must be a relative motion between the coil of wire and a magnet.

Faraday and Henry made the following observations about electromagnetic induction :
1. A current is induced in a coil when it is moved (or rotated) relative to a fixed magnet.
2. A current is also induced in a fixed coil when a magnet is moved (or rotated) relative to the fixed coil.
3. No current is induced in a coil when the coil and magnet both are stationary relative to one another.
4. When the direction of motion of coil (or magnet) is reversed, the direction of current induced in the coil also gets reversed.
5. The magnitude of current induced in the coil can be increased :
(a) by winding the coil on a soft iron core,
(b) by increasing the number of turns in the coil,
(c) by increasing the strength of magnet, and
(d) by increasing the speed of rotation of coil (or magnet).

Fleming's Right-Hand Rule for the Direction of Induced Current

Fleming's right-hand rule : Hold the thumb, the forefinger and the centre finger of your right-hand at right angles to one another. Adjust your hand in such a way that forefinger points in the direction of magnetic field, and thumb points in the direction of motion of conductor, then the direction in which centre finger points, gives the direction of induced current in the conductor.

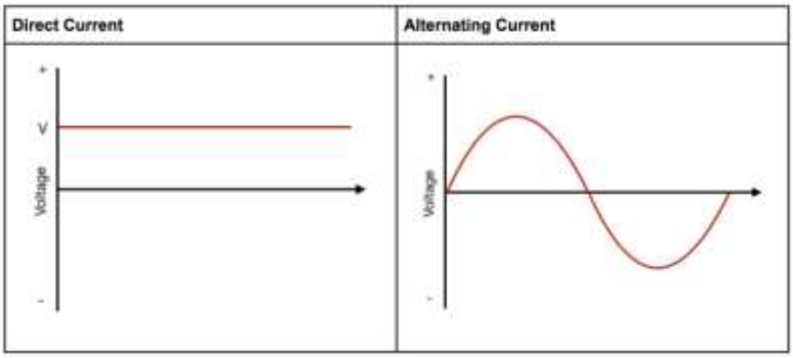




Direct Current and Alternating Current

If the current flows in one direction only, it is called a direct current. Direct current is written in short form as D.C. (or d.c.) The current which we get from a cell or a battery is direct current because it always flows in the same direction. The positive (+) and negative (–) polarity of a direct current is fixed. Some of the sources of direct current (or d.c.) are dry cell, dry cell battery, car battery and d.c. generator.

If the current reverses direction after equal intervals of time, it is called alternating current. Alternating current is written in short form as A.C. (or a.c.). Most of the power stations in India generate alternating current. The alternating current produced in India reverses its direction every 1/100 second. Thus, the positive (+) and negative (−) polarity of an alternating current is not fixed. Some of the sources which produce alternating current (or a.c.) are powe house generators, car alternators and bicycle dynamos.



ELECTRIC GENERATOR

The electric generator converts mechanical energy into electrical energy.

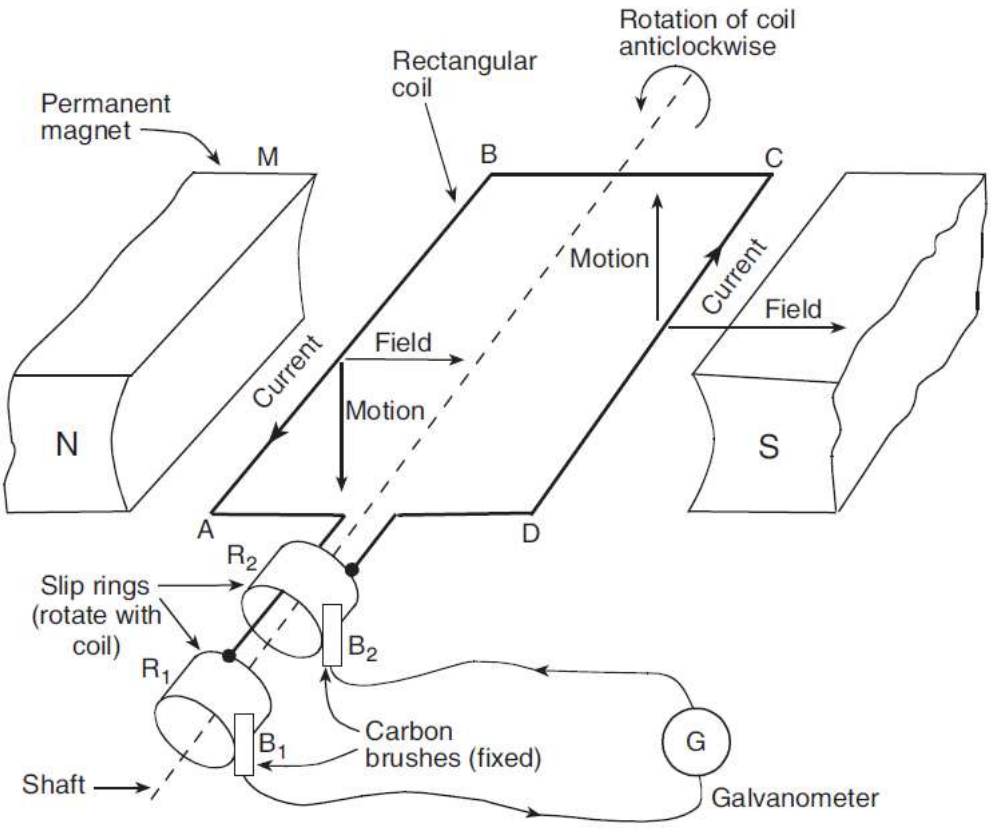
Principle of Electric Generator

The electric generator works on the principle that when a rectangular Coil is moved in a magnetic field, then current is induced in the conductor.

Electric generators are of two types :

1. Alternating Current generator (A.C. generator),
2. Direct Current generator (or D.C. generator)

<u>A.C. GENERATOR</u>



Construction of an A.C. Generator

A simple A.C. generator consists of a rectangular coil ABCD which can be rotated rapidly between the poles N and S of a strong horseshoe-type permanent magnet M (see Figure 32). The coil is made of a large number of turns of insulated copper wire. The two ends A and D of the rectangular coil are connected to two circular pieces of copper metal called slip rings R1 and R2. As the slip rings R1 and R2 rotate with the coil, the two fixed pieces of carbon called carbon brushes, B1 and B2, keep contact with them. So, the current produced in the rotating coil can be tapped out through slip rings into the carbon brushes. The outer ends of carbon brushes are connected to a galvanometer to show the flow of current in the external circuit (which is produced by the generator).

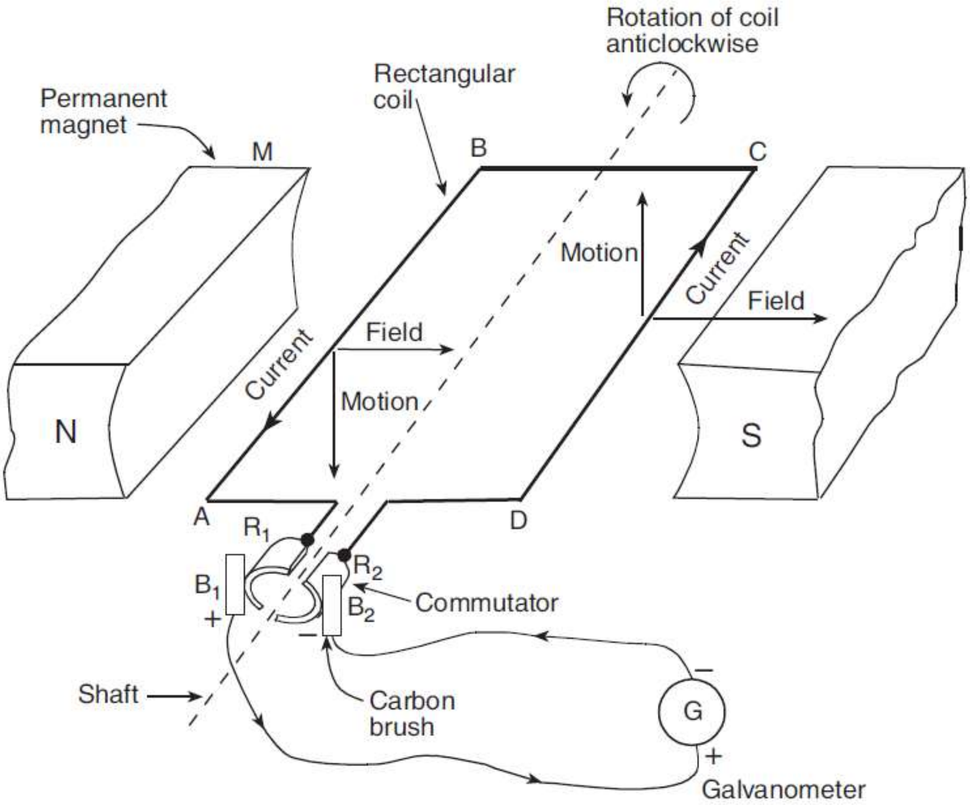
Working of an A.C. generator

(i) As the coil rotates in the anticlockwise direction, the side AB of the coil moves down cutting the magnetic field lines near the N-pole of the magnet, and side CD moves up, cutting the magnetic field lines near the S-pole of the magnet (see Figure). Due to this, induced current is produced in the sides AB and CD of the coil. On applying Fleming's right-hand rule to the sides AB and CD of the coil, we find that the currents are in the directions B to A and D to C. Thus, the induced currents in the two sides of the coil are in the same direction, and we get an effective induced current in the direction BADC (see Figure). Thus, in the first half revolution (or rotation) of coil, the current in the external circuit flows from brush B1 to B2.

(ii) After half revolution, the sides AB and CD of the coil will interchange their positions. The side AB will come on the right hand side and side CD will come on the left side. So, after half a revolution, side AB starts moving up and side CD starts moving down. As a result of this, the direction of induced current in each side of the coil is reversed after half a revolution giving rise to the net induced current in the direction CDAB (of the reversed coil). The current in the external circuit now flows from brush B2 to B1.

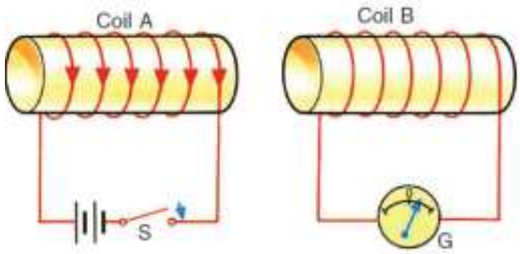
D.C. GENERATOR

if we replace the slip rings of an A.C. generator by a commutator, then it will become a D.C. generator.

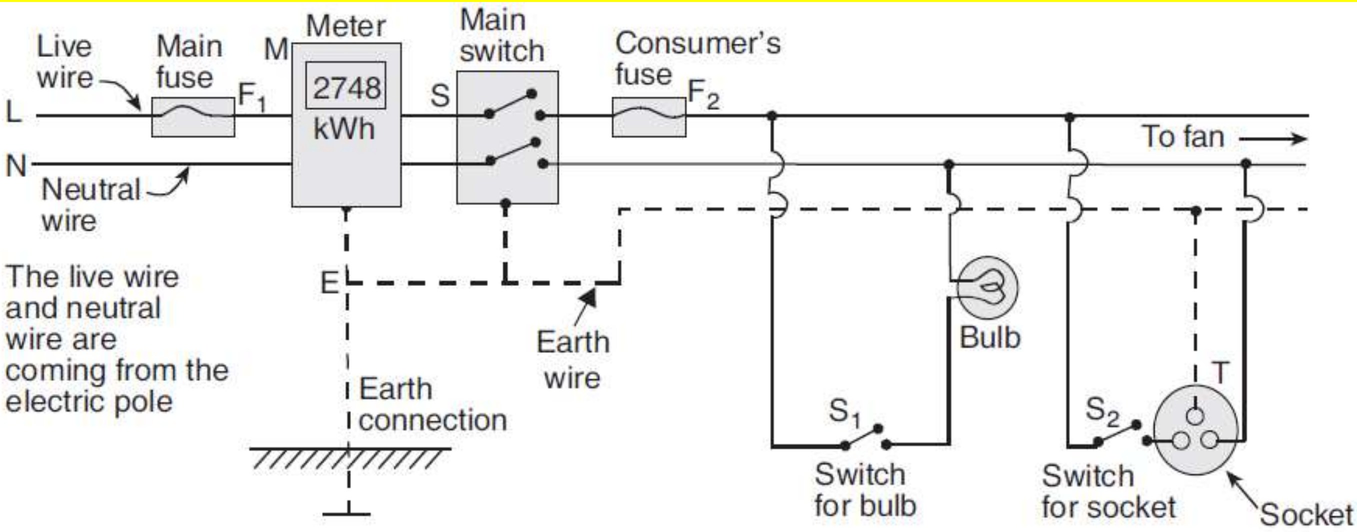


Electromagnetic Induction Using Two Coils

if current is changed in one coil, then current is induced in the other coil kept near it.



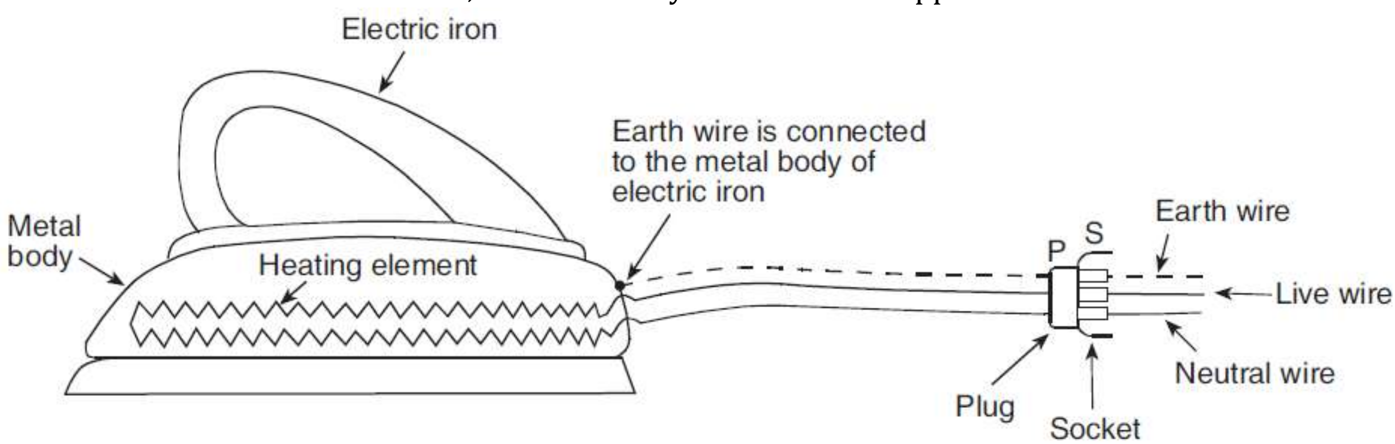
DOMESTIC ELECTRIC CIRCUITS (OR DOMESTIC WIRING)



Note - In order to distinguish between the live wire, neutral wire and earth wire, the wire having red plastic covering is made live wire, the wire having black plastic covering is made neutral wire, and the wire having green plastic covering is made earth wire.

Earthing of Electrical Appliances

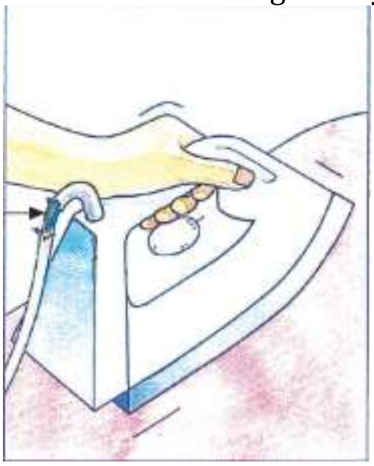
To avoid the risk of electric shocks, the metal body of an electrical appliance is "earthed".



Electric Fuse

An extremely large current can flow in domestic wiring under two circumstances : short circuiting and overloading.

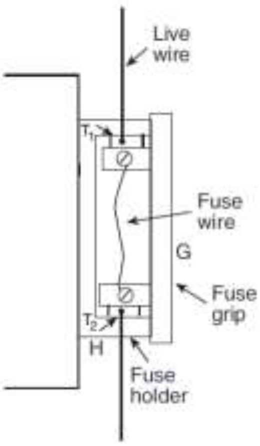
(i) Short Circuiting - If the plastic insulation of the live wire and neutral wire gets torn, then the two wires touch each other. This touching of the live wire and neutral wire directly is known as short circuit. When the two wires touch each other, the resistance of the circuit so formed is very, very small. Since the resistance is very small, the current flowing through the wires becomes very large and heats the wires to a dangerously high temperature, and a fire may be started.

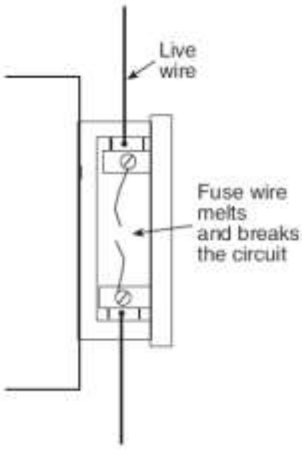


(ii) Overloading

If too many electrical appliances of high power rating (like electric iron, water heater, air conditioner, etc.,) are switched on at the same time, they draw an extremely large current from the circuit. This is known as overloading the circuit. Overloading can also occur if too many appliances are connected to a single socket. Now, due to an extremely large current flowing through them, the copper wires of household wiring get heated to a very high temperature and a fire may be started.

A fuse is a safety device having a short length of a thin, tin-plated copper wire having low melting point, which melts and breaks the circuit if the current exceeds a safe value. The thickness and length of the fuse wire depends on the maximum current allowed through the circuit. An electric fuse works on the heating effect of current.





Fuses are used to protect the individual domestic electrical appliances from damage which may be caused due to excessive current flow through them.

Sample Problem 1. An electric oven of 2 kW power rating is operated in a domestic electric circuit (220 V) that has a current rating of 5 A. What result do you expect ? Explain.

Sample Problem 2. A circuit has a fuse of 5 A. What is the maximum number of 100 W (220 V) bulbs that can be safely used in the circuit ?

Hazards of Electricity (or Dangers of Electricity)

1. If a person happens to touch a live electric wire, he gets a severe electric shock. In some cases, electric shock can even kill a person.
2. Short-circuiting due to damaged wiring or overloading of the circuit can cause electrical fire in a building.
3. The defects in the household wiring like loose connections and defective switches, sockets and plugs can cause sparking and lead to fires.

----- End of Chapter-----