1. PROPERTY OF MAGNETISM

It was seen that certain ores could attract bits of iron and they always pointed in a particular direction when suspended freely. These ores were named as Magnetite.
This property of attracting small pieces of iron is referred to as Magnetism.
Therefore, a Magnet is a substance, which has both attractive and directive properties. Magnet is also known as Lodestone and it is chemically the oxide of iron (Fe_3O_4).

2. TYPES OF MAGNETS

Magnets are of two types:

2.1 NATURAL MAGNETS

They are weak and mostly irregular in shape.

2.2 ARTIFICIAL MAGNETS

When natural magnets are rubbed against iron or steel bars, the same property of attraction is communicated to these bars. They can be strong and have any desired shape and length.

2.3.1 Types of artificial magnets

(a) **Bar Magnets:** They may be cylindrical or rectangular in shape.
(b) **Magnetic Needle:** It is in the form of an elongated rhombus. The pole regions almost contract to the points at the ends of the needle while the remaining region is a neutral zone. The magnetic needle is either pivoted to a nail or suspended so that it can rotate freely.
(c) **Magnetic compass:** It is a compact form of magnetic needle, which is pivoted at the center of a small box, made of brass having a glass top.
The north pole of this needle is generally painted red.

Use of Magnetic Compass

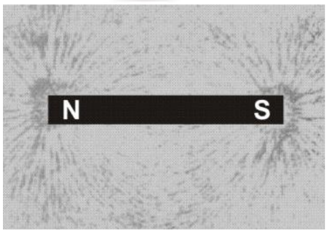
(i) To check the polarity of a magnet.
(ii) To find the direction of magnetic field.
(iii) To find the magnetic north-south direction.

3. MAGNETIC FIELD AND MAGNETIC FIELD LINES

All magnets have a space around them in which the force of attraction and repulsion can be detected. This space is known as **magnetic field.** We can describe the magnetic field around a magnet by Magnetic field lines. These are the curved paths along which magnetic force is acting on them in the magnetic field of the bar magnet. These lines are called **magnetic lines of forces.**

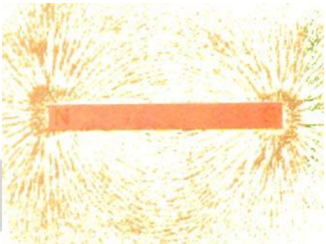
3.1 MAGNETIC FIELD LINES

To know the magnetic lines of forces, place a magnet on a cardboard sheet and gently sprinkle some iron filings uniformly over it. The iron filings are found to arrange themselves in a pattern.



3.2 TRACING MAGNETIC FIELD LINES OF A BAR MAGNET USING A MAGNETIC COMPASS

Take a paper sheet and fix it on a drawing board by pins. Place a bar magnet and mark its boundary. Now place a small compass needle close to South Pole of the magnet and mark two pencil dots at two ends of the needle. Now move the compass is such a manner that one end (N) of the needle coincides with the second pencil dot. Mark the position of the other end(s) with a dot. Repeat this process of moving the needle and marking dots at its two ends till its South Pole reaches the North Pole of the magnet. Get a smooth curve by joining the dots. This smooth curve represents a magnetic field line. By repeating the above process from the same pole of the magnet but different points, other magnetic field lines can be traced.



3.3 PROPERTIES OF MAGNETIC FIELD LINES

1. A magnetic field line is directed from North Pole to South Pole **outside** the magnet.
2. A magnetic field line is a closed and continuous curve. (We have not shown magnetic field lines inside the magnet where these are directed from South Pole to North Pole).
3. The magnetic field lines are crowded near the pole where the **magnetic field is strong** and are far apart near the middle of the magnet and far from the magnet where the **magnetic field is weak.**
4. The magnetic field lines never intersect each other because if they do so, these would be two directions of magnetic field at that point, which is not possible.
5. In case the field lines are parallel and equidistant, these represent a **uniform magnetic field.** The Earth's magnetic field is uniform in a limited space.

3.4 OERSTED DISCOVERY-EXPERIMENTAL EVIDENCE OF RELATION BETWEEN ELECTRICITY AND MAGNETISM

It was thought that electricity and magnetism have no relationship with each other. When current-carrying conductor was placed parallel to the axis of the needle and the needle was deflected, it was much against expectations. On reversing the direction of current, the needle moved in the opposite direction. On further investigation, Oersted found that the direction of deflection of the needle depended not only on the direction of current but also on whether the conductor was above or below the needle. Thus, a great discovery in the history of electricity and magnetism was made purely by accident.

Oersted experiment demonstrated that **around every conductor carrying an electric current, there is a magnetic field.** In other words, we can produce magnetism from electric current.

3.5 AMPERE'S SWIMMING RULE

Let the observer imagine himself to be swimming along the conductor in the direction of the current and facing the magnetic needle, then the North Pole of the needle will be deflected towards his left hand.

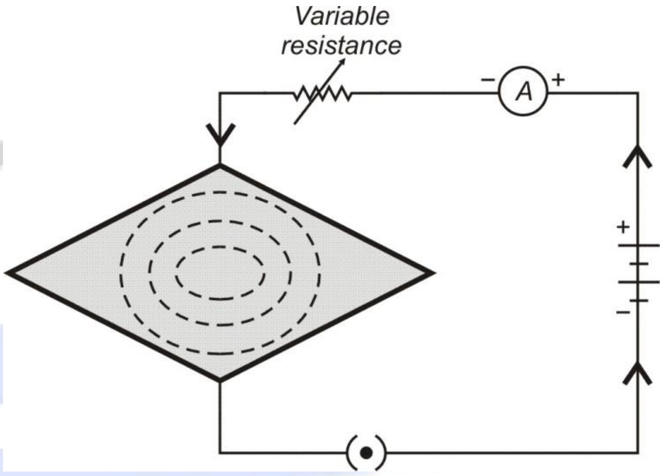
3.6 MAGNETIC FIELD DUE TO A CURRENT-CARRYING STRAIGHT CONDUCTOR

When a current is passed through a straight conductor (conducting wire), a magnetic field is produced around it. This magnetic field can be traced by means of iron filings or a small compass needle as we have done in case of a bar magnet.

Take a thick straight conductor (copper wire) *XY* and pass it through the centre *O* of a thick cardboard. Connect the ends of the conductor to the terminals of a battery through a rheostat *Rh*, a key *K* and an ammeter *A* so that the current flows from *Y* to *X*. When we sprinkle some iron filings on the cardboard, these arrange themselves in concentric circles around O, when the cardboard is gently tapped. These concentric circles represent the magnetic field lines. This shows that **there exists a magnetic field around a straight current-carrying conductor and it is in the form of concentric circular field lines with the conductor at the centre.**

In order to know the direction of the magnetic lines, we plot the field lines with the help of a compass needle. **The North Pole of the compass points in the direction of the field at any point (say P).** The direction of these field lines is anticlockwise as shown in figure.

Diagram showing magnetic field lines of a straight current carrying conductor.

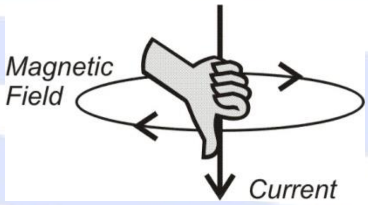


If the direction of the current is reversed so that the current flows from *X* to *Y*, the direction of the field lines is also reversed, i.e., these field lines are clockwise as shown in figure.

3.6.1 Direction of magnetic field: right-hand thumb rule

To find the direction of magnetic field due to a straight current-carrying conductor, we use the Right-Hand thumb rule. **Imagine the straight conductor in your right hand such that the thumb points in the direction of current. The direction of curling of fingers of the right hand gives the direction of magnetic field lines.**

Right hand thumb rule



3.7 MAGNITUDE (*B*) OF MAGNETIC FIELD

1. If the current (*I*) in the conductor *XY* is **increased,** the deflection of the needle of the compass (used for mapping the field) also **increased.** Since deflection of the compass is a measure of *B*, it is clear that magnetic field (*B*), increases with the increase in current (*I*), i.e.,

   $$\boldsymbol{B \propto I} \qquad \text{... (i)}$$

2. If the distance (*r*) of the compass from the conductor is **increased,** the deflection of the needle **decreases,** i.e.,

   $$\boldsymbol{B \propto \frac{1}{r}} \qquad \text{... (ii)}$$

3. Combing (i) and (ii), we get

   $$\boldsymbol{B \propto \frac{I}{r}} \qquad \text{... (iii)}$$

3.7.1 Unit of magnetic field

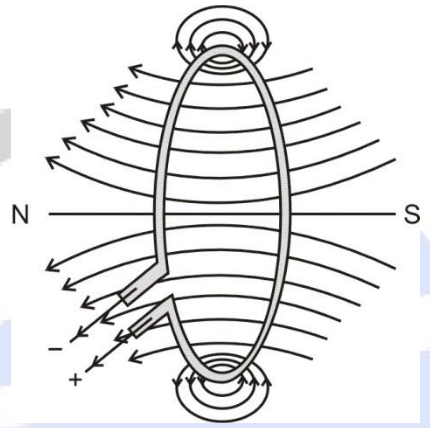
When current (*I*) is measured in ampere (*A*) and distance (*r*) in metre (*m*), magnetic field (*B*) is expressed in a unit named **tesla (T)**.

3.8 MAGNETIC FIELD DUE TO A CURRENT-CARRYING CIRCULAR COIL

Soon after Oersted's discovery of magnetic effect of a current-carrying wire, Ampere found that a loop of wire also had a magnetic field.

In order to find the magnetic field due to a coil, it is held in a vertical plane and is made to pass through a smooth cardboard in such a way that the centre (*O*) of the coil lies at the cardboard. A current is passed through the coil and iron filings are sprinkled on the cardboard. These iron filings arrange themselves in a pattern similar to one shown in the figure.

Current carrying circular coil



3.8.1 Conclusions

1. The **magnetic field lines near the coil are nearly circular and concentric.** This is due to the reason that the segments of the coil in contact with the board at the points *A* and *B* are almost like straight conductors. The direction of the field lines can also be found by applying Right-Hand Thumb Rule.
2. The field lines are in the same direction in the space enclosed by the coil.
3. Near the centre of the coil, the field lines are nearly straight and parallel. As such **the magnetic field at the centre of the coil can be taken to be uniform.**
4. The direction of the magnetic field at the centre is perpendicular to the plane of the coil.
5. As we move towards the centre of the coil, the strength of magnetic fields (one due to the semicircular segment of the coil through A and the other due to the semicircular segment through B assist each other.

3.8.2 Direction of magnetic field: clock rule

In the above case, on testing with a compass, it is found that the front face of the coil is a South Pole and its back face is a North Pole.

Looking at the face of the coil, if the current around that face is in clockwise direction, the face is the South Pole; while if the current around that face is in the anticlockwise direction, the face is the North Pole.

The rule can be remembered with the help of the following tip shown in the figure.

3.8.3 Magnitude (B) of magnetic field

The magnitude of the magnetic field (*B*) at the centre of the coil is

1. Directly proportional to the current (*I*) flowing through it, i.e.,

$B \propto I$ ... (i)

2. Inversely proportional to the radius (*r*) of the coil, i.e.,

$$B \propto \frac{1}{r} \quad \text{... (ii)}$$

3. Directly proportional to the total number of turns (*N*) in the coil, i.e.,

$B \propto N$ ... (iii)

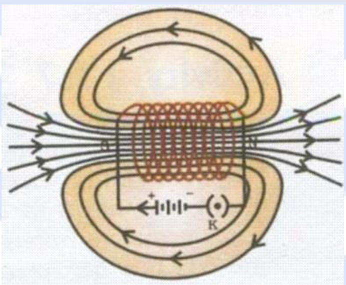
This is due to the reason that the current in all the circular turns of the coil is in the same direction. As such, the resultant magnetic field due to the coil is equal to the sum of the fields due to all these turns.

Combining (i), (ii) and (iii), we obtain

$$B \propto \frac{NI}{r} \quad \text{... (iv)}$$

3.9 MAGNETIC FIELD DUE TO A CURRENT-CARRYING SOLENOID

An insulated copper wire wound on a cylindrical cardboard (or plastic) tube such that its length is greater than its diameter is called a solenoid. The solenoid is from Greek word for "channel". To obtain the pattern of magnetic field due to a solenoid, cut a slit in a hard cardboard in such a way that the length of the slit is equal to the length of the solenoid and the width of the slit is equal to the diameter of the solenoid. Fix the solenoid (AB) in the slit in such a manner that the axis of the solenoid is in the plane of the cardboard. The ends of the solenoid are connected to a battery through a rheostat (*Rh*) and a key (*K*). Sprinkle iron filings on the board after passing current through the solenoid. On tapping the board, the iron filings arrange themselves in the pattern similar to one shown in figure. The magnetic field lines can also be mapped with the help of a compass needle. The arrows on the field lines are marked in the direction in which the North Pole of the compass needle points, as shown in the figure.



Solenoid

3.9.1 Conclusions

1. The magnetic field lines inside the solenoid are nearly straight and parallel to its axis. Thus, **the magnetic field inside a solenoid is uniform.**
2. The magnetic field lines are exactly identical to those due to a cylindrical bar magnet with one end of the solenoid acting as a South Pole and its other end as a North-Pole. Thus, **a current-carrying solenoid behaves like a bar magnet with fixed polarities at its ends.**

As a result of this:

(i) A current-carrying solenoid, when freely suspended, sets itself in the North South direction exactly in the same manner as a bar magnet does i.e. it acquires the directive property of a bar magnet.

(ii) **A current-carrying solenoid acquires the attractive property of a bar magnet.** As such, iron filings are attracted to it when these are brought near it.

3.9.2 Direction of Magnet Field

The end of the current-carrying solenoid at which the current flows anticlockwise behaves as a North

Pole while that end at which the direction of current is clockwise behaves as a South Pole as shown in figure. This is according to the clock rule, which has earlier been stated.

3.9.3 Magnitude of magnetic field (*B*)

The magnitude of the magnetic field inside the solenoid is

(i) Directly proportional to the current (I) flowing through the solenoid, i.e.,

$B \propto I$ ... (i)

(ii) Directly proportional to the number of turns per unit length of the solenoid (*n*) and not on the total number of turns on the solenoid, i.e.

$B \propto n$ ... (ii)

($n = \frac{N}{l}$, where N is the total number of turns in the solenoid and *l* is its length)

Combining (i) and (ii),

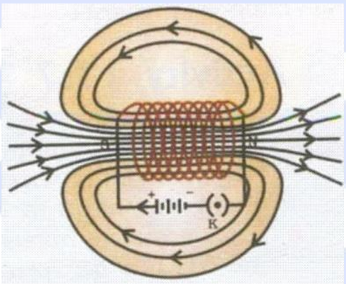
$B \propto nI$ ... (iii)

4. ELECTROMAGNETS AND PERMANENT MAGNETS

4.1 ELECTROMAGNET

An electromagnet is a temporary strong magnet and is just a solenoid with it's winding on a soft iron core.

An electromagnet consists of a soft iron core AB placed inside a solenoid. The current in the solenoid can be adjusted with a rheostat *Rh* in the circuit having a battery and a key, *K* as shown in figure. An electromagnet acquires the magnetic properties only when an electric current is passed through the solenoid. Once the current is switched off, it almost loses its magnetic properties as the retentivity (the ability to retain magnetism) of soft iron is very low. The **strength of the electromagnet** depends upon:



In order to provide a strong magnetic field in a small region, an electromagnet is made in the U-shape as shown in figure. Such a magnet is called a **horse-shoe magnet.**

4.1.1 Uses of Electromagnets

(i) Electromagnets are used in electrical devices such as an electric bell, an electric fan, telegraph, an electric train, an electric motor, generator etc.

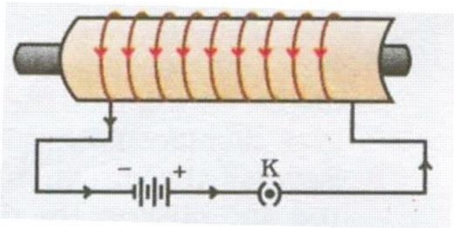
(ii) For lifting and transporting large masses of iron in the form of girders.

(iii) In medical practice for removing pieces of iron from wounds.

4.2 PERMANENT MAGNET

A permanent magnet is made from steel. As steel has more retentivity than iron, it does not lose its magnetism easily.

A steel bar is placed inside a solenoid AB and the current is switched on and off with help of key K, figure. On removing and testing the bar, it is found to be magnetised. It is of no use to pass the current through the solenoid for a long time because the bar will not be magnetised beyond a certain limit. On the other hand, the solenoid may be damaged due to overheating.



Apart from different varieties of steel (carbon steel, chromium steel, cobalt and tungsten steel), some alloys like **Alnico** (Aluminium, Nickel. Cobalt alloy of iron) and **Nipermag** (an alloy of iron, nickel, aluminum and titanium) are used to make very strong permanent magnets.

4.2.1 Uses of Permanent Magnets

Permanent magnets are used in

(i) Electric meters (galvanometers, voltmeters, ammeters, speedometers etc.)
(ii) Microphones and loudspeakers and
(iii) Electric clocks.

4.3 DIFFERENCE BETWEEN AN ELECTROMAGNET AND A PERMANENT MAGNET

ELECTROMAGNET	PERMANENT MAGNET
1. An electromagnet is a temporary magnet as it can readily be demagnetised by stopping the current through the solenoid.	1. A permanent magnet cannot be readily demagnetised.
2. An electromagnet produces a strong magnetic field whose strength can be changed by changing the current through the solenoid.	2. The magnetic field of a permanent magnet is comparatively weak and its strength cannot be changed.
3. The polarity of an electromagnet can easily be reversed by changing the direction of current through the solenoid.	3. The polarity of a permanent magnet is fixed and cannot be easily reversed.

5. FORCE ACTING ON A CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD

Oersted discovered that a current-carrying conductor exerts a force on a compass needle (i.e. a magnet). Andre Ampere suggested that the reverse should also be true i.e. a magnet must also exert an equal and opposite force on current-carrying conductor, which was experimentally found to be true. **When a current-carrying conductor is placed in a magnetic field, it experiences a force, except when it is placed parallel to the magnetic field.**

The force acting on a current-carrying conductor in a magnetic field is due to interaction between:

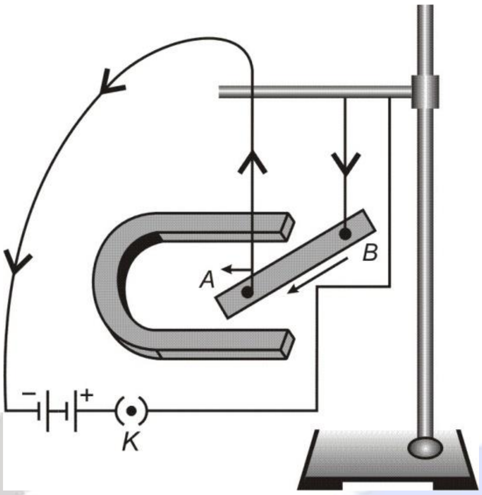
(i) magnetic field due to current-carrying conductor and
(ii) external magnetic field in which the conductor is placed.

The resultant of these two magnetic fields is not uniform. It is weaker on one side of the conductor than on its other side. The conductor, therefore, experiences a resultant force in the direction of the weaker magnetic field.

5.1 THE KICKING WIRE EXPERIMENT

The experiment illustrated in figure has been designed to show the relation between:

(a) direction of force acting on a wire (i.e., a conductor) carrying current.
(b) direction of current flowing through it and
(c) direction of the magnetic field in which the wire is placed.



A straight wire with connection at its upper end hangs between the poles of U-shaped magnet and its lower end dips in a small pool of mercury in a depression cut in a piece of wood. An electric circuit is provided so that the current can be adjusted to the minimum value (with the help of a rheostat, *Rh*) required for the working of the experiment because a large current results in the heating of the wire. The following observations are made.

(i) When the key *K* is closed, the current flows downwards and the hanging wire swings forwards (shown by dotted line). This causes the wire to leave contact with mercury and break the circuit. When the wire falls back to its original position, it remakes contact with mercury and the action is repeated.

(ii) On reversing the battery connections, the current in the wire flows upwards and it swings backwards out of mercury.

(iii) The direction of force on the wire is also reversed if the direction of the magnetic field is reversed. The direction of the magnetic field can be reversed by turning the magnet over, i.e., by interchanging the positions of north and south poles of the magnet.

(iv) In case the wire is placed parallel to the magnetic field, it experiences no force.

5.2 MAGNITUDE OF FORCE

It has experimentally been found that the force (*F*) acting on a current-carrying conductor placed in a magnetic field in a direction perpendicular to the direction of magnetic field is:

(i) directly proportional to the current (I) flowing through the conductor, i.e.,

$F \propto I$ ... (i)

(ii) directly proportional to the length (*l*) of the conductor inside the magnetic field, i.e.,

$F \propto \ell$ ... (ii)

(iii) directly proportional to the magnitude (B) of the magnetic field, i.e.,

$F \propto B$ ... (iii)

Combining (i), (ii) and (iii), we get

$F \propto I \ell B$

or $F = K I \ell B$

where *k* is a constant of proportionally. In SI units, *k* = 1.

Thus, $F = I \ell B$ ... (iv)

5.2.1 Unit of B (magnetic filed)

As stated earlier, the SI unit of *B* is called tesla (T).

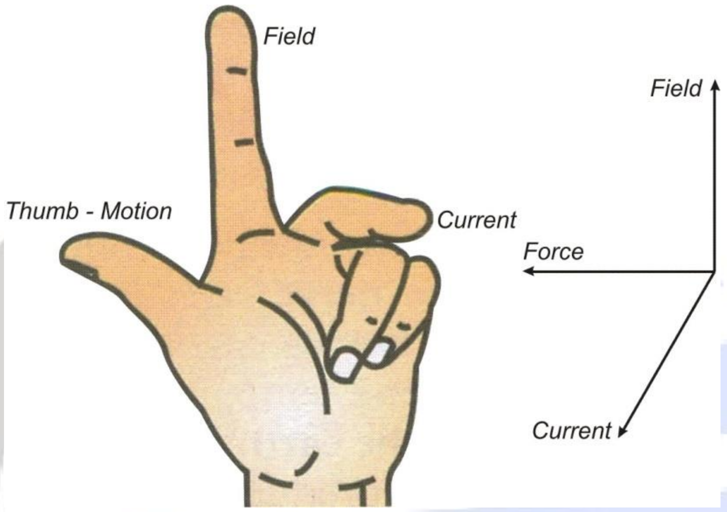
In case, I = 1 ampere, l = 1 metre and F = 1 newton, B = 1 tesla. Thus,

The magnitude of magnetic field is 1 tesla (T) if a conductor of length 1 metre (m) carrying a current of 1 ampere (A) experiences a force of 1 newton (N) when placed perpendicular to the direction of magnetic field.

5.2.2 Direction of Force

From the experiment described above, it is noticed that initially, the current, the magnetic field and the direction of the force on the wire, all three are mutually at right angles to each other.

5.2.3 Fleming Left-Hand Rule (Motor Rule)



Stretch the thumb, the first finger and the central finger of the left hand so that they are mutually perpendicular to each other. If the first (fore) finger points in the direction of the magnetic field, the central finger points in the direction of current, then the thumb points in the direction of motion of the conductor (i.e., direction of force on the conductor).

6. FORCE ACTING ON A CHARGE MOVING IN A MAGNETIC FIELD

We have just learnt that a current-carrying conductor experiences a force when placed in a magnetic field. But we know that current is due to charges in motion. Thus, it is clear that **a charge moving in a magnetic field experiences a force, except when it is moving in a direction parallel to it.**

6.1 DIRECTION OF FORCE

Since the direction of current is the same as that of the motion of a positive charge, the direction of force acting on it, when moving perpendicular to direction of magnetic field, is the same as that acting on a current-carrying conductor placed perpendicular to the direction of magnetic field. The direction of force is given by **Fleming's left-hand rule.** Obviously, the force acting on a negative charge moving in a direction perpendicular to the magnetic field is opposite to that acting on a positive charge.

6.2 CONSEQUENCES OF EFFECT OF MAGNETIC FIELD ON MOVING CHARGES

1. The effect of magnetic field on moving charges has been used to build machines, called **particle accelerators** (e.g., cyclotron etc.). These machines accelerate charged particles (like protons etc.) to give them very high kinetic energies. These high-energy particles are used to study the structure of the atom.
2. We know that the Earth has a magnetic field around it. High energy charged particles coming from the Sun in the form of cosmic rays, experience a force when these enter the Earth's magnetic field. Near the equator of the Earth, these particles are trapped in certain regions, called **Van Allen Belts,** after the name of American physicist, **James Van Allen** who discovered them in 1958 using satellites.

6.3 CHARACTERISTIC OF MAGNETIC FORCE

1. Magnetic force acts only on moving charges and not on stationary charges.
2. No magnetic force acts on a charge if it is moving along the direction of the magnetic field.
3. The direction of magnetic force is perpendicular to
   (i) the direction of velocity of the charge and
   (ii) the direction of the magnetic field.
4. The magnetic force (F) depends on the charge (q), velocity (v) and the strength (B) of the magnetic field i.e. $F = q\,v\,B$ (in case the direction of v is perpendicular to the direction of B).
5. The magnetic force (F) acting on a current-carrying conductor placed perpendicular to the direction of magnetic field (B) is given by $F = \ell I B$.

   where I is the current flowing in the conductor, ℓ is its length in the magnetic field.

7. DIFFERENCE BETWEEN ELECTRIC FORCE AND MAGNETIC FORCE

1. Magnetic force is always perpendicular to the magnetic field whereas electric force is collinear (i.e., along the same line) with the electric field.
2. Magnetic force is velocity dependent, i.e., it acts only when the charge of particle is in motion whereas electric force is independent of the state of rest or of motion of the charged particle.
3. Magnetic force does no work when the charged particle is displaced while electric force does work in displacing the charged particle.
4. Magnetic force (F_m) is much weaker than the electric force (F_e), i.e., F_M/F_e is negligibly small (around 10^{-25}).

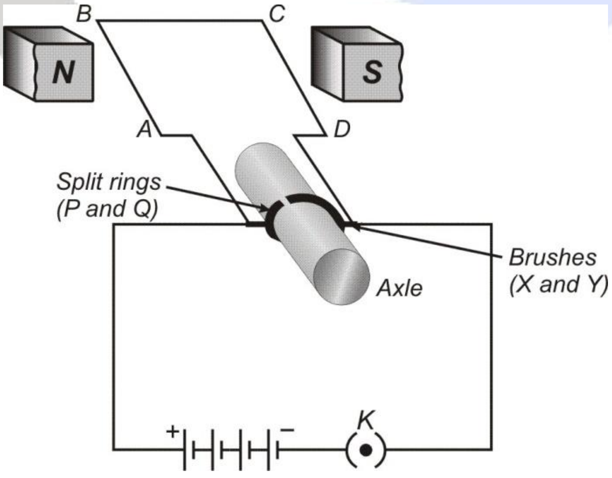
8. ELECTRIC MOTOR (DC MOTOR)

An electric motor is a device for converting electric energy into mechanical energy. Thus, an electric motor is the reverse of an electric generator.

There are two types of electric motors:

(i) AC motor and

(ii) DC motor. We shall here be describing DC motor. The principle of a DC motor is very much different from that of an AC motor. It is important to remember that all the electric appliances like fan, air-conditioner, coolers, washing machines, mixers and blenders work on AC (house-hold power supply) and as such have AC motors installed in them.



8.1 PRINCIPLE

When a coil carrying current is placed in a magnetic field, it experiences a torque. As a result of this torque, the coil begins to rotate.

8.2 CONSTRUCTION

It consists of the following five parts:

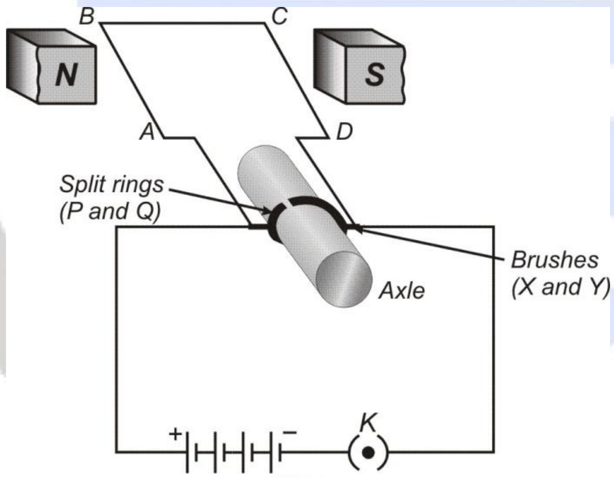
1. **Armature:** The armature *ABCD* consists of a large number of turns of insulated copper wire wound over a soft iron core.
2. **Field Magnet:** The magnetic field (*B*) is supplied by a permanent magnet *NS*.
3. **Split-ring or Commutator:** These are two halves of the same metallic ring. The ends of the armature coil are connected to these halves, which also rotate with the armature.
4. **Brushes or Sliding Contacts:** These are two flexible metal plates or carbon rods *X* and *Y* which are so fixed that they constantly touch the revolving rings.
5. **Battery:** The battery consists of a few cells and is connected across the brushes. The brushes pass the current to the rings from where it is carried to the armature.

8.3 WORKING

The working of a DC motor will be clear form the following discussion.

(a) Let us suppose that the battery sends current to the armature in the direction shown in figure. Applying Fleming's Left Hand Rule (Motor Rule), we find that arm ***AB*** experiences a force which is acting outwards and perpendicular to it and arm ***CD*** experiences a force which is acting inwards and perpendicular to it. These two forces form a couple whose torque makes the armature rotate in the anticlockwise direction.

(b) After the armature has completed half a revolution (i.e., has turned through 180º), the direction of current in the arms ***AB*** and ***CD*** is reversed. Now arm ***CD*** experiences an outward force and arm ***AB*** experiences an inward force figure. The armature thus continues to rotate about its axis in the same, i.e., anticlockwise direction.



The **speed of rotation of the motor** can be increased by

(i) increasing the strength of the current through the armature,
(ii) increasing the number of turns in the coil of the armature,
(iii) increasing the area of the coil, and
(iv) increasing the strength of the magnetic field.

8.4 USES OF DC MOTORS

1. These are used in electric fans (exhaust, ceiling or table) for cooling and ventilation.
2. These are used for pumping water.
3. Big DC motors are used for running tramcars.
4. Small DC motors are used in various toys.

9. ELECTROMAGNETIC INDUCTION

We know from Oersted's experiment that a current produces a magnetic field. The reverse be will also true and a magnet can be used to produce current Michael Faraday began to work on this problem in 1825. For six years, he experimented with magnets and coils of wire until one day in desperation he threw the magnet down into the coil and observed that a momentary current was produced in the coil.

9.1 FARADAY'S EXPERIMENT

The experimental arrangement used by Faraday consists of a coil, C of a few turns. A sensitive galvanometer, G is included in series with the coil. Faraday's observations were as follows.

1. When the magnet is **stationary,** there is **no deflection** in the galvanometer.
2. When the **North Pole** of the magnet is brought **towards** the coil, a current flows in the coil as shown in figure and the galvanometer shows deflection towards the **right.**
3. If the motion of the magnet is **stopped,** the galvanometer again **shows no deflection** as shown in figure. Thus, the current in the coil flows as long as the magnet is moving.
4. If the magnet is moved **away** from the coil, the current flows in a direction opposite to that in the case b and the galvanometer shows deflection towards **left.**
5. If instead of the North Pole, the **South Pole** of the magnet is either brought **towards** the coil or moved **away** from the coil the directions of induced currents in the two cases are **opposite.**
6. In case the magnet is moved faster with velocity *v'* instead of *v* (either towards or away from the coil), the deflection in the galvanometer increases.

9.2 CONCLUSIONS OF FARADAY'S EXPERIMENT

From his experiment, Faraday arrived at the following three conclusions:

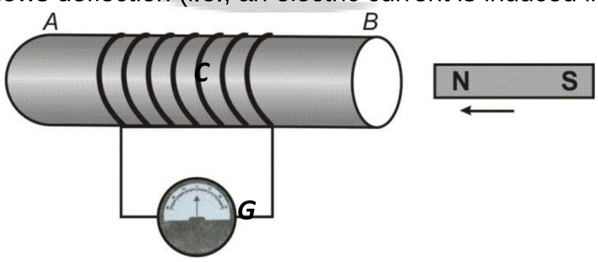
1. The galvanometer shows deflection (i.e., an induced current flows in the coil) only when there is a relative motion between the coil and the magnet.
2. The direction of deflection (i.e., of the induced current in the coil) is reversed if the direction of relative motion between the coil and the magnet is reversed.
3. The deflection in the galvanometer (i.e., the induced current in the coil) increases if the magnet and the coil are rapidly moved with respect to each other.

9.3 FARADAY'S EXPLANATION

1. (a) When the magnet and the coil, *C* are at rest with respect to each other, **the total number of magnetic field lines,** called **magnetic flux** remains constant. It is due to this reason that the galvanometer, *G* shows no deflection (i.e., there is no induced current in the coil) as shown in figure.

Constant magnetic flux in the coil does not induce current in it.

(b) Whenever there is relative motion between the coil and the magnet, (suppose the magnet moves towards the coil) the magnetic flux linked with the coil changes. It is due to this reason that he galvanometer shows deflection (i.e., an electric current is induced in the coil).



2. When the direction of relative motion between the magnet and the coil is reversed i.e., instead of bringing the magnet and the coil **towards** each other, if they taken **away** from each other, the direction of deflection in the galvanometer (i.e., the induced current in the coil) is also reversed. It is due to the

this reason that when we bring the magnet and the coil **closer** to each other, the magnetic flux linked with the coil **increases** whereas when these are moved **away** from each other, the magnetic flux linked with the coil **decreases.** Thus, it is the change (whether an increase or a decrease) in magnetic flux in the coil, which induces current in the coil. Increasing magnetic flux induces current in one direction whereas decreasing magnetic flux induces current in the opposite direction.

3. When the magnet and the coil are moved rapidly with respect to each other, the galvanometer deflection (i.e., the induced current in the coil) increases. This is due to the reason that the rate of change of magnetic flux in the coil increases. Thus,

The current produced in the coil by changing magnetic flux linked with it is called the induced current and the corresponding potential difference is called the induced potential difference or induced electromotive force (emf). The phenomenon is called electromagnetic induction.

It is important to note that the induced current (or induced potential difference) is not like the one due to an electric cell. In an electric cell, it is the chemical energy that is converted into electric energy (i.e., current). In case of electromagnetic induction, the induced current is due to changing magnetic flux in the coil. Since to change magnetic flux, we have to do work to cause relative motion between the magnet and the coil, it is this **work (i.e., mechanical energy)** that is converted into **electric energy.**

The phenomenon of generation of an electric current in a circuit from magnetic effect i.e., by changing the magnetic flux linked with it is called electromagnetic induction.

9.4 FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION

Faraday, on the basis of his experiments, formulated the following two laws of electromagnetic induction.

1. **Whenever there is a change in magnetic flux linked with a coil, an electric current (and *pd*) is induced. This induced *pd* lasts so long as there is a change in the magnetic flux linked with the coil.**
2. **The magnitude of the induced current (and *pd*) is directly proportional to the rate of change of magnetic flux linked with the coil.**

If the rate of change of magnetic flux remains uniform, a steady *pd* is induced. If the circuit of the coil is closed, a current flows in the coil due to induced *pd* at its ends. It is clear that the magnitude of induced *pd* depends on

(i) the change in magnetic flux and (ii) the time in which flux changes

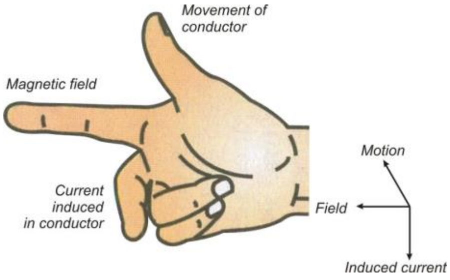
Obviously

(i) more the change in magnetic flux, more is the induced *pd* and

(ii) faster the change in magnetic flux, more is the induced pd.

9.5 ACTIVITY TO SHOW DIRECTION OF INDUCED CURRENT-FLEMING'S RIGHT-HAND RULE (DYNAMO RULE)

1. A galvanometer (G) is connected in series with a cell and a suitable high resistance (not shown in figure) and the direction of deflection in the galvanometer is noted when a small current is passed in a known direction.



Flemings right hand rule

2. The galvanometer is now connected to the ends of a straight wire *XY* placed at right angles to the magnetic field between two opposite magnetic poles *S* and *N*. If the wire is moved downwards, the galvanometer indicates that an induced current (*I*) flows.
3. When the wire is moved upwards, the direction of the induced current is reversed.

9.6 FLEMING'S RIGHT-HAND RULE (DYNAMO RULE)

Stretch the thumb, the fore finger and the central finger of the right hand so that they are mutually perpendicular to each other. If the first (fore) finger points in the direction of magnetic field, the thumb points in the direction of motion of the conductor, then the central finger points in the direction of induced current.

9.7 HOW TO MEMORISE

Thu**M**b represents **M**otion, **F**irst (**F**ore) finger represents **F**ield and **C**entral finger represents **C**urrent (induced).

9.7.1 It should be clearly noted that the Fleming's Right-Hand Rule is applied when we are given

(i) the direction of magnetic field and
(ii) the direction of motion of the conductor and we are to find the direction of the induced current.

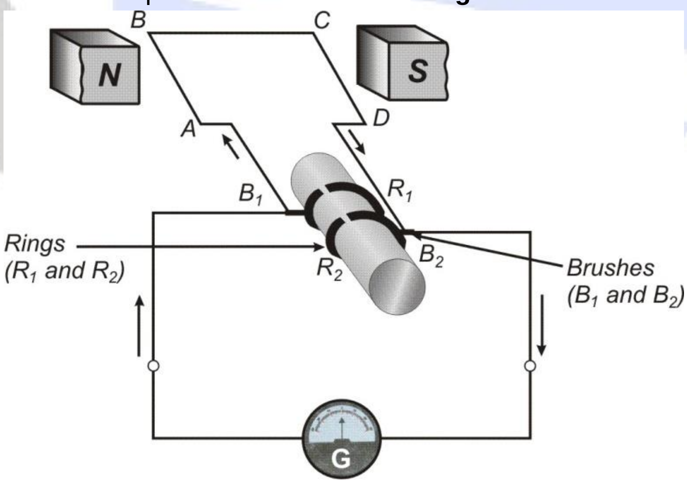
9.7.2 It may be recalled that Fleming's Left-Hand Rule is applied when we are given

(i) the direction of the magnetic field
(ii) the direction of flow of current and we are to find the direction of force on the conductor (i.e. the direction of motion of the conductor).

10. ELECTRIC GENERATORS, DIRECT CURRENT AND ALTERNATING CURRENT

A generator or dynamo is a machine used for generating electric current by converting mechanical energy into electrical energy.

When the current produced by a dynamo changes continuously in magnitude and periodically in direction several times in a second, the current is known as **alternating current** (written in short as AC) and the machine that produces it is called an **AC generator.** But when the current produced by a dynamo does not change in direction and magnitude, it is called the **direct current** (written in short as DC) and the machine that produces it is called a **DC generator.**



DC generator

Thus, **an electric current which changes its direction (i.e., polarity) after a certain fixed interval of time is called alternating current.** Most of the our electric energy requirements are met by *AC* which is generated by the power plants (hydroelectric, thermal and atomic).

10.1 FREQUENCY OF AC

The number of cycles completed by the *AC* in one second is called the frequency of *AC*.

The frequency of *AC* in India is 50 Hz (hertz) which means that *AC* changes its polarity after (1/100)s as it completes one cycle, (i.e., from +ve to –ve and from – ve to +ve) in (1/50)s.

Further, **an electric current which always flows in the same direction is called direct current.** The polarities (+ve and –ve) of *DC* are fixed. The current supplied by a cell or a battery is *DC*.

10.2 ADVANTAGES OF AC OVER DC

1. With the help of a transformer, *AC* of any desired voltage can be obtained.
2. The power wastage in *AC* transmission is almost negligible and as such the cost of transmission is low.
3. *AC* can be controlled (using a choke coil) and the energy loss is very small whereas *DC* can be controlled **only** by using ohmic resistances which involve huge energy loss in the form of heat.
4. When required, *AC* can be changed to *DC*.
5. *AC* machines are very stout and durable and do not need much maintenance.

10.3 DISADVANTAGES OF AC OVER DC

1. *AC* is more dangerous than *DC* as it attracts a person towards it whereas *DC* repels. *AC* gives a serious shock to a person as compared to *DC*.
2. *AC* cannot be used for electroplating, electrotyping and other such electrolytic processes. In such cases, *DC* has to be used.

11. ALTERNATING CURRENT (AC) GENERATOR

An *AC* generator converts mechanical energy into electric energy.

11.1 PRINCIPLE

Whenever in a closed circuit (i.e., a coil), the magnetic field lines change, an induced current is produced.

11.2 CONSTRUCTION

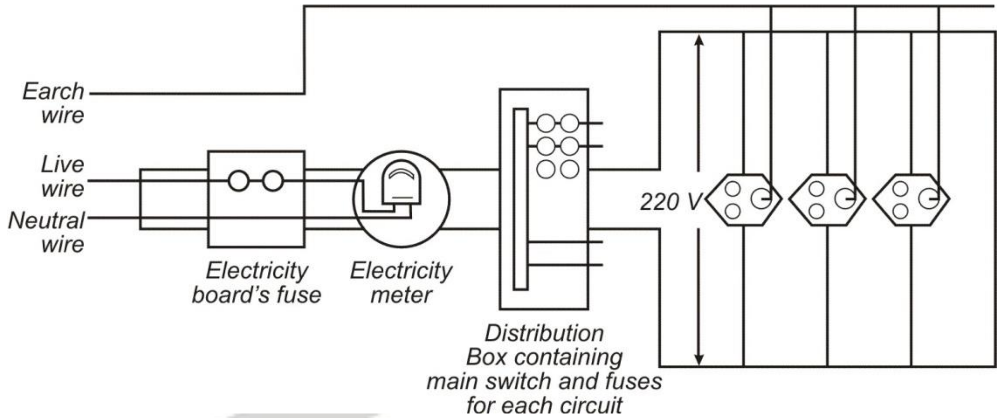
It consists of the following four parts.

1. **Armature:** Armature (*abcd*), also called the coil, consists of a large number of turns of insulated copper wire wound over a soft iron core. It revolves around an axle between the two poles of a strong magnet.
2. **Field Magnet:** The magnetic field (*B*) is supplied by a permanent magnet in a small dynamo (also called a **magneto**) and by an electromagnet in case of a big commercial dynamo (usually called a generator). The poles of the magnet are shown as *N-S* in figure.
3. **Slip Rings:** R_1 and R_2 are two hollow metal rings held at different heights. The end d of the armature coil is connected to ring R_1. The end *c* of the coil is passed through R_1 without touching it and is connected to R_2. These rings rotate with the rotation of the armature.
4. **Brushes or Sliding Contacts:** B_1 and B_2 are flexible metal plates or carbon rods. These are called brushes or sliding contacts. B_1 is in constant touch with R_1 and B_2 is in constant touch with R_2. It is with the help of these brushes that the induced current is passed on from the armature and the rings to the external circuit containing a resistance, *R* and a galvanometer *G*. Brushes are stationary i.e., these do not rotate with the rotation of the armature.

11.3 DIRECT CURRENT (DC) GENERATOR

The principle, construction and working of a DC generator is the same as that of an AC generator except that in place of slip-rings as sliding contacts, we have a split-ring or a commutator.

12. DOMESTIC ELECTRIC CIRCUITS



1. **Electric Cable or Overhead Wires:** The electric power to a house is supplied either through overhead wires or through underground cables. The cable has three separate insulted wires:
   (a) **live wire** (or phase or positive)
   (b) **neutral wire** (or negative) and
   (c) **earth wire.**
   The **live** wire has usually **red** insulation cover, **neutral** wire has **black** insulation cover and the **earth** wire has **green** insulation cover. **As per the new International Convention, live wire has brown coloured insulation cover whereas neutral and earth wires have light blue and green (or yellow) insulation covers.** The potential difference between the live and neutral wire is 220 V. The neutral and the earth wires are connected together at the local sub-station so that both of them are at zero potential.
2. **Pole Fuse:** Before the electric lines enter a house, the agency supplying electricity, places a fuse (called the **pole fuse** or **company fuse**) in the live wire. The current rating of this fuse depends upon the load sanctioned by the agency to that house.
3. **Energy Meter or kWh Meter:** After the company fuse, the cable is connected to the energy meter, which records the electricity consumption of the house in kilowatt, hour (kWh). The earth wire from the meter is locally earthed in the compound of the house.
4. **Main Fuse:** The live wire coming out from the output terminals of kWh meter has another fuse in it, which is called the main fuse.
5. **Main Switch:** Beyond the main fuse, the live and the neutral wires are connected to the main switch. It is a double pole switch and has an iron covering. The covering of the main switch is also locally earthed. The switch can cut off the live and the neutral wires from the household circuit by operating a single lever.
6. **Distribution Board:** Power lines coming from the main switch are taken to the distribution board. It is from the distribution board that the wires go to the different parts of the house through fuses in the board.
7. **House-Wiring:** There are two systems of wiring by which the power is distributed to a house: **(a) The Tree System (b) The Ring System.** We shall be describing the **tree system** of wiring though **the ring system** is rapidly replacing the tree system. In tree system of wiring, different branch lines are taken out from the distribution board to different parts of the house in much the same way as the branches from the trunk of a tree. Each branch line is taken to a room through a fuse in the live wire. Figure shows the tree system of wiring in a house from the distribution board to different rooms and places in the house.

13. SALIENT FEATURES OF TREE SYSTEM OF WIRING

(i) Different circuits are connected in **parallel** so that if there is a short-circuiting in one distribution circuit, its fuse will blow off without affecting the supply in the other circuits.
(ii) The neutral wire (*N*) and the earth wire (*E*) is common to all circuits.
(iii) All the appliances in a room are connected in parallel so that they work at the same voltage.
(iv) The connections from the live wire (*L*) is taken to one terminal of the appliance through a switch (*S*). The other terminal is connected to the neutral wire (*N*) to complete the circuit.

13.1 DISADVANTAGE OF TREE SYSTEM OF WIRING

(i) Since all circuits originate from the main distribution board, longer length of the wire is required for wiring various rooms and other places in the house.
(ii) When a fuse in one particular line blows off, all the appliances in that line are disconnected.
(iii) Plugs and sockets of different current capacities are required for different appliances depending upon the wattage.
(iv) On account of large length of wire, it is an expensive wiring system.
(v) It takes a long time to be installed.

All these disadvantage are removed in the ring system.

13.2 WHY IS SERIES ARRANGEMENT NOT USED FOR DOMESTIC CIRCUITS?

In domestic circuits, series arrangement not used because of the following reasons:

1. The total potential difference available (usually 220 volts) is divided between various appliances in the circuit according to their resistances since the current flowing through all the appliances is the same. Thus, each appliance will not get the required potential difference for it to operate properly.
2. If one of the appliances is out of order, e.g., if a bulb gets fused, all the appliances in the circuit will stop working, as the circuit gets broken.
3. All the appliances will work simultaneously whether we want them to work or not, thereby involving a lot of power wastage.
4. If we switch off any one of the appliances, the circuit is broken and all the appliances will stop working.

13.3 SHORT-CIRCUITING

In general, **short-circuiting occurs when the ends of a circuit are connected by a conductor of very low resistance as compared to that of the circuit.** In household connections, short-circuiting occurs when the **live** (positive) wire and the **neutral** (negative) wire come in direct contact with each other. This happens due to (i) damage to the insulation of the power-lines (ii) a fault in an electric appliance due to which current does not pass through it. On account of short-circuiting, resistance of the circuit decreases to a very small value and consequently the current becomes very large. This large current results in heating of live wires, which produces sparking at the point of short-circuiting. This sparking sometimes causes fire in a building. (Apart from short-circuiting, the increase in current in the circuit and consequent heating may also be due to overloading of the circuit).

13.4 ELECTRIC FUSE: A SAFETY DEVICE

To avoid incidents like electric shock, fire, damage to an electric appliance due to (i) short-circuiting or (ii) overloading (withdrawing current beyond a specified limit) in a circuit, an electric fuse is the most important safety device.

An electric fuse is a device, which is used in series to limit the current in an electric circuit so that it easily melts due to overheating when excessive current passes through it. A fuse is a wire of a material with very low melting point.

A fuse wire is made of a wire of an alloy of lead (75%) and tin (25%), which melts at around 200ºC. Thus, when either due to short-circuiting or overloading, a heavy current flows through the circuit, the fuse wire gets heated and melts. Consequently, the circuit is broken and the current stops flowing in it. A few important points regarding a fuse are as follows.

1. In household supply, **a fuse is always connected in live wire and not in the neutral wire under any circumstance.** Though it will melt even when connected with neutral wire, the electric appliance will continue to be in contact with the live wire. Thus, when the electric appliance is touched, it will give shock.
2. **A fuse is always connected in the beginning of the circuit** before any appliance is connected. This is done to protect the appliance from getting damaged.
3. Fuses of various current capacities are available. Remember that **thicker the fuse wire, the greater is its current capacity.**
4. **A fuse used must be of current capacity (also called current rating) less than the maximum current which a circuit or an appliance can withstand.** A fuse of current capacity of 5 A is put in a line meant to supply power to lights (i.e., bulbs) and fans whereas a fuse of 15 A current capacity is meant for a line which operates an electric heater or a geyser, etc.

13.5 EARTHING

Many electric appliances of daily use like electric press, toaster, refrigerator, table fan etc. have a metallic body. If the insulation of any of these appliances melts and makes contact with the metallic casing, the person touching it is likely to receive a severe electric shock. This is due to the reason that the metallic casing will be at the same potential as the applied one. Obviously, the electric current will flow through the body of the person who touches the appliance. To avoid such serious accidents, the metal casing of the electric appliance is earthed. Since the earth does not offer any resistance, the current flows to the earth through the earth wire instead of flowing through the body of the person. Moreso, due to very low resistance (almost nil) offered by the earth wire, the current in the circuit rises to a very high value, thereby melting fuse in that circuit and cutting off its electric supply.

13.6 ROLE OF MAGNETISM IN MEDICINE AND ORGANISMS

In our body, small electric current travels along the nerve cells due to ions. This current produces a very weak magnetic field (about one billionth time weaker than the Earth's magnetic filed) in our body. Heart and brain are the two main organs in our body where this magnetic field is quite significant. The magnetic field in our body enables us to obtain the images of its different parts by using a technique called **MRI (M**agnetic **R**esonance **I**maging). On analysing the images obtained through MRI, we are able to make a medical diagnosis, e.g., location and size of a tumour in brain etc. Thus, magnetism plays an important role in modern medical science.

Apart from this, there are certain organisms, which have the ability to sense Earth's magnetic field and travel from one place to another. For example, some type of fishes are able to detect magnetic field by using special receptors whereas in certain organisms, crystals of magnetite enable to move along the Earth's magnetic field.