Magnetic Effects of Electric Current

CLASS-10TH CHAPTER-13

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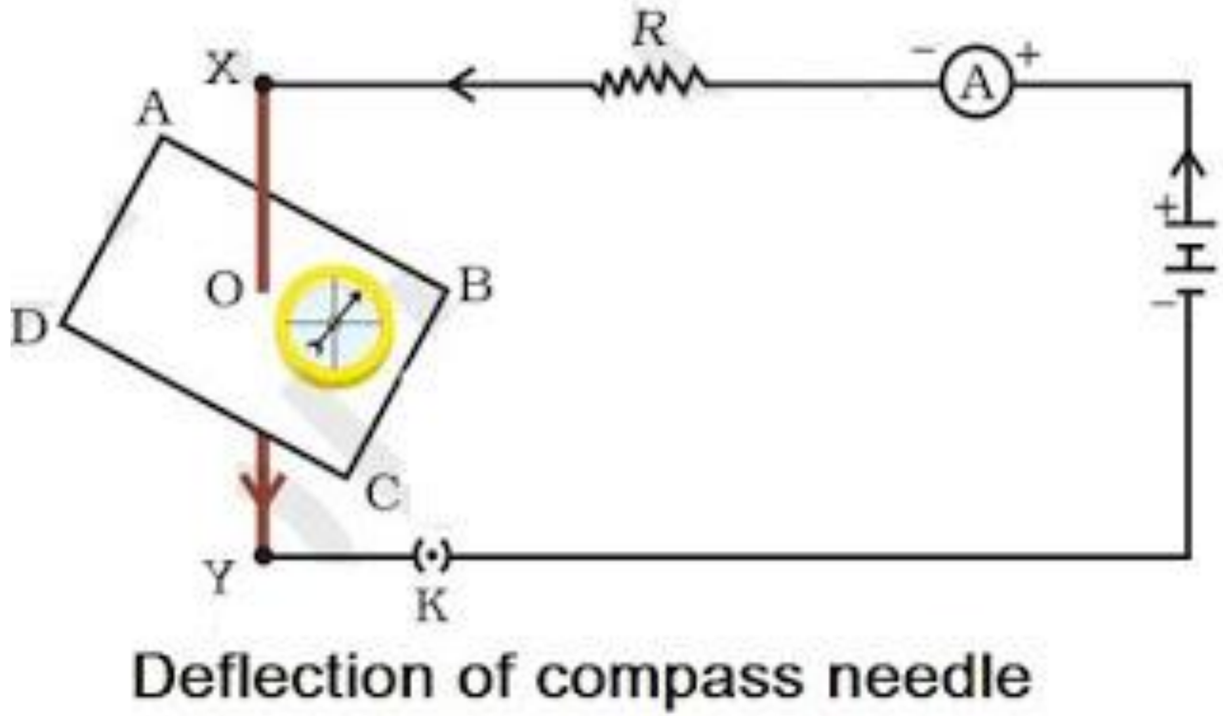
- In the previous Chapter on 'Electricity' we learnt about the heating effects of electric current.
- What could be the other effects of electric current? We know that an electric current-carrying wire behaves like a magnet.
- The electric current through the copper wire has produced a magnetic effect.
- Thus we can say that electricity and magnetism are linked to each other.
- Then, what about the reverse possibility of an electric effect of moving magnets?
- In this Chapter we will study magnetic fields and such electromagnetic effects.
- We shall also study about electromagnets and electric motors which involve the magnetic effect of electric current, and electric generators which involve the electric effect of moving magnets.



Compass needle is deflected on passing an electric current through a metallic conductor

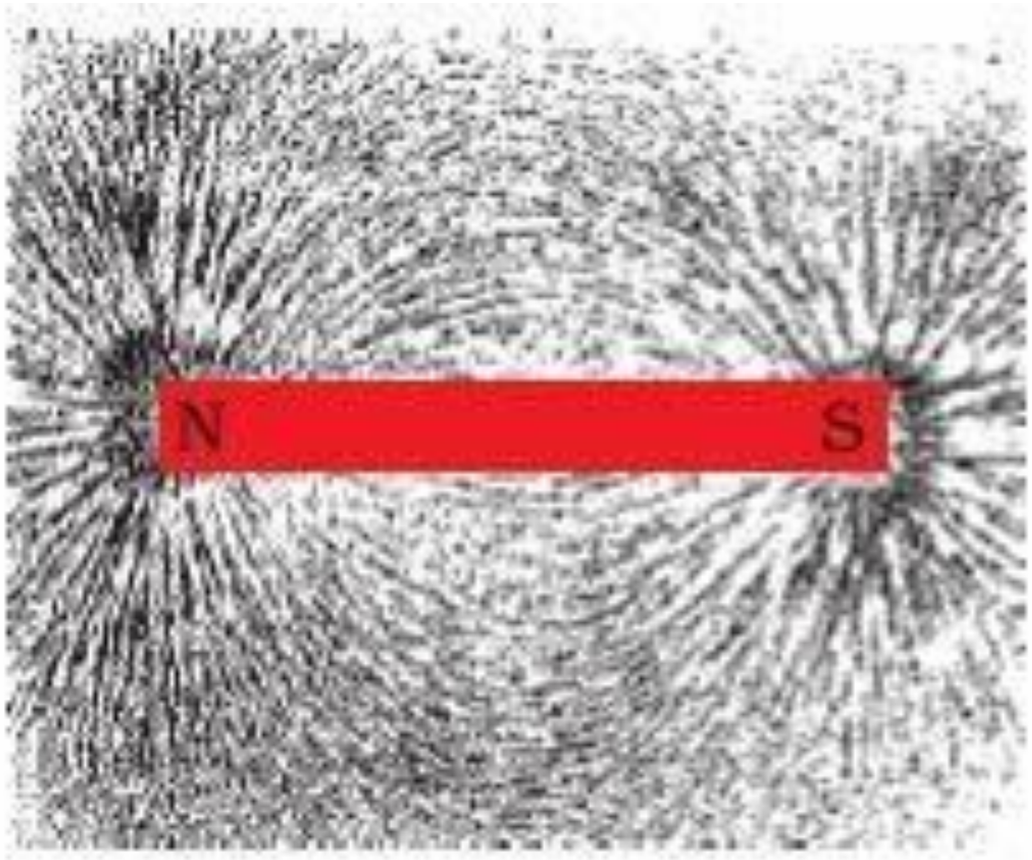
MAGNETIC FIELD AND FIELD LINES

- We are familiar with the fact that a compass needle gets deflected when brought near a bar magnet.

- A compass needle is, in fact, a small bar magnet. The ends of the compass needle point approximately towards north and south directions.

- The end pointing towards north is called *north seeking* or north pole. The other end that points towards south is called *south seeking* or south pole.

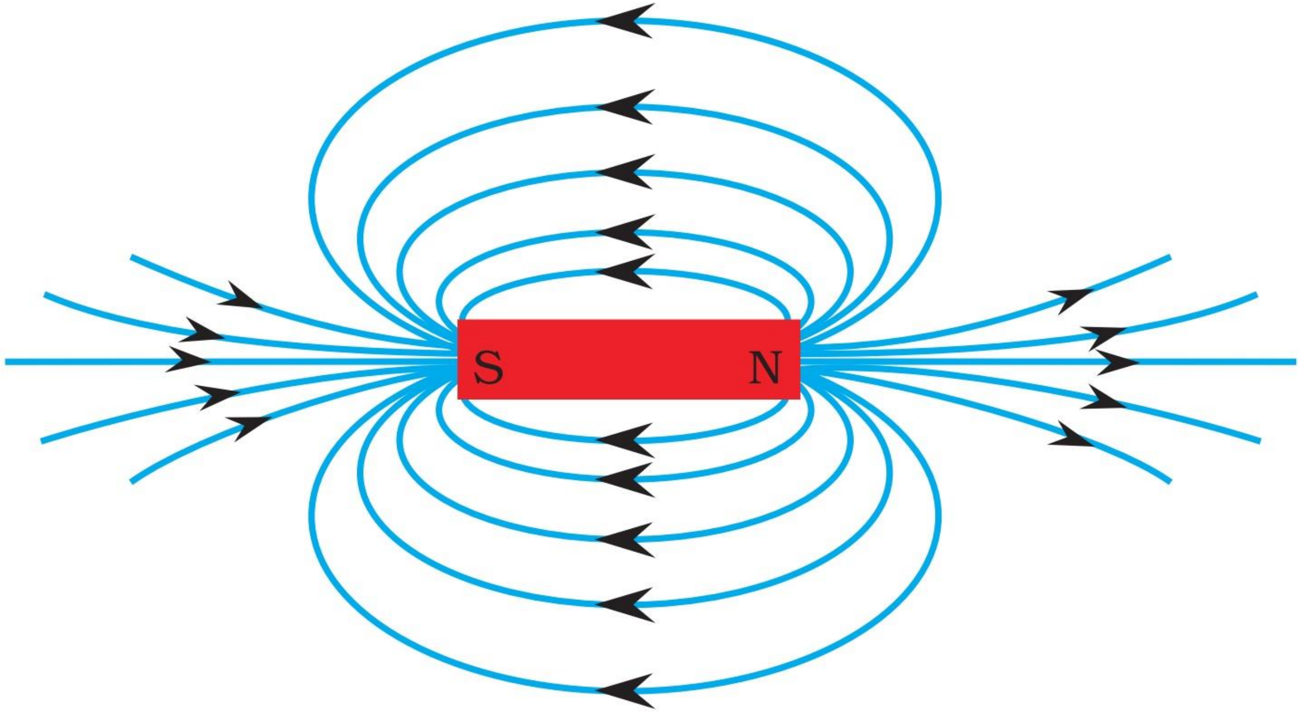
- Through various activities we have observed that like poles repel, while unlike poles of magnets attract each other.



Iron filings near the bar magnet align themselves along the field lines.

- The iron filings arrange themselves in a pattern as shown in the diagram.
- Why do the iron filings arrange in such a pattern? What does this pattern demonstrate? The magnet exerts its influence in the region surrounding it.
- Therefore the iron filings experience a force. The force thus exerted makes iron filings to arrange in a pattern.
- The region surrounding a magnet, in which the force of the magnet can be detected, is said to have a magnetic field.
- The lines along which the iron filings align themselves represent magnetic field lines.
- Are there other ways of obtaining magnetic field lines around a bar magnet? Yes, you can yourself draw the field lines of a bar magnet.

Drawing a magnetic field line with the help of a compass needle



Field lines around a bar magnet

- Magnetic field is a quantity that has both direction and magnitude.
- The direction of the magnetic field is taken to be the direction in which a north pole of the compass needle moves inside it.
- Therefore it is taken by convention that the field lines emerge from north pole and merge at the south pole.
- Inside the magnet, the direction of field lines is from its south pole to its north pole. Thus the magnetic field lines are closed curves.
- The relative strength of the magnetic field is shown by the degree of closeness of the field lines.
- The field is stronger, that is, the force acting on the pole of another magnet placed is greater where the field lines are crowded.

- No two field-lines are found to cross each other. If they did, it would mean that at the point of intersection, the compass needle would point towards two directions, which is not possible.

MAGNETIC FIELD DUE TO A CURRENT-CARRYING CONDUCTOR

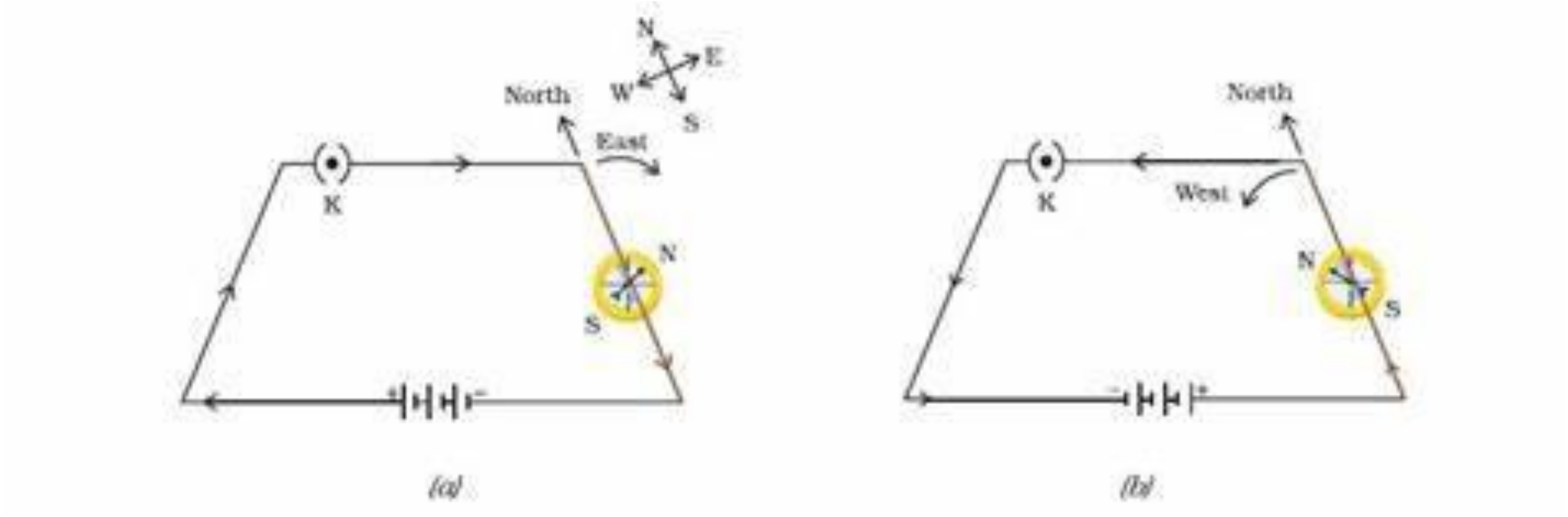
Magnetic Field due to a Current through a Straight Conductor

- Magnetic field lines due to current a current carrying straight conductor.

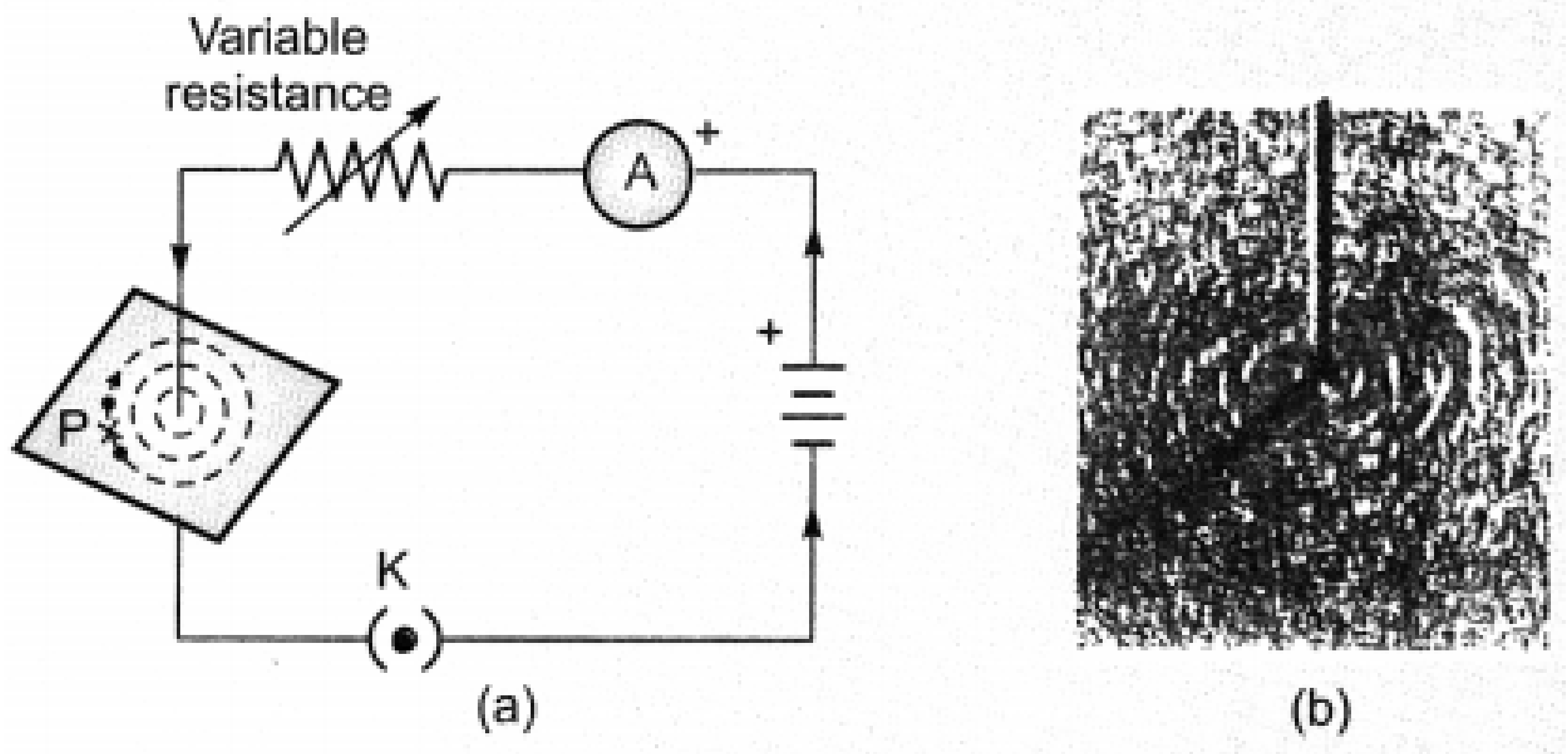
- A current carrying straight conductor has magnetic field in the form of concentric circles, around it.

- Magnetic field of current carrying straight conductor can be shown by magnetic field lines.

- The direction of magnetic field through a current carrying conductor depends upon the direction of flow electric current.



A simple electric circuit in which a straight copper wire is placed parallel to and over a compass needle. The deflection in the needle becomes opposite when the direction of the current is reversed.



(a) A pattern of concentric circles indicating the field lines of a magnetic field around a straight conducting wire. The arrows in the circles show the direction of the field lines. (b) A close up of the pattern obtained

- Let a current carrying conductor be suspended vertically and the electric current is flowing from south to north.
- In this case, the direction of magnetic field will be anticlockwise. If the current is flowing from north to south, the direction of magnetic field will be clockwise.
- The direction of magnetic field, in relation to direction of electric current through a straight conductor can be depicted by using the Right Hand Thumb Rule. It is also known as Maxwell’s Corkscrew Rule.

Right-Hand Thumb Rule

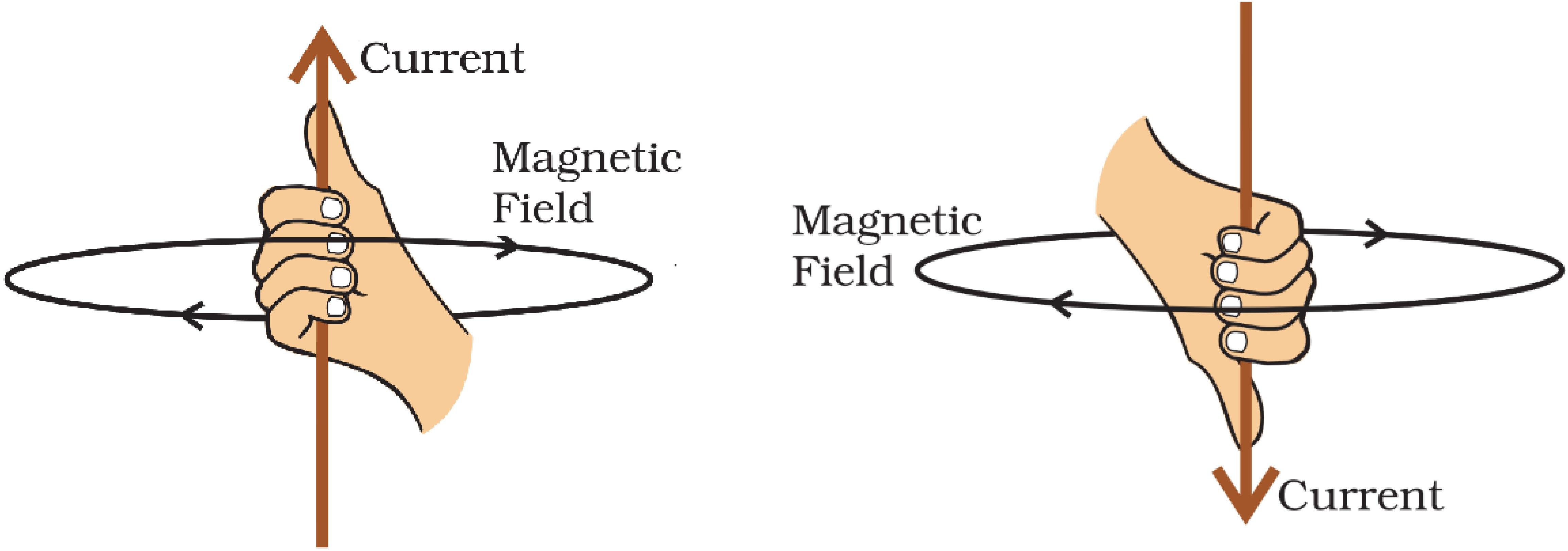
- A convenient way of finding the direction of magnetic field associated with a current-carrying conductor.

- Imagine that you are holding a current-carrying straight conductor in your right hand such that the thumb points towards the direction of current.

- Then your fingers will wrap around the conductor in the direction of the field lines of the magnetic field.

- This is known as the right-hand thumb rule. *This rule is also called Maxwell's corkscrew rule. If we consider ourselves driving a corkscrew in the direction of the current, then the direction of the rotation of corkscrew is the direction of the magnetic field.*

Maxwell's Right Hand Thumb Rule



Magnetic Field due to a Current through a Circular Loop

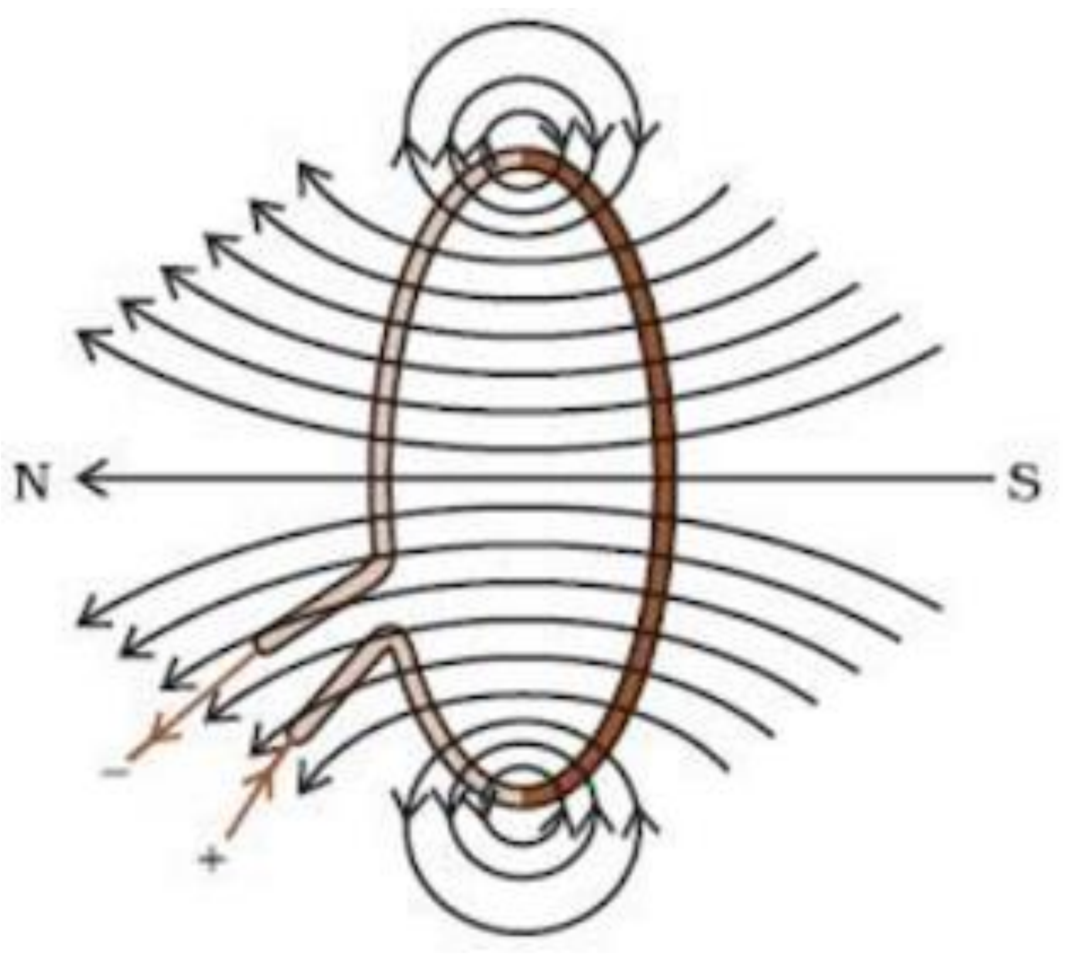
- We have so far observed the pattern of the magnetic field lines produced around a current-carrying straight wire.

- Suppose this straight wire is bent in the form of a circular loop and a current is passed through it. How would the magnetic field lines look like?

- We know that the magnetic field produced by a current-carrying straight wire depends inversely on the distance from it.

- Similarly at every point of a current-carrying circular loop, the concentric circles representing the magnetic field around it would become larger and larger as we move away from the wire.

- By the time we reach at the center of the circular loop, the arcs of these *big* circles would appear as straight lines.



Magnetic field lines of the field produced by a current-carrying circular loop

- Every point on the wire carrying current would give rise to the magnetic field appearing as straight lines at the center of the loop.

- By applying the right hand rule, it is easy to check that every section of the wire contributes to the magnetic field lines in the same direction within the loop.

- We know that the magnetic field produced by a current-carrying wire at a given point depends directly on the current passing through it.

- Therefore, if there is a circular coil having n turns, the field produced is n times as large as that produced by a single turn.

- This is because the current in each circular turn has the same direction, and the field due to each turn then just adds up.

Magnetic Field due to a Current in a Solenoid

- A coil of many circular turns of insulated copper wire wrapped closely in the shape of a cylinder is called a solenoid.

- The pattern of the magnetic field lines around a current-carrying solenoid is . Compare the pattern of the field with the magnetic field around a bar magnet. Do they look similar?

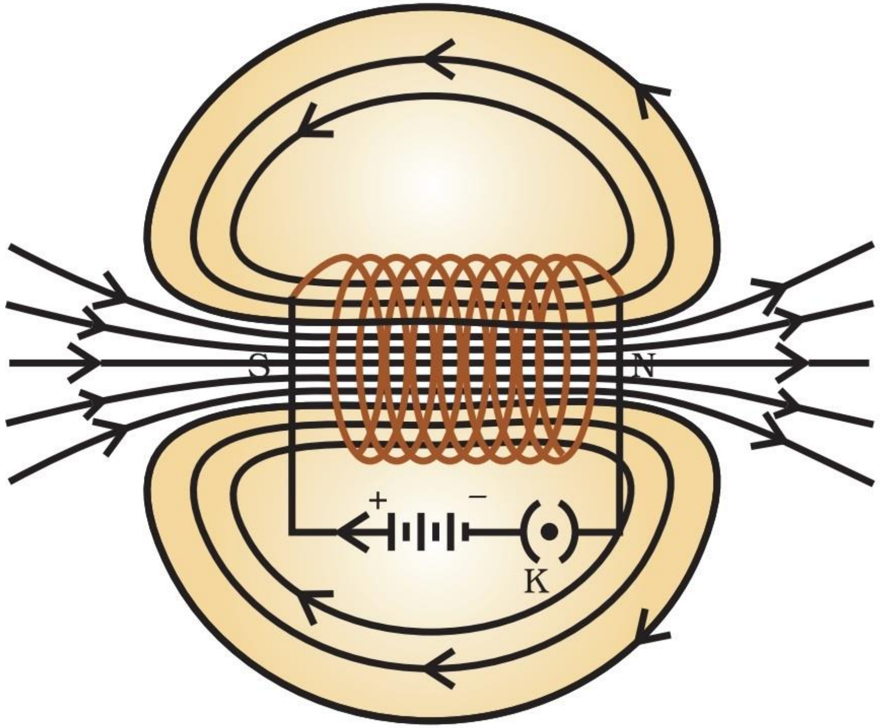
- Yes, they are similar. In fact, one end of the solenoid behaves as a magnetic north pole, while the other behaves as the south pole.

- The field lines inside the solenoid are in the form of parallel straight lines.

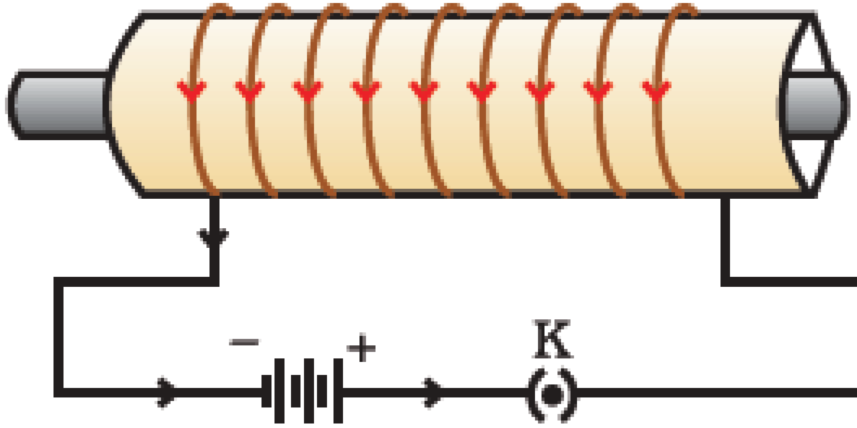
- This indicates that the magnetic field is the same at all points inside the solenoid. That is, the field is uniform inside the solenoid.

- A strong magnetic field produced inside a solenoid can be used to magnetize a piece of magnetic material, like soft iron, when placed inside the coil. The magnet so formed is called an electromagnet.

Magnetic Field in a Solenoid



Field lines of the magnetic field through and around a current carrying solenoid.



A current-carrying solenoid coil is used to magnetize steel rod inside it – an electromagnet.

FORCE ON A CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD

- We have learnt that an electric current flowing through a conductor produces a magnetic field.

- The field so produced exerts a force on a magnet placed in the vicinity of the conductor.

- French scientist Andre Marie Ampere (1775–1836) suggested that the magnet must also exert an equal and opposite force on the current-carrying conductor.

- The displacement of the rod in the above activity suggests that a force is exerted on the current-carrying aluminum rod when it is placed in a magnetic field.

- It also suggests that the direction of force is also reversed when the direction of current through the conductor is reversed.

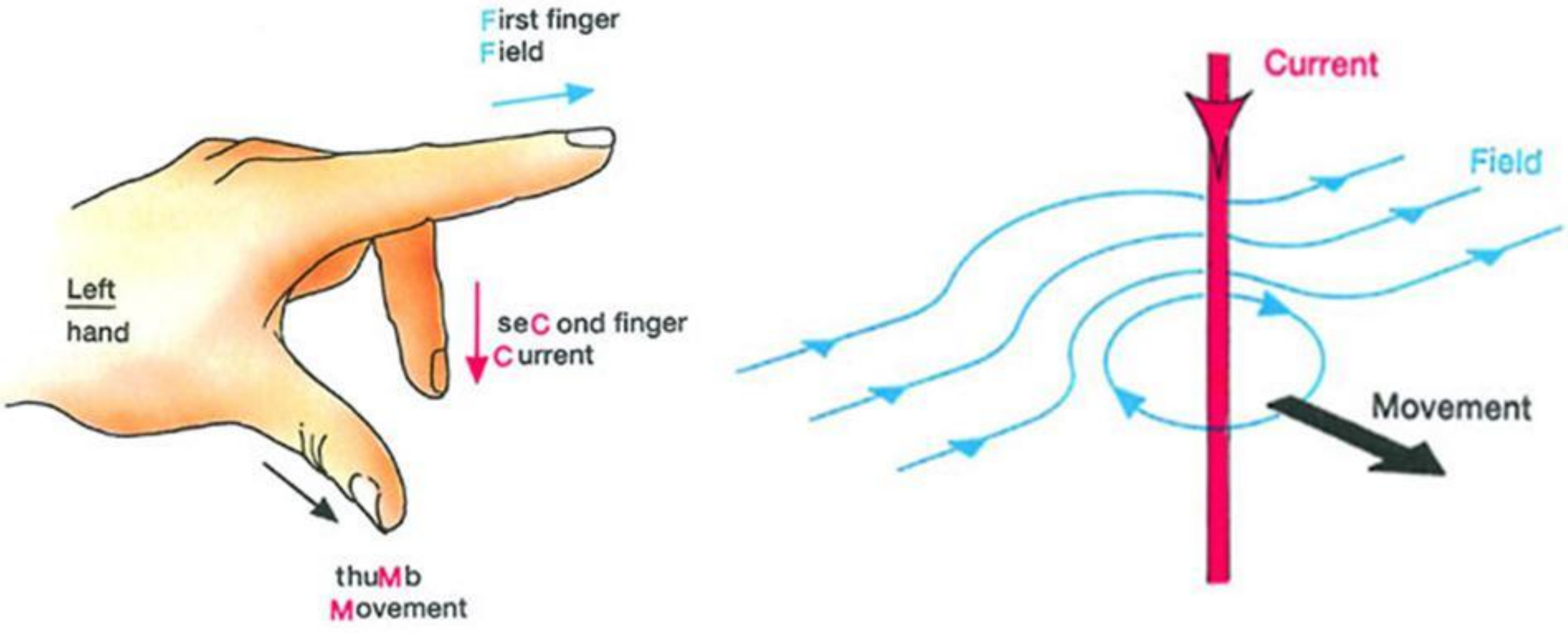
- Now change the direction of field to vertically downwards by interchanging the two poles of the magnet. It is once again observed that the direction of force acting on the current-carrying rod gets reversed

- It shows that the direction of the force on the conductor depends upon the direction of current and the direction of the magnetic field.

- Experiments have shown that the displacement of the rod is largest (or the magnitude of the force is the highest) when the direction of current is at right angles to the direction of the magnetic field.

- According to this rule, stretch the thumb, forefinger and middle finger of your left hand such that they are mutually perpendicular.

- If the first finger points in the direction of magnetic field and the second finger in the direction of current, then the thumb will point in the direction of motion or the force acting on the conductor.



Fleming's left-hand rule

- Devices that use current-carrying conductors and magnetic fields include electric motor, electric generator, loudspeakers, microphones and measuring instruments.

- In the next few sections we shall study about electric motors and generators.

More to Know

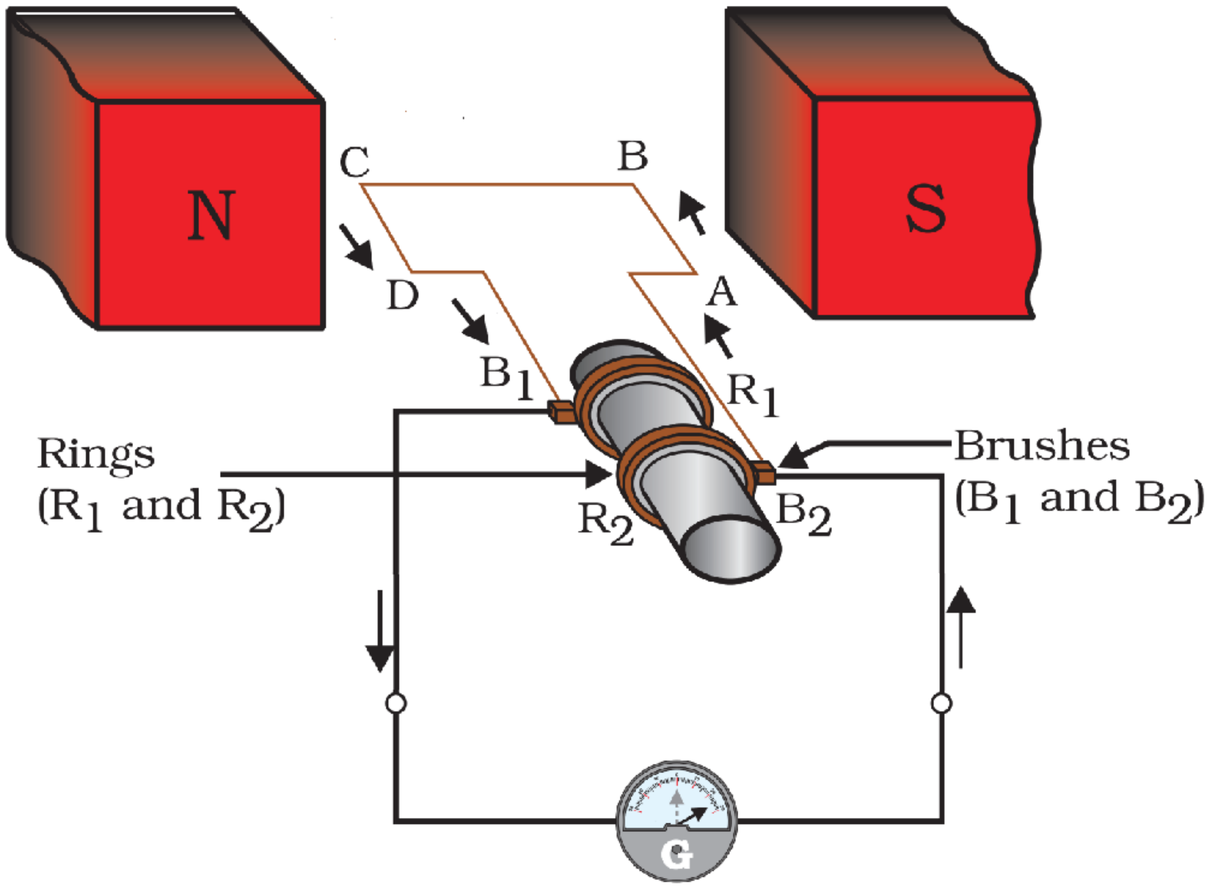
Magnetism in medicine

An electric current always produces a magnetic field. Even weak ion currents that travel along the nerve cells in our body produce magnetic fields. When we touch something, our nerves carry an electric impulse to the muscles we need to use. This impulse produces a temporary magnetic field. These fields are very weak and are about one-billionth of the earth’s magnetic field. Two main organs in the human body where the magnetic field produced is significant, are the heart and the brain. The magnetic field inside the body forms the basis of obtaining the images of different body parts. This is done using a technique called Magnetic Resonance Imaging (MRI). Analysis of these images helps in medical diagnosis. Magnetism has, thus, got important uses in medicine.

ELECTRIC MOTOR

- An electric motor is a rotating device that converts electrical energy to mechanical energy.
- Electric motor is used as an important component in electric fans, refrigerators, mixers, washing machines, computers, MP3 players etc.
- Do you know how an electric motor works? .
- The coil is placed between the two poles of a magnetic field such that the arm AB and CD are perpendicular to the direction of the magnetic field.
- The ends of the coil are connected to the two halves P and Q of a split ring. The inner sides of these halves are insulated and attached to an axle.
- The external conducting edges of P and Q touch two conducting stationary brushes X and Y, respectively.

Direction Reverses in Electric Generator



- Current in the coil ABCD enters from the source battery through conducting brush X and flows back to the battery through brush Y.
- Notice that the current in arm AB of the coil flows from A to B. In arm CD it flows from C to D, that is, opposite to the direction of current through arm AB.
- On applying Fleming’s left hand rule for the direction of force on a current-carrying conductor in a magnetic field.
- We find that the force acting on arm AB pushes it downwards while the force acting on arm CD pushes it upwards.
- Thus the coil and the axle O, mounted free to turn about an axis, rotate anti-clockwise. At half rotation, Q makes contact with the brush X and P with brush Y.

- Therefore the current in the coil gets reversed and flows along the path DCBA. A device that reverses the direction of flow of current through a circuit is called a commutator.

- In electric motors, the split ring acts as a commutator. The reversal of current also reverses the direction of force acting on the two arms AB and CD.

- Thus the arm AB of the coil that was earlier pushed down is now pushed up and the arm CD previously pushed up is now pushed down.

- Therefore the coil and the axle rotate half a turn more in the same direction.

- The reversing of the current is repeated at each half rotation, giving rise to a continuous rotation of the coil and to the axle.

- The commercial motors use (i) an electromagnet in place of permanent magnet; (ii) large number of turns of the conducting wire in the current carrying coil; and (iii) a soft iron core on which the coil is wound.

- The soft iron core, on which the coil is wound, plus the coils, is called an armature. This enhances the power of the motor.

ELECTROMAGNETIC INDUCTION

- We have studied that when a current-carrying conductor is placed in a magnetic field such that the direction of current is perpendicular to the magnetic field, it experiences a force.

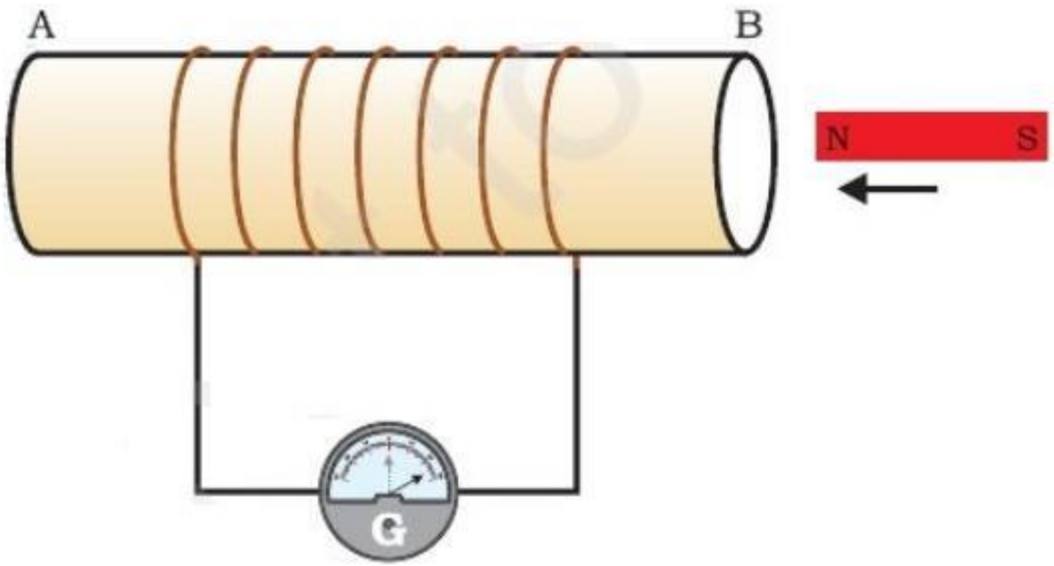
- This force causes the conductor to move. Now let us imagine a situation in which a conductor is moving inside a magnetic field or a magnetic field is changing around a fixed conductor.

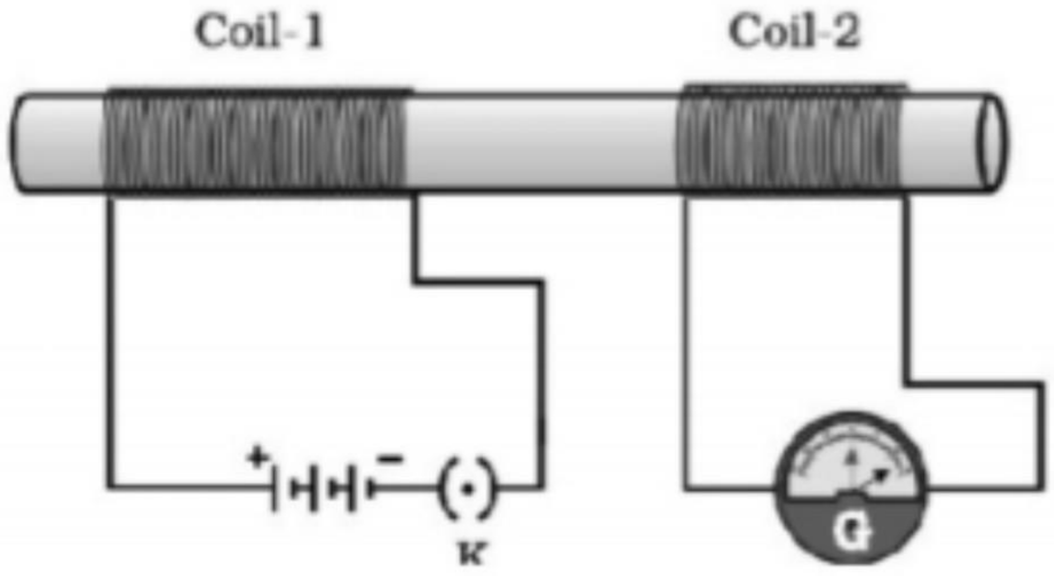
- What will happen? This was first studied by English physicist Michael Faraday. In 1831, Faraday made an important breakthrough by discovering how a moving magnet can be used to generate electric currents.

- You can also check that if you had moved south pole of the magnet towards the end B of the coil, the deflections in the galvanometer would just be opposite to the previous case.

- When the coil and the magnet are both stationary, there is no deflection in the galvanometer.

- It is, thus, clear from this activity that motion of a magnet with respect to the coil produces an induced potential difference, which sets up an induced electric current in the circuit.





Moving a magnet towards a coil sets up a current in the coil circuit, as indicated by deflection in the galvanometer needle.

Current is induced in coil-2 when current in coil-1 is changed

- In this activity we observe that as soon as the current in coil-1 reaches either a steady value or zero, the galvanometer in coil-2 shows no deflection.

- From these observations, we conclude that a potential difference is induced in the coil-2 whenever the electric current through the coil–1 is changing (starting or stopping).

- Coil-1 is called the primary coil and coil-2 is called the secondary coil.

- As the current in the first coil changes, the magnetic field associated with it also changes. Thus the magnetic field lines around the secondary coil also change.

- Hence the change in magnetic field lines associated with the secondary coil is the cause of induced electric current in it.

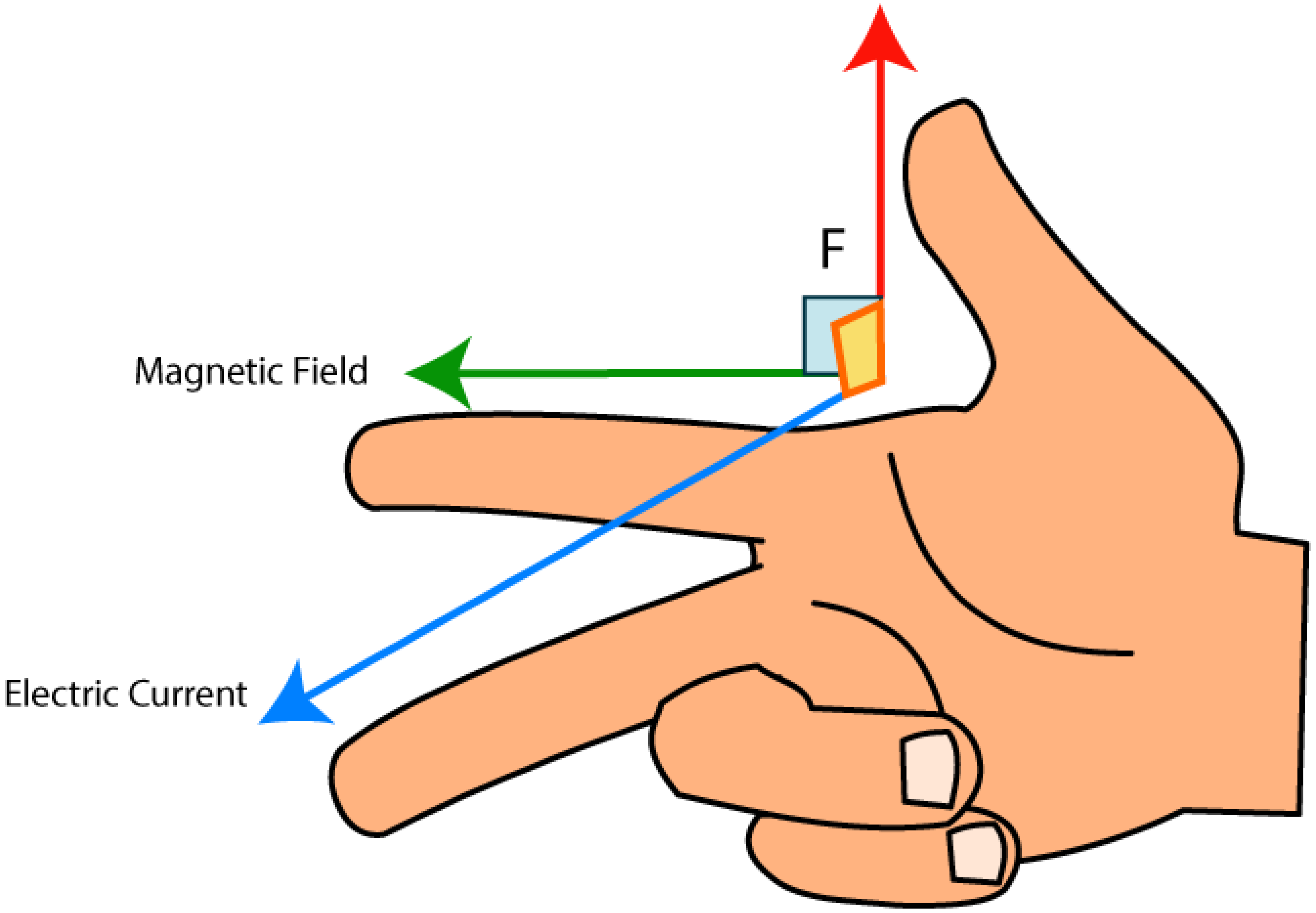
- This process, by which a changing magnetic field in a conductor induces a current in another conductor, is called electromagnetic induction.

- In practice we can induce current in a coil either by moving it in a magnetic field or by changing the magnetic field around it. It is convenient in most situations to move the coil in a magnetic field.

- The induced current is found to be the highest when the direction of motion of the coil is at right angles to the magnetic field. In this situation, we can use a simple rule to know the direction of the induced current.

- Stretch the thumb, forefinger and middle finger of right hand so that they are perpendicular to each other.

- If the forefinger indicates the direction of the magnetic field and the thumb shows the direction of motion of conductor, then the middle finger will show the direction of induced current. This simple rule is called Fleming’s right-hand rule.



Fleming's right-hand rule

ELECTRIC GENERATOR

- Based on the phenomenon of electromagnetic induction, the experiments studied above generate induced current, which is usually very small.

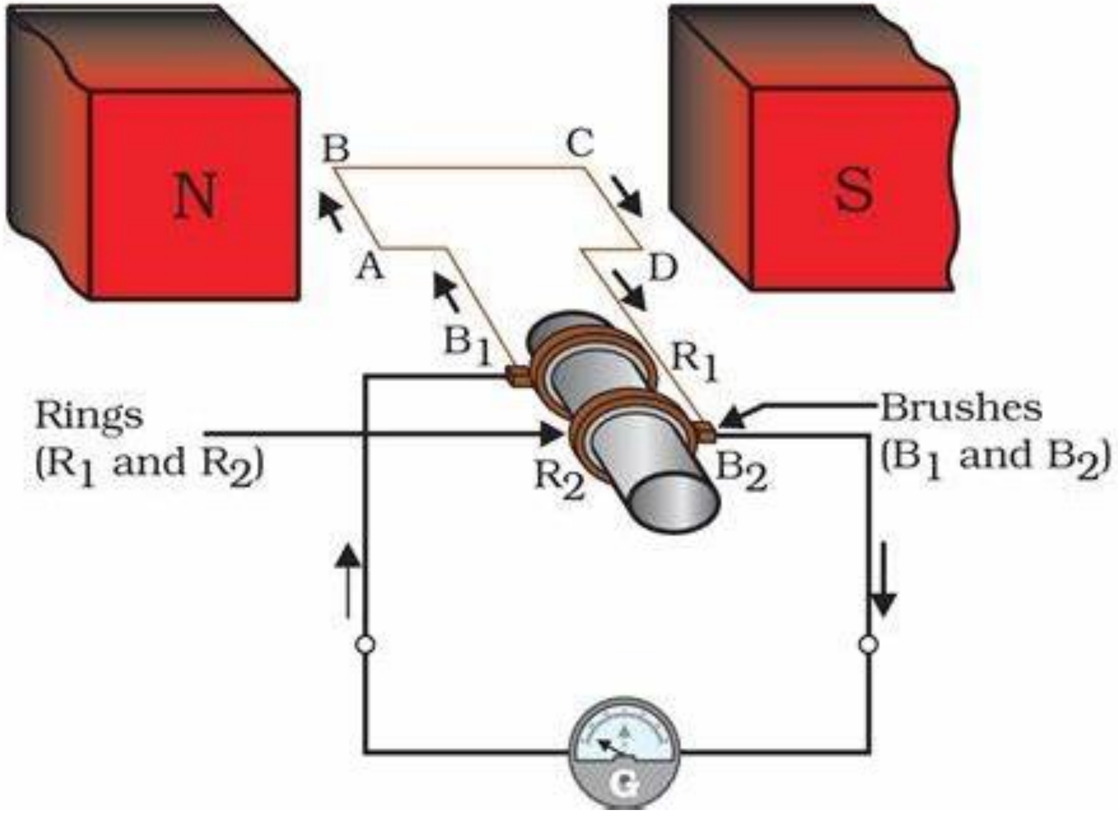
- This principle is also employed to produce large currents for use in homes and industry.

- In an electric generator, mechanical energy is used to rotate a conductor in a magnetic field to produce electricity.

- An electric generator, consists of a rotating rectangular coil ABCD placed between the two poles of a permanent magnet.

- The two ends of this coil are connected to the two rings R1 and R2. The inner side of these rings are made insulated. The two conducting stationary brushes B1 and B2 are kept pressed separately on the rings R1 and R2, respectively.

Electric Generator (AC)



- The two rings R1 and R2 are internally attached to an axle. The axle may be mechanically rotated from outside to rotate the coil inside the magnetic field. Outer ends of the two brushes are connected to the galvanometer to show the flow of current in the given external circuit.

- When the axle attached to the two rings is rotated such that the arm AB moves up (and the arm CD moves down) in the magnetic field produced by the permanent magnet.

- Let us say the coil ABCD is rotated clockwise in the arrangement. By applying Fleming’s right-hand rule, the induced currents are set up in these arms along the directions AB and CD.

- Thus an induced current flows in the direction ABCD. If there are larger numbers of turns in the coil, the current generated in each turn adds up to give a large current through the coil.

- This means that the current in the external circuit flows from B2 to B1. After half a rotation, arm CD starts moving up and AB moving down. As a result, the directions of the induced currents in both the arms change, giving rise to the net induced current in the direction DCBA.

- The current in the external circuit now flows from B1 to B2. Thus after every half rotation the polarity of the current in the respective arms changes.

- Such a current, which changes direction after equal intervals of time, is called an alternating current (abbreviated as AC). This device is called an AC generator.

- To get a direct current (DC, which does not change its direction with time), a split-ring type commutator must be used.

- With this arrangement, one brush is at all times in contact with the arm moving up in the field, while the other is in contact with the arm moving down. We have seen the working of a split ring commutator in the case of an electric motor

- Thus a unidirectional current is produced. The generator is thus called a DC generator.

- The difference between the direct and alternating currents is that the direct current always flows in one direction, whereas the alternating current reverses its direction periodically.

- Most power stations constructed these days produce AC. In India, the AC changes direction after every 1/100 second, that is, the frequency of AC is 50 Hz.

- An important advantage of AC over DC is that electric power can be transmitted over long distances without much loss of energy.

DOMESTIC ELECTRIC CIRCUITS

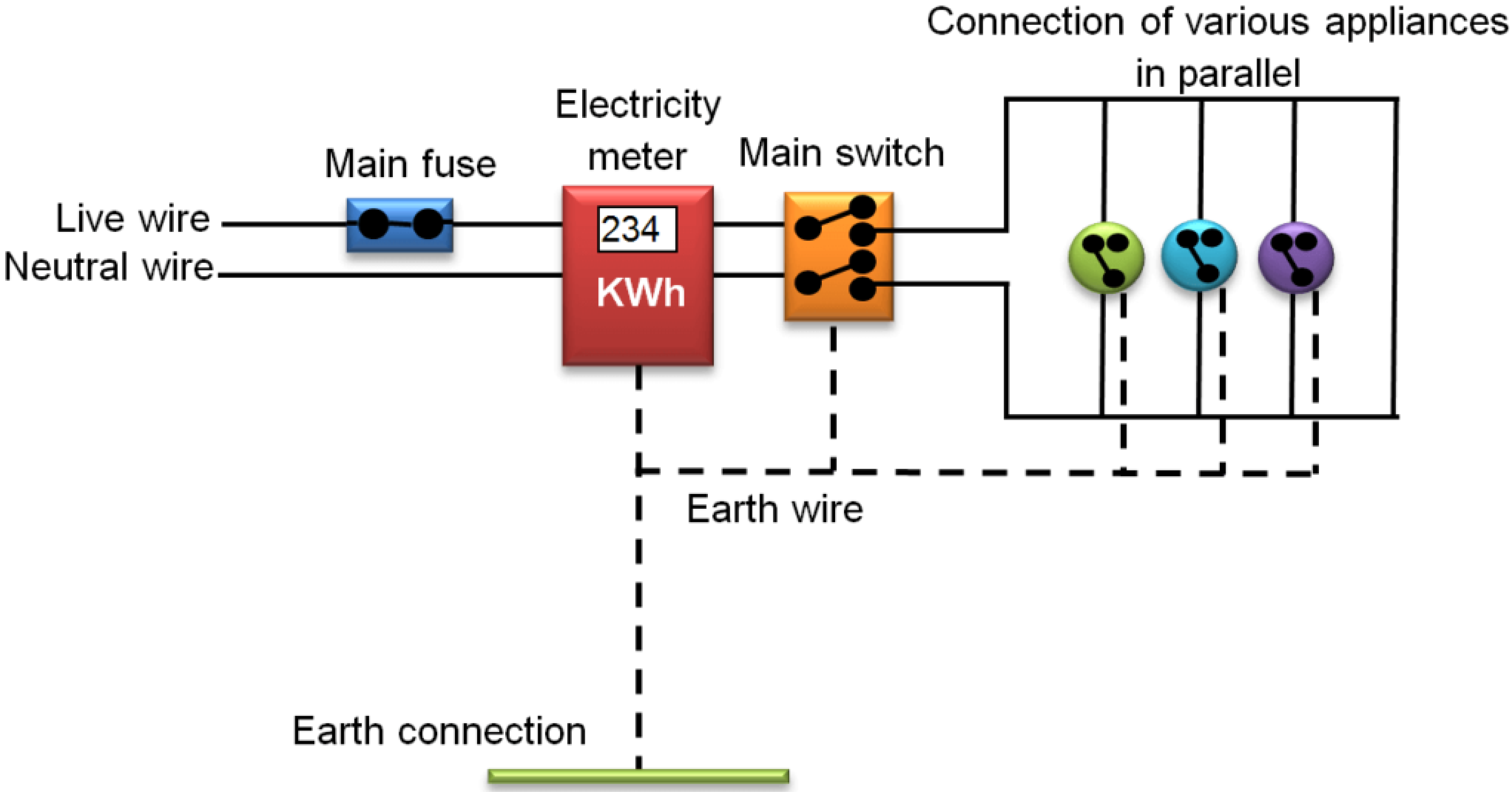
- In our homes, we receive supply of electric power through a main supply (also called mains), either supported through overhead electric poles or by underground cables.

- One of the wires in this supply, usually with red insulation cover, is called live wire (or positive).

- Another wire, with black insulation, is called neutral wire (or negative). In our country, the
- potential difference between the two is 220 V.

- At the meter-board in the house, these wires pass into an electricity meter through a main fuse.

- Through the main switch they are connected to the line wires in the house. These wires supply electricity to separate circuits within the house.



A schematic diagram of one of the common domestic circuits

- Often, two separate circuits are used, one of 15 A current rating for appliances with higher power ratings such as geysers, air coolers, etc.

- The other circuit is of 5 A current rating for bulbs, fans, etc. The earth wire, which has insulation of green colour, is usually connected to a metal plate deep in the earth near the house.

- This is used as a safety measure, especially for those appliances that have a metallic body, for example, electric press, toaster, table fan, refrigerator, etc.

- The metallic body is connected to the earth wire, which provides a low-resistance conducting path for the current.

- Thus, it ensures that any leakage of current to the metallic body of the appliance keeps its potential to that of the earth, and the user may not get a severe electric shock.

- A schematic diagram of one of the common domestic circuits. In each separate circuit, different appliances can be connected across the live and neutral wires.

- Each appliance has a separate switch to ‘ON’/‘OFF’ the flow of current through it. In order that each appliance has equal potential difference, they are connected parallel to each other.

- Electric fuse is an important component of all domestic circuits. We have already studied the principle and working of a fuse in the previous chapter.

- A fuse in a circuit prevents damage to the appliances and the circuit due to overloading. Overloading can occur when the live wire and the neutral wire come into direct contact. (This occurs when the insulation of wires is damaged or there is a fault in the appliance.)

- In such a situation, the current in the circuit abruptly increases.
- This is called short-circuiting. The use of an electric fuse prevents the electric circuit and the appliance from a possible damage by stopping the flow of unduly high electric current.
- The Joule heating that takes place in the fuse melts it to break the electric circuit.
- Overloading can also occur due to an accidental hike in the supply voltage. Sometimes overloading is caused by connecting too many appliances to a single socket.

THANKYOU….