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Dhiren M Doshi

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10

CBSE Living Science Physics

Class 10

Chapter 2: Magnetic Effects of Electric Current

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Learning Objectives

- ❖Mapping of magnetic field lines
- ❖Magnetic field due to a solenoid
- ❖Electromagnet
- ❖Force on a current-carrying conductor placed in a magnetic field
- ❖ Electric motor
- ❖Electromagnetic induction and its applications
- ❖Direct current and alternating current
- ❖ Electric generator
- ❖Three core cable wiring of the household circuits
- ❖Domestic electrical circuits (wiring system)
- ❖Earthing of electrical appliances

Oersted's experiment

In 1820, Hans Christian Oersted showed that electricity and magnetism were related phenomena. He experimentally demonstrated that an electric Current- carrying wire behaves like a magnet and produces a magnetic field in the space around it. The conductor behaves like a magnet till the electric current is flowing through it.

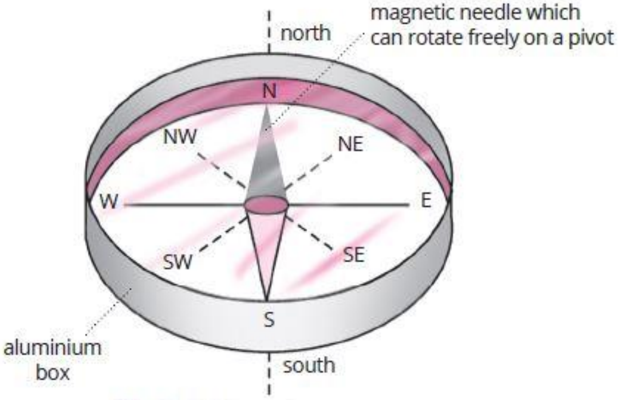
Properties of magnet

Some of the important properties of magnet are as follows:

1. A freely suspended magnet always points in the north–south direction (directive property).
2. A magnet attracts substances like iron, steel, nickel and cobalt by inducing magnetism in them (attractive property).
3. Like magnetic poles repel each other; unlike magnetic poles attract each other.
4. Magnetic poles always exist in pairs. It is not possible to have either a N pole alone or a S pole alone.

Magnetic Compass

It is an instrument having a small bar of magnet in the form of a needle, which can turn freely on a pivot or pin. The ends of the needle point towards the north and south directions. Apart from helping find the magnetic north – south direction, it also helps in tracing the magnetic field lines around a bar magnet.



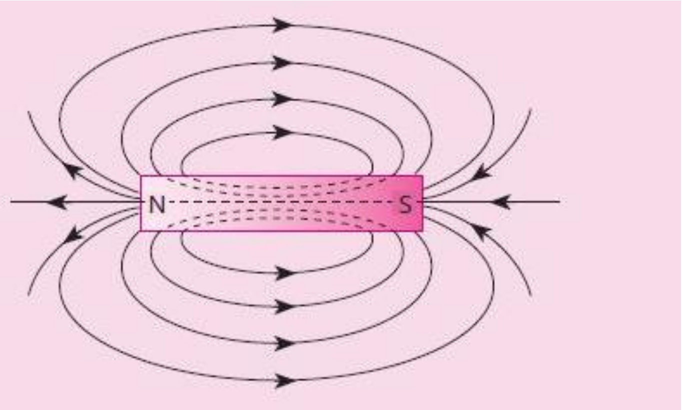
Mapping of Magnetic Field Lines

1. Iron Filings Method: When fine powder of iron filings is evenly sprinkled on a white sheet having a bar magnet in the middle of it, the filings rearrange themselves in the form of curves. These curves represent the magnetic field lines.

2. Compass Needle Method: When a small compass needle is placed close to a bar magnet on a sheet of paper and the needle's directions are traced at different points, it gives us a continuous curve that represents a magnetic field line of the bar magnet.

Magnetic Field Lines

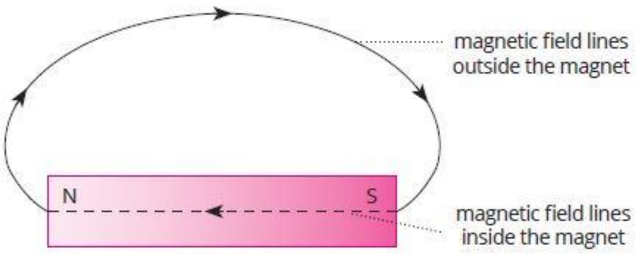
The region surrounding a magnet in which the force of a magnet can be detected is called its magnetic field. Stronger a magnet is, larger is its magnetic field. A magnetic field can be represented with the help of a set of imaginary lines called magnetic field lines or magnetic lines of force. Magnetic field is a vector quantity and it has both magitude and direction.



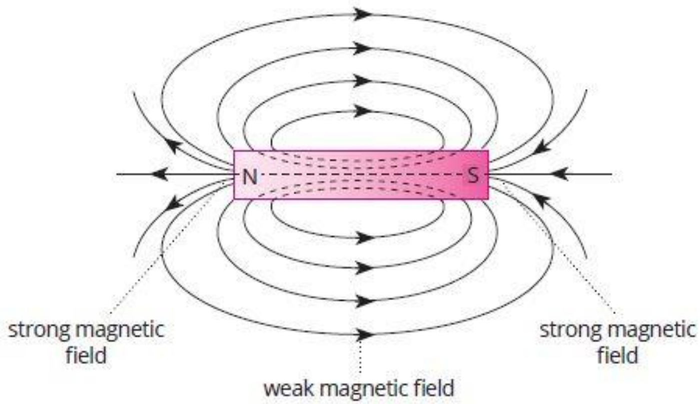
Magnetic field lines around a bar magnet

Properties of Magnetic Field Lines

- Each magnetic field line forms a closed curve. Outside the magnet, the direction of these lines is from the magnet's north pole to its south pole. Inside the magnet, the direction is from south pole to north pole.
- The relative strength of the magnetic field is shown by the degree of closeness of the field lines.
- No two magnetic field lines can intersect each other.
- The magnetic field lines emerge or come out of north pole and merge at south pole.
- Although magnetic field lines are not real, they represent a magnetic field that is real.



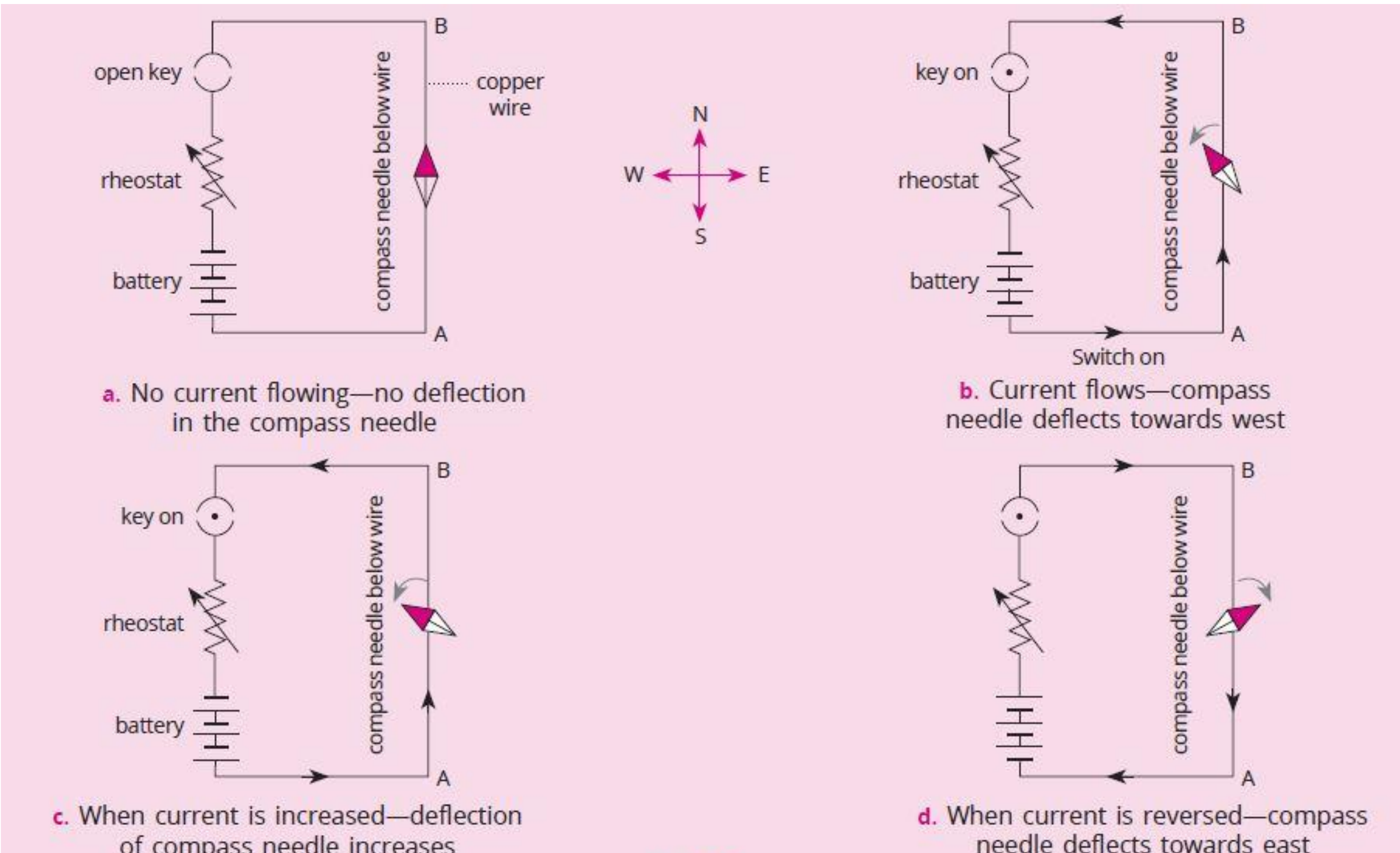
Magnetic field lines form closed curves



Magnitude of the magnetic field

Demonstration of the Magnetic Effect of Current: Oersted's Experiment

In 1820, Hans Christian Oersted accidentally discovered that a compass needle got deflected when a current carrying conductor was placed near it.



a. No current flowing—no deflection in the compass needle

b. Current flows—compass needle deflects towards west

c. When current is increased—deflection of compass needle increases

d. When current is reversed—compass needle deflects towards east

From the experiment (or Oersted's experiment) it was concluded that:

1. A current-carrying conductor produces a magnetic field.

2. The larger the value of the current in the conductor, stronger is the magnetic field and vice versa.

3. If the direction of current through a conductor (say copper wire) is reversed, then the direction of magnetic field produced by the electric current is also reversed.

Pattern of the Magnetic Field Generated by Current-carrying Conductors of Different Shapes

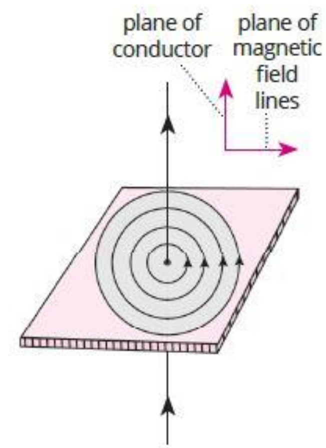
The pattern of the magnetic field generated by a current-carrying conductor depends on its shape.

Magnetic Field due to a Straight Current-Carrying Conductor

The properties of magnetic field lines around a straight conductor are as follows:

- The magnetic field lines are in the form of concentric circles around a straight conducting wire.

- The plane of the magnetic field lines is perpendicular to the straight conductor.
- If the direction of the current in the wire is reversed, the direction of the magnetic field lines is also reversed.
- When the direction of the current is downwards, the direction of the field lines is clockwise; when current is upwards, the field lines are anticlockwise.



- The strength of the magnetic field (*B*) is directly proportional to the current (*I*) passing through the conductor.

$$B \propto I$$

- The strength of the magnetic field (*B*) is inversely proportional to the distance (*r*) from the conductor.

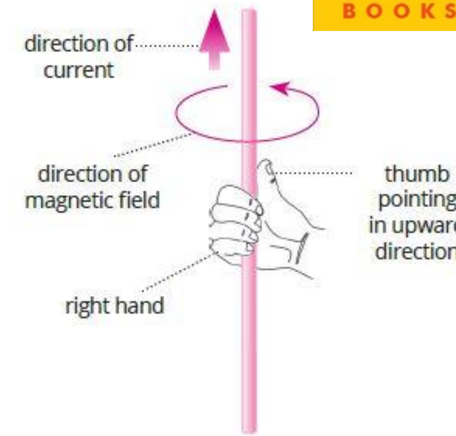
$$\text{Thus, } B \propto I / r$$

Rules for Determining the Direction of Magnetic Field

The direction of the magnetic field around a current-carrying conductor can be determined by the following rules.

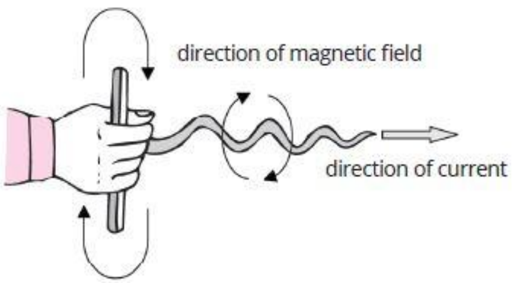
Right-Hand Thumb Rule

If a current-carrying conductor is imagined to be held in the right hand such that the thumb points towards the direction of the current, then the direction in which your fingers curl around the conductor gives the direction of the magnetic field lines.



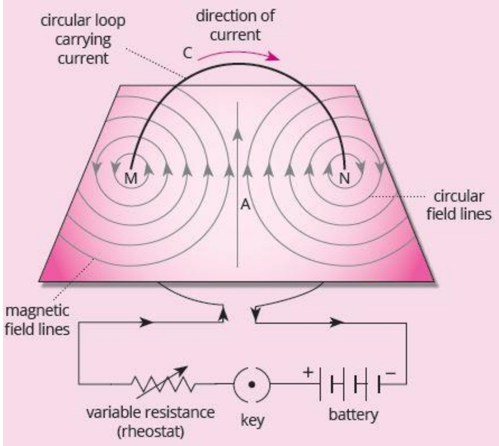
Maxwell's Corkscrew Rule

If the forward motion of an imaginary right-handed corkscrew is in the direction of the current through a straight conductor, then the direction of rotation of the handle gives the direction of the magnetic field lines.



Magnetic Field due to Current through a Circular Loop

The pattern of the magnetic field lines due to current through a circular loop is shown. At every point of the loop, the concentric circles represent magnetic field lines



Factors on which the strength of magnetic field produced by a current-carrying loop depends

1. The strength of the magnetic field (*B*) produced by a current-carrying loop is directly proportional to the amount of current (*I*) flowing through the loop, i.e. $B \propto I$. Higher the amount of current flowing through the loop, greater is the strength of magnetic field.

2. The strength of the magnetic field *B* is directly proportional to the number of turns in a circular loop, i.e. $B \propto n$. Larger the number of turns in a loop, greater is the strength of the magnetic field.

3. The strength of the magnetic field is inversely proportional to the radius *r* of the current carrying loop, i.e. $B \propto 1/r$. Smaller the radius of the current carrying loop, larger is the strength of the magnetic field.

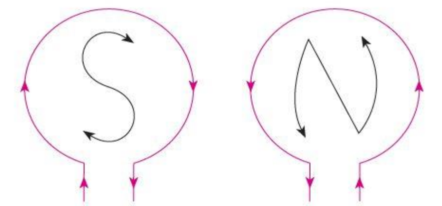
Clock Rule

Poles of the Coil

If a current-carrying coil is suspended by a thin elastic long string, it aligns itself along the north–south direction just like a compass needle or a freely suspended magnet. A current-carrying loop has two magnetic poles just like a magnet, and if allowed to rotate freely aligns itself along the north-south direction. The polarity of the face of the coil is given by the

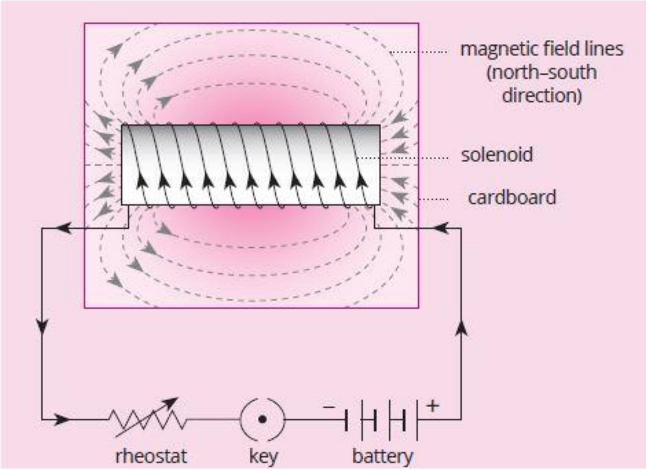
Clock Rule:

- If the current flows in the clockwise direction, the face of the coil behaves like the south pole.
- If the current flows in the anticlockwise direction, the face of the coil behaves like the north pole.



Magnetic Field due to a Current in a Solenoid

A coil of many circular turns of insulated copper wire wound closely in the shape of a cylindrical tube, whose diameter is less in comparison to its length is called a **solenoid**. When current is passed through a solenoid, it behaves like a magnet and develops a magnetic field around it.



Magnetic field lines due to a current-carrying solenoid

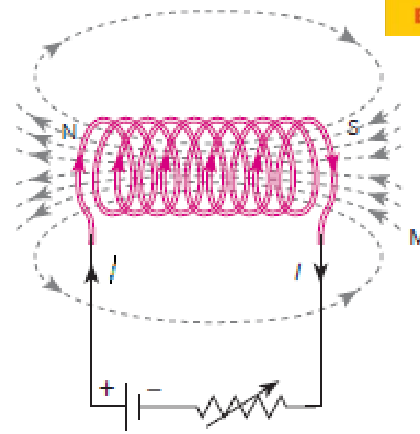
Properties of Magnetic Field Produced by a Current-carrying Solenoid

- A solenoid carrying current behaves like a bar magnet as its two ends act as the two poles of a magnet. It displays the same properties as a magnet.
- The magnetic field is uniform inside a solenoid. They are nearly parallel to each other and parallel to the axis of the solenoid.

- The intensity of the magnetic field (*B*) of a current-carrying solenoid depends on the following factors:

(a) Number of Turns: The strength of the magnetic field is directly proportional to the number of turns of the coil (*n*) i.e. $B \alpha n$.

(b) Strength of Current: The strength of the magnetic field is directly proportional to the strength of the current (*I*) flowing through the solenoid i.e $B \alpha I$

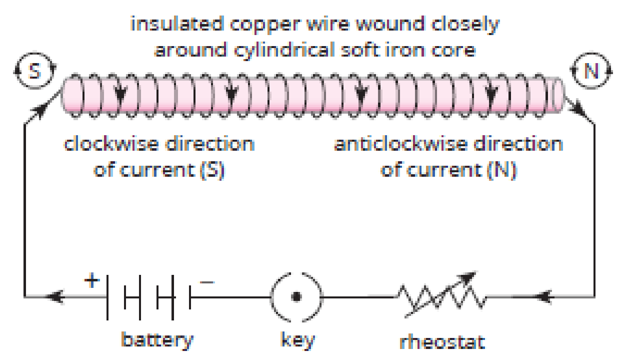


Magnetic field inside the solenoid

(c) Nature of the Core Material: The magnetic field produced is very strong when a soft iron core is placed along the axis of the solenoid.

Electromagnet

An electromagnet is a solenoid with a soft iron core. It is usually prepared by placing a soft iron core in a solenoid, or by winding a large number of turns of an insulated wire (generally insulated copper wire) around a cylindrical, soft iron core.



An electromagnet shows magnetic properties only as long as electric current flows through the solenoid. It loses the magnetic properties when the current is switched off. This is because soft iron has less retentivity.

Retentivity is referred to as the capacity of a material to retain the magnetic property in itself.

Advantages of an Electromagnet

- It gets demagnetised as soon as the current is switched off.
- The magnetic field strength of an electromagnet can be easily changed by changing the strength of the current in the coil or the number of turns in the solenoid.
- The polarity of an electromagnet can be changed by reversing the direction of current in the solenoid.

Uses of Electromagnets

- Construction of electrical devices like electric bells, loudspeakers, electric motors and telephones
- Lifting and transportation of heavy loads like large machines and scrap iron objects
- Separation of magnetic substances like iron and steel from non-magnetic ones in a heap of scrap
- Removal of pieces of iron from wounds or of steel splinter from the eye
- Magnetisation of steel bars

Force on a Current-carrying Conductor Placed in a Magnetic Field

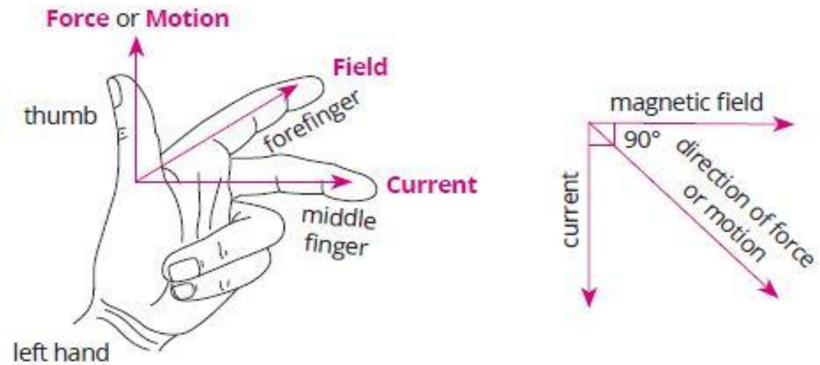
When a current-carrying conductor is held near a magnetic needle (or a compass), the magnetic needle gets deflected. This is because the magnetic field around the current-carrying wire exerts a mechanical force on the magnetic needle and produces a motion in it. The magnetic field produced by a magnet exerts a force on a current-carrying conductor and produces a motion in it.

Kicking wire experiment

- The magnetic field produced by a magnet exerts a force on a current-carrying conductor and produces a motion in it.
- The direction of motion of the conductor depends upon the direction of the current and the magnetic field.
- The current-carrying conductor, when placed in a magnetic field, moves in a direction perpendicular to the direction of the current as well as perpendicular to the direction of the magnetic field.
- The direction of force on a current-carrying conductor (i.e. the direction of movement of the conductor) placed in a magnetic field can be reversed by
  - reversing the direction of current flowing through the conductor.
  - reversing the direction of magnetic field.

Fleming's Left-Hand Rule

When a current-carrying wire (conductor) is placed in a magnetic field, a force is exerted on the conductor which makes the conductor move. Fleming's left-hand rule is used to find out the direction of motion of a current-carrying conductor when placed in a magnetic field.



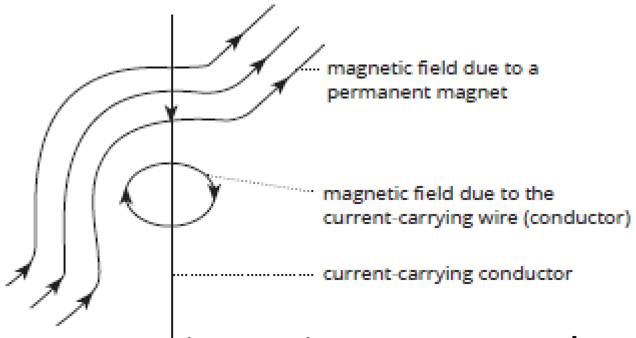
Fleming's left-hand rule

According to Fleming's left-hand rule: Stretch the forefinger, middle finger and the thumb of your left hand such that they are mutually perpendicular to each other. If the forefinger indicates the direction of magnetic field and the middle finger indicates the direction of current, then the thumb gives the direction of motion or the force acting on the conductor.

This force is due to two fields:

1. When current flows through the conductor, it produces a magnetic field around it.

2. Magnetic field of the permanent magnet acting on the conductor



The current-carrying wire moves when placed in a magnetic field due to resultant force

Electric Motor

An electric motor is a device that converts electrical energy into mechanical energy (kinetic energy). It is used to drive various types of machines and electrical appliances like fans, washing machines and mixer-grinders. There are two types of electric motor.

(a) **AC motor**, which works on an alternating current supply, for example in fans and washing machines, and

(b) **DC motor**, which works on direct current, for example in battery-operated toys. Here we will describe a simple DC motor.

Principle of an Electric Motor

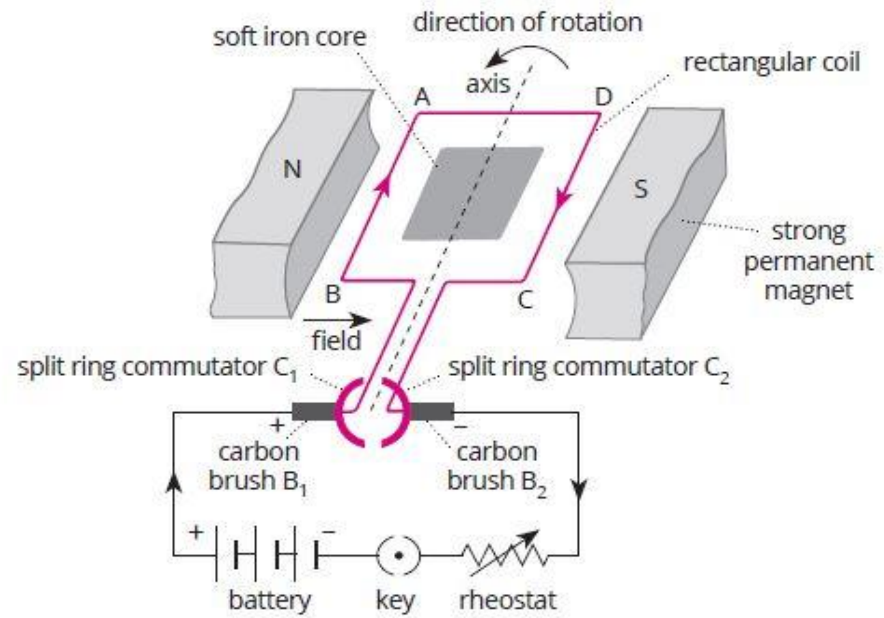
When an electric current is passed through a conductor placed at right angle to a magnetic field, a force perpendicular to both the magnetic field and the current acts on the conductor. This makes the conductor move. The direction of the motion of the conductor is given by Fleming's left-hand rule.

Construction of an Electric DC Motor

The basic design and various parts of an electric DC motor are described as follows.

- **Armature:** This is a rectangular coil ABCD of insulated copper wire wound on a soft iron core.

- **Horseshoe Magnet:** The coil is mounted on an axle and rotates about this axle between the curved N and S poles of a horseshoe magnet.
- **Split Ring Commutator:** It is a copper ring split into two parts C_1 and C_2, which are insulated from each other and mounted on the axle of the motor and rotate with it.
- **Brushes:** These are made of carbon (B_1 and B_2) and are in contact with the split rings.
- **Battery:** A battery is connected to the split rings through two brushes B_1 and B_2. The brush B_1 is connected to the positive terminal of the battery and brush B_2 is connected to the negative terminal of the battery.



Parts of a DC motor

Refer to pages 81-82 of textbook for **Working of a DC motor.**

Ways of Increasing the Speed of the Coil of a Motor

The speed of rotation of the coil of a motor can be increased by:

- increasing the current flowing in the coil
- increasing the number of turns in the coil
- increasing the area of cross section of the coil
- increasing the strength of radial magnetic field
- laminating the soft iron core.

Uses of a DC Motor

- For running machines in factories
- In electric locomotives, trolley-buses and tramcars
- As special motors to carry out heavy work like in a pump to force out oil from an oil well

Electromagnetic Induction

The process by which a changing magnetic field in a conductor induces a current in another conductor is called **electromagnetic induction**. The current so produced is called **induced current**. In practice, we can induce current in a coil by two methods:

- By moving a coil in a magnetic field
- By changing the magnetic field around the coil

The electromotive force (or voltage) produced is called induced e.m.f. Electromagnetic induction was discovered by Michael Faraday, and is used in many important devices today.

Factors on Which the Induced Current Depends

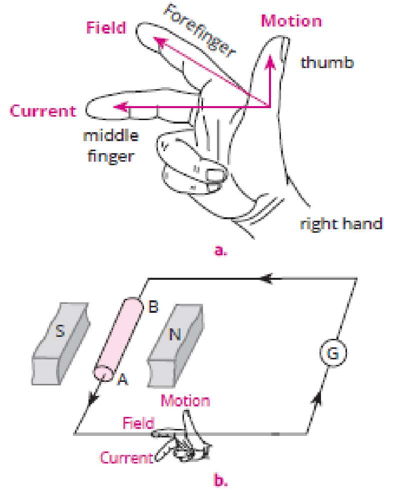
The strength of the induced current depends upon the following factors:

- **Strength of the magnetic field:** The strength of the induced current increases with the strength of the magnetic field (or power of the magnet).
- **Number of turns in the coil:** Larger the number of turns in the coil, stronger is the induced current.
- **Relative speed between the coil and the magnet:** Higher the relative speed between the coil and the magnet, stronger is the induced current.

Direction of induced e.m.f. and current

The direction of induced current produced in a straight conductor moving in a magnetic field is given by Fleming's right-hand rule.

According to this rule, stretch out the forefinger, middle finger and thumb of your right hand so that they are at right angles to one another .



Fleming's right-hand rule

If the forefinger points in the direction of magnetic field, thumb in the direction of motion of the conductor, then the middle finger will point in the direction of the induced current.

Direct Current and Alternating Current

The electric current which always flows in the same direction is called **direct current or DC**. Thus, for DC, the positive and negative polarities are fixed. The current obtained from a battery or a cell is direct current.

The electric current which reverses its direction after a certain fixed interval of time is called **alternating current**. Thus, in AC, the positive and negative polarities are not fixed. The electricity supplied to our homes and industry is alternating current. The alternating current in India changes direction after every 1/100 second.

Electric Generator

A machine that produces electricity by converting mechanical energy into electrical energy (electricity) for use in home and industry is known as **generator**.

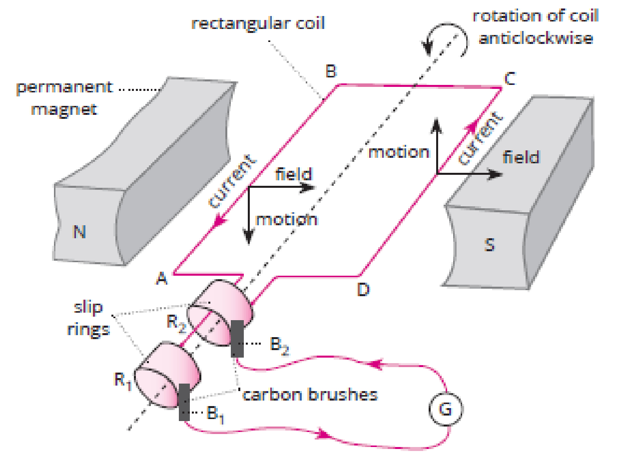
It works on the principle of electromagnetic induction, i.e. when a coil is rotated in a uniform magnetic field, then current is induced in it.

Electric generators are of two types:

1. Alternating current generator or AC generator

2. Direct current generator or DC generator

AC generator

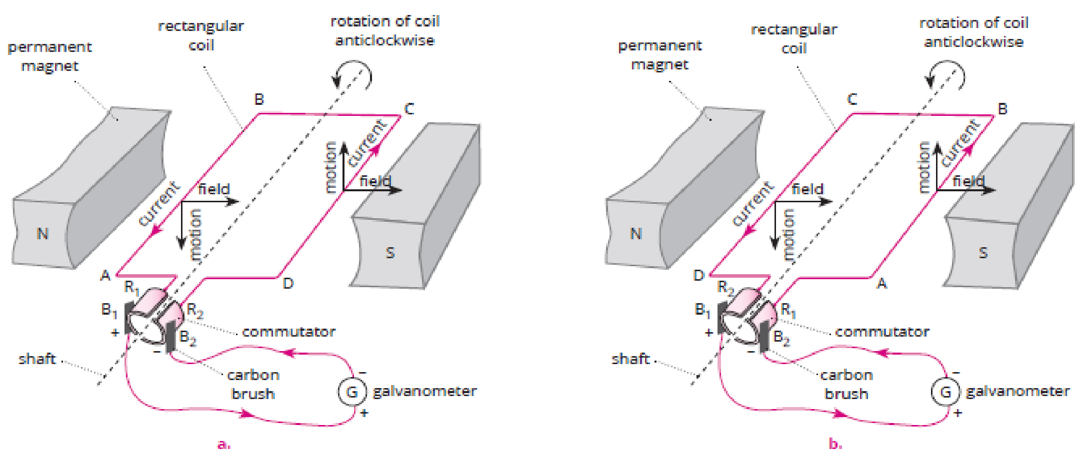


AC generator

An AC generator produces alternating current, which changes direction after equal intervals of time. It is also known as alternator.

In our country, the frequency of the alternating current supplied by the power generation units is 50 cycles per second (i.e. 50 Hz). Since in one rotation of the coil, current changes its polarity two times, this means the alternating current (AC) produced in our country changes polarity $2 \times 50 = 100$ times in one second.

Refer to pages 87-88 of textbook for **Working of a AC Generator.**



DC generator

Direct Current (DC) generator

A DC generator is a device which is used for producing direct current from mechanical energy.

Refer to page 88 of textbook for
Construction of a DC Generator.

Three Core Cable Wiring of the Household Circuits

The main supply of electric power is done in our homes using a three core cable. The three cables are:

1. Live wire (L) 2. Neutral wire (N) 3. Earth wire (E)

A wire with red insulation cover is called a **live wire** (or +ve, positive). Another wire with black insulation cover is called **neutral wire** (or –ve, negative).

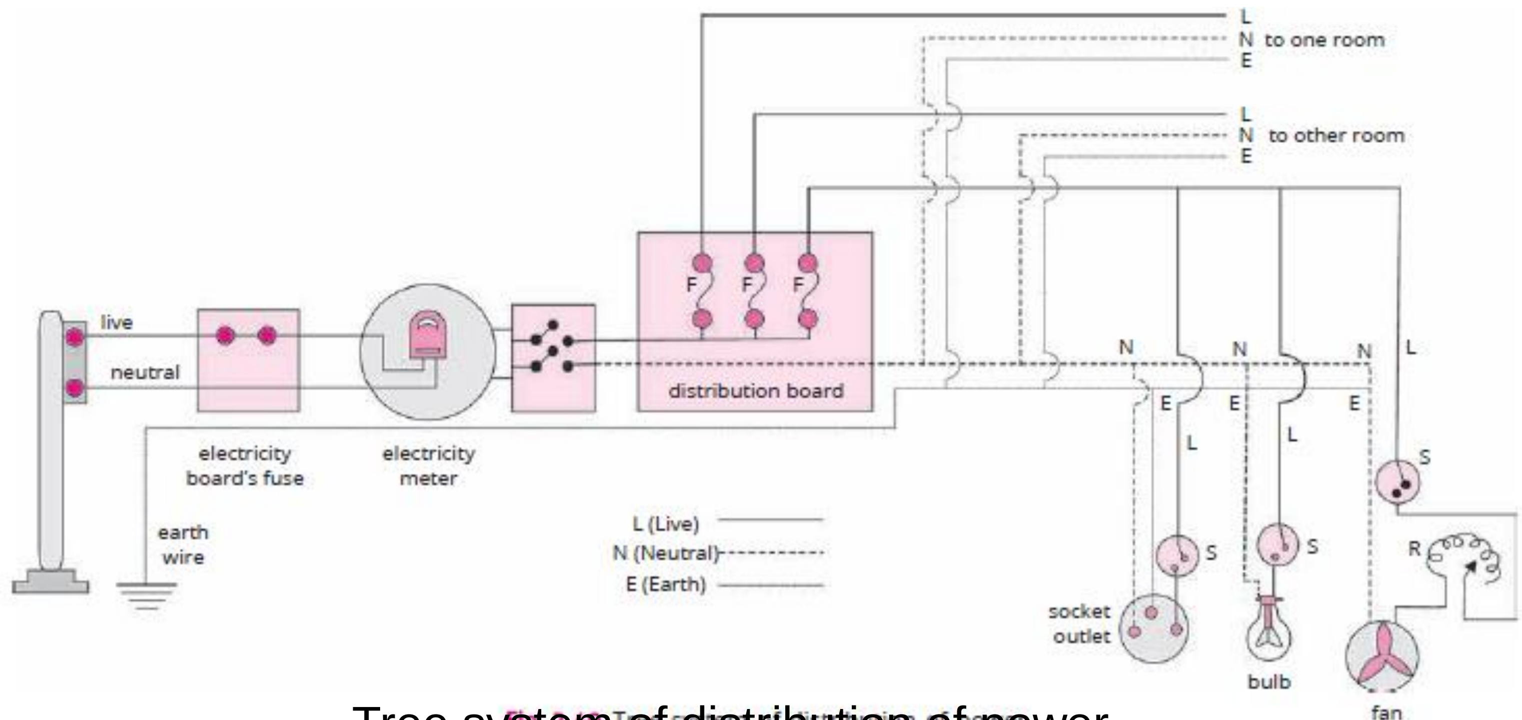
The wire with green insulation cover is called the **earth wire** (E, no charge).

Domestic Electrical Circuits (Wiring System)

The wires from the main switch enter the **distribution box**. In the distribution box, the main line is divided into two main circuits: one of **5 A** (**domestic light**) and another of **15 A** (**domestic power**). The domestic light (5 A line) is used for running appliances of low rating such as bulbs, tubelights, fans, radio and TV. The domestic power (15 A line) is used for running appliances of high rating such as electric iron, geyser and refrigerator.

Tree system of distribution of power

In this wiring system, various branch lines are taken from the distribution board. These lines are then connected to different parts of the house. This system of wiring is referred to as 'tree system' .



Tree system of distribution of power

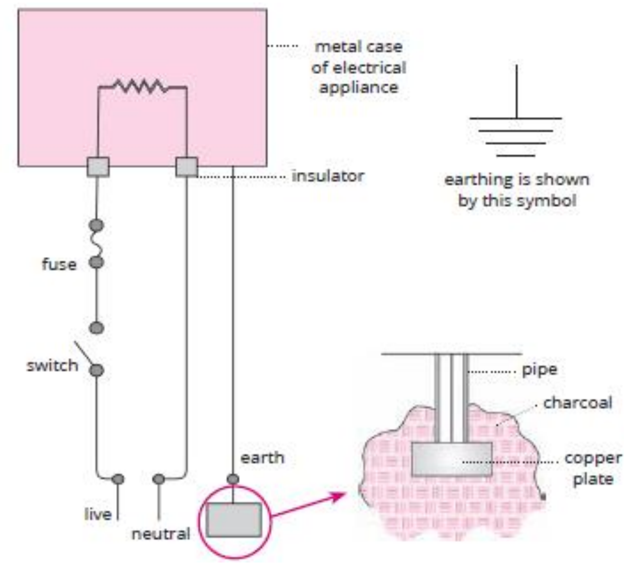
Earthing of Electrical Appliances

Connecting the metallic body of an electrical appliance to the earth (at zero potential) by a conducting wire to prevent electric shock is called the earthing of an appliance.

In a house, the local earthing is made near the electric meter. Earthing is done by connecting a metal plate to a thick copper wire surrounded by a hollow insulating pipe. The metal plate is buried deep (5 metres) into the earth.

Need for earthing appliances

1. Sometimes the insulation of a live wire may get damaged or worn out and it may come in contact with the metallic body of the appliance. When such an electrical appliance is connected to the mains, its body, if not connected to the earth wire, will also be raised to 220 V. If we happen to touch any part of this appliance, a very high current flows through our body into the earth and we get an electric shock.



Earthing of an electrical appliance

2. Earthing also saves the appliances from being damaged in case of short circuit and overloading. **The earth can be regarded as an electric sink** since excess current flows through the earthing to the earth

SUMMARY

1. Magnetic field lines: Magnetic field can be represented with the help of a set of lines called magnetic field lines or magnetic lines of force.

2. Magnetic field pattern: Concentric circles represent the magnetic field lines of a straight current-carrying wire.

3. Right-hand thumb rule: If a current-carrying conductor is imagined to be held in right hand such that the thumb points in the direction of current, then the direction in which your fingers curl around the conductor will give the direction of the magnetic field lines.

4. Solenoid: A coil of many circular turns of insulated copper wire wound closely in the shape of a cylindrical tube is called a solenoid.

5. Intensity of magnetic field of a current-carrying solenoid: It depends **a.** directly on the number of turns, **b.** directly on the current passing through the solenoid, **c.** when a soft iron core is placed.

6. Electromagnet: It is a solenoid with a soft iron core.

7. Force on current-carrying conductor in a magnetic field: Ampere suggested that magnetic field produced by a magnet exerts force on a current-carrying conductor and produces motion in it.

8. Fleming's left-hand rule: Stretch the forefinger, middle finger and the thumb of your left hand such that they are mutually perpendicular to each other. If the forefinger indicates the direction of magnetic field and the middle finger indicates the direction of current, then the thumb gives the direction of the force acting on the conductor.

9. Electromagnetic induction: Michael Faraday showed that a moving magnet can be used to generate electric current. This phenomenon is called electromagnetic induction. The current so produced in the conductor is called induced current.

10. Fleming's right-hand rule: Stretch the forefinger, middle finger and thumb of your right hand so that they are at right angles to one another. If the forefinger points in the direction of magnetic field, thumb in the direction of motion of the conductor, the middle finger will point in the direction of induced current.

11. Generator: An electric machine that produces electricity by converting mechanical energy into electrical energy.

12. Principle of a generator: When a coil is rotated in a uniform magnetic field then current is induced in it.

13. Fuse: It is the most important safety device, used for preventing short circuiting or overloading of circuits.