UNIT 15

ELECTROMAGNETISM

After studying this unit, the students will be able to:

- **a.** Explain by describing an experiment that an electric current in a conductor produces a magnetic field around it.
- **b.** Describe that a force acts on a current-carrying conductor placed in a magnetic field as long as the conductor is not parallel to the magnetic field.
- **c.** State that a current-carrying coil in a magnetic field experiences a torque.
- **d.** Relate the turning effect on a coil to the action of a D.C. motor.
- **e.** Describe an experiment to show that a changing magnetic field can induce e.m.f. in a circuit.
- **f.** List factors affecting the magnitude of an induced e.m.f
- **g.** Explain that the direction of an induced e.m.f opposes the change causing it and relate this phenomenon to conservation of energy.
- **h.** Describe a simple form of A.C. generator.
- **i.** Describe mutual induction and state its units.
- **j.** Describe the purpose of transformers in A.C circuits.
- **k.** Identify that a transformer works on the principle of mutual induction between two coils.

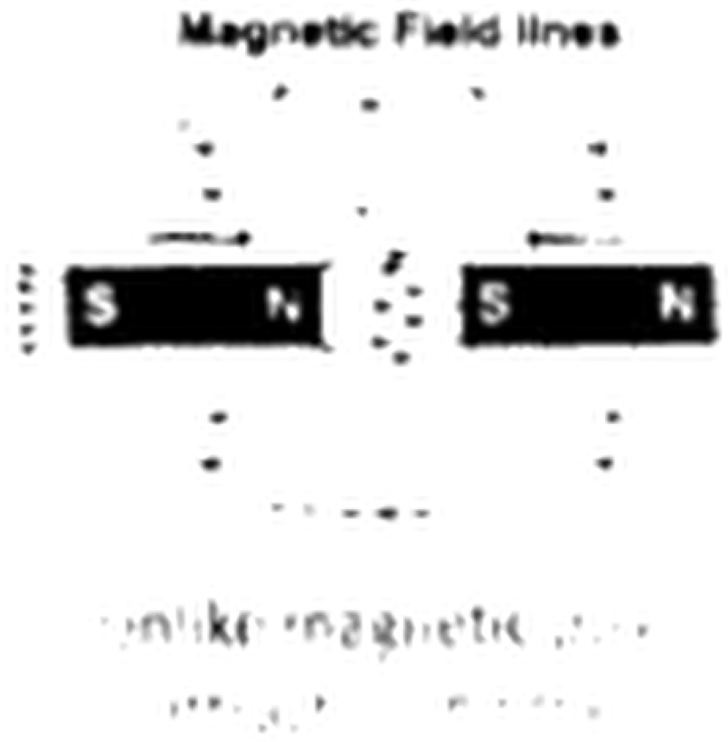
Q.1 Demonstrate by an experiment that a magnetic field is produced around a straight current-carrying conductor?

Answer

Magnetic effects of a steady current

Ampere discovered that when a current pass through a conductor it produces magnetic field around it.

To demonstrate this, we take a straight conductor wire and pass it vertically through a card board as shown in fig. 15.1 (a). Now connect the two ends of the conductor wire with the terminals of the battery so that current flows through the circuit in the clockwise direction.



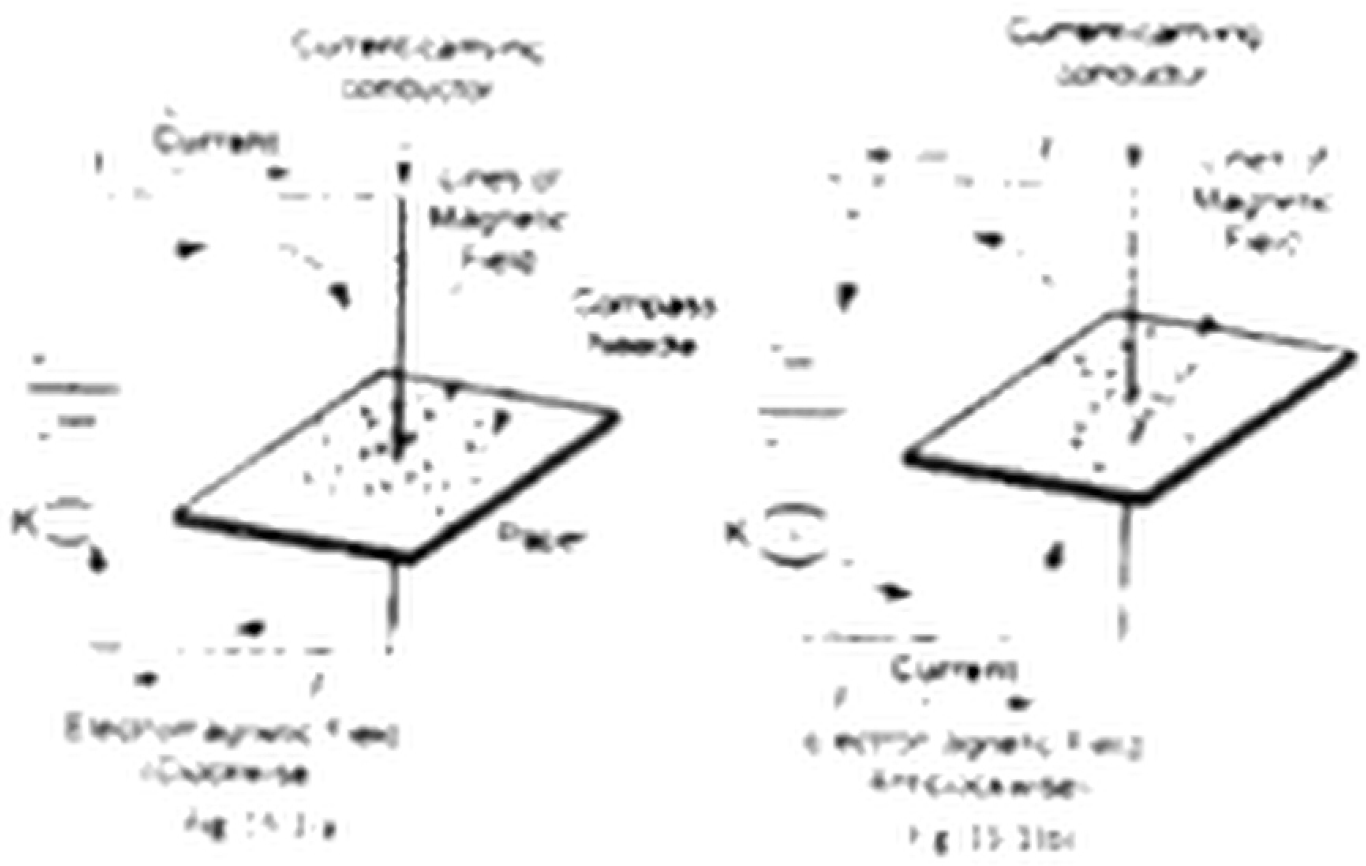
The lines of force of the magnetic field produced around the wire would be in the form of concentric circles.

If we put a compass needle at different points in the region of magnetic field, it will align along the direction of magnetic field.

Also, if we sprinkle some iron fillings on the card board around the wire, they will align themselves in concentric circles in the clockwise direction.

If we reverse the direction of the current by reversing the terminals of the battery, the compass needle also reverses its direction. '

Now the magnetic field lines will align in the anti-clock wise direction as shown in the figure 15.] (b).



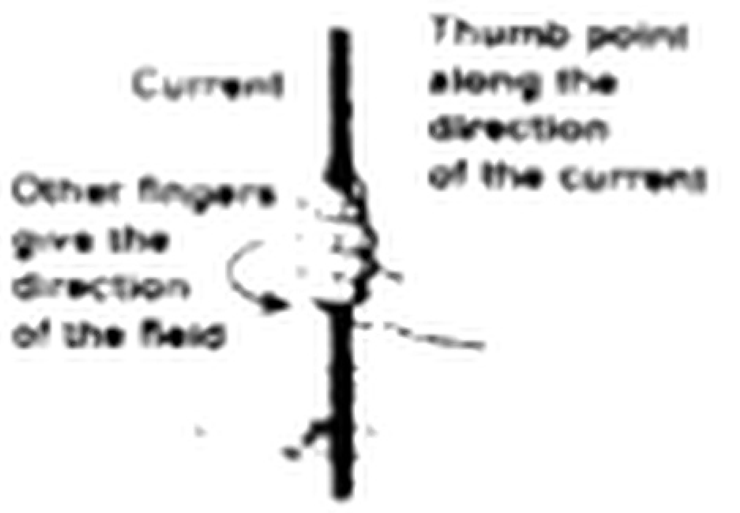
The magnetic field produced is stronger near the centre of the current carrying conductor and weaker farther away from it.

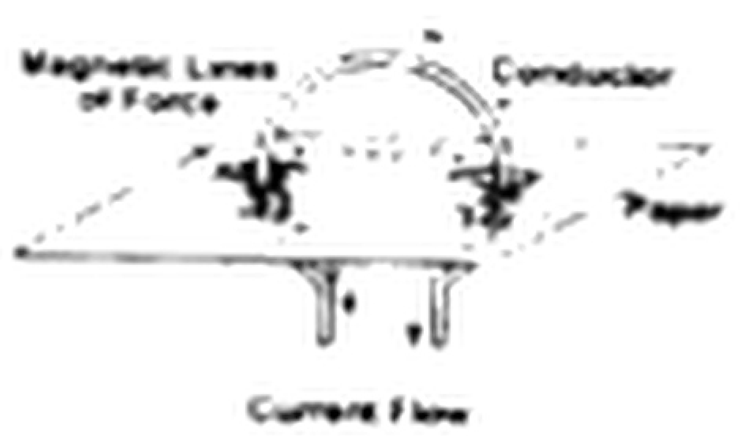
Q2 State and explain the rule by which the direction of the lines of force of the magnetic field around a current carrying conductor can be determined?

Answer

Right hand grip rule

"Grasp a wire with your right hand such that your thumb points in the direction of the conventional (positive) current. Then curling fingers of your hand will point in the direction of the magnetic field." It is called right hand grip rule.





Activity

Take a straight piece of wire and bend it into the form of a single loop. Now pass it through a card board having two holes. Connect the ends of loop to a battery so that a current start flowing through it as shown in fig. 15. 3. Now sprinkle some iron fillings on the card board. Note the pattern of the iron fillings that emerges on the card board.

Magnetic field of a solenoid

The long coil of wire consisting of many loops IS called a solenoid. The field from each loop in a solenoid adds to the fields of the other loops and creates greater total field strength as shown in the figure 15.4.

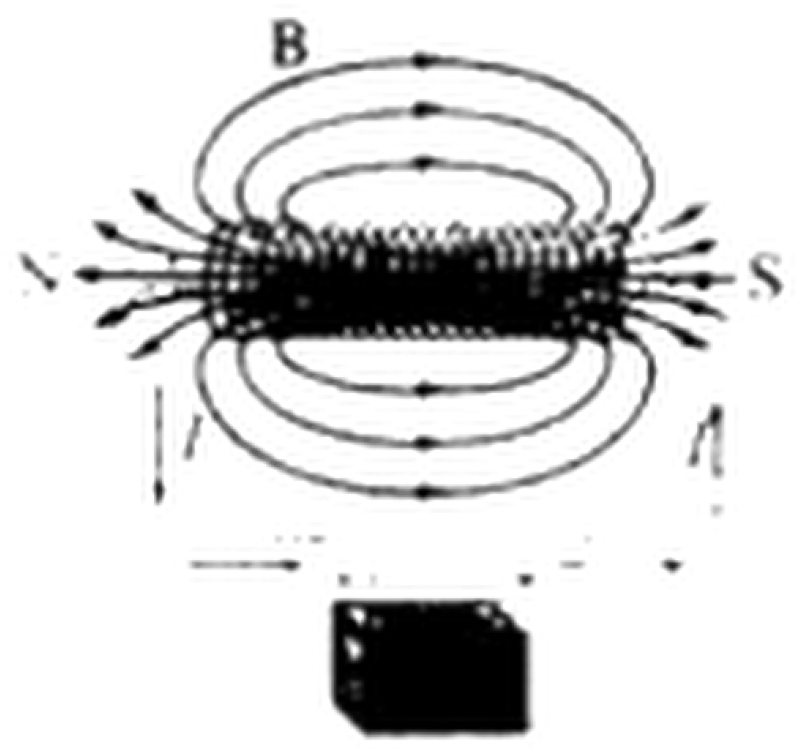


Fig. 15.4 Magnetic field due to a coil

Electric current in the coil of wire produces magnetic field which is similar to the magnetic field of a permanent magnet. When this current carrying coil is brought close to suspend bar magnet one end of the coil repels the north pole of the magnet. Thus, the current carrying coil has a north and a south pole and is itself magnet.

Electromagnet

The type of temporary, which is created when current flows through a coil, is called an electromagnet.

Direction of magnetic field

If we grip the coil with our right hand by curling our fingers in the direction of the conventional current, one thumb will indicate the north pole of the coil as shown in the figure15.5.

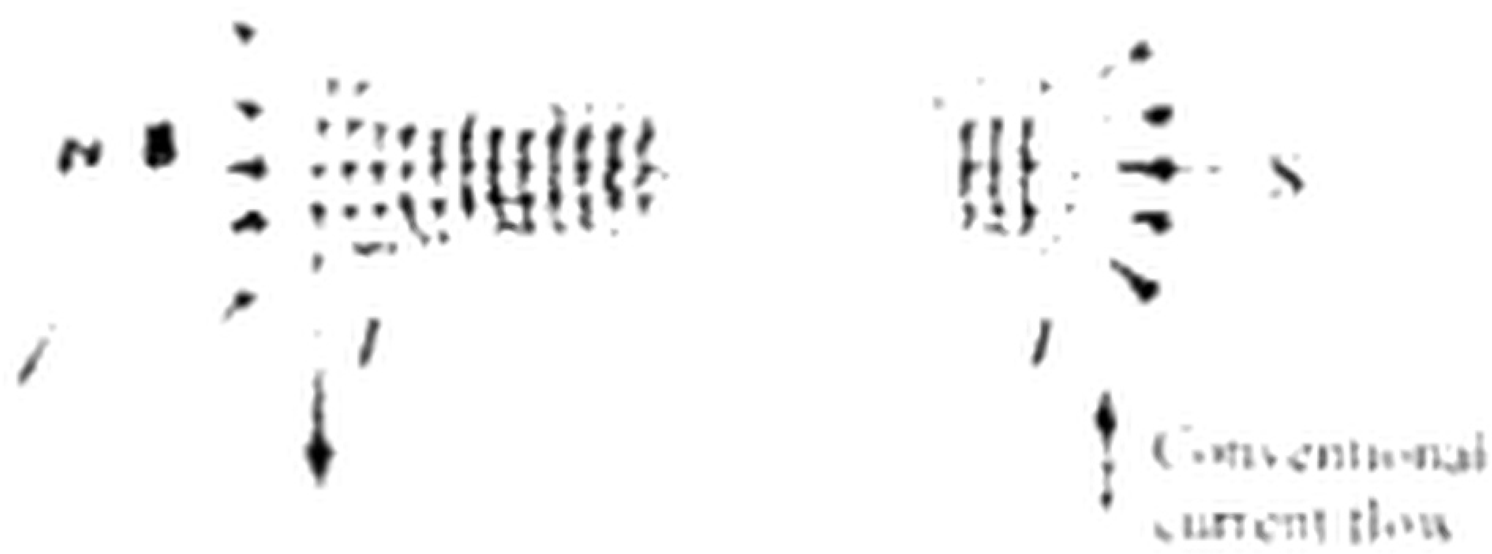
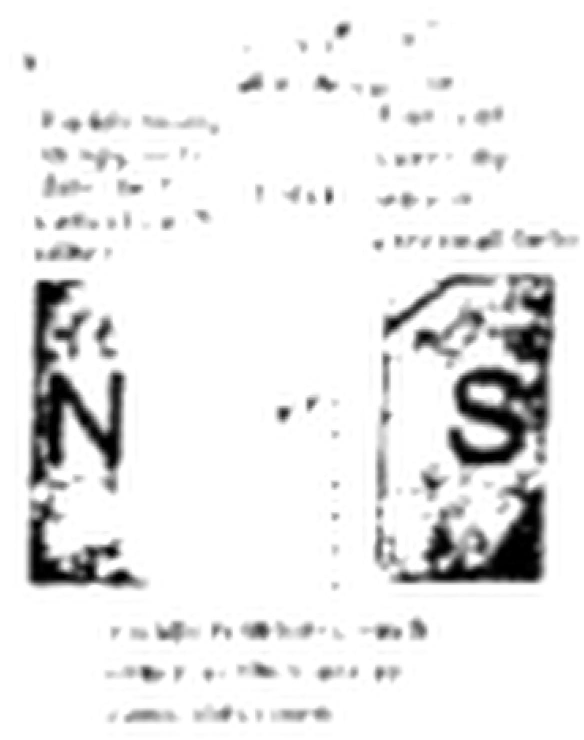


Fig. 15.5. Right hand grip rule for a coil

Q.3 When a straight current-carrying conductor is placed in a magnet field, it experiences a force. State the rule by which the direction of this force can be found out?

Answer

Since a magnetic field exerts force on a permanent magnet. It implies that current carrying wire should also experience a force when placed in a magnetic field.



The force on a wire in a magnetic field can be demonstrated using the arrangement shown in fig. 15.6. A battery produces current in a wire placed inside the magnetic field of a permanent magnet.

Current-Carrying wire produces its own magnetic field. Which interacts with the field of the magnet. As a result, a force is exerted on the wire.

Depending upon the direction of the current. the force on the wire either pushes or pulls it towards left as shown in fig. 15.6 (a) or towards right shown in fig. I5.6 (b).

Fig. 15.6 Force on a current carrying wire in magnetic field

Michael Faraday discovered that the force on the wire is at right angles to both the direction of the magnetic field and the direction of current. The force Is increased if:

1) The current in the wire is increased.

2) Strength of magnetic field is increased.

3) The length of the wire inside the magnetic field is increased.

Determining the direction of force

The direction of the force on a current carrying wire in a magnetic field can be found by using Fleming's left-hand rule stated as:

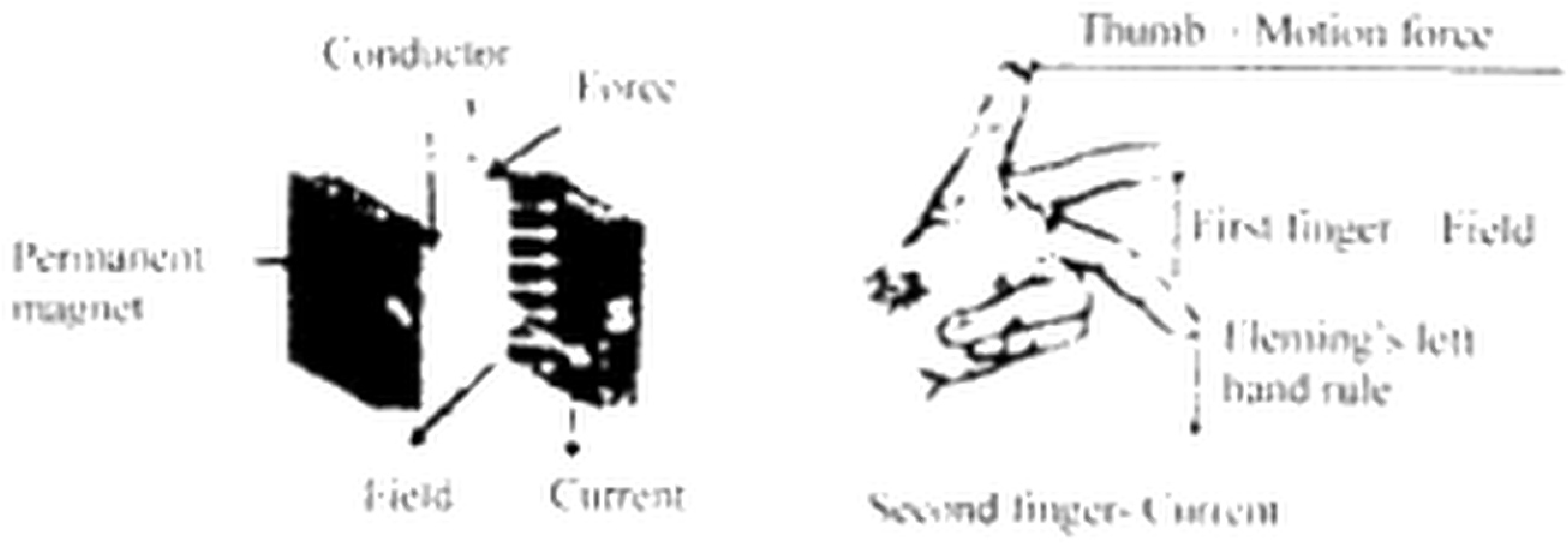


Fig. 15.7. Direction of force on a current-carrying conductor laced in a magnetic field

Fleming's left-hand rule

"Stretch the thumb, forefinger and the middle finger of the left hand mutually perpendicular to each other. If the forefinger points in the direction of the magnetic field. the middle finger in the direction of the current, then the thumb would indicate the direction of the force acting on the conductor."

Q.4 State that a current-carrying coil in a magnetic field experiences a torque?

Answer

If instead of a straight conductor, we place a current—carrying loop inside the magnetic field. the loop will rotate due to the torque acting on the coil. This is also the working principal of electric motors.

Consider a rectangular coil of wire with sides PO and RS, lying perpendicular to the

field, placed between the two poles of a permanent magnet (fig. 15.8). Now if the ends of the coil are connected with the positive and negative terminals of a battery, 3 current would start flowing through the coil. The current passing through the loop enters from one end of the loop and leaves from the other end.

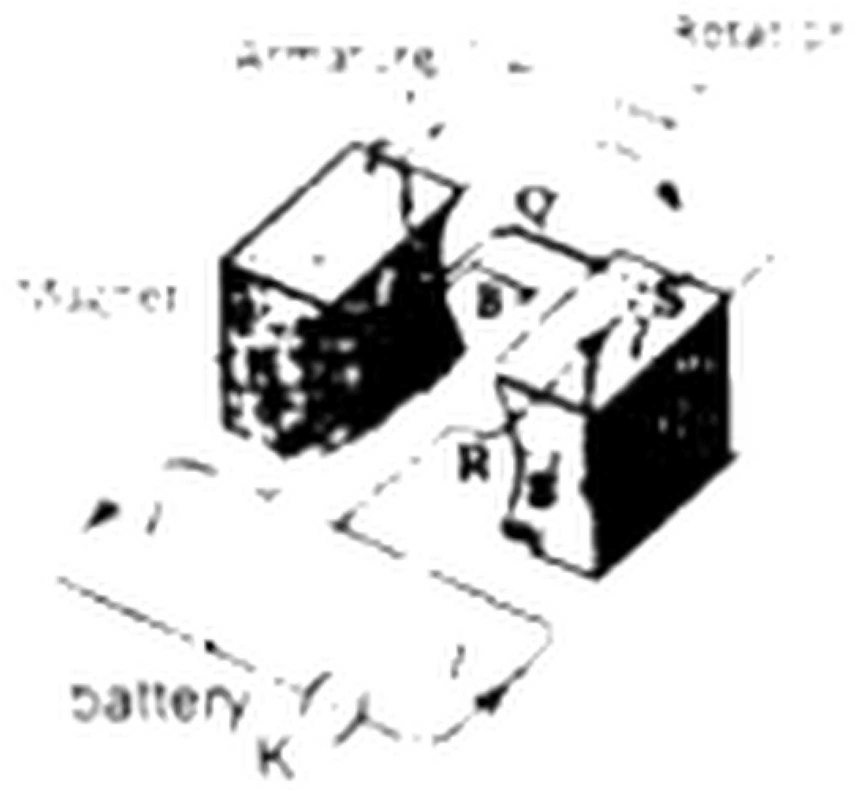


Fig. 15.8 A current-carrying coil in a magnetic field

Now apply Flemings left hand rule to each side of the coil. We can see that on PO side of the loop force acts upward, while on the RS side of the loop force acts downward it is because the direction of the current through the two sides of the loop facing the two poles is at right angles to the field but opposite to each other. The two forces which are equal in magnitude but opposite in direction form a couple. The resulting torque due to this couple rotates the loop, and the magnitude of the torque acting on the loop is proportional to the magnitude of the current passing through the loop.

If we increase the number of loops, the turning effect is greatly increased. This is the principle involved in electric motors.

Q.5 Write the construction and principle of working of DC motor.

Answer

Construction & working

I) A shown in fig. 15.9 that the simple coil placed in a magnet cannot rotate more than 90° The forces push the PQ side of the coil up and the RS side of the loop down until the loop reaches the vertical position. In this situation, plane of the loop is perpendicular to the magnetic field and the net force on the coil is zero.

So, the loop will not continue to turn because the forces are still up and down and balanced.

2) The coil can be rotated by reversing the direction of the current just as the coil reaches its vertical position.

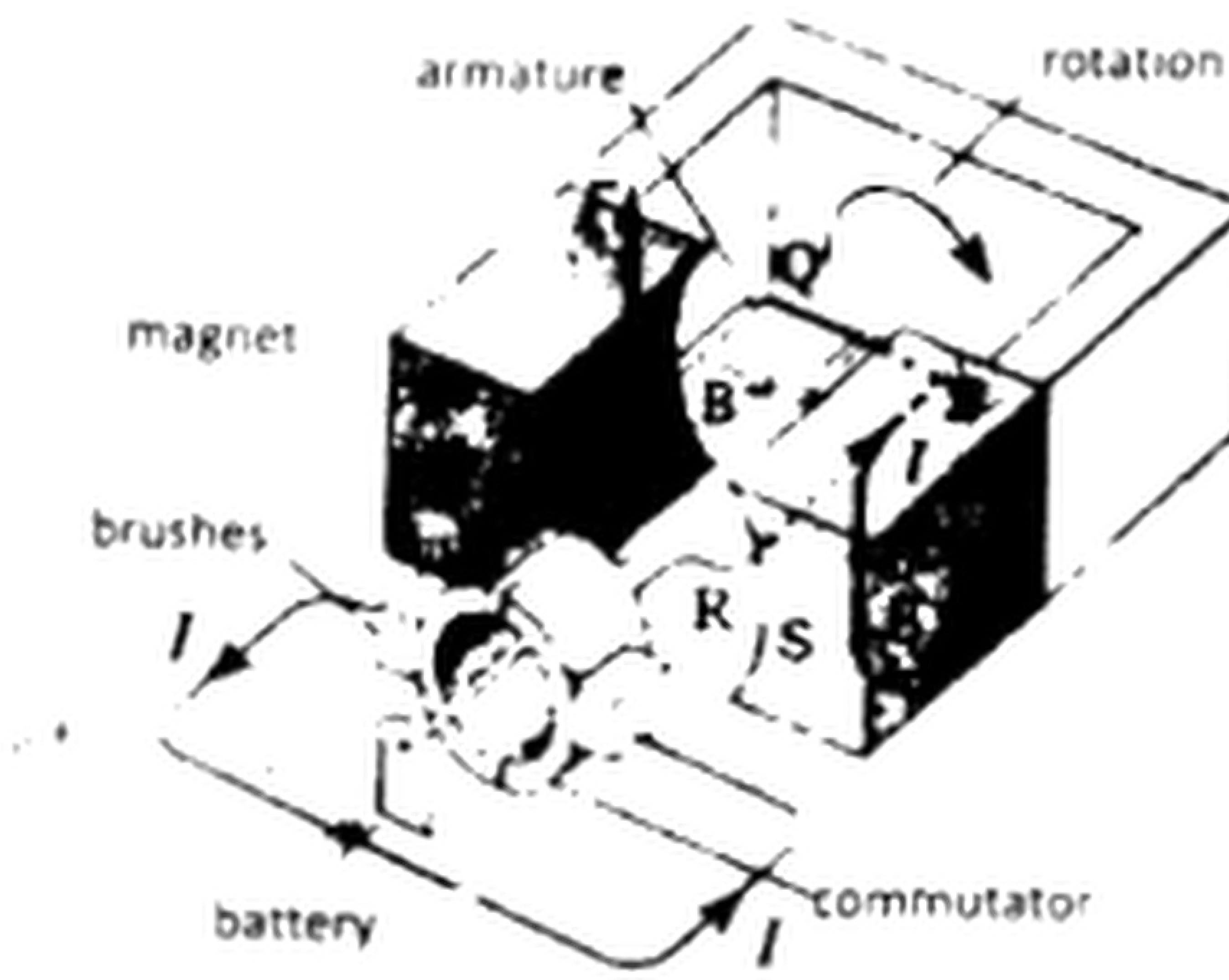


Fig. 15.9: Working principle of D.C. motor

3) This reverses direction of the current. The connection to coil is made through an arrangement of brushes and a ring that is split into two halves, called a split ring commutator.

4) Brushes. which are usually pieces of graphite, make contact which the commutator and allow current to flow into the loop. As the loop rotates. So does the commutator.

5) The split ring is arranged so that each half of the commutator changes brushes just as the coil reaches the vertical position. Changing brushes reverses the current in the loop. As a result, the direction of the force on each side of the coil is reversed and it continuous to rotate. This process repeats at each half turn, causing coil to rotate in the magnetic field continuously. The result 15 an electric motor, which Is an apparatus that converts electric energy into rotational kinetic energy.

6) In a practical electric motor the coil, called the armature, is made of many loops mounted on a shaft or axle. The magnetic field is produced either by permanent magnets or by an electromagnet, called a field coil.

The torque on the armature, and as a result, the speed of the motor is controlled by varying the current through the motor.

The total force acting on the armature can be increased by:

i) Increasing the number of turns on the coil.

ii) Increasing the current in the coil.

iii) Increasing the strength of the magnetic field.

iv) Increasing the area of the coil.

Q.6 What is electromagnetic induction? Describe simple experiments to demonstrate that a changing magnetic field can induce an e.m.f. in a circuit?

Answer

Magnetic field strength

The strength of magnetic field is defined as the number of magnetic lines 0f force passing through any surface.

1) The number of magnetic lines of force is maximum when the surface is held perpendicular to the magnetic lines of force as shown in figure 15.10.

2) It will be minimum when the surface is held parallel to the magnetic lines of force as shown in the figure 15.11.

Fig. 15.10: Maximum magnetic flux

Fig. 15.11: Minimum magnetic flux

Electromagnetic Induction

The process of generating an induced current in a circuit by changing the number of magnetic lines of force passing through it is called electromagnetic induction.

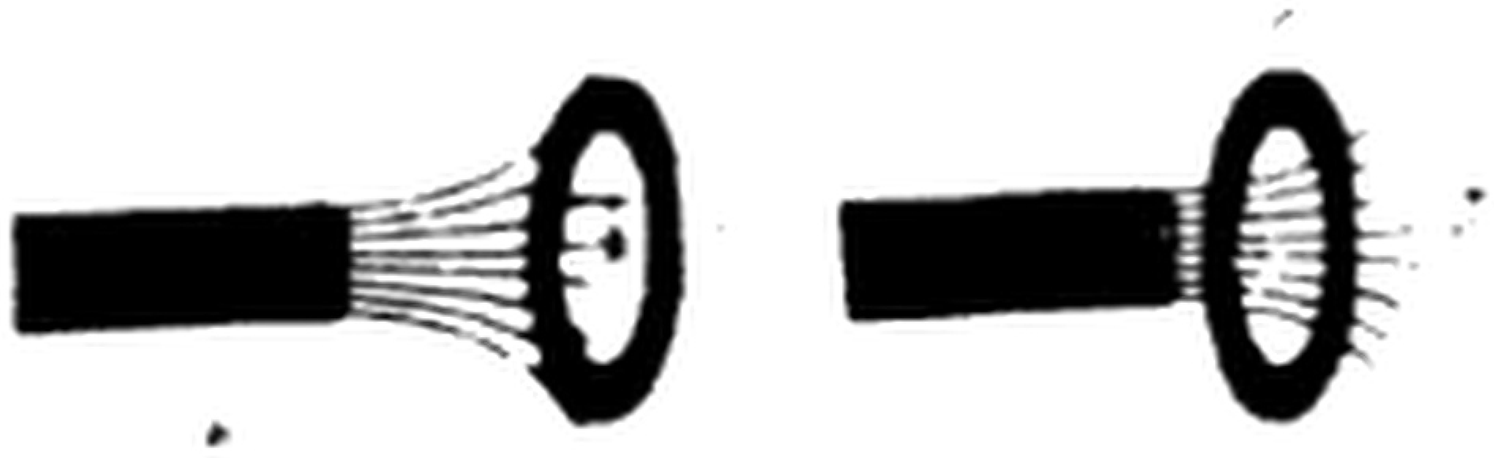


Fig. 15.12: Variation of magnetic field lines of force through a coil placed at different distances from the magnet

Explanation

If we place a coil in the magnetic field of a bar magnet, some of the magnetic lines of force will pass through it. If the coil is far away from the magnet, only a few lines will pass the coil as shown in the figure 15.12 (3).

However, if the coil is close to the magnet, a large number of lines of force will pass through it as shown in the figure 15.12 (b).

This means, we can change the number of magnetic lines of force through a coil by moving it in the magnetic field. This change in the number of magnetic field lines will induce an e.m.f in the coil.

Activity 1

Take a rectangular loop of wire and connect its two ends with a galvanometer. Now hold the wire stationary or move it parallel to the magnetic field of a strong U-shape magnet.

Galvanometer shows no deflection and hence there is no current.

1) Now, move the wire downward through the field, current is induced in one direction (fig. 15.13 a).

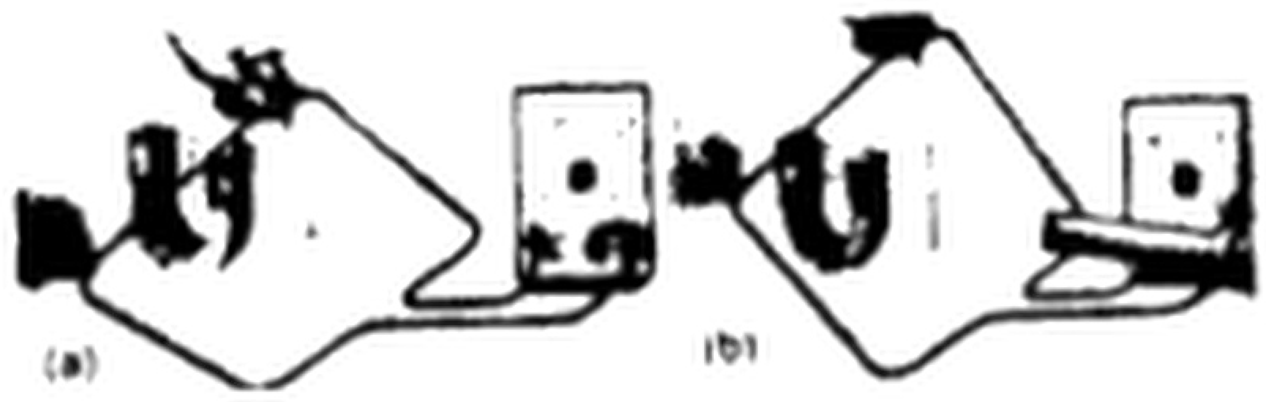


Fig. 15.13: Demonstration of electromagnetic induction by the movement of a wire loop in the magnet field

ii) Now move. the wire upward through the field, current is induced in the opposite direction (fig 15.13 b).

Activity 2

i) Take a solenoid and a magnet. When the magnet is stationary, no current is induced.

ii) When the magnet is moved towards the solenoid, the needle of galvanometer effects right, showing a current induced in the solenoid. "

iii) When the magnet is pulled away from the solenoid, the galvanometer deflects left, showing a current induced opposite in the solenoid.

Conclusion

It shows that due to relative motion between the coil and the magnet, an induced e.m.f or induced current is produced in the coil.

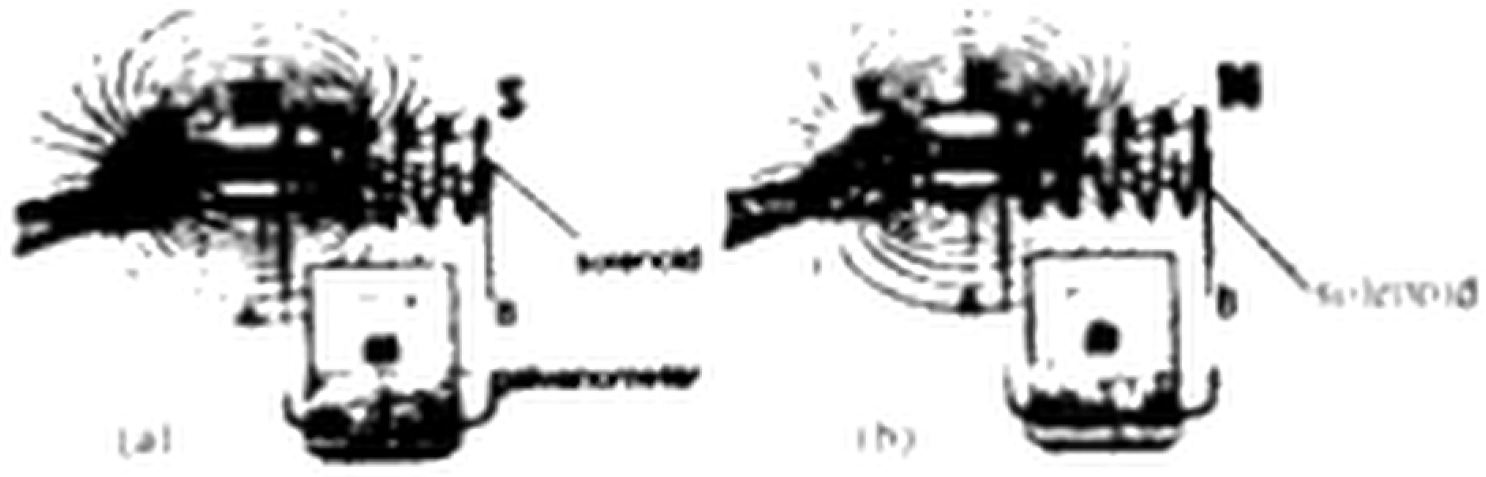


Fig. 15.14: Phenomenon of electromagnetic induction by the movement of a magnet through solenoid (a) Magnet moves towards the stationary solenoid (b) Magnet moves away from the stationary solenoid

Q.7 State Faraday's law? How the direction of induced e.m.f is determined by Lenz's law?

Answer

Faraday's law

The value of induced e.m.f in a circuit is directly proportional to the rate of change of number of magnetic lines of force through it.

i.e $$e.m.f = -N\frac{\Delta\varphi}{\Delta t}$$

Or $$e.m.f \propto \frac{\Delta\varphi}{\Delta t}$$

Where, $\frac{\Delta\varphi}{\Delta t}$ is rate of change of magnetic field lines.

Len's law

"The direction of an induced current in a circuit is always such that it opposes the cause that produces it."

Explanation

If we bring a north pole of a bar magnet near a solenoid, an e.m.f will be induced in the solenoid by electromagnetic induction as shown in the figure 15.15 (a).

The direction of the induced current in the solenoid by the induced emf will be such that it will repel the north pole of the magnet.

This is only possible if the right end of the solenoid becomes a north pole.

Hence, according to right hand grip rule, the direction of the induced current in the solenoid will be anticlockwise. Similarly, when we move the north pole of the magnet away from the solenoid, the direction of the induced current will be clockwise as shown in the figure 15.15 (b).

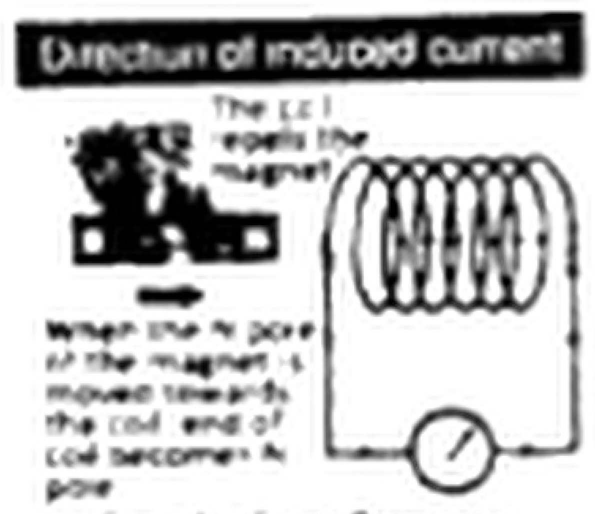


Fig 15.15 (a) Direction of induced current when magnet is moved towards the coil

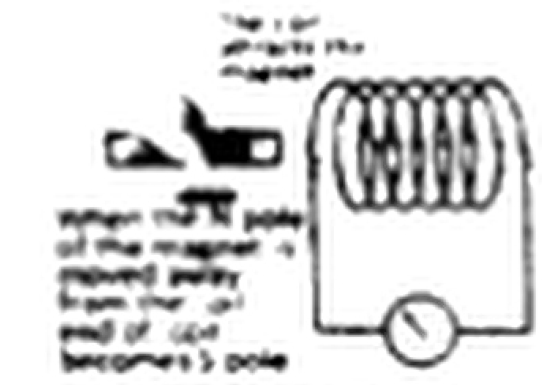


Fig 15.15 (b) Direction of induced currents when magnet is moved away the coil

Mechanical energy of our hand used to push the magnet towards or away from the coil results into electrical energy. Hence Lenz's law is a manifestation of the law of conservation of energy.

Q.8 Write the working of A.C. generator? How current is produced from a generator?

Answer

A.C. Generator

A device which converts 'the mechanical energy into electrical energy is called a generator. If it produces alternating current, it is called A.C. generator.


A generator inside a hydroelectric dam uses electromagnetic induction to convert mechanical energy of a spinning turbine into electrical energy

Working principle

If a coil is rotated in a magnetic field a current will be induced in the coil. The strength of this induced current depends upon the number of magnetic lines of force passing through the coil.

The number of lines of magnetic force passing through the coil will be maximum when the plane of the coil is parallel to the line» of force. This when a coil rotates in a magnetic field, the induced current in it continuously changes from maximum to minimum value and from minimum to maximum value and so on.

> **Connection:**
> A generator is a DC motor with its input and output reversed.

This is the basic principle on which an AC. generator works as shown in the figure 15.16.

1) The armature is arranged so that it can rotate freely in the magnetic field. As the armature turns, the wire loops cut through the magnetic field lines and induces e.m.f.

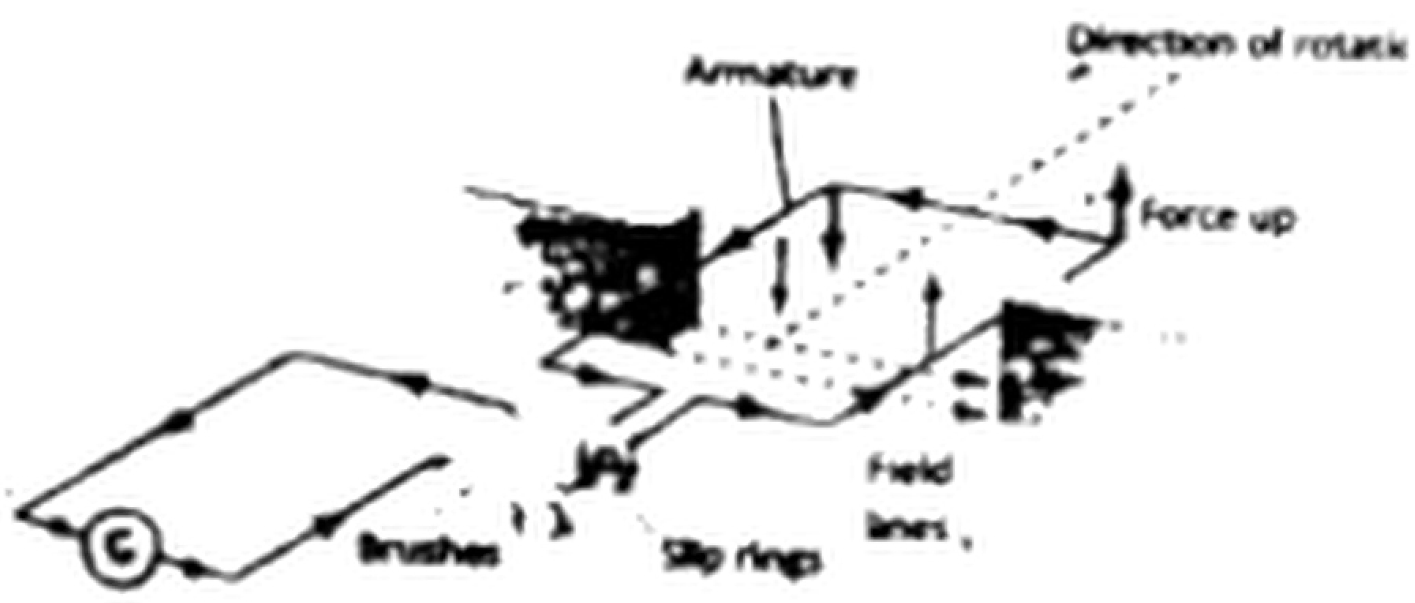
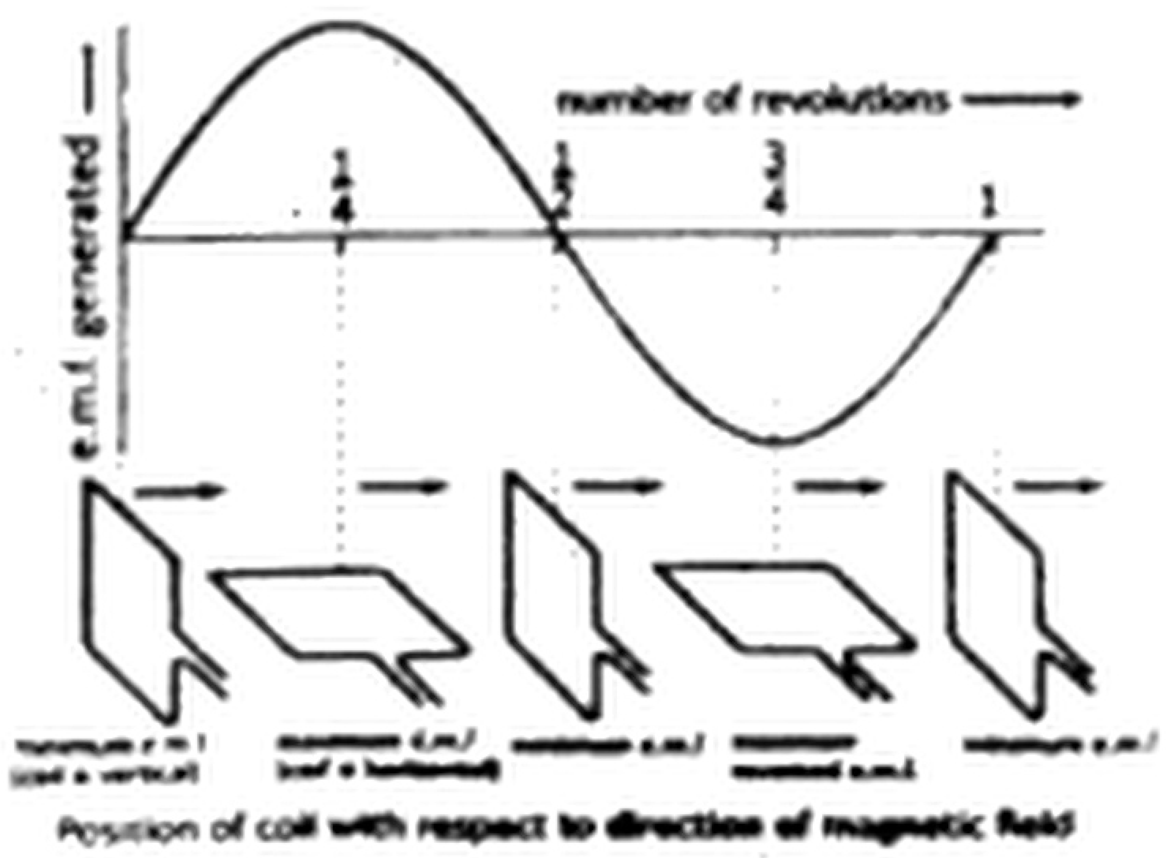


Fig. 15.16 A.C. Generator

2) The e.m.f. developed by the generator depends upon the length of the wire rotating in the field. Increasing the number of loops in the armature increases the wire length. thereby increasing the induced e.m.f.

Current from a generator

When a generator is connected in a closed circuit, the induced emf. generates an electric current. As the loop rotates, the strength and the direction of the current changes as shown in the figure 15.17.



1) The current is minimum when' the plane of the loop is parallel to the magnetic field: when the loop is in the vertical position.

2) As the loop rotates from the vertical to the horizontal position. It cuts through larger magnetic field lines per unit of the times thus the e.m.f and the current increase.

3) When the loop is in the horizontal position the plane of the loop becomes perpendicular to the field: so, the current reaches their maximum values.

4) As the loop continuous to turn, the change in the direction takes place each time the loop turns through 180^0. Thus, the e.m.f and the current change smoothly from zero to some maximum values and back to zero during each half turn of the loop.

Q.9 What do you understand by the term mutual induction? Name and define SI unit if the mutual inductance?

Answer

Mutual Induction

"The phenomenon of production of Induced current in one coil due to change of current in a neighboring coil is called mutual induction."

Do you know?

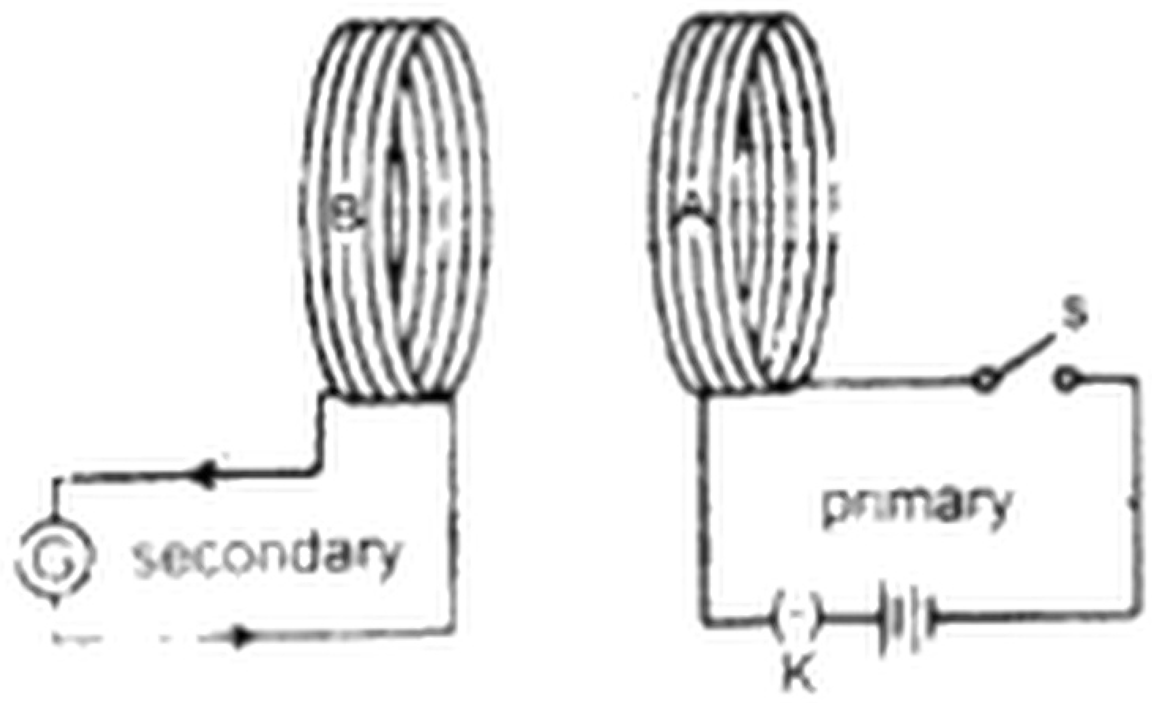
The magnetic field of a coil is identical to the field of a disk shaped permanent magnet

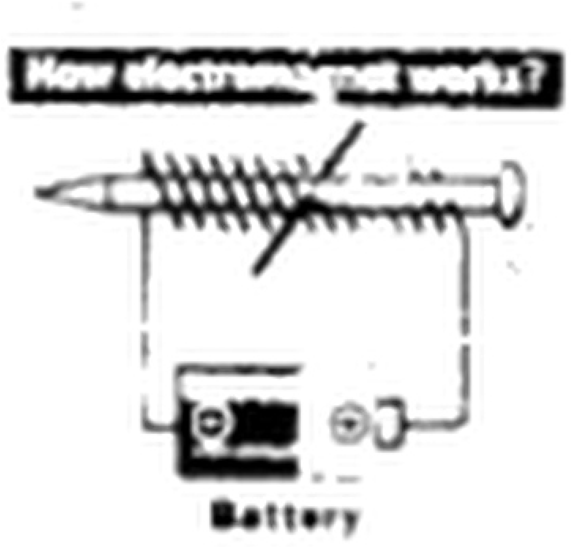
Explanation

Suppose a system of two coils A & B placed close to each other as shown in the figure 15.18.

The coil A is connected to a battery and a switch, while a sensitive galvanometer is connected to the coil B. We observe that as soon as the switch of the coil A is closed, the galvanometer shows a momentary deflection.

Similarly, when the switch IS opened the galvanometer again shows a deflection but this time its direction is opposite to that of the previous case.



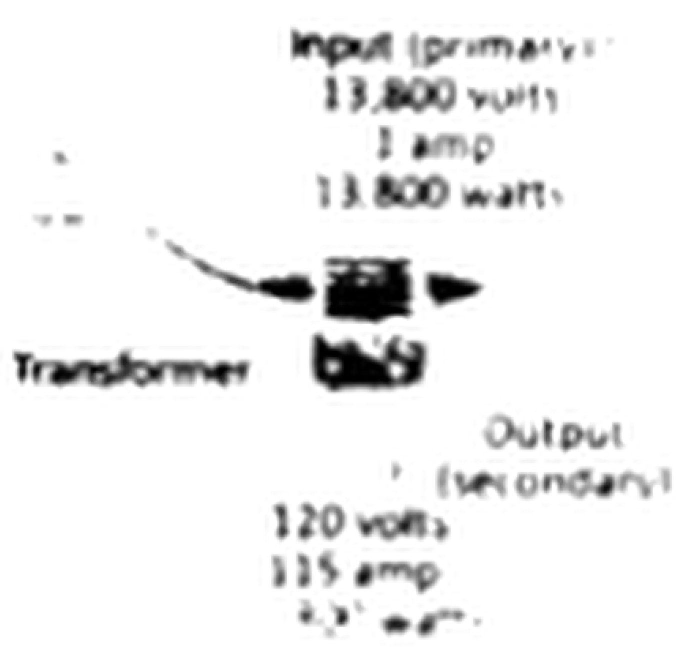


1) We can explain these observations using Faraday's Law of Electromagnetic Induction. When the switch of coil A is closed. It current is induced in the coil due to which magnetic field is developed across the coil.

2) Some of the magnetic lines of force of this field start passing through the coil 15. Since current is changing in the coil A, hence number of magnetic lines of force across the coil B also changes due to which a current is induced in the coil B in accordance with Faraday's law.

3) When current in the coil A becomes steady, number of magnetic lines of force across the cod A also become constant. Therefore, there is no more change in the number of magnetic lines of force through the coil B due to which induced current in coil B reduces to zero.

4) Similarly, when the switch of the coil A is opened, the flow of current through it stops and, in few moments, its magnetic field reaches to zero. The number of magnetic lines of force through the coil B decreases to zero due to which current is again induced in it but in opposite direction to that in the previous case.



Q10 What is a transformer? Explain the working of transformer in 'connection with mutual induction?

Answer

Transformer

"The device which is used to increase or decrease A.C voltages 15 called transformer."

It works on the principle of mutual induction.

Working of a transformer

A transformer has two coils, electrically insulated from each other, but wound around the same iron core. One coil is called "primary coil" and the' other coil is called "the secondary coil". Number of turns on the primary and the secondary coils are represented by N_p & N_s respectively. When the primary coil is connected to a source of A.C. voltage, the changing current creates a changing magnetic field, which is carried through the core to the secondary coil. In the secondary coil the changing field induces a varying e.m.f. This effect is called mutual inductance. The e.m.f. induced in the secondary coil, called the secondary voltage V_5, is proportional to the primary voltage V_D. These contrary voltages also depend on the ratio of the number of turns on the secondary coil to the number of turns on the primary coil, as shown by the following expression:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

Step-up transformer

If the secondary voltage is larger than the primary voltage, the transformer is called a step-up transformer as shown in the figure 15. 19 (a).

Step down transformer

If the secondary voltage is smaller than the primary voltage, the transformer is called step-down transformer as shown in the fig. 15.19 (b).

Power formula

In an ideal transformer. the electric power supplied to the primary circuit. An ideal transformer dissipates no power itself and for such a transformer we can write:

$$P_p = P_s$$
$$V_p I_p = V_s I_s$$

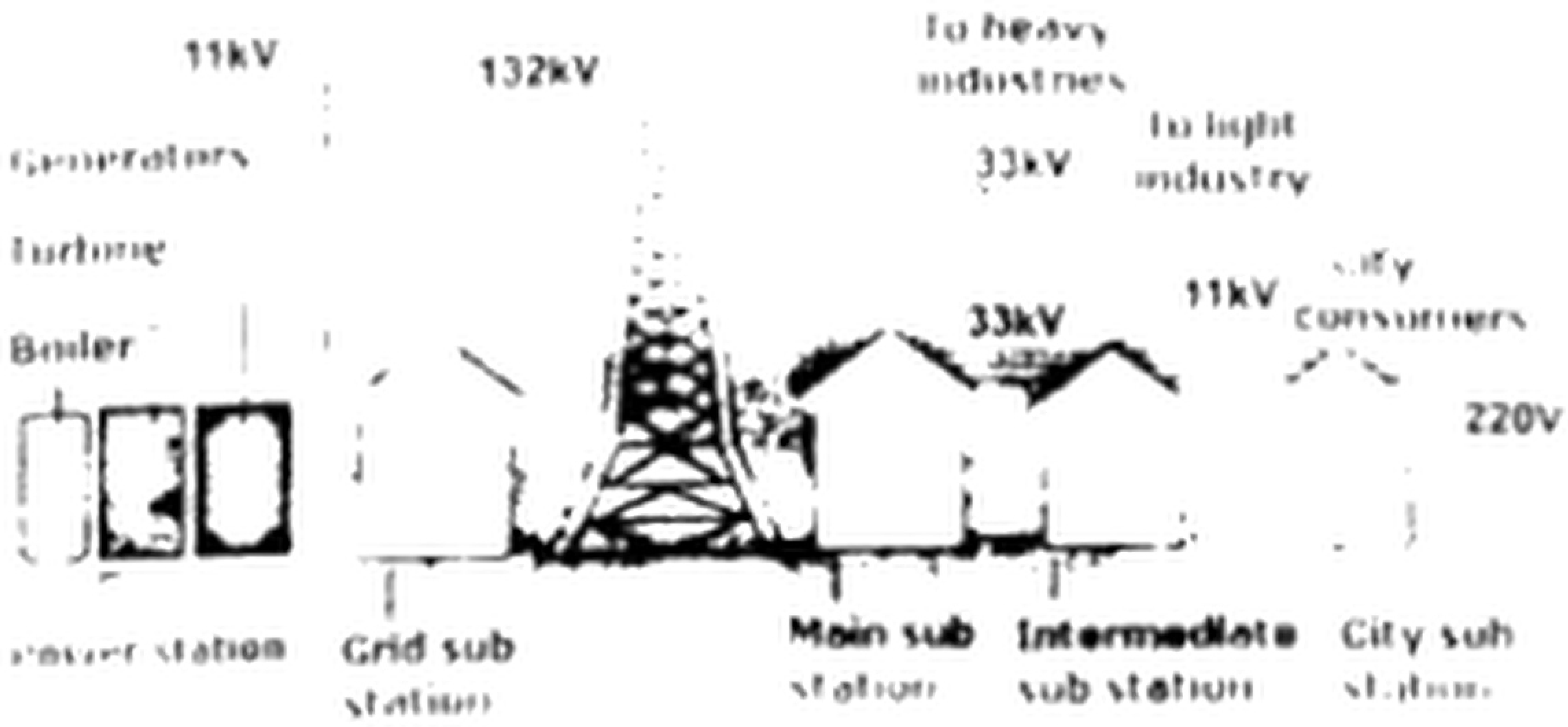
Q.11 Briefly write about the high voltage transmission?

Answer

Electric power is usually generated at places which are far from the places where it is consumed. The power is transmitted over long distances at high voltage to minimize the loss of energy in the form of heat during transmission.

As heat dissipated in the transmission cable of resistance 'R' is I^2Rt. Hence by reducing the current '1' through the cable. power loss in the~ form of heat dissipation can also be reduced. So, the alternating voltage is stepped up at the generating station.

It is then transmitted to the main substation. This voltage is stepped down and is transmitted to the switch (grid-station) or the city sub-station. At the city- - substation it is further stepped down to 220 V and supplied to the consumers. A schematic diagram of high voltage transmission is shown in figure 15.20.



Transformers work only with A.C therefore mains power is supplied at alternating current.

Q.12 Write any one application of electromagnet?

Answer

Electromagnet

Magnetic effect of current is called electromagnet. This effect is used in many devices like relay, electric bell etc.. Soft iron, gains and loses magnetism easily in such devices.

Relay

The relay is used to control a large current with the help of small current. A relay is an electrical switch that opens and closes under the control of another electrical circuit as shown in the fig. 15.21.

The 1st circuit (input circuit) supplies current to the electromagnet. The electromagnet is magnetized and attracts one end of the Iron armature. The armature then closes the contacts (2nd switch) and allows current to. flow in the second circuit.

When the first switch is- open again the current to the electromagnet stops. Now electromagnet loses its magnetism and the 2nd switch is opened. Thus, the flow of current stops in the 2nd circuit.

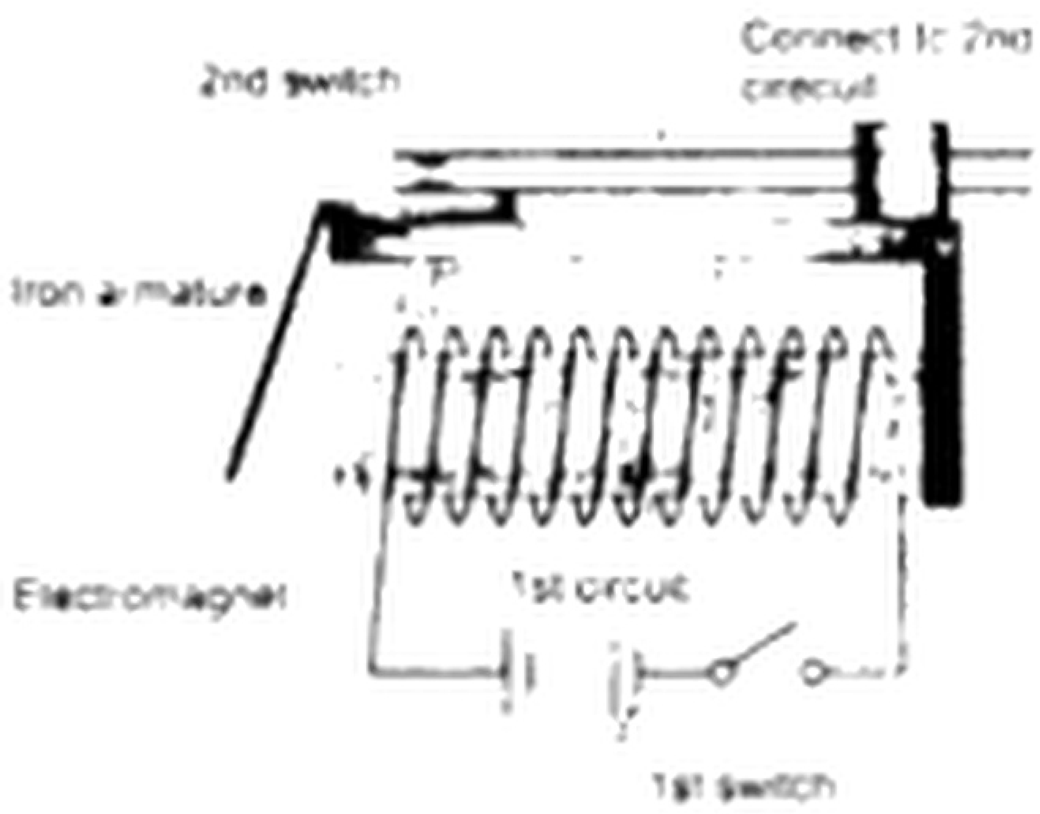


Fig. 15.21: Relay circuit