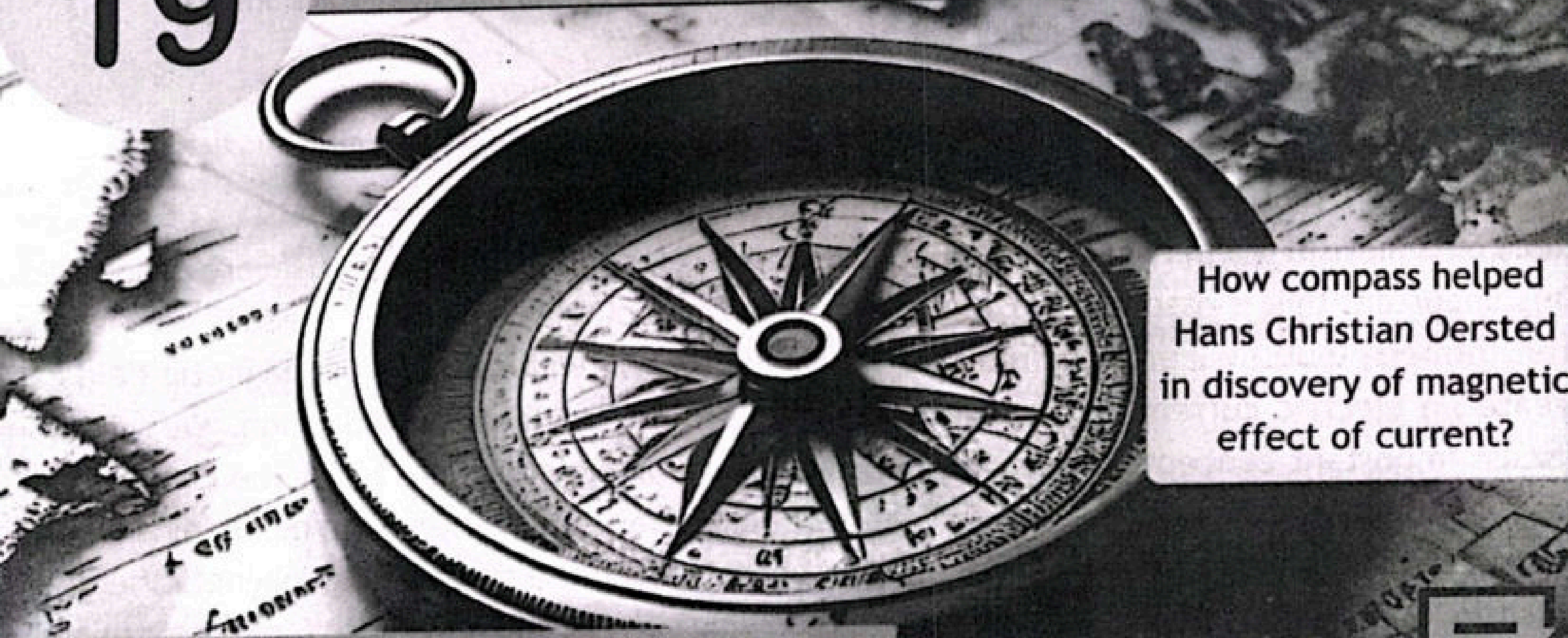
Unit
19 ELECTROMAGNETISM



How compass helped Hans Christian Oersted in discovery of magnetic effect of current?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-74] Describe an experiment to demonstrate electromagnetic induction.
- ✓ [SLO: P-10-E-75] Use the fact that the magnitude of an induced e.m.f. is affected by (a) the rate of change of the magnetic field or the rate of cutting of magnetic field lines, and (b) the number of turns in a coil, to solve simple electromagnetic problems.
- ✓ [SLO: P-10-E-76] Use the fact that the effect of the current produced by an induced e.m.f. is to oppose the change producing it (Lenz's law).
- ✓ [SLO: P-10-E-77] Describe how a.c. generators work.
- ✓ [SLO: P-10-E-78] Sketch and interpret graphs of e.m.f. against time for simple a.c. generators.
- ✓ [SLO: P-10-E-79] Describe the pattern and direction of the magnetic field due to currents in straight wires and in solenoids.
- ✓ [SLO: P-10-E-80] State the effect on the magnetic field of changing the magnitude and direction of the current.
- ✓ [SLO: P-10-E-81] Describe how the magnetic effect of a current is used in relays and loudspeakers.
- ✓ [SLO: P-10-E-82] Describe an experiment to show that a force acts on a current-carrying conductor in a magnetic field.
- ✓ [SLO: P-10-E-83] state and use the relative directions of force, magnetic field and current.
- ✓ [SLO: P-10-E-84] Describe the magnetic field patterns between currents in parallel conductors and relate these to the forces on the conductors.
- ✓ [SLO: P-10-E-85] state that a current-carrying coil in a magnetic field may experience a turning effect and that the turning effect is increased by increasing: (a) the number of turns on the coil, (b) the current (c) the strength of the magnetic field.
- ✓ [SLO: P-10-E-86] Describe the operation of an electric motor, including the action of a split-ring commutator and brushes.
- ✓ [SLO: P-10-E-87] State that it is theorized that the Earth's magnetic field is generated by the rotation of the Earth and its molten iron core that contains charged particles in motion.
- ✓ [SLO: P-10-E-88] Explain the principle of operation of a simple iron-cored transformer.

- ✓ [SLO: P-10-E-89] Use the terms primary, secondary coils and step-up and step-down transformer.
- ✓ [SLO: P-10-E-90] Use the equation $V_p/V_s = N_s/N_p$.
- ✓ [SLO: P-10-E-91] Justify the advantages of high-voltage transmission.
- ✓ [SLO: P-10-E-92] Describe the deflection of an electron beam by electric fields and magnetic fields.
- ✓ [SLO: P-10-E-93] Interpret waveforms on oscilloscopes.

Electromagnetism is a part of physics that studies how electricity and magnetism are connected. This important link is essential for many everyday technologies, including electric generators, transformers, loudspeakers, and relays. In this chapter, we will learn how a magnetic field can create an electric current through a process called electromagnetic induction. We will also discuss important concepts like Lenz's Law, which shows how currents resist the changes that produce them. Additionally, we will look at how a.c. generators work to turn mechanical energy into electrical energy and how changes in current influence the surrounding magnetic field. We will also investigate the forces acting on wires carrying current and how these forces help operate key devices. By the end of this chapter, you will see how electromagnetism powers many technologies in our modern world.

19.1 MAGNETIC FIELD DUE TO CURRENT CARRYING WIRE

Ampere discovered that when a current pass through a conductor, it produces magnetic field around it. To understand this fact, let's perform a simple activity.

ACTIVITY 19.1

Take a cardboard and a straight wire of conducting material.

- Make a hole at the centre of cardboard.
- Pass the wire vertically through a cardboard, as shown in the figure 19.1 (a).
- Connect the two ends of the wire with the terminals of the battery so that current (I) flows through the wire in the anti-clockwise direction.
- If we place a compass needle at different points in the region of magnetic field, it will align along the direction of magnetic field that would be in the form of concentric circles.
- If we reverse the direction of the current by reversing the terminals of the battery, the compass needle also reverses its direction, as shown in the figure 19.1 (b).
- The magnetic field produced is stronger near the current-carrying conductor and weaker farther away from it.

Conclusion: Following conclusion can be drawn from the above experiment.

- Current through a conducting wire creates a magnetic field around the wire.
- Magnetic field lines are circular and their direction depends on the direction of current.

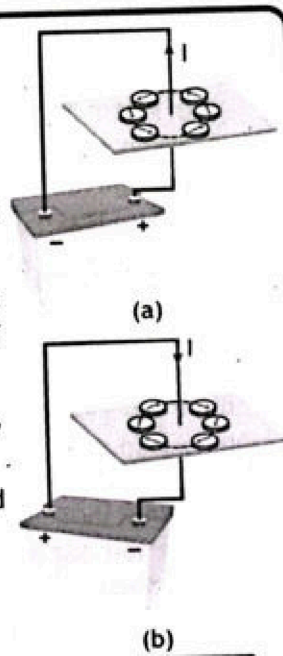
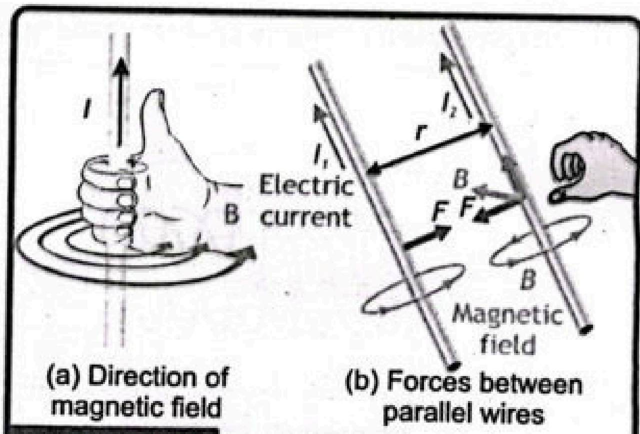


FIGURE 19.1

19.1.1 DIRECTION OF THE MAGNETIC FIELD OF CURRENT CARRYING WIRE

The direction of the magnetic field (B) around a current carrying straight wire can be determined by the right-hand rule, as shown in figure 19.2 (a).According to right-hand rule: If the wire is grasped in fist of right hand with the thumb pointed in the direction of the current, the fingers of the hand will curl in the direction of magnetic field.



(a) Direction of magnetic field (b) Forces between parallel wires

FIGURE 19.2 Current carrying conductors

19.1.2 PROPERTIES OF MAGNETIC FIELD LINES

Like electric field lines, magnetic field lines are also imaginary lines and don't exist physically. The properties of magnetic field lines are given below:

- Magnetic field lines emerge from north poles and ends on south poles.
- Magnetic field lines form closed paths.
- Tangent to the magnetic field lines gives the direction of magnetic field at any point.
- Magnetic field lines never intersect or cross each other.
- Density of magnetic field lines at any point indicates magnetic field strength at that point.

The properties of magnetic field lines help us to understand and visualize magnetic fields. These lines also help us to understand the working of magnets in electric motors and generators etc.

19.1.3 FORCES ON PARALLEL CURRENT CARRYING CONDUCTORS: When current in the two wires are in same direction, as shown in the figure 19.2 (b), then magnetic fields created along each of the two wires will be such that their opposite poles are in between the two wires. These opposite poles attract each other. Thus, two long parallel wires carrying a current in same direction attract each other. What will happen if the current is in opposite direction?

19.2 MAGNETIC FIELD DUE TO CURRENT CARRYING SOLENOID

A solenoid is a long, tightly wound (spring like) coil of wire, as shown in figure 19.3.

When current passes through a solenoid, magnetic field established around the solenoid. The field from each loop in a solenoid adds to the fields of the other loops and creates greater total field strength. The magnetic field of a solenoid is strong and uniform along its axis, whereas negligibly weak outside, as shown in figure 19.4 (a).

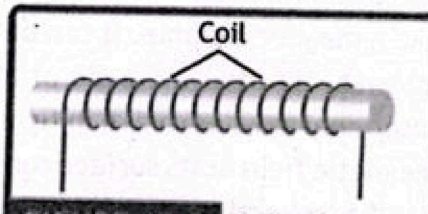
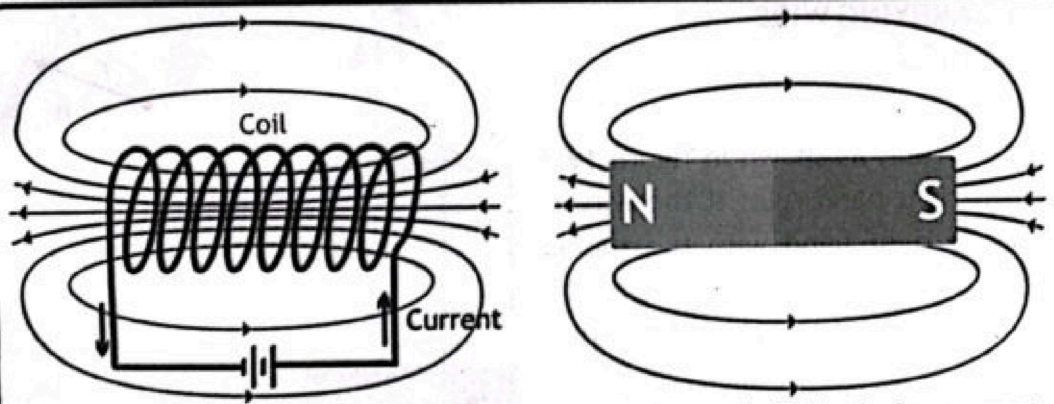


FIGURE 19.3 Solenoid

If we increase the magnitude of current the magnetic field will become stronger.



(a) Magnetic field of a solenoid (b) Magnetic field of a bar magnet

FIGURE 19.4 Current carrying conductors

When a current-carrying solenoid is brought close to a suspended bar magnet, one end of the solenoid repels the north pole of the bar magnet. Thus, the current carrying solenoid has a north and a south pole and behaves like a permanent bar magnet.

The direction of the magnetic field produced by a solenoid can be found with the help of right-hand rule, as shown in 19.5. According to this rule if we grip the coil with our right hand by curling our fingers in the direction of the conventional current, our thumb will indicate the north pole of the coil, which is along the axis of solenoid.

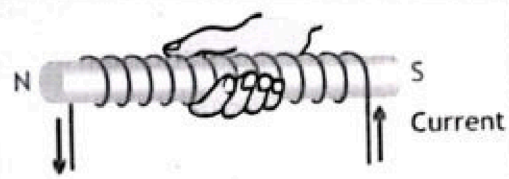


FIGURE 19.5 Right-hand rule for solenoid

19.3 EARTH'S MAGNETIC FIELD

The Earth can be thought of as containing an enormous bar magnet in its core, as shown in the figure 19.6. The magnetic south pole of Earth's magnet is at the geographic North Pole, and conversely magnetic North pole of Earth's magnet is at the geographic South Pole (as opposite magnetic poles attract and the north end of a magnet, like a compass needle, points toward Earth's South magnetic pole). The Earth's magnetic field appears like a magnetic dipole. It can be represented by the field of a bar magnet, tilted at an angle of about 11° with respect to Earth's rotational axis, as shown in figure 19.7. The magnitude of Earth's magnetic field at its surface ranges from 25 to 65 μT (0.25 to 0.65 G). It is several hundred times weaker than the field around the bar magnet.

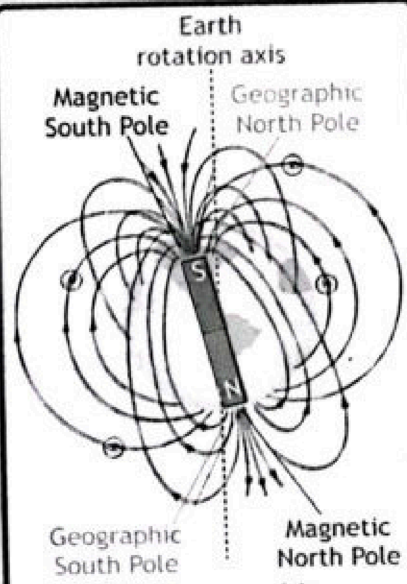


FIGURE 19.6 Earth's magnetic field

The magnetic field lines are parallel to the surface of the Earth at the equator, and normal to the Earth's surface at the magnetic poles.

The Earth's magnetic field (also known as the geomagnetic field) is generated by the rotation of the Earth and its molten iron core that contains charged particles in motion. Core is primarily made up of the molten magnetic material such as iron and nickel. Molten iron is a good conductor. The movement of this molten iron, driven by convection currents and influenced by Earth's rotation, creates electrical currents within the outer core. These currents produce a magnetic field, which maintains a stable and protective magnetic shield around the Earth. Earth's magnetic field starts in the core of the Earth, coming out into space forming a magnetosphere.

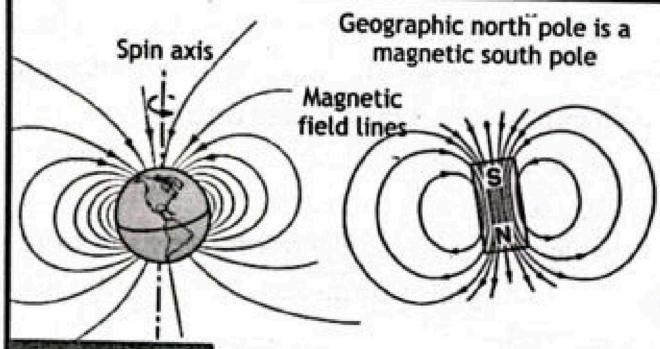


FIGURE 19.7 Sketch of the Earth's magnetic field

19.4 APPLICATION OF MAGNETIC EFFECT OF A CURRENT

There are many devices that work on magnetic effect of current. Two such devices are discussed here.

19.4.1 LOUDSPEAKERS

In a loudspeaker, the magnetic effect is a fundamental principle that enables the conversion of electrical energy into mechanical energy, which then produces sound. The loudspeaker consists of a permanent magnet and a coil of wire (known as the voice coil) which is attached to the speaker cone, as shown in figure 19.8.

When an electrical signal (corresponding to the sound to be produced) is passed through the voice coil, it creates a magnetic field around the coil. This magnetic field interacts with the magnetic field of the permanent magnet. Depending on the direction of the current, the voice coil is either attracted to or repelled from the permanent magnet. This movement of the voice coil causes the attached speaker cone to vibrate. These vibrations move the air particles around the speaker, creating pressure waves that our ears perceive as sound.

The amplitude of the electrical signal determines the volume of the sound. A larger current will cause a stronger magnetic field, resulting in larger vibrations and a louder sound.

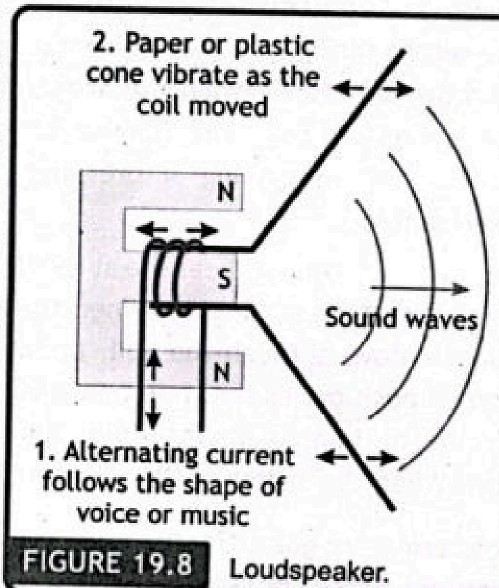


FIGURE 19.8 Loudspeaker.

19.4.2 RELAY

A relay is an electrical control device that facilitates interaction between the input and output circuits, as shown in figure 19.9 (a). It uses the magnetic effect of a current to control the output circuit. A mechanical relay consists of an electromagnet, a switch, and some mechanical parts to change the state of the switch when the electromagnet is turned on. Here are the main parts inside the relay:

A. Coil and core: A coil wound around a magnetic core makes up an electromagnet. It generates a magnetic field around it when an electrical current passes through the coil.

B. Armature: The armature is a movable component within the relay. When the coil is energized, the magnetic field it produces attracts the armature, causing it to move.

C. Return Spring: The return spring is connected to the armature, providing a restoring force when the coil is de-energized. It ensures that the armature returns to its original position when the electrical current through the coil ceases.

D. Moving Contact: Attached to the armature through the return spring, the moving contact physically moves with the armature. When the armature is attracted by the energized coil, the moying contact changes its position, either making or breaking contact with the fixed contacts.

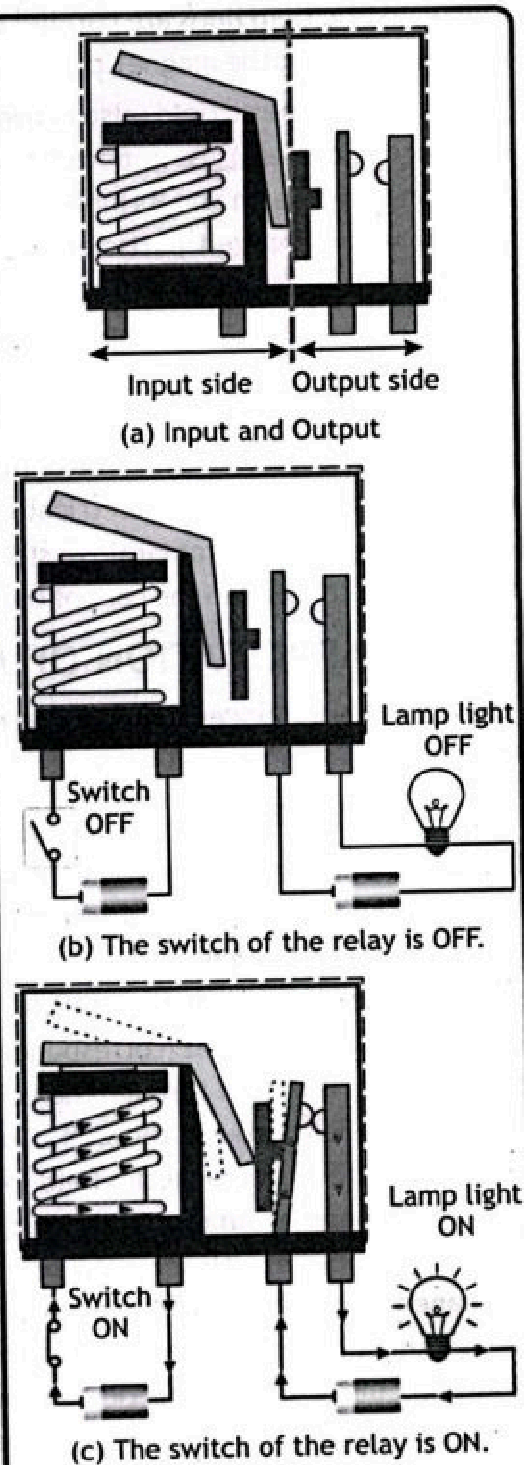


FIGURE 19.9 Relay

How a Relay Works: Let's see at how a lamp is turned on using a switch and a relay. When the switch is OFF, no current flows through the coil, armature remain in its normal position, as shown in figure 19.9 (b). In this way circuit of lamp remains open and lamp does not glow. When the switch is ON, current flows through the coil, armature got attracted toward the coil, as shown in figure 19.9 (c). In this way circuit of lamp get closed and lamp glows.

The circuit breaker uses mechanical relay to disconnects the electric supply automatically if current exceeds the normal value. It acts as a safety device in the same way as a fuse.

19.5 FORCE ON A CURRENT CARRYING CONDUCTOR PLACED IN MAGNETIC FIELD

When a current carrying conductor is placed in a magnetic field it experiences a force. Let us take a simple activity to observe this effect.

ACTIVITY 19.2

Take a battery, two magnets of different sizes and intensities, small aluminium rod AB, connecting wires and an iron stand.

Arrange the setup as shown in the figure 19.10. Now, bring the magnet with lower magnetic intensity closer to the aluminium rod. The rod deflects. Now observe the velocity of the rod. The displacement of the rod in the above activity suggests that a force is exerted on the current carrying conductor when it is placed in a magnetic field.

Now stable the rod and bring both the magnets closer together to ensure that the magnetic field is stronger than before. The rod moves towards the magnet but faster than before. This is possible only if the force acting on the rod is stronger than before. Thus, the force acting on a current carrying conductor placed in a uniform magnetic field increases with increase in field strength. When the current is switched off, the wire moves back to its original position. The direction of the force on the aluminium rod can be reversed by reversing:

- The direction of the current
- The direction of the magnetic field

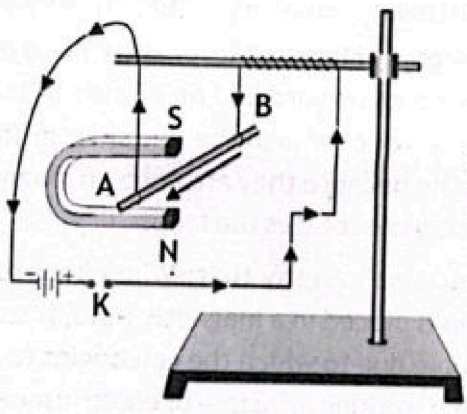


FIGURE 19.10

The conductor in a magnetic field experiences a force due to the reason that:

As a current-carrying wire produces its own magnetic field. When such wire is brought near an external magnetic field, the magnetic field of the wire interacts with the external magnetic field as a result a conductor experiences a force. The force is increased if

- The current in the wire is increased.
- Strength of magnetic field is increased.
- The length of the wire inside the magnetic field is increased.

The direction of the force on a current-carrying wire in a magnetic field is always perpendicular to that of the magnetic field and the current. It can be found by using Fleming's left hand rule, as shown in figure 19.11. Fleming's left hand rule can be defined as: 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.

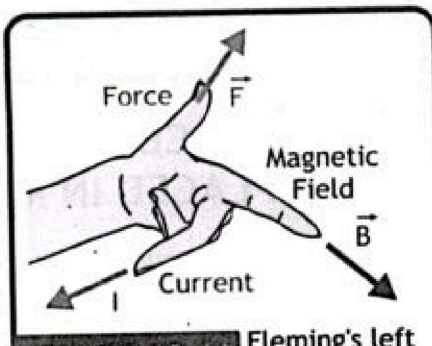


FIGURE 19.11 Fleming's left hand rule.

19.6 CURRENT CARRYING COIL IN A MAGNETIC FIELD

Consider a current carrying rectangular coil PQRS is lying perpendicular to the magnetic field of a permanent magnet, as shown in figure 19.12. Now if the ends of the coil are connected with the terminals of a battery, a current would start flowing through the coil.

Now apply Fleming's left hand rule to each side of the coil. We can see that on PQ side of the loop force acts upward and on RS side of the loop force acts downward (it is because the direction of the current through the two sides of the loop is opposite to each other). These two forces form a couple because they are equal in magnitude but opposite in direction. The resulting torque due to the couple rotates the loop.

Hence we can say that; When a current-carrying loop is placed in a magnetic field, it experiences a couple due to which the coil begins to rotate. This is the working principle of electric motors.

The turning effect (or torque) is increased by increasing:

(a) the number of turns on the coil.

(b) the magnitude of the current passing through the loop.

(c) the strength of the magnetic field.

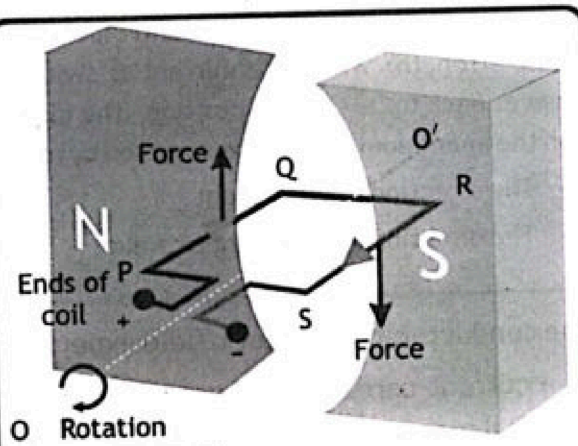


FIGURE 19.12 Current carrying coil

19.7 ELECTRIC MOTOR

When a current carrying coil placed in a magnetic field experiences a torque. This is the working principle of electric motors.

UNIT OPENER?

How compass helped Hans Christian Oersted in discovery of magnetic effect of current?

A Danish scientist Hans Christian Oersted while working with electricity he happened to have a compass (a device shown in cover picture of this chapter) near to a wire that he had connected to a battery. He noticed that the compass needle moved from its rest position of North.

Oersted had discovered that the current flowing in the wire had created a magnetic field strong enough to deflect the compass needle. He had accidentally discovered electromagnetism; that electricity and magnetism were inseparably interrelated.

An electric motor is device that converts electric energy into mechanical energy (rotational K.E). An electric motor is shown in the figure 19.13. It consists of:

- A rectangular coil, which is placed between the poles of permanent magnet.
- Brushes, that are usually pieces of graphite which allow current to flow into the coil.
- Split Ring Commutator (a ring that is split into two halves), as the coil rotates, so does the commutator.
- Permanent magnets or electromagnet to produce magnetic field.

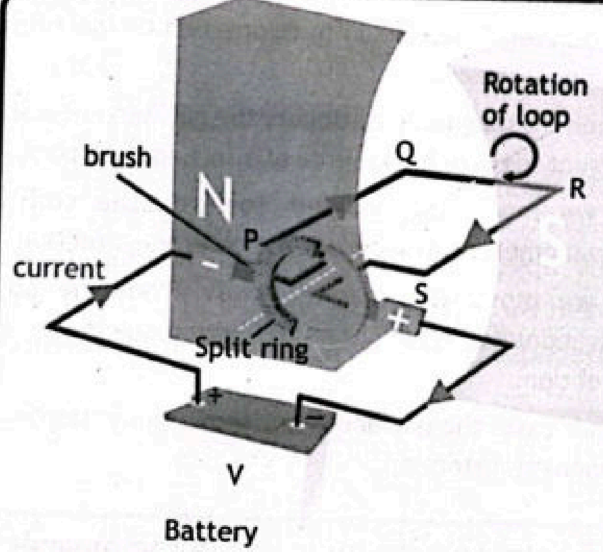
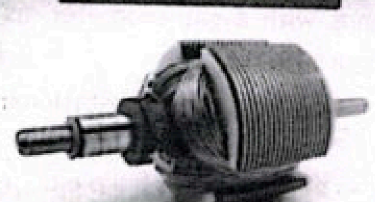


FIGURE 19.13 Electric motor

A simple coil placed in a magnetic field 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 (plane of the loop is perpendicular to the magnetic field). So the loop will not continue to turn because the forces are still up and down and hence balanced (the net force on the coil is zero). To reverse direction of current, the connection to coil is made through an arrangement of brushes and split ring commutator. The split ring is arranged so that each half of the commutator changes brushes just as the coil reaches the vertical position. Changing brushes reverse the current in the loop. As a result, the direction of the force on each side of the coil is reversed and it continues to rotate.

INFORMATION



In an electric motor, the coil is actually made up of many loops mounted on a shaft or axle. Such coil is called armature.

This process repeats at each half-turn, causing coil to rotate in the magnetic field continuously.

19.8 ELECTROMAGNETIC INDUCTION

Electromagnetic induction is the production of an electromotive force across a conductor when it is exposed to a varying magnetic field. Due to this electromotive force a current flow across the conductor. This can either happens when a conductor is placed in a moving magnetic field or when a conductor is constantly moving in a stationary magnetic field. To understand the phenomenon of electromagnetic induction let us perform the following activities.

ACTIVITY 19.3

Take a coil C of conducting wire and connect it to a galvanometer G, as shown in figure 19.14. Now bring a bar magnet near the coil.

- When the magnet is stationary the galvanometer shows no current so there is no source of e.m.f. in the circuit.
- If we move the magnet towards the coil C, the galvanometer will show deflection in one direction.
- If we move the magnet away from the coil, the galvanometer again shows deflection but in the opposite direction.

In either case, the galvanometer shows deflection as long as the magnet is in motion.

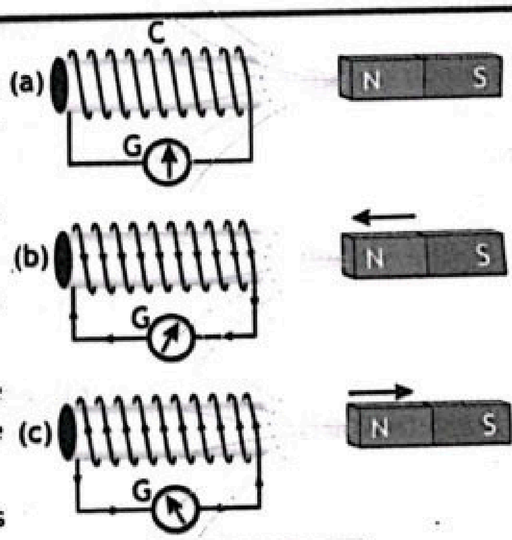


FIGURE 19.14

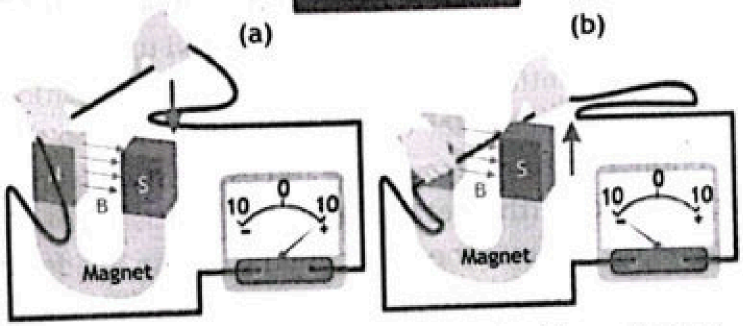
Now we take an activity in which the magnet is at rest but the conductor is moving.

ACTIVITY 19.4

Take a piece of wire and connect its two ends with a galvanometer, as shown in figure 19.15.

- Now hold the wire stationary or move it parallel to the magnetic field of a strong U-shaped magnet. Galvanometer shows no deflection and hence there is no current.

FIGURE 19.15



- Now move the wire downward through the field, current is induced in one direction (figure 19.15a).
- Now move the wire upward through the field, current is induced in opposite direction (figure 19.15b).

A. Conclusion: From the above two activities we conclude that *'an electromotive force (e.m.f) is induced in the coil when there is a relative motion between the coil and the magnet'.*

INFORMATION

The electromagnetic induction is a way of producing electrical energy in a circuit by using magnetic fields and not just by batteries. Everyday machines like generators and transformers work on the principle of electromagnetic induction.

B. Factors Affecting Induced e.m.f: The magnitude of induced e.m.f. is affected by the following factors:

(a) the rate of change of the magnetic field or the rate of cutting of magnetic field lines.

(b) the number of turns in a coil.

19.9 LENZ'S LAW

In 1834 a physicist Heinrich Lenz gave the idea that "**the direction of induced current in a circuit is always such that it opposes the cause which produces it**". This statement is called Lenz's Law.

To demonstrate the Lenz's law, consider the N-pole of the magnet towards the coil, as shown in figure 19.16 (a). As the N-pole of the magnet moves towards the coil, an e.m.f. will be induced in the coil by electromagnetic induction. The direction of the induced current in the coil by the induced e.m.f. will be such that it will repel the north pole of the magnet. This is only possible if the left end of the solenoid becomes a north pole.

Hence, according to right hand grip rule, the direction of the induced current in the coil will be anticlockwise.

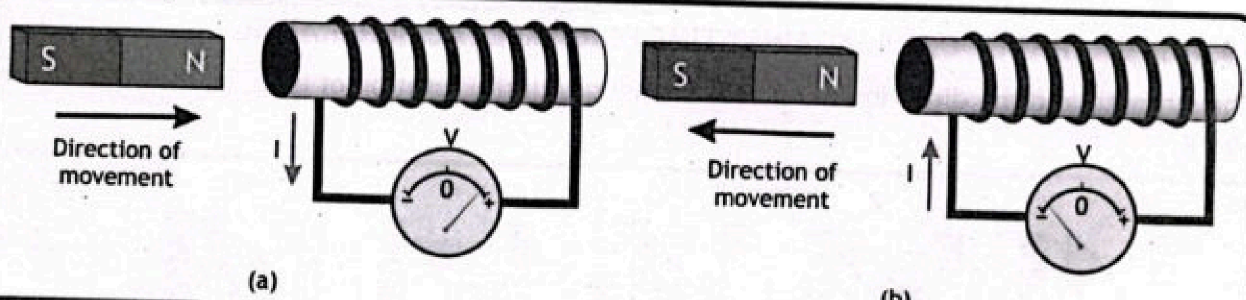


FIGURE 19.16 Lenz's Law.

Similarly, when we move the north pole of the magnet away from the coil, as shown in figure 19.16 (b). The direction of the induced current will be clockwise. In this case, left end of coil becomes South Pole. Hence in both the cases, the direction of induced current generates a magnetic field that oppose the motion of the bar magnet.

19.10 ELECTRIC GENERATOR

Electricity is one of the most important necessities of everyday life. So, to generate electricity is our main concern. There are many ways to produce electricity but the most common way is to generate electricity through generators.

As we have studied that an electromotive force (e.m.f) is induced in the coil when there is a relative motion between the coil and the magnet'. This is the working principle of electric generator.

A.C generator converts mechanical energy into electrical energy.

An alternating current generator is shown in figure 19.17. It consists of a coil/ armature, two slip rings that are made up of copper, two carbon brushes and a permanent magnet. When the coil is made to rotate in a magnetic field by some mechanical means, an induced e.m.f. is induced in the coil. When such coil is connected to some external circuit the current flows through the external circuit by slip rings. As the armature rotates, the strength and the direction of the current changes. Current can also be generated by rotating magnet setup and keeping the coil stationary.

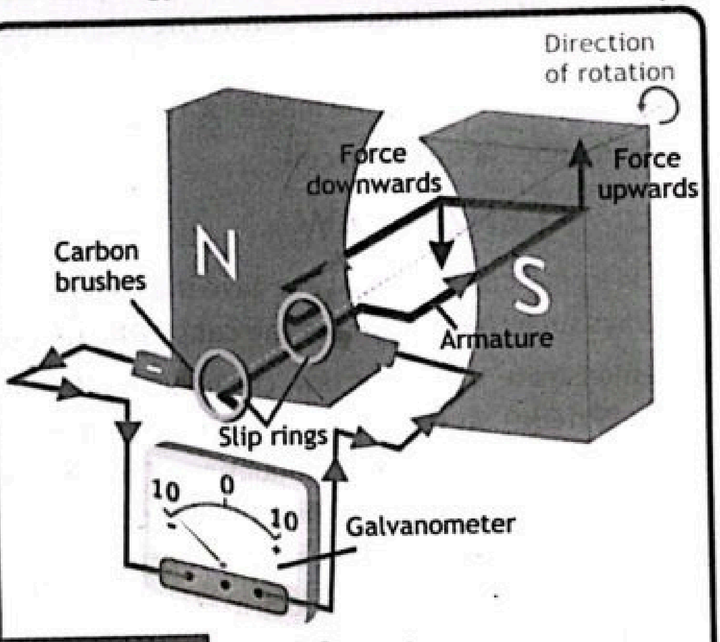


FIGURE 19.17 An AC Generator

19.10.1 GRAPHS OF E.M.F. AGAINST TIME FOR SIMPLE AC GENERATOR

The strength and the direction of current changes with the rotation of loop, as shown in figure 19.18.

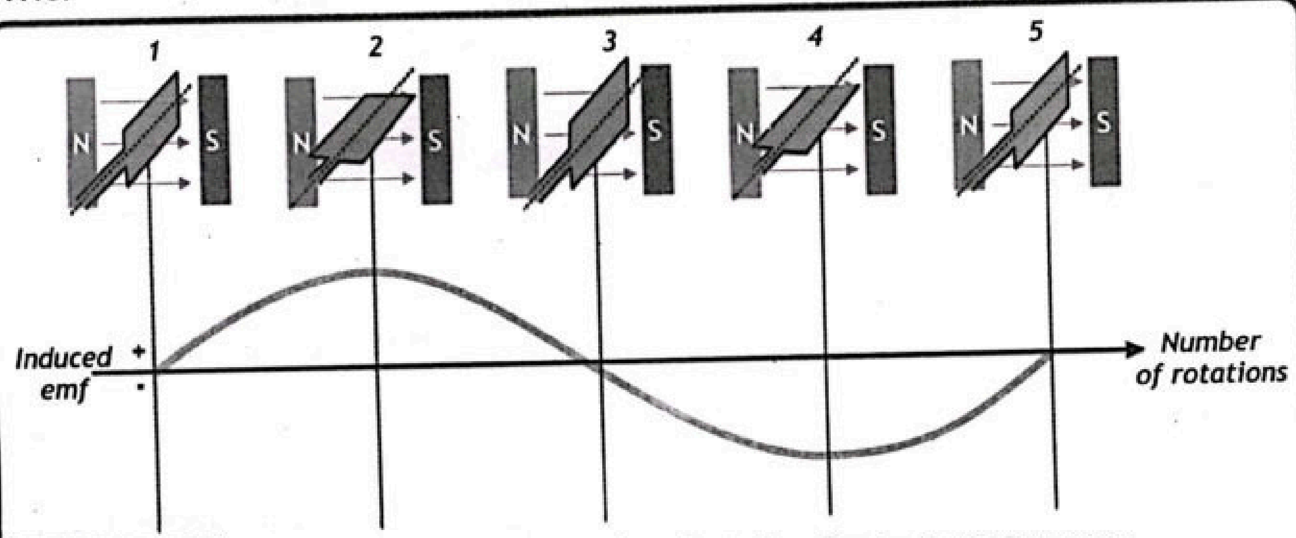
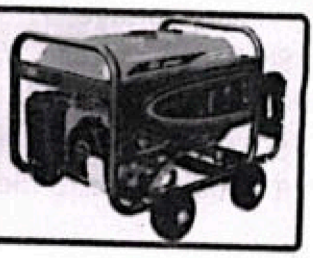


FIGURE 19.18 Graphs of e.m.f. against Number of rotations for simple AC Generator

The diagram shows how the e.m.f of the generator varies as its coil is rotated clockwise. Thus, the e.m.f change smoothly from zero to some maximum values and back to zero during each half-turn of the loop. Basically, you can see that the output is alternating; it is a maximum when the coil is horizontal and zero when the coil is vertical.

INFORMATION

The generation of electricity through generator is an important application of electromagnetic induction. The domestic electricity supply has a frequency of 50 hertz, which means that the generator makes fifty revolutions each second.



19.11 TRANSFORMER

Many devices in our homes, such as game systems, printers, mobile chargers and stereos use transformers. Transformer is an electrical device which is used to increase or decrease the value of an alternating voltage.

A transformer consists of three main parts: primary coil, secondary coil and a laminated iron core. Both the primary and secondary coils are wounded on two different sides of a laminated iron core. The primary coil is connected to the input electrical supply, which has to be AC to work properly. An AC current through the coil creates a changing magnetic field which is concentrated through the iron core.

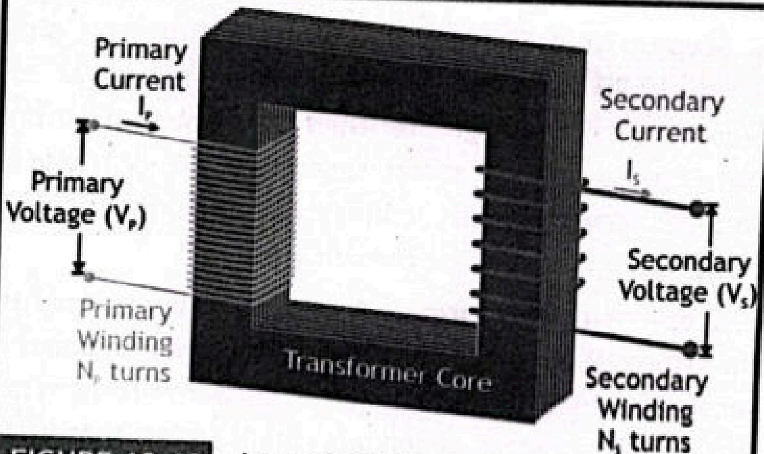


FIGURE 19.19 A transformer

When the primary coil is connected to a source of AC voltage V_P, 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 an alternating e.m.f called the secondary voltage V_S. The secondary voltage is proportional to the primary voltage V_P. The secondary voltage also depends of the ratio of number of turns N_S on the secondary coil to the number of turns N_P on the primary coil, as shown the following expression:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \quad \text{— 19.1}$$

This is the basic equation for transformer.

Example 19.1

A step-down transformer converts 240 V into 12 V. If there are 2000 turns on the primary coil, then find the number of turns on the secondary coil.

GIVEN:

Primary voltage 'V_P' = 240 V

Secondary voltage 'V_S' = 12 V

Turns in primary 'N_P' = 2000

REQUIRED:

Turns in secondary 'N_S' = ?

SOLUTION:

The basic transformer equation is: $\frac{V_S}{V_P} = \frac{N_S}{N_P}$ or $N_S = \frac{V_S}{V_P} \times N_P$

putting values $N_S = \frac{12\,V}{240\,V} \times 2000$ Therefore $\boxed{N_S = 100}$ **ANSWER**

The secondary coil should only have 100 turns compared to 2000 turn in the primary.

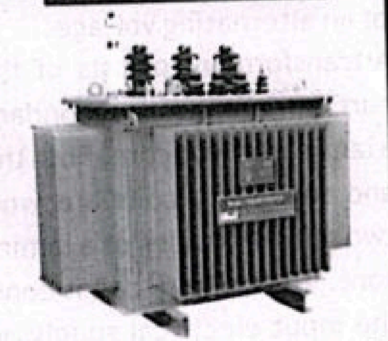
19.11.1 TYPES OF TRANSFORMER

There are two types of transformer: step-up and step-down.

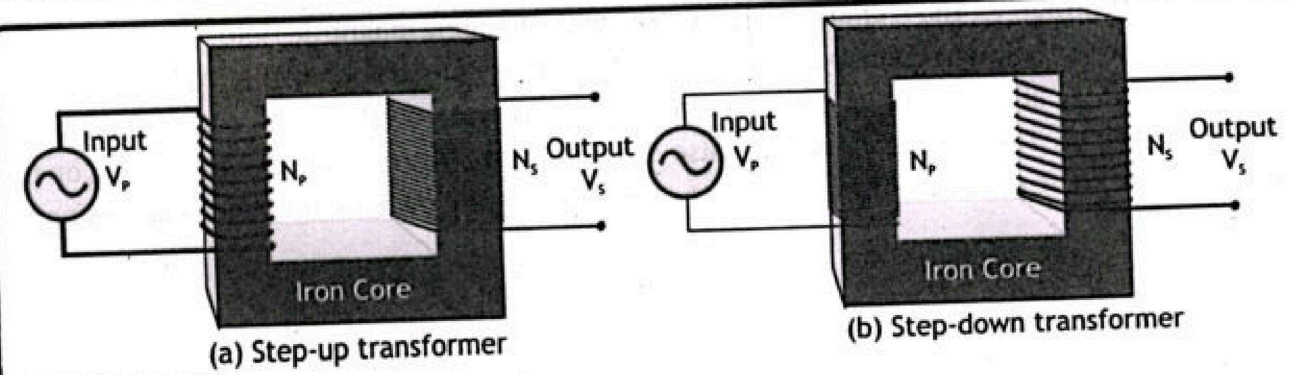
A. Step-up Transformer: A step-up transformer is shown in the figure 19.20 (a). In step-up transformer number of turns in secondary coil (N_S) is greater than the number of turns in primary coil (N_P), so voltage across secondary coil (V_S) is greater than voltage across primary coil (V_P). Hence function of step-up transformer is to increase the voltage.

B. Step-down Transformer: A step-down transformer is shown in the figure 19.20 (b). In step-down transformer number of turns in secondary coil (N_S) is less than the number of turns in primary coil (N_P), so voltage across secondary coil (V_S) is less than voltage across primary coil (V_P). Hence function of step-down transformer is to decrease the incoming voltage.

INFORMATION



A step-down transformer is installed in our streets which decrease the voltage to 220 volts.



(a) Step-up transformer

(b) Step-down transformer

FIGURE 19.20 Types of transformer.

19.11.2 IDEAL TRANSFORMER

In an ideal transformer, the electric power delivered to the secondary circuit is equal to the power supplied to the primary circuit.

An ideal transformer dissipates no power itself, and for such a transformer, we can write:

Power in primary = Power in secondary

$$\text{or} \quad I_S V_S = I_P V_P \qquad (19.2)$$

19.11.3 HIGH ELECTRIC POWER TRANSMISSION

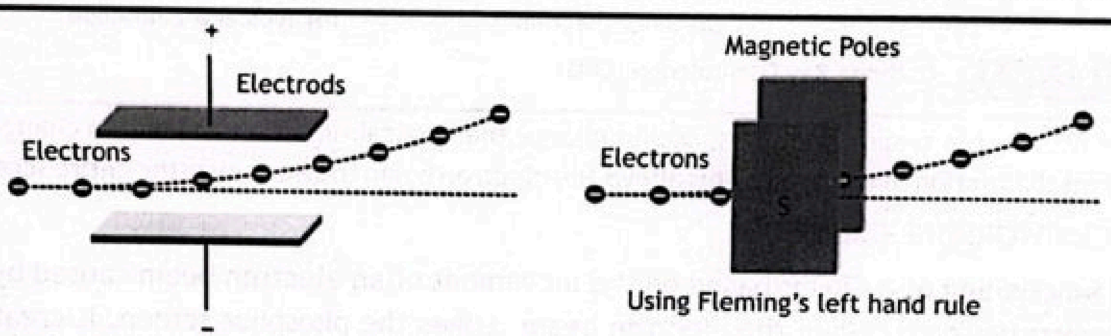
Electric power is usually generated at places which are far away from the places where it is consumed. The power is transmitted over long distances at high voltage to minimize the loss of energy in the form of heat during transmission. As heat dissipation in the transmission cable of resistance R is I^2Rt. Hence, by reducing the current through the cable, power loss in the form of heat dissipation can also be reduced. High-voltage transmission allows for more efficient transmission over longer distances. High-voltage transmission reduce infrastructure costs by reducing the need for intermediate substations, requires fewer lines and towers, so increasing economic benefits.

Thus, high-voltage transmission in modern power systems, enabling efficient, reliable, and economic transmission of electricity over long distances.

19.12 DEFLECTION OF AN ELECTRON BEAM

When a charge particle such as electron passes through an electric or magnetic field, it shows deflection.

A. Deflection of electrons by electric field: When an electron beam passes through an electric field then the electrons are deflected towards the positive plate, as shown in the figure 19.21 (a). The reason for this is that electrons are attracted by the positive charges and are repelled by the negative charges due to electric force. The degree of deflection of electrons from



(a) Deflection of electrons by electric field (b) Deflection of electrons by magnetic field

FIGURE 19.21 Deflection of electron in electric and magnetic fields.

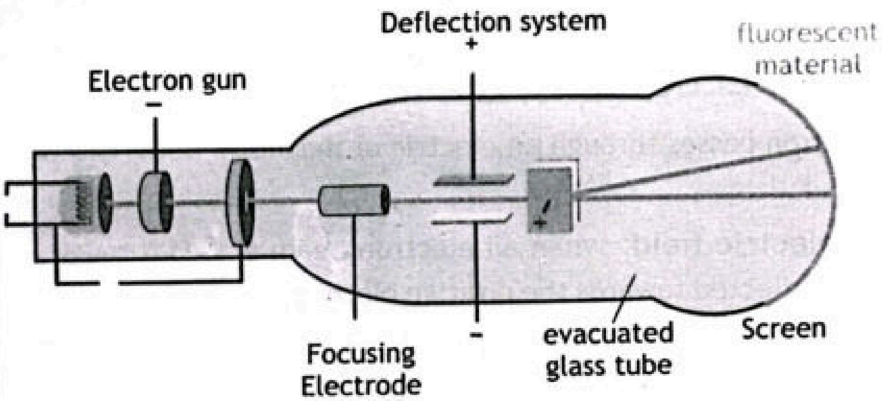
their original direction is proportional to the strength of the applied electric field E.

B. Deflection of electrons by magnetic field: When an electron beam passes through a magnetic field then the electrons are deflected, as shown in the figure 19.21 (b). The degree of deflection of electrons from their original direction depends on the velocity of electron, strength of the applied magnetic field and the angle at which the electron enters into the magnetic field.

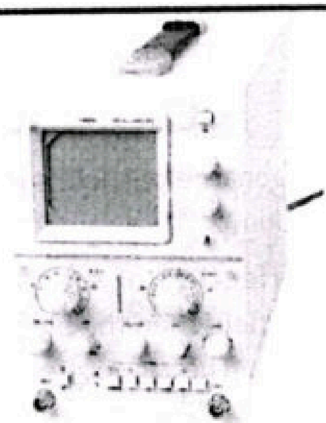
19.13 CATHODE RAY OSCILLOSCOPE (CRO)

The cathode ray oscilloscope (CRO) is an electrical instrument that converts electric signals into visual signals for displaying and analyzing waveforms and other electronic phenomena.

The block diagram of the CRO can be seen in figure 19.22 (a), where the electron beam from the electron gun is focused onto a fluorescent screen by the focusing electrode. This results in a visible spot at the center of the screen where the electron beam hits. The visible spot is created because the screen is coated with a thin layer of phosphor, which emits light when struck by electrons. The horizontal and vertical plates, located between the focusing electrode and the screen, detect the beam based on the input signal.



(a) Block diagram



(b) Typical oscilloscope

FIGURE 19.22 Cathode Ray Oscilloscope (CRO)

The deflector has two mechanisms, one to change the vertical direction and one to change the horizontal direction of the beam. This allows the electron beam to sweep over the entire screen.

19.13.1 WORKING PRINCIPLE

The functioning of a CRO is based on the movement of an electron beam caused by the electrostatic force. When the electron beam strikes the phosphor screen, it creates a bright spot. A Cathode Ray Oscilloscope directs electrostatic energy onto the electron beam from two vertical directions.

The spot on the phosphor screen moves as a result of these two perpendicular electrostatic forces, creating the required waveform of the input signal.

19.13.2 WAVEFORMS ON OSCILLOSCOPE

A typical waveform of a signal received from an AC source is display on an oscilloscope, as shown in the figure 19.23. It is showing the time on the horizontal axis and potential difference on the vertical axis.

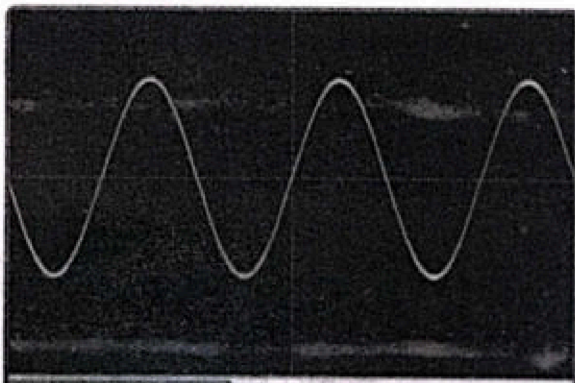


FIGURE 19.23 Waveform on screen

SUMMARY

- **Right-hand rule for current carrying wire** is that the wire is grasped in fist of right hand with the thumb pointed in the direction of the current, the fingers of the hand will curl in the direction of magnetic field. This is the right-hand rule for current carrying wire.
- **Two long parallel wires carrying a current** in same direction attract each other.
- **Right-hand rule for solenoid** is that If we grip the coil with our right hand by curling our fingers in the direction of the conventional current, our thumb will indicate the north pole of the coil, which is along the axis of solenoid.
- **The Earth's magnetic field** is generated by the rotation of the Earth and its molten iron core that contains charged particles in motion.
- **Relay** is an electrical control device that facilitates interaction between the input and output circuits.
- **Current carrying conductor is placed in a magnetic field** experiences a force.
- **Fleming's left hand rule** is that 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.
- **Working principle of electric motors** is when a current-carrying loop is placed in a magnetic field, it experiences a couple due to which the coil begins to rotate.
- **Electric motor** is device that converts electric energy into mechanical energy.
- **Electromagnetic induction** is the production of an electromotive force across a conductor when it is exposed to a varying magnetic field.
- **Lenz's Law** states that the direction of induced current in a circuit is always such that it opposes the cause which produces it.
- **A.C generator** converts mechanical energy into electrical energy.
- **Transformer** is an electrical device which is used to increase or decrease the value of an alternating voltage.
- **Step-up transformer** is used to increase the incoming voltage.
- **Step-down transformer** is used to decrease the incoming voltage.
- **The waveform on oscilloscope** can be controlled by applying electric field of suitable magnitude.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option in the following questions.

1. The presence of a magnetic field can be detected by a

   A. small mass B. stationary positive charge
   C. stationary negative charge D. magnetic compass

2. A DC motor converts:

   A. mechanical energy into electrical energy
   B. mechanical energy into chemical energy
   C. electrical energy into mechanical energy
   D. electrical energy into chemical energy

3. Which of the following device works on the principle of electromagnetic induction?

   A. Magnetic compass B. Motor C. Transformer D. Oscilloscope

4. Voltage in the secondary coil of transformer does not depend upon

   A. frequency of source B. primary voltage C. power losses D. turns ratio

5. Which of the following quantities remain constant in an ideal step-up transformer?

   A. current B. voltage C. power D. heat

6. Step-up transformer has a transformation ratio of 3:2. What is the voltage in secondary, if voltage in primary is 30 V?

   A. 15 V B. 45 V C. 90 V D. 300 V

7. Toward which magnetic pole of Earth is the north pole of a compass needle attracted?

   A. The north pole of a compass needle is attracted to the north magnetic pole of Earth, which is located near the geographic North Pole of Earth.

   B. The north pole of a compass needle is attracted to the south magnetic pole of Earth, which is located near the geographic North Pole of Earth.

   C. The north pole of a compass needle is attracted to the north magnetic pole of Earth, which is located near the geographic South Pole of Earth.

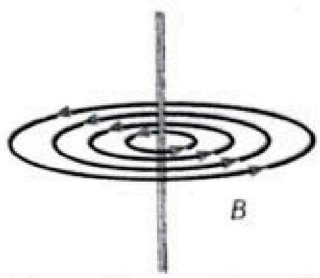
   D. The north pole of a compass needle is attracted to the south magnetic pole of Earth, which is located near the geographic South Pole of Earth.

8. The step-up transformer:
   A. increases the input current
   B. increases the output voltage
   C. has more turns in the primary
   D. has less turns in the secondary coil
9. A step up transformer is used before electricity is transmitted by overhead cables. Select the statement that explains why this is done.
   A. It increases the voltage to increase the speed at which the electricity travels.
   B. It increases the voltage to reduce energy loss in the cables.
   C. It increases the current to increase the speed at which the electricity travels.
   D. It increases the current to reduce energy loss in the cables.
10. Which of the following does not change in an ordinary transformer?
   A. power
   B. Frequency
   C. Current
   D. Voltage

CONSTRUCTED RESPONSE QUESTIONS

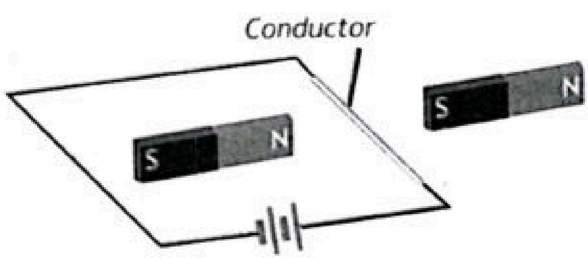
QII. Follow the directions to respond to the following questions.

1. In which direction the current must be flowing through the conductor to create the magnetic field shown in the diagram? Up or Down?



2. In the following diagram, will there be a North pole or a South pole at the left side of the solenoid? Also draw its magnetic field having arrows to show its direction.

3. A current carrying conductor is place in the magnetic field, as shown.



a) In which direction will the conductor move? Up, down, left or right?

Ans: ____________________

b) If the magnetic field was reversed then in which direction will the conductor move?

Ans: ____________________

c) If both the magnetic field and the current are reversed, then in which direction will the conductor move?

Ans: ____________________

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. How does a generator differ from a motor, and what is their relationship to each other?
2. Why is a transformer ineffective with DC voltage?
3. Explain the relationship between the direction of a current-carrying conductor and the magnetic field it produces.
4. Describe the interaction between a current-carrying conductor and a magnetic field, and how to determine the direction of the force exerted.
5. Why is high voltage used for long-distance transmission of electrical power?
6. Design an experiment to generate an electric current using a coil of wire and a bar magnet.
7. What factors influence the strength of an induced electromotive force (EMF)?
8. Compare and contrast the two primary types of transformers.
9. Identify three devices that operate on the principle of electromagnetic induction.

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Design an experiment to qualitatively demonstrate the existence of a magnetic field around a current-carrying conductor.
2. Describe an experimental setup to induce an EMF in a circuit using a changing magnetic field. How can you measure the induced EMF?
3. Explain Lenz's law in your own words, and provide a real-world example to illustrate its application.
4. Define an alternating current (AC) generator. Draw a labeled diagram and explain its components and operation. How does it convert mechanical energy into electrical energy?
5. What is an AC motor? Draw a labeled diagram and explain its components and operation. How does it convert electrical energy into mechanical energy?
6. Define a transformer. Explain its principle of operation, components, and applications. How does it change the AC voltage?

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. A step-up transformer has a turn ratio of 1:100. An alternating supply of 20 V is connected across the primary coil. What is the secondary voltage?

   (Ans. 2000 volts)

2. A step-down transformer has a turns ratio of 100:1. An ac voltage of amplitude 170 V is applied to the primary. What is the voltage across the secondary?

   (Ans. 1.7 volts)

3. Calculate the input voltage if it draws 0.5 A. Also calculate turn ratio of primary to secondary coil if a transformer is rated for an output of 100 W and 8.3 A. Also identify the type of transformer.

   (Ans. 200 volt, 1:16.6, step down)

4. Calculate the output power and output current of the following step-down transformer. The value of input current is 0.050 A (Assuming that the transformer is 100% efficient).

   (Ans. 11.5 W, 1.9 A)

5. A transformer in an adapter steps up a 115 V to the 230 V needed for a hair dryer. A current of 5 A flows through the hairdryer. Assuming that the transformer is 100% efficient, calculate the current drawn from the mains supply.

   (Ans. 10 A)