CHAPTER **8**

ELECTRICITY

Electricity is the most important, convenient and controllable form of energy in the modern times. It can be easily converted to light, heat and mechanical energies for using in our homes for-lighting ; operating fans, washing machine etc. It is also used in schools, hospitals, industries and so on. In this chapter we shall study to answer some basic questions viz. what is the basis of electricity ? How does electric current flow in electrical circuits ? What are the factors that affect the flow or regulate the current in electrical circuits ? We shall also discuss the application of heating effect of electric current in household electric appliances. In fact, it is now difficult to imagine a world without electricity.

8.1 Electric Charge; Current and Circuit

The word electricity means the energy associated with electric charges such as electrons either stationary or in motion. We also know that in air current and water current in rivers – air particles and water particles are flowing respectively. Likewise electric current is said to flow in a wire of conductor, if the electric charges flow continously through it. Let us take up an example. In a torch, you have seen that there are cells(or a battery when placed in proper order) to provide the flow of electric charges i.e. to constitute an electric current through the bulb. Such a current makes the bulb to glow. We have also observed that the bulb glows giving out light only when the switch of the torch is on. What is the function of the switch? Now, you know that a switch provides a conducting link for the electric current between the cell and the bulb. **Such a continuous and closed path of an electric current is called an electric circuit**. When the switch of the torch is turned off the bulb does not glow because the circuit is broken.

The electric current is expressed by the quantity of charge flowing through a particular area in unit time i.e. it is the rate of flow of electric charges through the conductor. Thus, larger the rate of flow of charge the greater is the current.

8.1.1 Direction of Electric Current

When electricity was invented, a long time back, two types of charges : positive and negative charges were known. But electron was not discovered at that time. So, electric current was considered to be the flow of positive charges and this direction was taken to be the direction of electric current. **Thus the conventional direction of electric current is from positive terminal of a cell or battery to the negative terminal through the outer circuit.** So in circuit diagrams you will see an arrowhead on the connecting wire pointing from the positive terminal of the cell or battery towards the negative terminal. In circuits using metallic wires, electrons constitute the flow of charges and actual direction of electron flow is from negative terminal to the positive terminal of the cell or battery which is opposite to the direction of conventional current.

8.1.2 Expression of Electric Current

Amount of charge flowing through a given cross-section of a conductor per unit time constitutes electric current. If a net charge 'Q' flows across any cross-section of a conductor, perpendicular to the direction of current flow, in time 't' then the current 'I' through the cross-section is $I = \frac{Q}{t}$ . . . 8.1

The SI unit of electric charge is coulomb (C) while that for electric current is ampere(A), named after the French scientist, Andre-Marie Ampere (1775–1836). Thus one ampere of electric current is constituted by the flow of one coulomb of charge per second, that is given by $1\,A = \frac{1\,C}{1\,s}$

(Since an electron possesses negative charge of 1.6×10^{-19} C, 1C of charge is equivalent to the charge contained in nearly 6×10^{18} electrons)

The electric current in a circuit is measured by an instrument called **ammeter**. It is always connected in series in a circuit. Figure 8.1 shows the schematic diagram of typical electric circuit comprising a cell, a torch light bulb, an ammeter and a switch in the form of a plug key. It may be noted that the electric current flows in the circuit from the positive terminal of the cell through the bulb and ammeter.

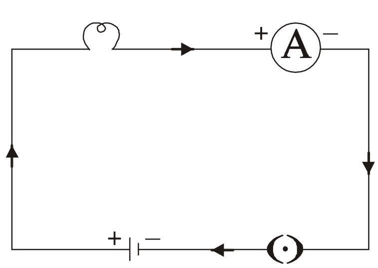


Figure 8.1 A schematic diagram of an electric circuit

Smaller quantities of current are expressed in milliampere ($1mA=10^{-3}$ A) or in microampere ($1A=10^{-6}$ A), or in nanoampere($1nA=10^{-9}$ A).

Example 8.1 **A current of 0.4 A is made to pass through an electric circuit for 15 minutes. Find the amount of electric charge that flows through the circuit.**

Solution We are given, I = 0.4 A; t = 15 min = 15 × 60s.

From Eq (8.1), we have

$$Q = I\,t$$
$$= 0.4\text{ A} \times (15 \times 60)\text{s}$$
$$= 4 \times 15 \times 6 \text{ As} = 360 \text{ C}.$$

Try to Answer

1. **What do you mean by an electric circuit ?**
2. **Define one ampere of current.**
3. **Calculate the number of electrons in 4.8 C of electric charge.**

8.2 Electric Potential and Potential Difference

The charges do not flow in a metallic wire by themselves just as water in a perfectly horizontal pipe or tube does not flow by itself. Then we can put a question – What makes the electric charges to flow ? In order to answer let us consider the analogy of flow of water in a pipe. When one end of the pipe is connected to a tank of water which is kept at a higher level than the other end of the pipe then water flows out. This flow is due to the pressure difference between the two ends of the tube, caused by gravity. For flow of charges in a conducting wire, say copper wire, gravity has no role to play but the electrons move only if there exists a difference of electric pressure along the conductor or conducting wire. This difference of electric pressure is called the **potential difference**. This difference of potential is generated by a battery, consisting of one or more cells. The chemical action within such cells generates the electric potential difference between its terminals, even when no current is drawn from it i.e. when no electric circuit is connected to the cell. When the cell is connected to an electric circuit, the potential difference sets the charges (electrons) in motion within the conductor and produces an electric current. In order to maintain the current in a given circuit, the cell has to expend its stored chemical energy.

Note that in metals each atom allows some of its outermost electrons to detach from it and to move quite freely in the whole of the metal. When an electron is detached from the atom, the atom becomes positively charged. Such a charged atom is called a **positive ion**. So the metal can be visualised as collection of positive ions fixed in their respective positions and a large number of free electrons moving here and there. These free electrons are not bound to any specific atom or location but wander throughout the body of the metal with random speeds and directions, as shown in figure 8.2.

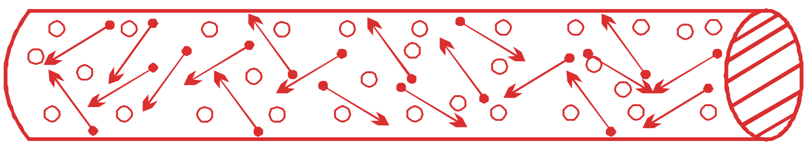


Figure 8.2

A schematic diagram of random motion of electrons

o ⟶ positive ion

• ⟶ electron.

When a potential difference is maintained across the metal, the electrons move in a more systematic way and in a specific direction towards the positive terminal of the cell or battery in the circuit. The schematic diagram is shown in figure 8.3.

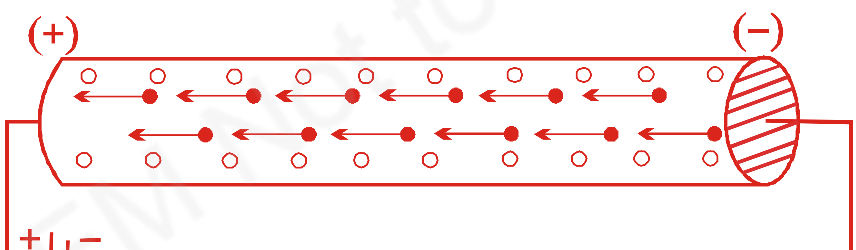


Figure 8.3 Schematic diagram of motion of electrons under applied potential difference.

o ⟶ positive ion

• ⟶ electron.

The electric potential difference between two points in an electric circuit carrying current is defined as the amount of work done to move a unit charge from one point to the other.

Thus, potential difference (V) between two points = $\dfrac{\text{Work done (W)}}{\text{Charge (Q)}}$

$\frac{W}{Q}$ $\frac{W}{It}$

V = = ... 8.2

The SI unit of potential difference is one volt (V), named after Alessandro Volta (1745–1827), an Italian physicist. One volt is the potential difference between two points in a current carrying conductor when one joule of work is to be done in order to move a charge of one coulomb from one point to the other.

Thus, $1\text{volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$

OR, $1\text{V} = \frac{1\text{ J}}{1\text{ C}} = 1\text{ J/C} = 1\text{ JC}^{-1}$ 8.3

The potential difference is measured by means of an instrument called **voltmeter**. This instrument is always connected in parallel across the points whose potential difference is to be measured.

Example 8.2 **How much work will be done in moving a charge of 2.5C across two points having a potential difference of 6V ?**

Solution Amount of charge Q flowing between the two points = 2.5 C

Potential difference between the points, V = 6 volt.

Thus, the amount of work done in moving the charge is

W = VQ

= 6 volt × 2.5 C

= 15.0 J

Example 8.3 **Calculate the amount of work done by a battery in a circuit where a current of 2 A flows for 1 min between two points of potential difference 2V.**

Solution Quantity of charge flowing in 1 min is Q = 2A × (1 × 60)s

= 120C

Potential difference = 2V

Thus, the amount of work done,

W = VQ = 2V × 120C = 240 J.

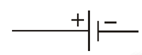
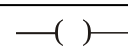
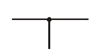
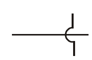
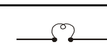
Try to Answer

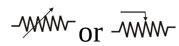
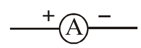
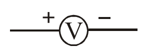
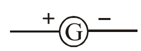
1. What is the device that can maintain a potential difference across a conductor?
2. What is meant by saying that the potential difference between two points is 1 volt ?
3. How much energy is given to 2 coulomb of charge passing through a cell of 1.5 volt?

8.3 Electrical Symbols

It is convenient to draw a schematic diagram for electrical circuits in which different components used in the circuit are represented by symbols. Conventional symbols for commonly used electrical components are given in Table 8.1.

Table 8.1 *Symbols of some commonly used components in electrical circuit diagrams*

Sl. No	Components	Symbol
1.	An electric cell	
2	A battery (a combination of cells)	
3.	Connecting wire	
4.	An open switch	
5.	An open plug key	
6.	A closed switch	
7.	A closed plug key	
8.	A wire joint	
9.	Wires crossing without contact	
10.	Electric bulb	

11.	A resistor of fixed resistance	
12.	Variable resistance or rheostat	
13.	Ammeter	
14.	Voltmeter	
15.	Galvanometer	
16.	Electric fuse	

8.4 Ohm's Law

So far, we have studied potential difference as the cause of current flow along a conductor. Let us explore the relationship between potential difference across a conductor and current flowing through it, with the help of an Activity.

Activity 8.1

Take a nichrome wire of suitable length say 0.5 m, an ammeter, a votlmeter, a plug key and four torch cells of 1.5 volt each. Set up a circuit as shown in figure 8.4

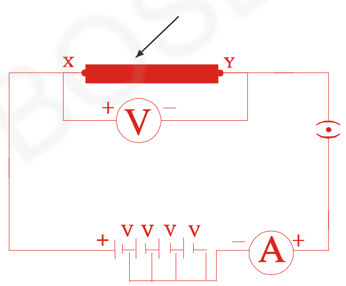


Figure 8.4 Electric circuit for the Activity 8.1

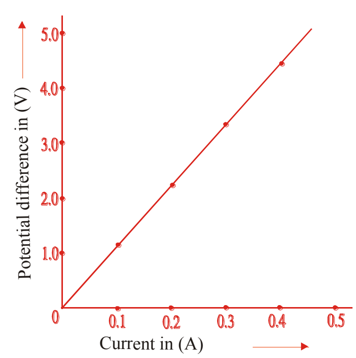


Figure 8.5 V–I Graph for a wire of metal

First use one cell only as the source in the circuit. Note the reading in the ammeter for the current I and the reading in the voltmeter for the potential difference V across the nichrome wire in the circuit.

Enter or tabulate the readings in the Table 8.2 given below.

In the next step, connect two cells in the circuit and note the respective readings of the ammeter and votmeter and enter the readings in the Table 8.2.

Repeat the above steps using three cells and then four cells in the circuit in turn. Calculate the ratio of voltage (V) across the nichrome wire to current (I) flowing through the wire for each step of observation.

Table 8.2

Step No.	Number of cells in the circuit	Current through the nichrome, I in ampere	Potential difference across the nichrome wire, V in volt	$\frac{\text{V volt}}{\text{I ampere}}$
1	1			
2	2			
3	3			
4	4			

In this Activity you will see that the ratio of V to I almost remains the same for each step of observation. Now plot a graph of the potential difference (V) against current (I) . The graph will be a straight line passing through the origin as shown in Fig. 8.5 Thus the value of is a constant ratio. This is Ohm's law.

Since the unit of potential difference is one volt (V) and that of the current is ampere (A), the ratio is in .

In 1827, a German physicist George Simon Ohm (1787 – 1854) found out the relationship between the current flowing through a metallic conductor (wire) and the potential difference across its ends. **He stated that at a constant temperature the current flowing through a conductor is directly proportional to the potential difference across its ends. The above statement is called Ohm's law.**

If 'I' is the current flowing through a conductor and 'V' is the potential difference (or voltage) across its ends then according to the above law :

$$V \propto I$$

OR $\frac{V}{I}$ = a constant (R) 8.4

OR V = I R 8.5

In equation (8.4), R is a constant called 'resistance' of the conductor. The value of this constant depends on the nature of the material of the conductor, length, area of cross-section and temperature of the conductor. It is the property of a conductor to resist the flow of charges through it. In other words, every conductor (metal) offers some resistance to the flow of current and to increase the amount of current through it proportionally, more energy per coulomb of charge is required. The SI unit for resistance of a conductor is ohm, represented by the Greek letter . The above equation can also be written as :

$R = \frac{V}{I}$ 8.6

If potential difference across the ends of a conductor is 1 volt and the current through it is 1 ampere, then its resistance R, at that temperature is 1 ohm.

Thus, $1\,\Omega = \frac{1V}{1A}$

From equation 8.5, we get, $I = \frac{V}{R}$ 8.7

From equation 8.7, it is obvious that the current through a conductor is inversely proportional to its resistance. If the resistance is doubled the current gets halved and vice-versa. In practice it is necessary to vary the current in an electric circuit. A component or a device is generally used to regulate the quantity of current in the circuit without changing the voltage of the source. This device is called **rheostat**. Thus a rheostat is used to change the resistance in the circuit.

8.4.1 Resistance of conductors

Activity 8.2

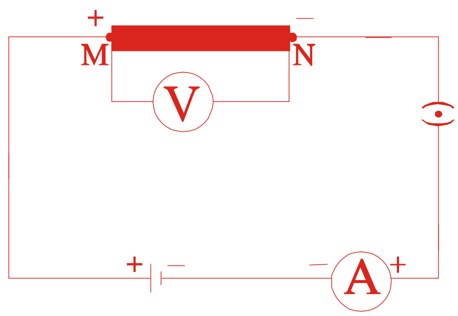


Figure 8.6

Make the connection as shown in Fig. 8.6. Then place wires each of 50cm in length and having the same area of cross-sections but of different metals e.g. iron, copper, nichrome, silver, aluminium etc. in turn across MN. Bulbs of differents wattages may also be used in the gap MN.

Complete the circuit by connecting the iron wire in gap MN. Plug the key and note down the readings of ammeter and voltmeter. Take out the key from the plug as soon as the readings are noted.

Replace the iron wire by copper wire in the gap MN and note the readings of the ammeter and voltmeter as in the above step.

Now, repeat the above step with torch bulb in the gap MN of the circuit.

Are the ammeter and voltmeter readings differ for different wires and for different bulbs connected in the gap MN ?

What do the above observations indicate ?

Repeat this Activity by keeping any other wires in the gap and note down the readings of the ammeter in each case. Analyse the observations.

In the above Activity you will notice that the current is different for different components. This indicates that the conductors having identical dimensions and temperature but of different materials offer resistance to the flow of current to different degrees. This means that certain components offer easy path for the flow of current while the others resist the flow. In other words, certain material components offer more resistance to the flow of electric current than others. This property of a material component due to which it opposes the flow of electric current through it is called electrical resistance or simply **resistance** of the conductor.

In the above we have learnt that the motion of electrons in the body of the conductor in an electric circuit constitutes an electric current. However, the motion of electrons in a conductor are not completely free. Their motions are restrained as they collide with other electrons and with the atoms and ions present in the body of the conductor.

Thus, the motion of electrons through a conductor is retarded by its resistance and plays an important role in electric circuits. Any component of a given size in the circuit which offers low or negligible resistance is a good conductor. Sometimes, components of a circuit are designed to offer high or appreciable resistance to the flow of current. They are called the **resistors**. A component of identical size that offers a higher resistance is a poor conductor. An insulator of the same size offers even higher or infinite resistance to the flow of current.

8.5 Factors on which the Resistance of a Conductor Depends

There are a number of factors on which the resistance of a conductor at a constant temperature depends. To study those factors, let us take up the following Activity.

Activity 8.3

Connect a cell, an ammeter, a nichrome wire of fixed length, a plug key as shown in a circuit given in Fig. 8.7. Let the nichrome wire be of length '*l*' cm and marked 'X'.

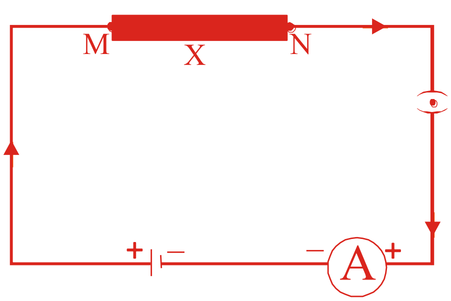


Figure. 8.7(a) Electric circuit to study the factors affecting resistance of conducting wire.

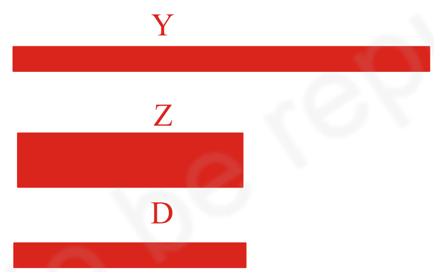


Figure 8.7(b) Different wires

Connecting the gap MN by the sample wire 'X', plug the key and note the current, I_1 A (say) indicated by the ammeter reading.

Replace the nichrome wire 'X' by another wire of nichrome of same thickness but twice the length i.e. 2*l* cm which is marked as 'Y' shown in Fig. 8.7 (b). Record the current I_2 A (say) from the ammeter reading.

Now, replace the wire 'Y' by a thicker nichrome wire marked 'Z' having the same length '*l*' cm as that of the sample marked 'X'. A thicker wire has a larger cross-sectional area. Again record the current I_3 A (say) from the ammeter reading.

In the next step, connect a copper wire marked 'D' in Fig. 8.7 (b) in the gap MN of the circuit. The wire 'D' has the same length and same cross-sectional area as that of the first nichrome wire marked 'X'. Record the current I_4 A (say) from the ammeter reading.

After examining the currents in each of the steps, you will notice the difference in the current. This result shows that the current depends on (i) the length of the wire (conductor) (ii) the area of cross-section of the wire (iii) the nature of the material of the respective wires though they have the identical geometrical dimensions.

It is observd that the ammeter reading i.e. the quantity of current decreases to one-half when the length of the nichrome wire is doubled though they have the same cross-sectional areas. The ammeter reading is increased when a thicker wire of the same meterial and of the same length is used in the circuit. A change in the ammeter reading is observed when a wire of different material but of the same length and of the same area of cross-section is used in the circuit.

Using Ohm's law given in (Eqs. 8.5 to 8.7), we can understand that the resistance of a metallic conductor of a given material at constant temperature is directly proportional to its length (l) and inversely proportional to its area of cross-section (A). That is

$$R \propto l \quad \ldots\ldots\ldots\ldots \quad 8.8$$

and $$R \propto \frac{1}{A} \quad \ldots\ldots\ldots\ldots \quad 8.9$$

Combining Eqs. 8.8 and 8.9 we have,

$$R \propto \frac{1}{A}$$

OR, $$R = \frac{\rho l}{A} \quad \ldots\ldots\ldots\ldots \quad 8.10$$

Thus, $$\rho = \frac{RA}{l} \quad \ldots\ldots\ldots\ldots \quad 8.11$$

Here (rho) is a constant of proportionality and is called the electrical resistivity of the material of the conductor. The SI unit of '' is m (ohm-metre) and it is characteristic property of the material. In general, the metals and their alloys have low resistivity in the range of 10^{-8} m to 10^{-6}m. They are treated as good conductors of electricity. The substances like rubber and glass which are well known insulators have resistivity of the order of 10^{12} to 10^{17} m. Both the resistance and resistivity of a material vary with temperature.

Note : Ohm's law does not hold for the flow of currents through electrolytic cells, vacuum tubes, semi-conductor devices and electric discharge tubes. They are called non-ohmic substances.

The electrical resistivity of some substances at 20^0 C are given in Table 8.3 (Need not to memorise but values can be used for solving problems whenever required.)

Table 8.3 : ***Electrical resistivity of some materials at 20^0 C.***

Substance	Material	Resistivity (m)
	Silver	1.60×10^{-8}
	Copper	1.62×10^{-8}
	Aluminium	2.63×10^{-8}
	Tungsten	5.20×10^{-8}
Metals	Nickel	6.84×10^{-8}
	Iron	10.00×10^{-8}
	Chromium	12.9×10^{-8}
	Mercury	94.0×10^{-8}
	Manganese	1.84×10^{-6}
	Constantan (alloy of copper and nickel)	49×10^{-6}
Alloys	Manganin (alloy of copper, manganese, nickel)	44×10^{-6}
	Nichrome (alloy of nickel, chromium, manganese and iron)	100×10^{-6}

Insulators	Glass Hard rubber Ebonite Diamond Paper (dry)	$10^{10} - 10^{14}$ $10^{13} - 10^{16}$ $10^{15} - 10^{17}$ $10^{12} - 10^{13}$ 10^{12}

Example 8.4 **A 4.5 V battery is connected to a bulb of resistance 9. Calculate the current through the bulb.**

Solution We have given V = 4.5 V ; R = 9 Ω

From the Eq. 8.7, we get the current through the bulb,

$$I = \frac{4.5V}{9\Omega} = 0.5A$$

Example 8.5 **When a heater draws a current 4A from a battery, the terminal potential difference across it is 24V. What current will the heater draw when it is connected across a battery of 60 V ?**

Solution We are given the potential difference, V = 24V ; current, I = 4A

From Ohm's law, the resistance of the heater, $R = \frac{V}{I} = \frac{24}{4} 6 \quad \Omega$

When the potential difference applied is 60V, the current I' passing through the heater will be

$$I' = \frac{V}{R} = \frac{60V}{6\Omega} = 10\ A$$

Thus, the current through the heater becomes 10 A.

Example 8.6 **The resistance of a wire is 50 at 20^0 C. If the length and diameter of the wire are 1m and 5×10^{-4} m respectively, calculate the resistivity of the material of the wire.**

Solution We are given the resistance R of the wire = 50 Ω ; the diameter 'd' = 5×10^{-4} m and the length 'l' = 1m.

Thus, from Eq. 8.11, the resistvity of the material of the wire is

$$\rho = \frac{RA}{l} = \frac{R.\pi d^2}{4l} \left[\because \text{the area of cross-section , } A = \frac{\pi d^2}{4} \right.$$

Substituting the values in the above, we get

$$\rho = \frac{50\times 22\times\left(5\times 10^{-4}\right)^2}{7\times 4\times 1} = 9.82\times 10^{-6}\,\Omega\text{m}$$

Thus, the resistivity of the metal at 20^0C is 9.82×10^{-6} m.

Eample 8.7 **A wire of certain length has a resistance of 4Ω .The wire is elongated or stretched to double its length. Calculate the new resistance of the wire.**

Solution We are given, R = 4Ω

When the wire is stretched to double its length, the area of cross-section would be half. Thus a wire of length '*l*' and area of cross-section 'A' becomes of length 2*l* and area of cross-section $\frac{A}{2}$ respectively.

Thus, from Eqn. 8.11, we get

$$R = \frac{\rho l}{A}$$

And $R_1 = \dfrac{\rho \times 2l}{\frac{A}{2}}$ Where R_1 is the new resistance.

$$\therefore \quad \frac{R_1}{R} = \frac{4\rho l}{A}\times\frac{A}{\rho l} = 4$$

Hence, $R_1 = 4R = 4 \times 4 = 16\Omega$

The new resistance of the wire is 16.Ω

Try to Answer

1. Name the factors on which the resistance of a conductor depends.
2. Through which of the wires – a thick one and a thin one of the same material will current flow easily, when connected to the same battery or cell ? Why ?
3. Suppose the potential difference across an electrical component of fix resistance decreases to half of its former value. What change will occur in the current passing through it ?

8.6 Combination of Resistances (or Resistors)

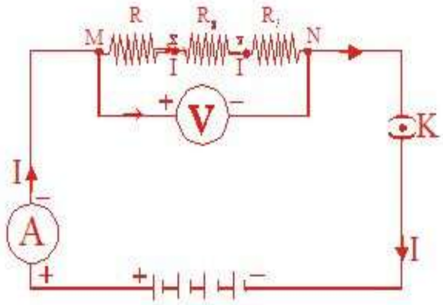


Figure 8.8 Resistors in series

In the preceding sections, we have learnt about potential difference, current and resistances in simple electric circuits. We have also noticed how the current through a conductor depends upon its resistance and potential difference applied across its ends. In electrical circuits of radio, television and electrical gadgets, we often use resistors in various combinations in order to get the required current in the circuit. There are two methods of joining two or more resistors in a circuit. The methods are (i) series combination and (ii) parallel combination. Figure 8.8 shows an electric circuit in which three resistors of resistances R_1, R_2, R_3 are joined end to end.

The resistors are connected end to end between the points M and N. Here, the resistors are said to be in series.

Figures 8.9 shows another combination of resistors in which the resistors R_1, R_2, R_3 are connected together between the points M and N of the circuit. Here, the resistors are said to be combined in parallel.

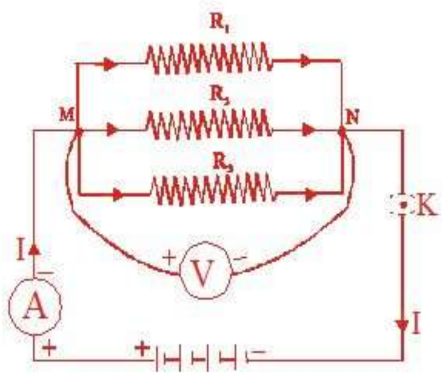


Figure 8.9 Resistors in parallel

8.6.1 Resistors in Series

In order to know the value of the current flowing through the circuit when a number of resistors are connected in series and value of equivalent resistance, let us perform the following Activity.

Activity 8.4

Take three resistors having values like $2\,\Omega$, $4\,\Omega$, $6\,\Omega$ and a battery 12V for performing this activity. Connect them as shown in Fig. 8.8.

Plug the key and note the ammeter reading.

Change the position of ammeter to anywhere in between the resistors. Record the ammeter reading for each of the positions of it.

Try to observe for any change in the value of current through the ammeter.

You will observe that the value of current in the ammeter will remain the same independent of its position in the circuit. This result shows that in a series combination of resistors the current is the same through each of the resistors irrespective of resistance and is equal to the total current of the circuit. Now, note down the reading V volt (say) of the voltmeter.

In the next step, take out the plug key and disconnect the voltmeter. Now insert the same voltmeter across the ends M and X of the resistor R_1 as shown in figure 8.10.

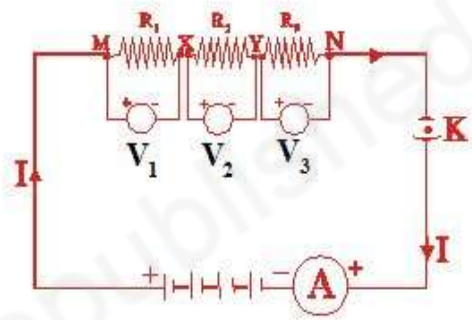


Figure 8.10

Now, plug the key and record the potential difference V_1 across the resistor R_1.

In the same manner, measure the potential difference V_2, V_3 across the resistors R_2, R_3 respectively. Try to observe the relation between V_1, V_2, V_3 and V.

From the record, you will find that the potential difference V is equal to the sum of potential differences V_1, V_2 and V_3. This shows that the total potential difference across a combination of resistors in series is always equal to the sum of potential differences across the indivitual resistors.

Thus, $V = V_1 + V_2 + V_3$ 8.12

Referring to the circuit in Fig. 8.10, let I be the current through the circuit. The current through each of the resistors is also I (from the above Activity). It is now possible to replace the three resistors joined in series by an equivalent single resistor having a resistance R_S such that the potential difference across it is 'V' when the current 'I' through the circuit remains the same.

Applying Ohm's law to the entire circuit, we get

$V = I R_S$ 8.13

Again, applying Ohm's law to the individual resistors, we have,

$$V_1 = I\,R_1 \qquad \ldots\ldots\ldots\ldots \quad 8.14$$

$$V_2 = I\,R_2 \qquad \ldots\ldots\ldots\ldots \quad 8.15$$

$$V_3 = I\,R_3 \qquad \ldots\ldots\ldots\ldots \quad 8.16$$

From Eq. 8.12, $I\,R_S = I\,R_1 + I\,R_2 + I\,R_3$

OR $$R_S = R_1 + R_2 + R_3 \qquad \ldots\ldots\ldots\ldots \quad 8.17$$

Hence, we can conclude that when two or more resistors are combined in series, the equivalent or resultant resistance R_S equals to the sum of their individual resistances and R_S is greater than the greatest of the individuals.

8.6.2 Resistors in Parallel

Referring to the circuit given in figure 8.9, let us try to understand the current flowing through each of the resistors and potential difference across each with the help of the following Activity.

Activity 8.5

Make a parallel combination MN of three resistors R_1, R_2, R_3 and complete the circuit connections as shown in the Figure 8.9.

Plug the key and note the ammeter reading as well as the voltmeter reading. The ammeter reading 'I' ampere (say) and voltmeter reading 'V' volt (say) give the total current in the circuit and total potential difference across the parallel conbination MN respectively.

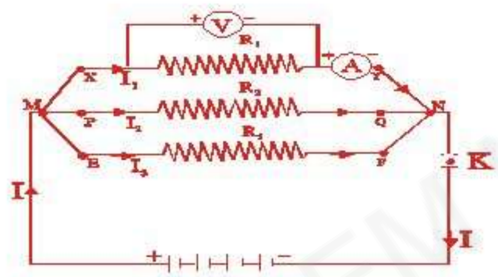


Figure 8.11

Remove the plug from the key, ammeter and voltmeter from the circuit. Then complete the circuit connection as shown in the figure 8.11. Here, voltmeter is connected across R_1 while the ammeter is connected in series to R_1.

Insert the plug in the key and note the ammeter reading, say, I_1 and voltmeter reading V_1, and then remove the plug. Now connect voltmeter across R_2 and ammeter in series to it. Insert the plug and note the reading I_2 of the ammeter and voltmeter reading V_2. Then remove the plug. Repeat the observation for the branch EF and let I_3 and V_3 be the ammeter reading and voltmeter reading respectively. Analyse the relationship between (a) I_1, I_2, I_3 and I (b) V_1, V_2, V_3 and V.

From the Activity, it is observed that the total current I is equal to the sum of the separate currents flowing through each branch of combination.

Thus, $I = I_1 + I_2 + I_3$ 8.18

and $V = V_1 = V_2 = V_3$

It is now possible to replace the three resistors joined in parallel by an equivalent resistor having a resistance R_p (say) such that the total current 'I', from Ohm's law, is given by

$$I = \frac{V}{R_p} \qquad \text{. . . . . 8.19}$$

Again, applying Ohm's law to each branch resistor, we have,

$$I_1 = \frac{V}{R_1}\ ;\ I_2 = \frac{V}{R_2}\ ;\ I_3 = \frac{V}{R_3} \qquad \text{. . . . . 8.20}$$

Combining the Eqs. 8.18, 8.19 and 8.20, we have,

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

OR $$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad \text{. . . . . 8.21}$$

Thus, we may conclude that the reciprocal of the equivalent resistance of a group of two or more resistors connected in parallel is always equal to the sum of the reciprocals of the individual resistances. This means that R_p is less than the least of the resistances in the grouping.

8.6.3 Laws of Combination of Resistances

(i) Series combination :–

(a) The combined resistance of any number of resistors connected in series is equal to the sum of individual resistances.

(b) The same current flows through all resistors irrespective of the value of resistance.

(c) The potential difference across each individual resistor is directly proportional to the resistance.

(ii) Parallel combination :–

(a) The reciprocal of the combined resistance of any number of resistors connected in parallel is equal to the sum of the reciprocal of all the resistances.

(b) The potential difference across each individual resistor remains same, irrespective of the values of the resistance.

(c) The current flowing through each of the resistors is inversely proportional to the value of resistance.

8.6.4 How are the Household Electric Appliances/Components connected to the Mains Supply ?

You have seen different electrical components used in a house. For example, electric bulb, fan, toaster, heater, iron, television, radio receivers etc. They need electric currents of widely different values to operate properly. Thus it becomes obviously impracticable to connect those different components in series, since each of them needs different current to operate properly. Moreover, the total resistance will increase with the increasing number of components and the smaller will be the current flowing through the series arrangement. Thus none of the components may operate, if the arrangement were in series. This is the disadvantage of series combination. Another major disadvantage of series combination is that when one of the components gets fused, the circuit is broken and none of the components will work. Series connection is generally used in 'fairy light' to decorate buildings, temples on festivals and marriage celebrations etc. If the system does not work, it is very difficult and time consuming task for the electricians to locate and replace the dead bulb.

On the other hand, if the above cited components were combined in parallel, the circuit divides the total current to the components acordingly. Since, the total resistance in a parallel circuit is decreased with the increasing number of resistors or components (Eq. 8.21), more and more current will be drawn from the source i.e. mains supply. This is helpful particulary when each component has different resistance and requires different current to operate properly. Another major advantage for parallel connection of electric components is that when one of the components gets fused or fails, the other components are not affected. That is why in the household, the electric wiring is done in parallel circuits.

Example 8.7 **A resistor of 10 Ω is connected in series to an electric bulb of 20 Ω. The combination is connected to a battery of 6V comprising four cells, (Fig 8.12). Calculate (i) total resistance of the circuit (ii) total currrent in the circuit (iii) potential difference across the bulb and the resistor.**

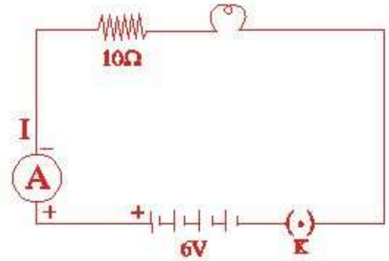


Figure 8.12 An electric bulb and a resistor connected in series to a battery

Solution The resistance R_1 of the bulb = 20 Ω and that of the conductor, $R_2 = 10\,\Omega$

Then the total resistance of the circuit,

$R_S = R_1 + R_2 = 20+10 = 30\ \Omega$

The total potential difference, V = 6V

Applying Ohm's law, the current flowing through the circuit,

$$I = \frac{V}{R_S} = \frac{6V}{30\Omega} = 0.2\ A$$

Again, potential difference across the bulb,

$V_1 = I \times R_1 = 0.2 \times 20 = 4\ V$

And, potential difference across the resistor,

$V_2 = I \times R_2 = 0.2 \times 10 = 2V$

Here, $V_1 + V_2 = 4V + 2V = 6V$ = the total potential difference across the battey terminal.

Example 8.8 **Consider the circuit shown in (Fig. 8.13). Calculate the potential difference across each resistor.**

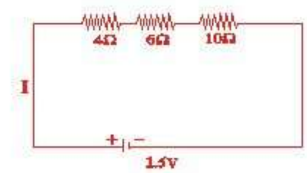


Figure 8.13

Solution The three resistors are in series and the equivalent resistance, $R_S = 4\,\Omega + 6\,\Omega + 10\,\Omega = 20\,\Omega$

Current through the circuit, $I = \frac{1.5V}{20\Omega} = 0.075A$

The same current of 0.075 A passes through all the resistors. Applying Ohm's law, the potential difference across the 4 Ω resistor = 0.075 ×4 = 0.3V

across the 10 Ω resistor = 0.075 ×10 = 0.75V

across the 6 Ω resistor = 0.075 × 6 = 0.45V

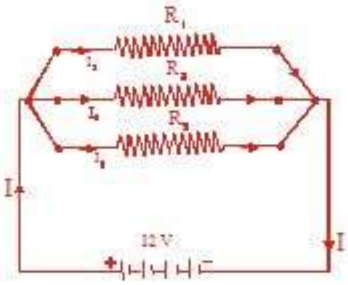


Figure 8.14

Example 8.9 Three resistors $R_1 = 4\,\Omega$; $R_2 = 10\,\Omega$; $R_3 = 20\,\Omega$ are arranged in parallel across a 12V battery as shown in Figure 8.14. Calculate the (i) total circuit resistance (ii) current in the circuit (iii) current through each resistor.

Solution Total circuit resistance, R_p is given by [Eq. 8.21],

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{4} + \frac{1}{10} + \frac{1}{20}$$

OR $$\frac{1}{R_p} = \frac{5+2+1}{20} = \frac{8}{20} = \frac{2}{5}$$

$$\therefore \quad R_p = \frac{5}{2} = 2.5\,\Omega$$

Current through the circuit, $I = \dfrac{V}{R_p} = \dfrac{12}{2.5} = 4.8$ A

Applying Ohm's law, the current

through R_1, $I_1 = \dfrac{V}{R_1} = \dfrac{12}{4} = 3.0$ A

through R_2, $I_2 = \dfrac{V}{R_2} = \dfrac{12}{10} = 1.2$ A

through R_3, $I_3 = \dfrac{V}{R_3} = \dfrac{12}{20} = 0.6$ A

Since the resistors are in parallel, the total current is $I_1 + I_2 + I_3$

$= (3.0 + 1.2 + 0.6) = 4.8$ A

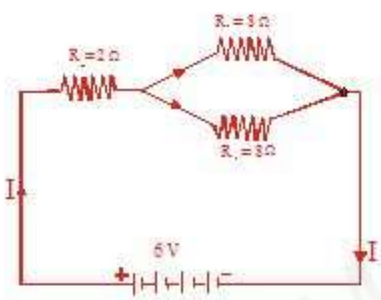


Figure 8.15

Example 8.10 Find the current supplied by the battery in the circuit shown in Fig. 8.15 .

Solution Suppose we replace the parallel combination of R_2 and R_3 by R_p, which is the equivalent resistance.

Then from Eq. 8.21 we have,

$$\frac{1}{R_p} = \frac{1}{8} + \frac{1}{8} = \frac{2}{8} = \frac{1}{4}$$

$\therefore R_p = 4\,\Omega$

Thus, the total resistance,

$$R = R_1 + R_p = 2\,\Omega + 4\,\Omega = 6\,\Omega$$

To calculate total current supplied by the battery, we use Ohm's law and get

$$I = \frac{V}{R} = \frac{6}{6} = 1A$$

8.7 Heating Effect of Electric Current

In section 8.2 we have learnt that the potential difference between the terminals of the cell is generated with the help of chemical reaction in it. This potential difference sets the electrons in motion along a definite direction. As a result, current flows through conductor and resistor or a system of resistors connected to the battery. At the same time the cell which is the source of electrical energy has to keep expending its stored energy. Where does the energy go ? Out of the total energy expended, a part may be consumed in maintaining the current for useful work such as in rotating the blades of an electic fan while the remaining part may be expended in the form of heat energy resulting to raise of temperature of electric gadgets viz. television, fan etc. As an example, you must have observed the rise in temperature of table fan or television when used continuously for longer time. On the other hand , if the electric circuit comprises purely resistive components i.e. resistors only, the source energy of the battery gets dissipated in the form of heat energy. This is called the heating effect of current. Because of this effect, when an electric current is passed through nichrome wire which have high resistance, it becomes very hot and produces heat. In other words, the heating effect of current is obtained by the transformation of electrical energy into heat energy. This effect is utilised in devices like electric heater, electric kettle and cooker, electric iron etc.

Imagine a resistor R connected across the terminals of a battery. Let I be the current flowing through it when the potential difference across it is V, shown in the Fig. 8.16. The amount of electrical work done in moving the charge Q through a potential difference V is VQ. If 't' is the time during which the amount of charge Q flows through, as explained above, the source must supply an energy equal to VQ.

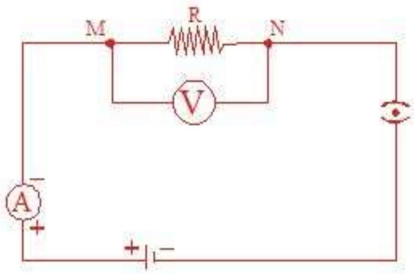


Fig. 8.16.

Hence the energy input to the circuit by the source (i.e. battery) per unit time is

$$\frac{VQ}{t} = VI \qquad \ldots\ldots\ldots\ldots \quad 8.22$$

Here, $I = \frac{Q}{t}$

In other words the energy supplied to the resistive circuit by the battery in time *t* is VI t. Thus, the energy supplied gets dissipated as heat in the resistor. That is, the amount of heat 'H' produced in time 't' is

$$H = VIt$$

$$= I^2Rt \qquad \ldots\ldots\ldots\ldots \quad 8.23$$

[From Ohm's law, (Eq 8.5), V = IR]

When V is in volt, I is in ampere, t is in second and H is in joule.

The above relation is known as Joule's law of heating.

The law states that heat produced in a resistor is directly proportional to

(i) the square of the current for a given resistance

i.e. $H \propto I^2$ when R is constant.

(ii) the resistance for a given current

i.e. $H \propto R$ when I is constant.

(iii) the time for which the steady current flows through the given resistance i.e. $H \propto t$ when R and I remain constant.

For using the Eq. 8.23, the current through the resistor is calculated from the relation $I = \frac{V}{R}$

8.7.1 Applications of Heating Effect of Electric Current

Since electrical conductors have resistance, whether large or small, the generation of heat in a conductor is an inevitable consequence. In electrical circuits, the inevitable heating can increase the overall or ambient temperature of the components and may lead to alter their properties. In most of the circuits, radiating devices are used to reduce the excessive heating.

On the other hand heating effect of electric current has many useful household applications. The appliances such as electric toaster, electric iron, electric oven, electric cooker, electric kettle, electric immersion heater are some of the familiar devices based on Joule's heating.

The heating effect of electric current is utilised in electric bulbs for producing light. When electric current passes through a thin, high resistance tungsten wire called the filament of the bulb, the filament becomes white hot since it retains as much of the heat generated as is possible and emits light. Since the melting point of tungsten is about 3380^0 C, it does not melt inside the bulb. The filament is also thermally isolated by using insulating supports. The bulbs are usually filled with chemically inactive nitrogen and argon gases at low pressure. This prolongs the life of the filament. A larger part of the power consumed by the filament appears as heat while a smaller part of it is in the form of light radiated. It must be noted that the same amount of electric current flowing through the filament of tungsten produces enormous heat but negligible heat is produced in the connecting copper wires. This is because of the fact that tungsten filament has very high resistance whereas connecting copper wires have very low resistance.

Another important and common application of heating effect of electric current is **electric fuse** in electric circuits. When the current in electric circuits and appliances rises too much, the fuse wire gets heated to such an extent that it melts and breaks the circuit. Thus, a fuse wire protects the circuit components. The fuse wire is placed in series with the device. The fuse wire is made of a metal or alloy of **low melting point** and of **high resistivity**. A cheaper varity of fuse wire is made of an alloy of tin and copper. The thickness and length of fuse wire depends on the maximum current permissible through the circuit. The fuse wire is generally encashed in a cartridge of procelain or similar material with metal ends and with a marking of rated current as 0.3A, 0.5 A, 1A, 2A, 3A, 5A, etc. As an example, if an electric appliance is of maximum current 4.5A then a 5 A fuse must be used.

8.8 Electric Power

In class IX, you have studied that the rate of doing work is power. In one sense, it is also the rate of consumption of energy. Equation (8.22) gives the rate at which electrical energy is dissipated or consumed in an electric circuit. Thus the electric power P is given by

$$P = VI$$

$$\text{OR,} \quad P = IR \times I = I^2 R = \frac{V^2}{R} \quad \ldots\ldots\ldots\ldots \quad 8.24$$

The SI unit of power is watt (W). 1 watt is the power consumed by a device that carries 1A of current when operated at a potential difference of 1V.

$$\text{Thus, } 1\text{watt(W)} = 1 \text{ volt (V)} \times 1 \text{ ampere (A)}$$
$$= 1\text{VA}$$

The unit 'watt' is very small. In actual practice a much larger unit called kilowatt (kW) is used. 1 kW = 1000W. Since the electrical energy is the product of power and time, the unit of electrical energy is watt hour (Wh) which is the energy consumed when 1W of power is used for 1 hour. The commercial unit of electrical energy is 'kilowatt hour' (kWh) and is commonly known as one unit of energy.

$$1 \text{ kWh} = 1000 \text{ watt} \times (60 \times 60) \text{ second}$$
$$= 3.6 \times 10^6 \text{ watt second}$$
$$= 3.6 \times 10^6 \text{ joule (J)} = 3.6 \text{ MJ}$$

Note : We pay the electricity department for providing electrical energy to move electrons through the houshold electric gadgets like bulb, fan, motor for water pump, television etc. In fact electrons are not consumed in an electric circuit. We pay for energy that we use.

Try to Answer

1. Why does the connecting wires i.e. the cord of an electric iron or an electric heater not glow while the heating element glows ?

Example 8.11 A potential difference of 250 V is applied across a resistance of 500 Ω in an electric iron. Calculate (i) the current through the resistor (heating element) (ii) power of the electric iron (iii) heat energy produced in joule in 30 seconds.

Solution (i) The current through the resistor can be calculated by using Ohm's law :

$$\text{Thus, the current } I = \frac{V}{R} = \frac{250V}{500\Omega} = 0.5A$$

(ii) The power P = VI

$= 250 \times 0.5$ VA or J/s or Watt

$= 125$W

(iii) The heat energy produced can be calculated by using the formula

$$H = I^2 \times R \times t$$
$$= (0.5)^2 \times 500 \times 30$$
$$= 0.25 \times 500 \times 30$$
$$= 25 \times 5 \times 30$$
$$= 3750 \text{ J}$$

Example 8.12 **An electric motor marked (or rated) 750 W operates 8 hours/day in a workshop. What will be the cost of energy to operate it for one month (i.e. 30 days) at Rs 3.00 per unit of energy ?**

Solution Total energy consumed in 30 days would be

750 W × 8 hours/day × 30 days

= 750 × 8 × 30 Wh

= 180000 Wh

= 180 kWh

Thus, the cost of energy for 30 days is 180 kWh × Rs 3.00/kWh = Rs 540.00

POINTS TO REMEMBER

i. The motion of electrons through a conductor constitutes the (flow of) electric current.

ii. The direction of current is taken opposite to the direction of flow of electrons.

iii. The SI unit of charge is coulomb (C).

iv. The SI unit of current is ampere (A).

v. To set the electrons in motion through an electric circuit, a cell or a battery is required. A cell or a battery generates a potential difference across its terminals.

vi. The SI unit of potential difference is volt (V).

vii. The resistance is an inherent property that resists the flow of electrons in a conductor. Resistance controls the magnitude of current.

viii. The SI unit of resistance is Ohm (Ω).

ix. Ohm's law – The potential difference across the ends of a metallic wire is directly proportional to the current flowing through it, provided its temperature remains constant.

x. The resistance of a conductor is directly proportional to its length ;inversely proportional to its area of cross- section and depends on the nature of the material of the conductor.

xi. The resistivity of a conductor or an alloy of metals is independent of the geometrical dimensions but depends on the nature of material and temperature of it.

xii. When two or more resistors are combined in series, the equivalent resistance is equal to the sum of their individual resistances. The equivalent resistance, R_s is greater than the greatest of the individuals.

xiii. When two or more resistors are combined in parallel, the equivalent resistance, R_p is given by $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ ...... and R_p is less than the least among the individuals.

xiv. The electrical energy dissipated in a resistor is given by

$$W = V \times I \times t = I^2 Rt = \frac{V^2}{R}.t = \text{power} \times \text{time of current flow.}$$

xv. The SI unit of power is watt (W).

xvi. The commercial unit of electrical energy is kilowatt hour (kWh) ; $1kWh = 3.6 \times 10^6$ J.

EXERCISES

1. 3×10^{17} electrons cross in 30 seconds through an area. What is the electric current? $(1.6 \times 10^{-3}\,A)$

2. The potential at a point is 20V. Calculate the amount of work done to bring a charge of 0.5 C from infinity to this point. (10 J)

3. A potential difference of 20V appears across the ends of a resistor when 2.5 A of current is passed through it. What is the resistance of the resistor? $(8\,\Omega)$

4. How much charge flows through a wire carrying 2.5 A of current in 20 minutes? $(3 \times 10^{3}\,C)$

5. A nichrome wire has diameter 1.0mm and resistivity of 1.0×10^{-4} Ω m. Calculate the required length of this wire to make a resistance of $14\,\Omega$. (11cm)

6. A copper wire of certain length has a resistance of $10\,\Omega$. What will be its resistance after stretching to double its length? $(40\,\Omega)$

7. Two resistors of resistances $10\,\Omega$ and $20\,\Omega$ are connected in parallel. A battery supplies a current of 6A to the combination shown in the circuit in Fig. 8.17. Calculate the current in each resistor.

$$(i_1 = 4A\,;\, i_2 = 2A)$$

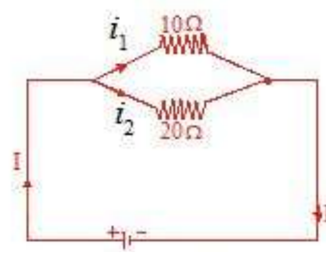


Fig. 8.17

8. You are given three resistors of resistance 1,2,3 ohms. Show by diagrams, how with the help of these resistors you can get resistance of

(i) $6\,\Omega$ (ii) $1.5\,\Omega$ (iii) $2.2\,\Omega$ (iv) $\frac{6}{11}\,\Omega$ (v) $\frac{11}{3}\,\Omega$

9. A resistor of $10\,\Omega$ is combined in parallel with another resistor of 'X' Ω. The resultant resistance of the combination is found to be $3.75\,\Omega$. What is the value of 'X'? $(6\,\Omega)$

10. How many resistors of $200\,\Omega$ each are required in parallel combination, so as to carry 5A on a 200V line supply? (5)

11. Suppose there are a number of bulbs rated at 220V – 100W each. How many bulbs can be connected in parallel across a 220V supply line, if the maximum permisible current is 5A only ? (11)

12. Calulate the anergy transferred in kWh by a 5A current flowing through a resistance of 2 Ω for 40 minutes. (0.033)

13. An electric bulb is rated at 220V – 200W. What is the resistance of the filament ? (242 Ω)

14. Two resistors of 10 Ω and 20 Ω are connected in series acorss a 12V battery. Calculate the power consumed by each of them respectively. (1.6W; 3.2W)

15. If the potential difference between the ends of a fixed resistor is doubled, to how much does the electric power change ? (4 times)

16. Which one will consume more energy – (i) a 300W Television set in 1 hr. (ii) 1000W electric heater in 10 minutes ? (Television set)

17. State whether an electric heater will consume more or less electrical energy per second when the length of its heating element is reduced. Give an explanation for your answer. (More electrical energy)

18. Is it possible to have a particle with charge 2.0×10^{-19} C . (No)

19. A bulb is rated as 250V ; 0.4A. Find its (i) resistance (ii) power . (625 Ω ; 100W)

20. An electric kettle rated at 220V, 2.2 kW, works for 3 hours. Find the energy consumed and current drawn. (6.6 kWh ; 10A)

21. **A piece of nichrome wire of resistance R is cut into four equals parts. These parts are then combined in parallel. If R' is the equivalent resistance of the parallel combination then the ratio $\frac{R}{R'}$ will be**

(A) 16 (B) 4 (C) $\frac{1}{4}$ (D) $\frac{1}{16}$ (A)

22. **The term that does not represent the electrical power of a circuit is**

(A) I^2R (B) IR^2 (C) $\frac{V^2}{R}$ (D) VI (B)

23. **An electric bulb is rated 220V – 100W.The same is operated at 110V due to load shedding. The actual power consumed will be**

(A) 100 W **(B)** 75 W **(C)** 50 W **(D)** 25 W (D)

24. **Two identical heating coils are first connected in series and then in parallel across the same potential difference. The ratio of heat generated in series to that of parallel would be**

(A) 1:1 **(B)** 1:2 **(C)** 1:4 **(D)** 4:1 (C)

25. **A positive charge free to move is released from rest. It will move towards the regions of**

(A) lower potential **(B)** higher potential

(C) equal potential **(D)** any of the above (A)

26. **Joule/coulomb is the same as**

(A) watt. **(B)** volt. **(C)** ohm. **(D)** ampere. (B)

27. **An ammeter is always connected in .... and a voltmeter in .... The proper words for the empty places are respectively.**

(A) series ; series **(B)** parallel ;parallel

(C) series ; parallel **(D)** parallel ; series (C)

28. **Three equal resistances, when combined in series have equivalent resistance of 90. Their equivalent resistance when combined in parallel will be**

(A) 60Ω **(B)** 30 Ω **(C)** 20 Ω **(D)** 10 Ω (D)

29. Why is the series arrangement of components not used for domestic circuits ? Explain.

30. Why are copper and alluminium wires usually used for transmission of electricity ? Explain.

★★★★★★

CHAPTER

9

MAGNETISM

We are familiar with bar magnet and magnetic compass. Any magnet has two poles at its ends. They are north pole and south pole, irrespective of shape. A magnetic compass needle is a very light needle-shaped magnet being pivoted at its centre and free to rotate about the pivot in a horizontal plane. The needle is enclosed in a small case with a fixed glass cover. When no magnet is around the magnetic needle it sets parallel to the south-north direction of the earth. When two magnets are kept close to each other they exert forces on each other, due to the magnetic field created around. Such magnetic field can also be produced by a current carrying conductor. In this chapter you shall study about the fields due to bar magnet and current carrying conductor along with the principle of an electric motor.

9.1 Magnetic Field and Lines of Force

When there is no magnet or magnetic material in the vicinity of a magnetic compass needle, the needle stays parallel to the south-north direction of the earth. If a magnet is brought close to the needle, it deflects in general. This is because the magnet produces a magnetic field and this field exerts a deflecting force on the needle. The direction of the needle from its south pole to the north pole gives the direction of the magnetic field produced by the magnet.

In order to study the above phenomenon you can take up the following Activity.

Activity 9.1

Take a bar magnet, a magnetic compass needle, a white sheet of paper, a wooden board and some drawing pins. Place the magnetic compass on the sheet of paper fixed on the board with the help of drawing pins. Remove any magnet or magnetic material far away from the board. Now, note the position of the magnetic needle as shown in Figure 9.1. Again, suspend the bar magnet from an unspun cotton thread to its middle. The other end of the thread is tied to a stand as shown in Figure 9.2.

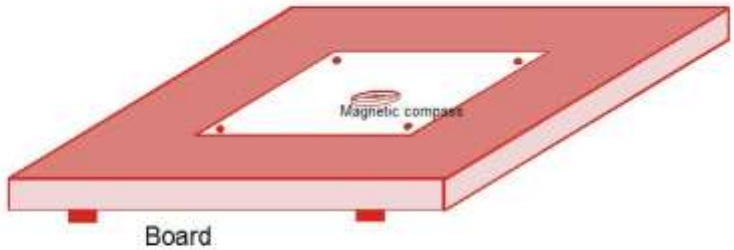


Figure 9.1 A compass needle on the board

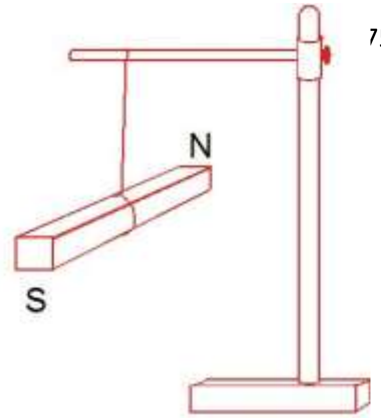


Figure 9.2 A suspended bar magnet

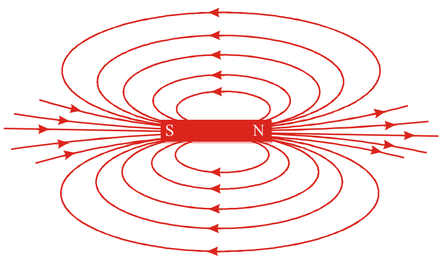
Mark the direction in which it comes to rest. Turn the magnet gently by your hand to point it in another direction and leave it. Notice, the direction in which it finally settles. The tip of the bar magnet which points towards the north is its north pole while the tip that points towards south is its south pole.

1. A freely suspended magnet always points in the south-north direction, (directive property).
2. A magnet always attracts substances like iron, steel, cobalt, nickel, (attractive property).
3. Like magnetic poles repel each other but unlike magnetic poles attract each other.
4. Magnetic poles always exist in pairs (magnetic monopole does not exist).
5. The region surrounding a magnet in which the magnetic force can be detected is called its magnetic field.

Activity 9.2

Place a compass needle close to the north pole. Mark the position of the north pole of the needle. Shift the compass needle so that its south pole falls at the same point where its north-pole was situated in the previous positions, a shown in Figure 9.3 Again, mark the position of the north pole of the needle.

Repeat the procedure till the needle reaches near the south pole of the bar magnet. You will see that the deflection of the needle increases as the needle is nearer to the poles.

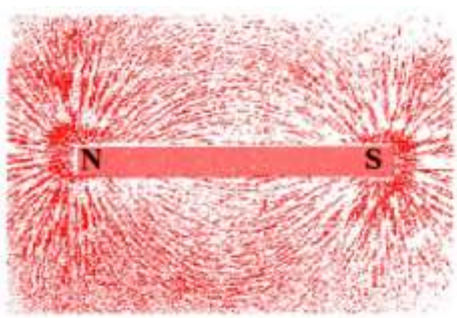


Now connect the marked points using a pencil. A close curve is obtained [It represents a magnetic line of force]. A member of lines of force due to the bar magnet which is shown in Figure 9.4. No two field-lines are found to cross each other. If they cross, the compass needle would point towards two directions at the point of crossing each other – which is not possible.

Figure 9.4

A magnetic line of force is used to indicate the direction of the magnetic field. The field at any point is along the tangent to the line of force at that point.

The magnetic lines of force can also be obtained without using a compass needle. Take a glass plate with a bar magnet as shown in Figure 9.5



Sprinkle iron filings on the glass plate and then gently tap the plate with your finger. You will observe the iron filings arranging themselves in a regular pattern, as shown in the same figure. This regular pattern shows the magnetic lines of force due to the magnet. The relative strength of the magnetic field is shown by the degree of closeness of the field lines, being closer in the stronger regions near the poles.

Figure 9.5

9.2 Magnetic Field produced by Current Carrying Wire

Does an electric current carrying wire behave like a magnet or produce a magnetic field ? Let us perform the following Activity to answer the above questions.

Activity 9.3

Take a straight copper wire XY in an electric circuit as shown in Figure 9.6. The position of the wire XY is set parallel to the needle of the magnetic compass.

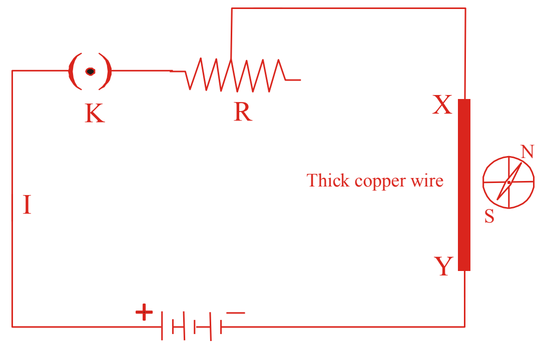


***Figure 9.6** Compass needle is deflected on passing current*

Now, pass the electric current through the circuit by inserting key into the plug key. Observe the change in the position of the needle of the magnetic compass. Also observe the position of the needle in the compass after removing the key from the plug.

We see that the needle is deflected when the current is made to pass through the circuit and it returns to the earlier position when the current is cut off. What does it mean ? It means that the electric current through the copper wire produces a magnetic field. In other words a current carrying conductor behaves as a magnet. This is called magnetic effect of electric current or electromagnetism. Here we shall study about electromagnetism and electric motors which involves the magnetic effect of electric current.

*Hans Christian Oersted, Danish Physicist, in 1820 accidentally discovered that a compass needle placed in parallel and close to a metallic wire carrying electric current got deflected. Through this observation Oersted showed that electricity and magnetism are related phenomena. His research work later created technologies such as electric motor, radio, television etc. The unit of magnetic field strength is named **oersted** in honour of him.*

Repeat the Activity 9.3, by varying the amount of electric current with the help of rheostat 'R'. You will observe that the amount of deflection of needle also changes; being larger with the increase of current through the circuit and vice-versa.

9.3 Magnetic Field due to a Straight Conductor Carrying Current

In order to find the direction of the magnetic field produced by a straight conductor carrying current, let us take up the following Activity.

Activity 9.4

Take a long copper wire, a battery of two or three cells of 1.5 V each and a plug key. Connect accordingly as shown in the Figure 9.7(a).

Adjust the position of the copper wire parallel to and above the needle of the magnetic compass.

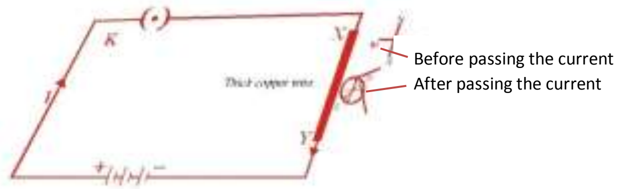


Figure 9.7(a) An electric circuit to observe magnetic effect of current

Insert the key in the plug key and observe the direction of deflection of the north pole of the needle. If the current flows from north to south, the north pole of the compass needle would move towards the east as shown in Figure 9.7(a).

Reverse the cell connection in the circuit as shown in the next Figure 9.7(b). You will observe the change in the direction of deflection of the needle because the direction of current flow is from south to north. That is the needle moves towards west. It means that the direction of magnetic field produced by the current is also reversed.

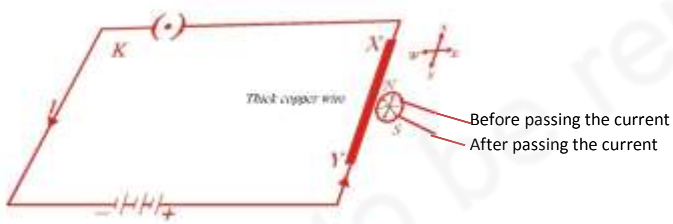


Figure 9.7(b) The deflection of the needle becomes opposite when the direction of current is reversed

9.2.1 Magnetic Field due to a Straight Conductor Carrying Current

From the above section you have learnt that the direction of the magnetic field generated depends on the direction of current flow. You must have an eagerness to know further dependence such as – “Does the pattern depend on the shape or configuration of conductor carrying current”?

To understand that we shall first consider the pattern of the magnetic field around a straight conductor carrying current through the following Activity.

Activity 9.5

Use a battery of 12 V, a variable resistance, an ammeter, a plug key and a long straight thick copper wire of length about 30cm and a rectangular cardboard with a circular hole at the centre.

Insert the copper wire XY through the hole in the card board so that it is normal to the plane of the board. Care must be taken so that the card board does not slide up and down freely.

Then connect the copper wire vertically between X and Y as shown in Figure 9.8,. Sprinkle some iron filings uniformly on the cardboard.

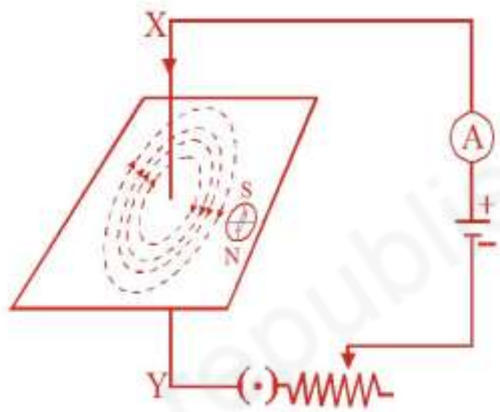


Figure 9.8

Close the key and note the current in the ammeter. The value of the current can be fixed to a desired value by adjusting the position of the variable of the rheostat at a fixed position.

Now, gently tap the cardboard a few times with the finger. In doing so, ensure that the copper wire remains vertical and cardboard is exactly normal to the wire. You will see, finally, that the iron filings align themselves forming a pattern of concentric circles with the copper wire (i.e.hole) as centre.

What do these concentric circles indicate ? They represent the magnetic field lines produced by the current carrying straight conductor.

What about the direction of the magnetic field ? To ascertain the direction, place a magnetic compass at a point over a circle as shown in the same figure. Notice the direction of deflection of needle. The direction of north pole of the needle would give the direction of the magnetic field lines. Mark the direction using an arrow.

Check whether the direction of the magnetic field lines get reversed or not with the change in the direction of current flow along the copper wire. You will observe that the direction of the field lines gets reversed. The strength of such magnetic field decreases as the distance from the wire increases.

9.2.2 Right-Hand Thumb Rule

The direction of magnetic field generated by a straight conductor carrying current can be conveniently found out. Imagine that you are holding a straight conductor carrying current in your right hand such that the thumb points towards the direction of the current, as shown in Figure 9.9. The other fingures will wrap around the conductor which gives the direction of field lines of the magnetic field associated with the straight current.

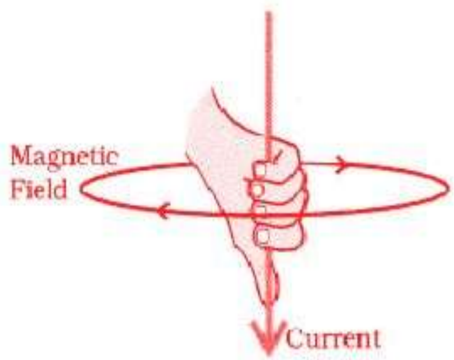


Figure 9.9 Right hand thumb rule

This is known as **right-hand thumb** rule. The above result is also given by Maxwell's corkscrew rule. If we consider ourselves driving a corkscrew using a screw driver, in the direction of advancing current, then the direction of rotation of corkscrew gives the direction of the magnetic field.

Example 9.1 **Suppose a current flows along a horizontal conductor in south to north direction. What will be the direction of the magnetic field at points (i)directly below (ii) directly above it?**

Solution The current is in south to north direction. Applying right-hand thumb rule, the direction of the magnetic field, at a point below the wire, will be from east to west. While the direction of the magnetic field above the wire will be from west to east.

9.2.3 Magnetic Field due to a Current through a Circular Loop or Coil (of wire)

You are familiar with the direction of magnetic field lines produced around a straight conductor carrying current. Imagine that the same conductor is bent in the form of circular loop and then a current is passed through it. How would the magnetic field lines look like ? Let us try to visualise.

We have learnt that the magnetic field associated with a straight conductor carrying current decreases in magnitude with increasing distance from the conductor. As a result, at every point of a current carrying circular loop, the concentric circles representing the magnetic field around it, would become larger and larger as one moves away from the common centre i.e. the conductor.

By the time when we reach the centre of the circular loop, the arcs of these big circles would appear as straight lines, as shown in Figure 9.10. Thus, every point on the wire carrying current would give rise to the magnetic field appearing as straight lines at the centre of the loop. It is easy to check that every section of the wire contribute to the magnetic field lines in the same direction within the loop.

Now, you have already learnt that magnetic field produced by a current carrying wire at a given point depends directly on the magnitude of the current passing through it. Therefore, if there is a circular coil consisting of 'n'– number of turns, the field produced by this will be n–times as large as that produced by a loop of single turn carrying the same current as that of the coil. The above is supported by the fact that the current in each circular turn has the same direction and strength and hence the field due to each turn just adds up.

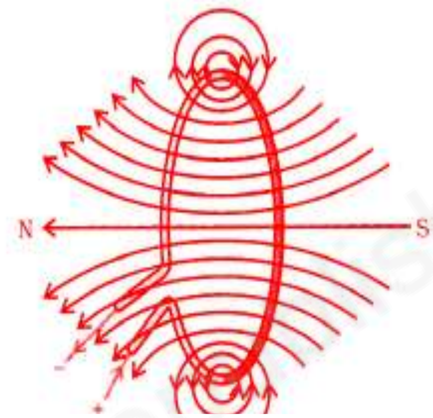


Figure 9.10 Magnetic field lines of the field produced by current carrying circular loop.

To understand magnetic field pattern due to circular coil of large number of turns carrying current, let us perform the following Activity.

Activity 9.6

Prepare a rectangular cardboard with two holes. Then wind a circular coil of fine insulated copper wire through the holes as shown in Figure 9.11 so that winding is normal to the plane of the cardboard.

Connect the ends of the coil with a battery through a plug key as shown in Figure 9.11. Sprinkle some iron filings uniformly on the cardboard. Thereafter, plug the key. Finally, tap the cardboard gently a few times with finger. Note the pattern of the arrangement of the iron filings. The pattern would appear as shown in Figure 9.11. The lines of force are circular near the wire but they become straight and parallel at the middle point M of the coil. In fact, each small segment of the coil is surrounded by such magnetic lines of force. At the centre of the coil, all the lines of force add each other due to which the strength of magnetic field increases.

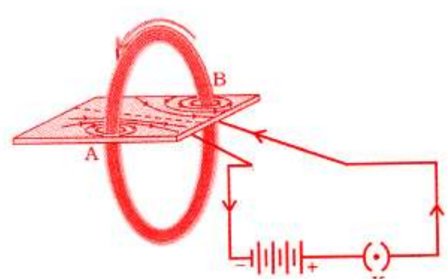


Figure 9.11 Magnetic lines of force due to circular coil or a wire, carrying current.

Thus, the strength of the magnetic field produced by a current carrying circular coil can be increased : (i) by increasing the number of turns of wire in the coil (ii) by increasing the current through the coil (iii) by decreasing the radius of the coil.

Moreover, a circular coil carrying current behaves as thin disc shaped magnet, whose one face is north pole and the other face is south pole.

9.2.4 Magnetic Field due to a Current in a Solenoid

A solenoid is a long coil of many circular turns of insulated copper wire, wrapped closely in the shape of cylinder whose radius is very small in comparison with the length of the winding. (When a long wire is coiled over a non-conducting hollow cylinder in the shape of a spring so that the turns are closely spaced and insulated from each other, it is called a solenoid). The structure of a solenoid is shown in Figure 9.12. In certain solenoid, an iron rod of proper size is inserted inside the hollow tube. Thin rod is called core.

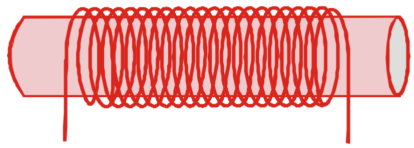


Figure 9.12 A solenoid

The free ends of the solenoid wire are connected to a battery through a key. When a current is passed through the winding, a magnetic field is established. The magnetic field inside the solenoid is almost constant in magnitude and direction. The pattern of the magnetic field is shown in Figure 9.13. Compare the pattern of the field with the magnetic field around a bar magnet (Fig 9.4). Do they look similar ? Yes, they are similar. This shows that one end of solenoid behaves as a magnetic north-pole, while the other behaves as the south-pole, due to the passage of current.

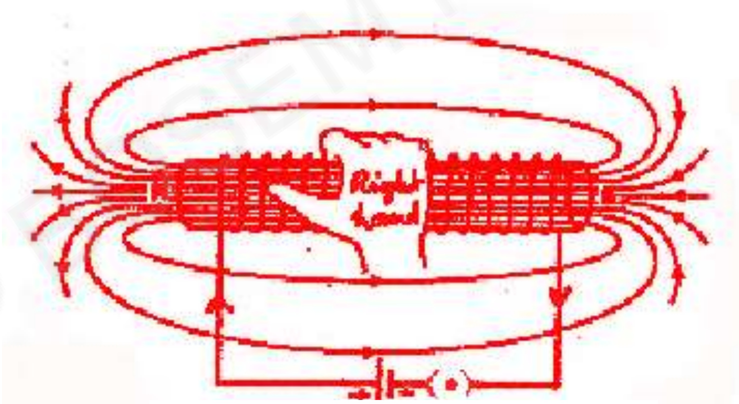


Figure 9.13 Magnetic field lines around a current carrying solenoid.

Again imagine that you are holding the solenoid in your right hand with the fingers curled along the direction of current through the winding. The direction of the thumb points always towards the end where the north pole appears. The field lines inside the solenoid are in the form of parallel straight lines.

This pattern shows that the strength of field is the same at all points inside the solenoid i.e., the field is uniform inside the solenoid.

The strength of the magnetic field depends on (i) the current : the larger the current the stronger is the magnetic field. (ii) the number of turns per unit length: the larger the number, the stronger is the magnetic field.

The north pole and south pole of a current carrying solenoid may be interchanged by reversing the current direction in it.

The magnet formed by passing an electric current in a solenoid is temporary i.e. magnetism exists so long current flows and it is no more when the current is off.

The strong magnetic field produced inside a current carrying solenoid can be used to magnetize a piece of magnetic material, such as soft iron rod, when placed inside the solenoid as shown in Figure 9.14. The magnet so formed is called an electromagnet. We can easily change the strength of a given electromagnet by changing the value of current flow. The strength of an electromagnet depends on (i) the number of turns per unit length in the coil – the strength increases with the increasing number of turns (ii) the current flowing in the coil – if the current in the coil is increased the strength increases.

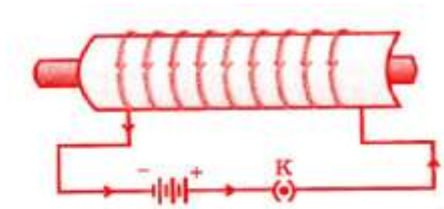


Figure 9.14 An electromagnet

Try to Answer

1. Why don't two magnetic lines of force belonging to the same field intersect each other ?
2. Draw magnetic field lines or magnetic lines of force around a bar magnet.
3. Write the properties of magnetic lines of force.
4. Applying right hand thumb rule, find out the direction of the magnetic field inside and outside a loop of wire carrying current in the clockwise direction and lying on the plane of the table or the page.

9.3 Force on a Current-Carrying Conductor in a Magnetic Field

We have already learnt that an electric current flowing through a conductor produces a magnetic field or in short, a conductor carrying current is associated with a magnetic field. The field so produced can exert a force on a magnet (magnetic needle of a compass) when placed in the vicinity of the conductor. French scientist – Andre Marie Ampere (1775–1836) suggested that the magnet must also exert an equal and opposite force on the current carrying conductor. The nature and direction of the force due to a magnetic field acting on a current-carrying conductor can be studied through the following Activity.

Activity 9.7

Take an aluminium rod XY of about 2mm in diameter and about 5cm in length. Using two plastic rings suspend it from a fixed support through two light strings connected to these rings.

Bring a horse-shoe magnet near the aluminium rod so that the north pole lies on one side of the aluminium rod while the south pole lies on the other side. Here, the line joining the poles of the magnet is vertical and perpendicular to the suspended aluminium rod.

Connect the rod in series to the battery through the plug key K. Now pass a current through the rod from the end X to Y as shown in Figure. 9.15

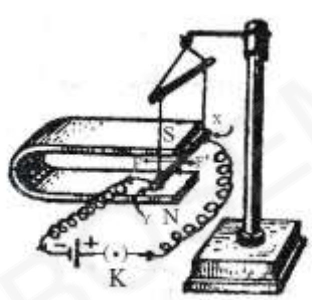


Figure 9.15

What do you observe ? You will observe that the rod is pulled towards 'F'. If you remove the magnet the rod will regain its original position. On the other hand, if the current is off by opening the key the rod will also regain its original position. Thus you can understand that only when the rod of aluminium carries a current, the magnetic field exerts a force on it

Repeat the experiment by reversing magnetic field direction i.e., with the south pole taking the position of the north pole and vice-versa. What will happen to the rod ? The rod will be pushed in opposite direction, F'. The same result will be seen if you reverse the direction of current, without changing the position of the poles of horse shoe magnet.

We conclude that

1. When a current carrying wire is placed in a magnetic field, a force acts on the wire.
2. The direction of force depends on the direction of the magnetic field as well as direction of the current.

Experiments have shown that the displacement of the rod is largest or the magnitude of the force is largest, when the direction of current is at right angles to the direction of magnetic field in which the conductor is placed.

In Activity 9.7, the direction of the current and that of the magnetic field are perpendicular to each other and found that the force is perpendicular to both of them. Thus, all are perpendicular to one another.

9.3.2 Fleming's Left -Hand Rule

The direction of the force on a current carrying conductor (or wire) placed in a magnetic field may be easily obtained by a simple rule known as Fleming's Left-Hand rule, which was suggested by Professor J.A Fleming of England.

Figure 9.16 Fleming's Left-Hand rule

According to this rule, stretch the thumb, forefinger and middle finger of your left hand such that they are mutually perpendicular (Fig. 9.16). If the forefinger points in the direction of magnetic field and middle finger points in the direction of current then the thumb will point in the direction of motion or the force acting on the conductor.

9.4 Electric Motor

An electric motor is a rotating device that converts electrical energy to mechanical energy of a rotating system known as the **shaft** . Anything connected to the shaft rotates with it. In short an electric motor converts electrical energy into mechanical (Kinetic) energy. It is an important component in electric fans, refrigerators, washing machines, grinders, mixers, computers etc. Let us try to know how an electric motor works.

An electric motor consists of a coil of insulated copper wire. The copper wire is tightly wound over a soft-iron core to form a coil of a large number of turns, as shown in Fig. 9.17. The core with the coil is called the **armature**. The armature is fixed on the shaft of the motor.

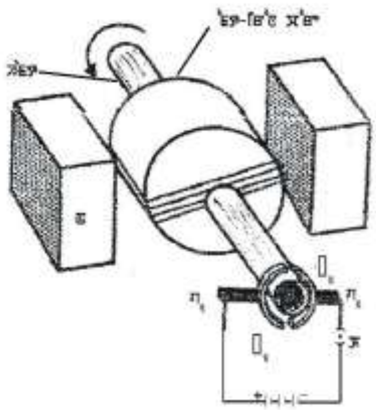


Figure 9.17 A simple electric motor

Strong and permanent magnetic north and south poles are fixed facing each other. The coil is kept between them, so that the coil lies in a magnetic field directed from the north pole to the south pole. The two free ends of the coil are connected to the two halves C_1 and C_2 of a split ring. The inner sides of C_1 and C_2 are insulated electrically and fixed on the shaft. The external conducting edges of C_1 and C_2 touch two conducting stationary brushes B_1 and B_2 respectively. The brushes are 180^0 apart from each other, as shown in the Figure 9.17. The brushes are connected to the terminals of a battery. At any instant of time, one brush touches only one split ring, when the shaft rotates i.e. when the motor works.

9.4.1 Working of the Motor

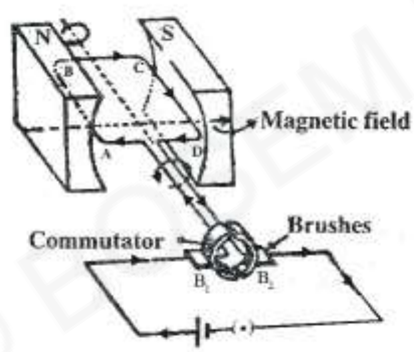


Figure 9.18(a)

When the battery is connected to the motor, the current in the coil ABCD enters through the conducting brush B_1 and flows back to the battery through the brush B_2. In the portion shown in Fig. 9.18(a). The current in the left arm is a long AB while that in right arm is along CD. As these currents are flowing in a magnetic field, forces are exerted on them. As given by Fleming's Left-Hand rule . AB is pushed down while the arm CD is pushed up. As a result, the coil and the shaft together known as the armature mounted free to turn about an axis, rotate anti-clockwise. At half rotation C_2 is in contact with the brush B_1 while C_1 is in contact with the brush B_2. Therefore, the current in the arms AB and CD gets reversed as shown in Fig. 9.18(b) and flows along DCBA. Here, the change of direction of the current flow through the circuit is carried out by the split rings and the two taken together is called **commutator**.

Thus, the current in the coil is from D to C to B to A. On applying Fleming's Left-Hand rule the arm AB of the coil that was earlier pushed down is now pushed up while the arm CD previously pushed up is now pushed down and anti-clockwise rotation of the armature continues.

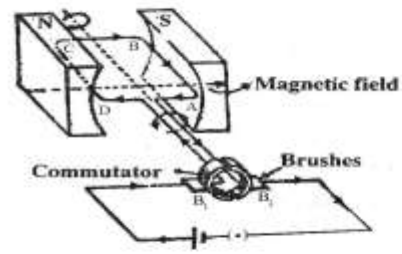


Figure 9.18(b)

Therefore, the coil and the shaft together rotates half a turn more in the same direction. The reversing of direction of current flow is repeated at each half rotation and it gives rise to a continuous rotation of the armature, so long as the battery supplies current i.e. key remains close.

The commercial motors use (i) an electromagnet in place of permanent magnet (ii) large number of turns of insulated copper wire in the coil (iii) a soft iron core on which the coil is wound. By doing so, the power of the motor can be increased.

Try to answer

1. **State Fleming's Left-Hand rule.**
2. **What is the principle of an electric motor ?**
3. **What is the role of commutator ?**

POINTS TO REMEMBER

i. A compass needle is a small magnet pivoted at its centre so as to enable it to rotate freely in a horizontal plane.

ii. The end which points towards north is its north pole and the other end is called south pole

iii. A field line is the path along which a hypothetical free north pole would tend to move. These field lines around a magnet are used to represent a magnetic field. The resultant direction of the magnetic field at a point is given by the direction of motion of the north pole which is free to move.

iv. The field lines are closer in the region of stronger magnetic field.

v. A metallic conductor carrying an electric current has associated with a magnetic field due to the current, the magnetic field lines are a series of concentric circles with the wire as common centre. The direction of the field is given by the right hand (thumb) rule.

vi. The magnetic field due to a current carrying solenoid is similar to that of a bar magnet except that the direction of field can be reversed with the change in the direction of current through it.

vii. An electromagnet consists of a core of soft iron wrapped around with a coil of insulated copper wire.

viii. A current carrying conductor when placed in a magnetic field experiences a force. The force acting on the conductor is perpendicular to both the direction of magnetic field and the current which are also perpendicular to each other and is governed by the Fleming's Left-Hand Rule. This is the basis of an electric motor.

ix. Electric motor is a device which can convert electric energy into mechanical energy.

EXERCISES

1. Draw a sketch to show the magnetic lines of force due to a current carrying straight conductor.
2. Draw the magnetic lines of force due to a circular wire carrying current.
3. State the effect of inserting an iron core into a current carrying solenoid.
4. Describe how you will locate a current carrying wire embedded in a wall.
5. State right-hand thumb rule.
6. What is a solenoid ? Draw a sketch to show the magnetic lines of force produced by a current carrying solenoid.
7. What is an electric motor ? With the help of a diagram, describe the working of an electric motor.
8. What is the function of commutator in an electric motor ?
9. **A magnetic line of force is used to show the direction of**

   (A) south-north (B) a bar magnet

   (C) a compass needle (D) magnetic field. (D)

10. The magnetic lines of force inside a solenoid due to an electric current in it are nearly

(A) straight lines **(B)** circular lines
(C) parabolic lines **(D)** elliptic lines (A)

11. If the number of turns in a solenoid is increased, the strength of the electromagnet so formed will

(A) decrease **(B)** increase
(C) remain constant **(D)** become zero. (B)

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CHAPTER

10

ELECTROMAGNETIC INDUCTION

We have seen that an electric current can be produced using an electric battery. Can we have an electric current without any battery ? We are using electricity at our home. From where do we get the electric current in our home ? The electric current that we use in our home is generated at power plants also known as power stations. In this chapter we shall study the principle, working and uses of electric generator.

10.1 Electromagnetic induction

We have studied that a conductor carrying electric current perpendicular to the magnetic field experiences a force. This force causes the conductor to move. Can the reverse process be possible ? Can electric current be generated in the conductor when it moves perpendicular to the magnetic field ? This was first studied by English Physicist Michael Faraday. In 1831 he discovered that relative motion between a magnet and a coil can generate electric current in the coil. The phenomenon is known as electromagnetic induction.

To understand the discovery let us perform the following activity.

Activity 10.1

Take a coil of a large number of turns, a sensitive galvanometer and a strong magnet.

Connect the terminals of the coil to the galvanometer Figure 10.1. Push a pole, say N-pole of the magnet towards the end of the coil very quickly. Do you find any change in the galvanometer needle ? There is a momentary deflection

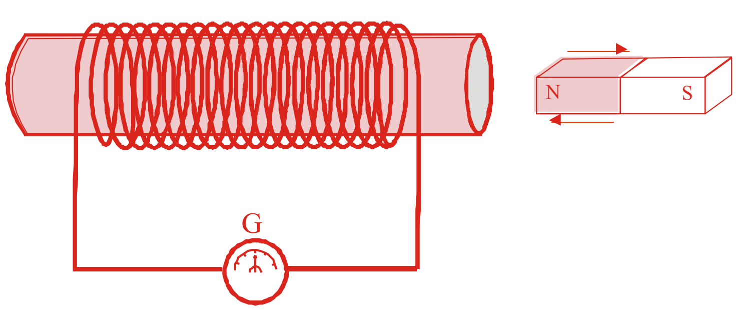


Figure 10.1

in the needle of the galvanometer. This indicates the presence of a current in the coil. The deflection becomes zero at the moment when the motion of the magnet stops.

Withdraw the N-pole of the magnet way from the coil very quickly. Do you find any deflection of the needle of the galvanometer ? There is a momentary deflection of the needle in the direction opposite to the first.

Repeat the experiment using the other end of the magnet i.e. S-pole of the magnet. Record the finding.

Keeping the magnet stationary move the coil towards and away from the magnet. Observe the deflection of the needle of the galvanometer. Observe the amount of deflection of the needle varying the speed of movement of the magnet or coil.

Whenever there is relative motion between the coil and the magnet electric current is developed in the coil. The phenomenon is known as electromagnetic induction. The current in the coil is called induced current and the potential difference developed between the ends of the coil is called induced voltage or induced e m f.

The result of Faraday's Experiment on electromagnetic induction may be summarised as follows

(i) Whenever there is a relative motion between a coil and a magnet an induced current flows in the coil. In another words, whenever there is a change in the number of magnetic lines of force linking with a coil an induced e m f is set up in the coil.

(ii) Induced current in the coil lasts only as long as there is change in number of magnetic lines of force linking with the coil.

(iii) The strength of induced e m f is directly proportional to the rate of change of magnetic lines of force linked with the coil.

In practice we can induce electric current in the coil either by rotating the coil in a magnetic field or by rotating a magnet (about a perpendicular axis) around the coil. It is convenient to rotate the coil in the magnetic field. The direction of the induced current depends upon the direction of the magnetic field and direction of motion of the coil. The induced current is found to be the highest when the direction of motion of the coil is at right angle to the magnetic field. In this situation, we can use a simple rule known as Fleming's right hand rule to know the direction of the induced current.

Fleming's right hand rule

Stretch the thumb, forefinger and middle finger of right hand so that they are perpendicular to each other as shown in the figure 10.2 . If the thumb shows the direction of motion of the conductor and the forefinger indicates the direction of the magnetic field, then the middle finger will show the direction of induced current in the conductor.

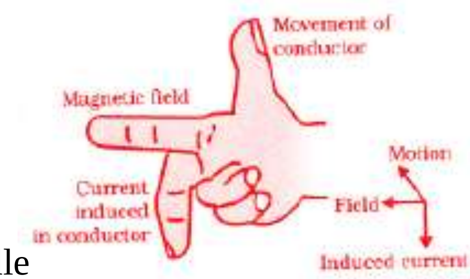


Figure 10.2

The principle of electromagnetic induction is used in the construction of generator, microphone, electric guitar, etc.

10.2 Electric Generator Principle

Electric generator works on the principle of electromagnetic induction. In electric generator mechanical energy is used to rotate a coil in a magnetic field to produce electricity. Hence, generator is a device to convert mechanical energy into electrical energy. When the coil is rotated in the magnetic field the direction of the induced current changes alternately. A commutator may be used to produce the current in the same direction. Generators are of two types – A C Generator (alternating current Generator) and D C Generator (direct current Generator)

Construction

Figure 10.3 shows a schematic diagram of an A C Generator. An A C Generator consists of

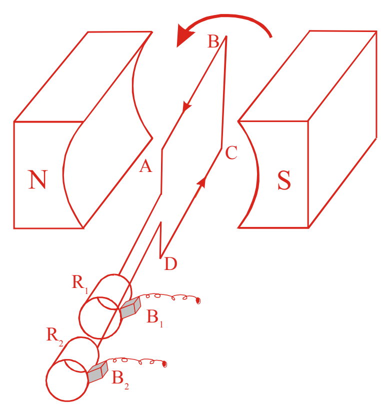


Figure 10.3

(i) Two pole pieces N–S of a permanent magnet.

(ii) An armature consisting of a number of turns of rectangular coils. There is an arrangement to rotate the coil about an axle perpendicular to the magnetic field with a high speed. (It is represented in the diagram with a single turn coil ABCD)

(iii) Two metal slip rings R_1 and R_2 connected to the two terminals of the coil.

(iv) Two stationary conducting brushes B_1 and B_2, kept pressed separately on the rings R_1 and R_2. The brushes are connected to two separate leading wires of an external load.

Working

At start let us assume that the plane of the coil is vertical with the side AB being uppermost and CD being lowermost. When the coil rotates the side AB moves downwards and CD moves upwards cutting across the magnetic field. Electric current is developed in the coil due to electromagnetic induction. Applying Fleming's right hand rule the direction of induced current will be along BA and DC. Now the current will complete its flow along DCBA then through R_1 to the external circuit or load and returning through R_2.

After the completion of half rotation the side AB will occupy the lowermost and CD the uppermost position. When the armature continues its rotation the side AB moves upwards and CD moves downwards cutting across the magnetic field. In this second half of rotation the current will flow along AB and CD completing its circuit along ABCD then through R_2 to the external load and returning through R_1. Thus the polarity of R_1 and R_2 changes alternately. After the completion of one rotation the armature will resume the starting position. Then the same cycle continues as the armature goes on rotating continuously. Thus the direction of current in the external circuit changes for every half rotation. Such current is known as alternating current (A C) and the generator is known as A C Generator.

If there are larger number of turns in the coil the current generated in each turn adds up to give a large current through the coil.

How frequently does the direction of the current change ? In a second the number of times the current flows in a given direction is known as frequency of the A C source. Frequency is the number of complete cycle in one second. Most of the A C generators are designed to have frequency 50 cycles per second (hertz- Hz). In such generators direction of current alters 100 times in a second.

D C Generator

To get a direct current (D C) which does not change the direction of current with time a split ring (a single ring splitted into two halves) is used as commutator. With this arrangement one brush is at all time in contact with the arm of the coil moving downwards in the field. While the other brush is in contact with the arm moving upwards. Such generator which sends current in a direction only is known as D C generator.

Figure 10.4 shows the schematic diagram of a D C Generator.

Difference between AC Generator and DC Generator

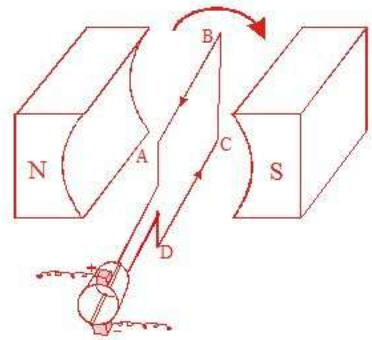


Figure 10.4

(i) In A C generator the direction of electric current reverses periodically. But in D C generator the current flows in one direction only.

(ii) In A C generator there are two metal slip rings connected to the terminals of the coil separately. While in D C. generator there are two split half rings (splitted into two halves from a single ring) connected to the terminals of the coil.

(iii) In A C generator the two conducting brushes are in contact with the two rings separately. While in D C Generator the brushes are in contact with the two halves(split ring) alternately in the right time. A brush is always in contact with the half of the ring where electric current flows out and another brush is always in contact with the half ring where electric current returns. Thus a brush is always (+)ve terminal and the other is always (–)ve terminal.

The nature of variation of the generated e m f from an A C generator is shown in the figure 10.5. When the plane of the coil is perpendicular to the magnetic field any side of the coil does not move across the magnetic field. In the first quarter of its rotation the rate of cutting across the field rises. Hence the e m f generated increases from zero to maximum value. During the second quarter e.m.f decreases and becomes zero. However, in the second half of the rotation the e m f generated follows the same pattern as obtain in the first half with the reversal in the direction of e m f only.

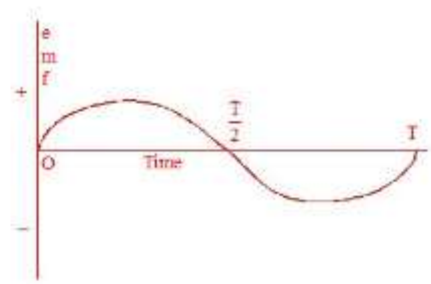


Figure 10.5

Advantage of AC over DC.

Voltage of A C can be stepped up or down easily with the help of a device called transformer. Energy loss in long distance transmission is large at low voltage and high current. It can be minimised by stepping up the voltage and reducing the current for long distance transmission. A C can be converted to D C more easily.

However, there are some devices where A C cannot be used directly.

10.3 Domestic electric circuits

We use different kinds of electrical appliances in our house. The electricity from a power station is transmitted through a long distance at high voltage. It is to minimise the loss of energy in the transmission line in the form of heat. The high voltage is reduced using a step down transformer at our locality. In our house we receive the electric power at 220 V. It is to suit with the domestic appliances commonly used.

The wiring inside the house is done according to our needs in different parts of the house.

The electric power lines enter our house through three wires consisting of live, neutral and earth. However, the live and the neutral wires are connected directly to the main supply through electricity meter.

The earth wire is connected to a large metal plate which is embedded deep in the earth in a moist region near the house. The earth wire carries no electricity. The neutral wire is maintained at the zero potential by connecting it to the earth at the power station. This provides the return path for the current. The live wire is at a high potential.

There is a colour convention for wiring. According to this convention

- live line has red insulation
- neutral has black insulation and
- earth has green insulation.

(in some countries black is used for live, white for neutral and green for earth).

In a house we use a number of appliances like electric bulbs marked 220V – 60W, 220 V – 100W, 220V – 200W, 220V–1000W, heater marked 220V – 1000W, electric iron marked 220V – 500W, electric fan marked 220V – 60W, etc. From this we must know that each of them requires 220V potential difference for proper functioning.

If a number of appliances are connected is series to the power supply the appliances cannot get the right potential difference and hence they cannot function properly. Another disadvantage of series connection is when the resistance of an appliance get fused or switched off the other appliances will not get the electric current and hence will not work. If the appliances are connected in parallel each appliance can get the proper voltage to function properly and separate switches can be put for each appliance. Another advantage of parallel connection is that even when one part is switched off or fused the other parts are not affected.

However, when connected in parallel each part will draw different current according to their rating. When they are used simultaneously the total current drawn from the main will be the sum total of the currents in each appliance. Hence, it may be very large.

Again a bulb marked 220V – 100W has a resistance of 484 ohms and will draw a current of about 0.45A. A heater of 220V – 2000W has a resistance of 24.2 ohms and will draw a current of about 9A. To carry a larger current we need thicker wires and better quality materials in switches and sockets.

The appliances used at our house may be categorised into two groups – (i) light power appliance – like electric bulb, fan, TV sets, radio, etc. which draw current less than 5 A and (ii) high power appliance – like heater, cooker, refrigerator, etc. which draws larger current above 5 A when a few of them are used simultaneously. So, it is convenient to provide two different main lines – 5A line and 15A power line through different boards for 5A and 15A sockets and switches. (They are available in the market with specification).

Some electrical appliances like bulbs, tubes, fans, need not be connected with earth. They have just two terminals to be connected to the live and neutral. A wire from the live line passes through a switch then to one terminal of the appliance. The neutral line is connected to the other terminal of the appliance. The switch is placed at a convenient height to enable us to operate it.

Some appliances have plugs instead of the permanently fixed terminals. An electric iron is an example. It has a plug at the end of the cord. The plug (may) contains three pins. The pins correspond to Earth, Neutral and Live generally marked with letters E N and L near the pins. For them we need socket. The socket is fitted permanently on a switch board and the three lines Earth, Neutral and Live are connected to the terminals at the back of the socket. Usually the live wire is passed through a switch before it is connected to the socket.

Role of fuse – a safety device

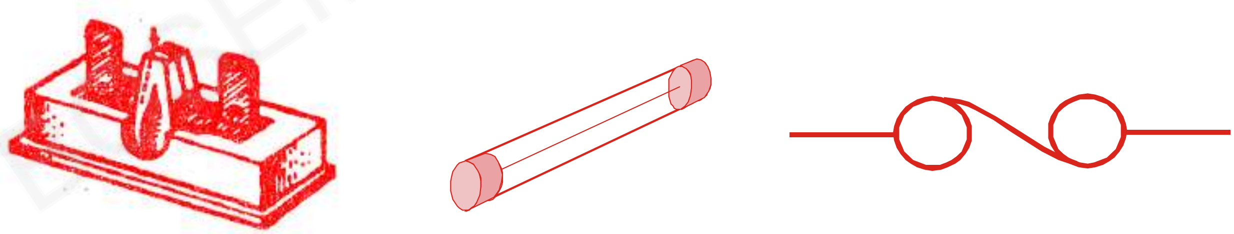
The wire used for wiring have limit for a certain maximum current to pass through them. If the current exceeds that limit, the wires may get over heated and cause fire. There are two main reasons for increasing current in the wires. They are – (i) Overloading (electrical power consumed by the appliance is greater than the maximum wattage) and (ii) short circuiting (direct connection of the live and neutral wires). Whenever there is short circuiting wires may be overloaded and at the same time at the point of short circuit sparking may occur and cause a fire.

Many precautions and safety measures are taken up to protect from the possible damages. All wires used in domestic electric circuits are coated with a layer of insulating material like rubber or plastic. So, the wires do not come in direct contact and short circuit does not occur. Besides there is division of circuits into different sections. This process not only facilitates repair of each section independently but also restricts the damage due to over loading or short circuiting.

The most important safety device used for protection of electrical circuits is the use of fuse. The fuse is a piece of wire made of material with a low melting point. Whenever a high current flows in the circuit due to overloading or short circuiting, the fuse gets heated then melts and disconnects the circuit from the main supply line. Fuse must be connected to the live wire.

Fuse wire is made of pure tin, but a cheaper variety is made of an alloy of tin and copper. The thickness and length of fuse wire depend on the maximum current permitted through the circuit.

Two types of electric fuse and circuit symbol of a fuse are shown in the figure 10.6.



(a) (b) (c)

Figure 10.6

Figure 10.7 shows a schematic diagram of a common domestic wiring.

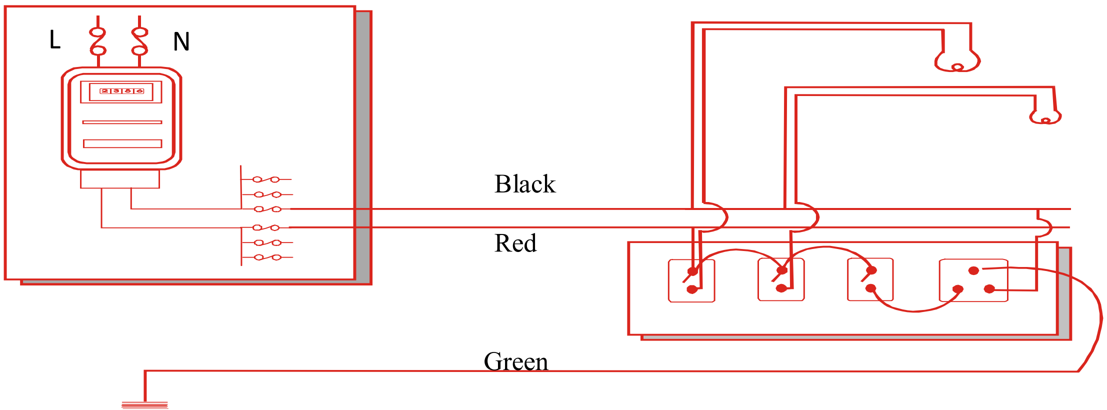


Figure 10.7

10.4 Hazards of electricity and precaution

Electricity is one of the most important and convenient sources of energy available to us. It can be used for different purposes. However, it is dangerous if certain precautions and safety measures are not taken up while use. You know that if you touch any point of the electric circuit you get shock (but don't try it). Sometimes the shocks are too severe to kill the person. The cracks or flaws in electric circuits (loose connection) defective switches, damaged wire, short circuit or overloading may cause sparking or overheating that may cause fire in the house. To avoid such hazards we require not only the safety devices of using fuse but also the following precautions in handling electric circuits.

(i) The metallic body of certain appliances like wattmeter, main switch, refrigerator, electric iron, computer, etc. must be connect to the earth wires. The reason for this is, if there is a slight leakage of current to the body of the appliance its potential remains the same as that of the earth and prevents from electric shocks.

(ii) All household wires must be of good quality and properly insulated (insulation thickness must be proper). Any exposed part must be insulated.

(iii) No direct handling must be done while repairing any part of a circuit. Use rubber hand gloves and wear rubber shoes or put off the main switch at the entry of main supply.

(iv) The tools like tester, pliers, screw drivers, pincers used in repairing should have proper insulation.

(v) One should not touch the metallic body of any electric appliance when they are switched on, if proper earthing is not given to them.

(vi) One should not touch any part of electric appliances and even the switches with wet skin and bare footed.

(vii) In case of fire, the main switch must be immediately switched off.

(viiii) Electric fuse should be used in each section. Proper fuse should be used. The practice of using ordinary copper wires instead of proper fuse wires can cause accident.

Despite of all precautions, it is possible that someone accidentally touches a live wire of the overhead domestic supply or inside the house. If this happen one should try to provide such a person with a support of some non-conducting materials like dry wood, plastic, rubber etc. One should try to pull away the person, who has contacted the live wire by not touching directly. The first and most appropriate step is to switch off the current at once.

Remember electricity is your friend so long as you take proper care. It can be fatal if you fail to observe the guidelines for using electricity.

10.5 Electric Power plants

From where do you get electricity at your home ? The electricity that we use is generated at power plants or station. In the power stations the armature of the generator is rotated by connecting its shafts to a prime mover. Power plants can be named according to the method used to rotate the armature. Some important ones are described below :

(a) Hydel (hydro electric) Power plants

In this type of power plant water at the higher level is allowed to fall on the blades of the turbine Figure 10.8. The pressure of water makes the blades of the turbine move making the armature (coil) of the generator rotate with a great speed. Then electricity is produced. Indira Gandhi Loktak Hydro electric project at Leimatak and Nungsangkhong Hydel power station at Ukhrul are examples of Hydel power plants.

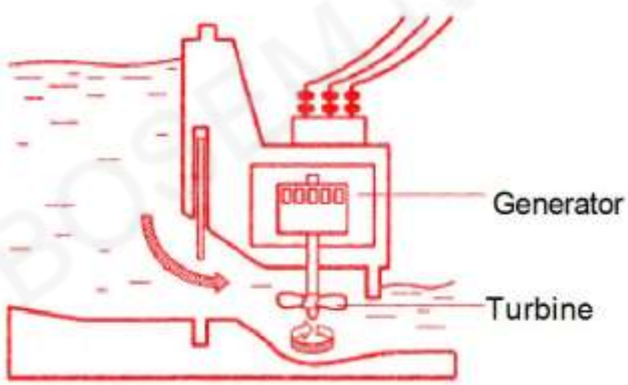


Figure 10.8 Hydel power plant

(b) Thermal Power plant

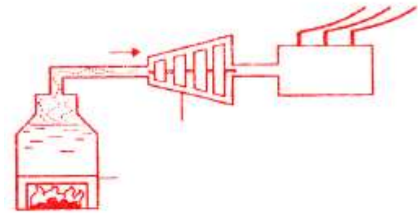


Figure 10.9 Thermal

In this type of power plant water is boiled using coal as fuel. Steam is produced at high pressure in the boiler. The steam is used to drive the turbine Figure 10.9. Then the armature coil of the generator is rotated. Thus electricity is produced.

(c) Nuclear Power plant

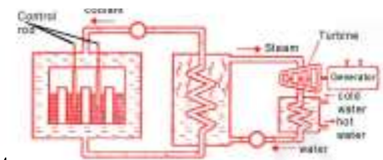


Figure 10.10 Nuclear Power

In nuclear power plant also known as Atomic Power plants the energy released through fission is used to produce steam by boiling water. The steam in turn, is used to rotate the turbine of electric generator Figure 10.10.

(d) Genset

Genset also known as Generator set is a small unit. In a Genset diesel, petrol or kerosene engine is used to rotate the armature coil of the generator. A genset can be small enough to meet the requirement of a single house or large enough to be used in a small industrial unit.

POINTS TO REMEMBER

i. When there is a change in the number of magnetic lines of force linked with a coil an induced e m f is developed in the coil. The phenomenon is known as electromagnetic induction.

ii. The strength of the induced e m f is proportional to the rate of change of the number of magnetic lines of force linked with the coil.

iii. The direction of the induced current in the coil is given by Flemings right hand rule.

iv. Electric generators work on the Principle of electromagnetic induction.

v. A generator converts mechanical energy into electrical energy.

vi. An A C has some advantages over D C.

vii. In domestic wiring earthing and use of proper fuse are very important.

viii. Power plants can be named according to the method used to rotate the armature.

EXERCISE

1. A coil of copper wire is connected to a galvanometer. What would happen if a bar magnet is (a) pushed into the coil very slowly ? (b) pushed into the coil very rapidly? (c) held at rest inside the coil ? (d) pulled out again rapidly ?
2. State the principle of the electric generator.
3. Explain with diagram the action of either A C generator or D C generator.
4. Distinguish between A C and D C.
5. What is the purpose of Fleming's right hand rule ?
6. A dynamo converts energy from one form to another. Name the two forms of energy in proper sequence.
7. A galvanometer is connected to the ends of a metal rod. The rod falls with its length horizontally extending East-West. What changes will you observe in the galvanometer? Explain the reason.
8. A galvanometer is connected to the ends of a metal rod. The rod falls with its length horizontally extending North-South. What changes will you observe in the galvanometer ?
9. Name two devices in which the principle of electromagnetic induction is used.
10. Many electrical appliances and circuits are earthed. What is the reason?
11. What is the usual colour code followed for connecting live, neutral and earth wire ?
12. What is meant by overloading in an electric supply ? How can it be prevented ?
13. What precautions should be taken to avoid overloading of domestic electric circuit ?
14. Why is material of low melting point chosen for fuse wire ?
15. What is short circuiting ? Mention the possible consequences of short circuiting.
16. Explain two safety measures commonly used in electric circuit and appliance.
17. What are the advantages of parallel connection of the domestic appliances in house hold wiring ?

18. For domestic wiring give reasons why sections are separated.
19. In a switchboard there are three switches no socket or any other element. How many wire will be going in the switch board ?
20. Is it possible to step up D C using a transformer ?
21. What is the use of a commutator in generator ?
22. Mention an important advantage of A C over D C.
23. Name three main types of power plants.
24. Which device is used to change the A C voltage ?
25. In a thermal power plant, how is the turbine rotated ?
26. How is the turbine rotated in a Hydel power plant.
27. What is the basic difference between thermal power plant and hydel power plant ?
28. How is the core of the coil of a Genset rotated to produce electricity ?

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CHAPTER

11

LIGHT

We see a number of objects around us. How do we see the objects ? We see the objects with the help of light emitted by them. Luminous objects like, the sun, lighted candles, etc. emit light of their own. We see the luminous objects with the help of light emitted by them. Then, how do we see non-luminous objects ? We see the non-luminous objects with the help of light falling on them. That is how we are reading this book.

Light travels rectilinearly in a transparent medium. The path of the light is turned back on falling on a polished surface. The phonomenon is known as reflection of light. What does happen when light passes through different media ? The path of light is mostly deviated when it passes through different media. The phenomenon is known as refraction of light. White light is splitted when it suffers refraction. Refraction occurs in human eye also. In this chapter we shall study the phenomena caused by reflection and refraction of light.

11.1 Reflection of light from plane surface

It is quite a common experience that when light from a torch light is directed towards a mirror the light beam is redirected back. This redirected light beam is known as reflected light and the phenomenon is called the reflection of light. If the direction of the incident beam be altered then the direction of the reflected beam will also change correspondingly. Thus the direction of reflected light depends on the direction of the incident light. Hence, reflection occurs under some laws. These laws are known as Laws of Reflection. Before discussing these laws let us acquaint with some terms and definitions first.

By using a proper slit, the beam of light comming out of a torch-light can be made narrower and narrower. Such a narrow beam can be taken as a ray of light though, in practice, it consists of a lot of light rays. In fact a ray of light is an imaginative assumption like that of a 'straight line' in geometry which has no breadth but only length. The point where incident light ray falls is called point of incidence. The vertical line perpendicular on the surface of reflection is known as the normal on the reflectives surface at the point of incidence. The angle between the incident ray and the normal is called the angle of incidence and the angle between the reflected ray and the normal is called the angle of reflection.

Laws of reflection

(i) The angle of incidence and the angle of reflection are always equal to each other.

(ii) The incident ray, the reflected ray and the normal at the point of incidence are always in the same plane known as plane of incidence.

These laws of reflection are applicable to all types of reflecting surfaces including spherical surfaces. If the reflecing surface is not perfectly polished the rays in a beam of light may be reflected irregularly. Then, diffused reflection occurs. The rays reflected from this book is an exmple of diffused reflection.

We dress up in front of a dressing mirror. What do you see through the mirror ? That is our image. The rays emitted from a point in front of the mirror after suffering regular reflection from the plane mirror appear to be emitted from an imaginary point behind the mirror. That imaginary point is the image of the point in front of the mirror. This is the virtual image formed by the plane mirror. If the reflection is not a regular reflection the rays will be reflected in different directions irregularly and they will not appear to be emitted from any single imaginary point. Hence, no image will be seen.That is why we cannot see our own image through this page. Here only diffused reflection occurs.

Activity 11.1

Use a plane mirror. Observe the image formed by it. What are the properties of the image formed by a plane mirror ?

The image is always virtual and erect. The size of the image is equal to that of the object. The image formed is as far behind the mirror as the object is in front of it. The image is laterally inverted.

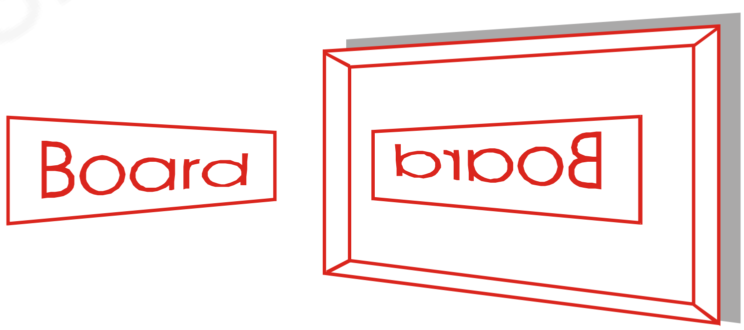


Figure 11.1

Try to answer

1. You see your image through a plane mirror at a distance of 2m from you. What is the distance of the mirror from you ?
2. A brick wall reflects the rays of light emitted from a candle lamp. But you do not see the image of the candle through the wall. What is the reason ?

11.2 Reflection from spherical mirror

Have you ever seen your own image through a curved surface like a shining spoon or side glasses of motor vehicles? How would be the image when the reflecting surface is a curved one ? To understand it let us perform the following activity.

Activity 11.2

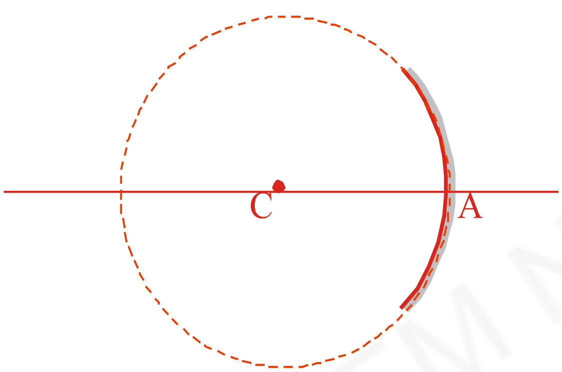


Figure 11.2

Take a large shining spoon. Try to see your own image through its curved side. Move the spoon away. Record the change of the image. Repeat the activity using the other side of the spoon. What can you conclude from this activity?

The most common type of curved mirror is the spherical mirror.

The spherical mirror is a part of a hollow sphere. Either the inner or outer side is a reflecting surface. If the inner side is reflecting surface the mirror is known as **concave mirror**. And, if the outer side is a reflecting surface the mirror is known as **convex mirro**r. Before we discuss the formation of image by spherical mirrors let us first acquaint with the terms and definitions which we will be using in the study.

Centre of curvature – Centre of carvature is the centre of the sphere of which the spherical mirror is a part.

Radius of curvature – The radius of the sphere, of which the mirror is a part, is known as radius of curvature.

Pole – The central point of the mirror or the point on the mirror directly facing the object is known as pole.

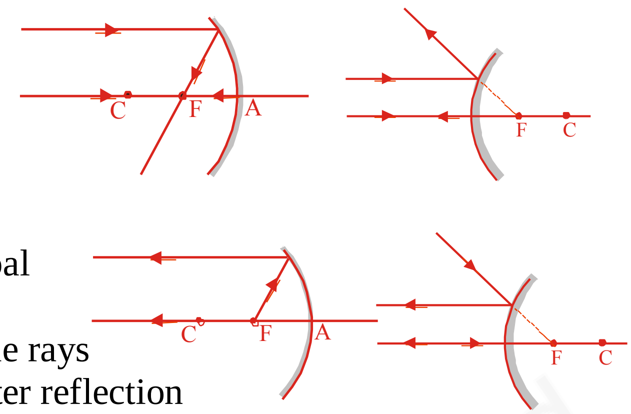


Figure 11.3

Principal axis – The straight line passing through the centre of curvature and pole of the mirror is called principal axis.

Principal section – It is the section of the mirror obtained with a plane passing through the principal axis. In a diagram a mirror is represented by its principal section with shade on the back side of the mirror.

Principal focus – It is a point on the principal axis. The rays incident on the mirror parallel to the principal axis, after reflection pass through (in the case of concave mirror) this point or appear to diverge (in the case of convex mirror) from this point.

The rays emitted from the principal focus in the case of concave mirror after reflection emerge parallel to the principal axis. In the case of convex mirror the rays converging towards principal focus are reflected parallel to the principal axis.

Focal length – Focal length is the distance between pole and principal focus. With the help of simple geometry you will be able to show that focal length is nearly equal to half of the radius of curvature.

Aperture – Aperture is the extent of the exposed portion of the mirror.

Two types of image

If the rays from a point object after reflection appear to diverge from or actually converge to a second point. The second point is known as image of the first point. If the rays appear to diverge from the second point this image is known as **virtual image**. Virtual images are always erect. If the rays actually converge to the second point the image is known as **real image**. Real images are always inverted. Real images can be focussed on a screen.

Using a concave mirror you can focus the rays from the sun at a point in front of the mirror. This is the real image of the sun. Assuming the sun is at infinity the rays from the sun are nearly parallel to each other. They focus at a point. The distance of the point from the mirror gives the measure of focal length of the concave mirror.

Image formed by spherical mirror

How would you locate the position of an image formed by a spherical mirror for an object, using ray diagram ? To locate the position of an extended object, placed on the principal axis you can follow the following steps.

Step I – Draw the principal section of the mirror showing distinctly the position of centre of curvature (C), and principal focus (F) on the principal axis (conveniently facing towards the left)

Step II– From the top of the extended object, on the principal axis trace the path of any two of the following rays

(a) a ray, incident on the mirror parallel to the principal axis. After reflection it passes through principal focus (F) in the case of concave mirror and appears to emit from (F) in the case of convex mirror.

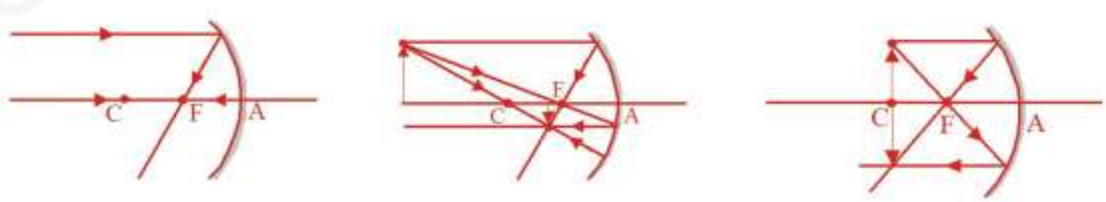
(b) a ray, incident on the mirror passing through the principal focus (F) in the case of concave mirror or approachig towards the principal focus (F) in the case of convex mirror. It is reflected back parallel to the pricipal axis.

(c) a ray, incident on the mirror passing through the centre of curvature (C) in the case of concave mirror or approaching towards the centre of curvature (C). It is reflected back normally. That is, it retraces back the path of the incident ray.

Step III– Find out the point where the two reflected rays intersect actually or intersect producing backwards.

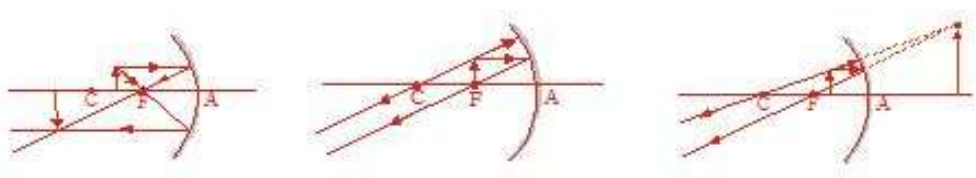
Step IV– Draw a perpendicular from the point of intersection on the principal axis. The perpendicular represents the image of the extended object. (While drawing ray diagram use arrow- head to show the direction of the ray)

The positions of images formed by a concave mirror when the object is placed at different positions are shown in the figure 11.4.



(a) Object at infinity *(b) Object beyond C.* *(c) Object at C.*

Figure 11.4(A)



(d) Object between C and F *(e) Object at F.* *(f)Object between F and A.*

Figure 11.4(B)

The position, nature and size of the image formed when the object is placed at different distances are summarised in the following table.

Table 11.1 Image formed by a concave mirror

Position of object	Position of image	Nature of image	Size of the image
Object at infinty	image formed at focus F	real and inverted	(infinitely) small point size
Object between infinity and C	image formed between C and F	real and inverted	smaller than the object
Object at C	image formed at C	real and inverted	same size as the object
Object between	image formed between	real and inverted	enlarged
C & F	C and infinity		
Object at F	image formed at infinity	real and inverted	highly enlarged
Object between Pole and F	image formed behind the mirror	virtual and erect	enlarged

Study the change of the size of the image when the object is moved form C to F.

In the case of convex mirror the image formed is shown in the figure 11.5 When the object is placed in front of the convex mirror the image is formed behind the mirror, virtual, erect and diminished in size.

Study the size of the image when the object is brought very close the mirror. What will be the size of the image when the object is placed just at the pole ?

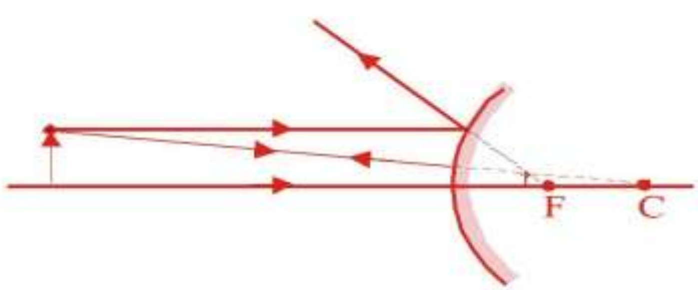


Figure 11.5

A plane mirror can be assumed as a spherical mirror having infinite radius of curvature.

Uses of spherical mirror

A concave mirror is used to produce parallel beam of light in the torch light, head light, search light etc. Dentists use it to see magnified image of small spots in the teeth. It is used as shaving mirror also. It is used to concentrate parallel beam of light.

In a reflecting type of telescope it is used as objective.

A convex mirror is used as rear viewer in vehicles. A convex mirror forms diminished virtual image, hence, its field of view is large. The image is also erect.

Mirror Equation

The object distance (u), image distance (v) and focal length (f) are related. Their relation is given by

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f} \qquad \text{Where } f=\frac{r}{2} \ [\,r-\textit{radius of curvature}]$$

While using the formula and to enable to indicate whether the point whose distance is measured is in front or behind the mirror certain sign conventions are used. There are some sets of sign convention. In this book we shall follow a set of sign convention called the New Cartesian Sign Convention.

New Cartesian Sign Convention

(i) All measurements of distance are made from the pole of the mirror.

(ii) If the measurement from pole be along the direction of the incident ray, a (+) sign is assigned to the value.

(iii) If the measurement from pole be against the direction of the incident ray then a (–) sign is assigned to the measurement.

Further, for convenience and for keeping similarity with that of Cartesian Co-ordinate System in assigning signs the pole of the mirror is made coincident with the origin of the perpendicular co-ordinate system and facing to the left side so that the direction of the incident ray may be from left to right.

In the above sign convention the focal length of a concave mirror is taken to be negative while that of a convex mirror is positive.

Magnification

The relative extent of the image with respect to the object size is the magnification produced by the spherical mirror. Thus, magnification of a spherical mirror is defined as the ratio of the image height to the object height. It is generally represented by (M).

$$\text{M} = \frac{\text{height of the image}(h_i)}{\text{height of the object}(h_o)}$$

The magnefication (M) is also related to the image distance (v) and object distance (u). Following the sign convention mentioned above.

$$\text{M} = \frac{(h_i)}{(h_o)} = -\frac{v}{u}$$

Using the equation above image-position corresponding to an object when placed at different positions can be solved. A few examples are given below.

Example 11.1 **An object 4cm high is placed at a distance of 20cm in front of a concave mirror of radius of curvature 60cm. Find the position, nature and size of the image.**

Solution From the question we have,

image distance, $v = ?$ height of the image, $h_i = ?$ height of the object, $h_o = 4\text{cm}$.

object distance, $u = -20\text{cm}$

radius of curvature $r = -60\text{cm}$

$\therefore$ focal length, $f = \frac{-60}{2} = -30\text{cm}$.

Using the relation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{v} + \frac{1}{-20} = \frac{1}{-30}$$

$$\Rightarrow \frac{1}{v} = -\frac{1}{30} + \frac{1}{20} = \frac{-2+3}{60} = \frac{1}{60} \quad \therefore v = 60\text{cm}$$

(+) sign shows that the image is behind the mirror and it is virtual.

Again, magnification $m = \frac{h_i}{h_o} = \frac{-v}{u}$

$$\therefore \ \frac{h_i}{4} = \frac{-60}{-20} = 3$$

$$\therefore \ h_i = 3 \times 4 = 12\text{cm.}$$

The image is formed 60cm behind the mirror, it is virtual 12 cm high and erect.

Example 11.2 **An object 4cm high is placed at a distance of 40cm in fornt of a concave mirror of radius of curvature 60cm. Find the position, nature and size of the image.**

Solution From the question we have,

image distance, $v = ?$ height of the image, $h_i = ?$ height of the object, $h_o = 4\text{cm}$

object distance, $u = -40\text{cm}$

focal length, $f = \frac{-60}{2} = -30\text{cm.}$

Using the relation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{v} + \frac{1}{-40} = \frac{1}{-30}$$

$$\Rightarrow \ \frac{1}{v} = -\frac{1}{30} + \frac{1}{40} = \frac{-4+3}{120} = \frac{-1}{120} \quad \therefore \ v = -120\text{cm}$$

The (–) sign shows that the image is in front of the mirror and real.

Again, magnification $m = \frac{h_i}{h_o} = \frac{-v}{u}$

$$\therefore \ \frac{h_i}{4} = \frac{-(-120)}{(-40)} = -3$$

$$\therefore \ h_i = -3 \times 4 = -12\text{cm.}$$

Thus the image is formed at a distance of 120 in front of the mirror. It is real, 12cm high and inverted.

Example 11.3 **It is intended to focus an image magnified 4 times on a screen using a concave mirror of focal length 20cm. Where should the object be placed?**

Solution From the question we have,

object distance, $u = ?$

magnification, $m = 4$

focal length, $f = -20$cm.

Let (x)cm be the object distance

$\therefore u = -x$

Since, $m = \dfrac{v}{u}$ (numerically) where v – image distance, u – object distance

We have, $v = 4x$. Since the image is focussed on the screen the image is real and formed in front of the mirror. So (v) is $(-)$ve.

$\therefore v = -4x$.

Using the equation $\dfrac{1}{v} + \dfrac{1}{u} = \dfrac{1}{f}$

We have,

$$\frac{1}{-4x} + \frac{1}{-x} = \frac{1}{-20}$$

$$\Rightarrow \frac{-5}{4x} = \frac{1}{-20} \Rightarrow \frac{4x}{5} = 20$$

$$\therefore x = \frac{20 \times 5}{4} = 25$$

Hence, object is to be placed at a distance of 25cm in front of the mirror.

Example 11.4 **Find the object distance to form an image magnified 4 times by a concave mirror of focal length 20cm.**

Solution Let (x)cm be the object distance

$\therefore$ Object distance, $u = -x$ cm

focal length, $f = -20$cm

magnification, $m = 4$

$\because m = \dfrac{v}{u}$ [numerically]

We have, $v = 4x$ [numerically]

When the image is real, $v = -4x$

Using the equation $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

We have,

$$\frac{1}{-4x}+\frac{1}{-x}=\frac{1}{-20}$$

$$\Rightarrow \frac{-1-4}{4x}=\frac{-1}{20}$$

$$\Rightarrow \frac{-5}{4x}=\frac{-1}{20}$$

$$\Rightarrow \frac{4x}{5}=20$$

$$\therefore x=\frac{20\times 5}{4}=25\text{cm}$$

To form real image the object is to be placed at 25cm in front of the mirror.

When the image is virtual (v) is (+)ve.

$$\therefore v=+4x$$

Using the equation $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

We have,

$$\frac{1}{+4x}+\frac{1}{-x}=\frac{1}{-20}$$

$$\Rightarrow \frac{1-4}{4x}=-\frac{1}{20}$$

$$\Rightarrow \frac{-3}{4x}=\frac{-1}{20}$$

$$\Rightarrow \frac{4x}{3}=20$$

$$\therefore x=\frac{20\times 3}{4}=15$$

$\therefore$ To form virtual image the object is to be placed at 15cm in front of the mirror.

Example 11.5 **A dentist uses a concave mirror of focal length 10cm to see a small spot on a patient's teeth. Find the magnification produced if a virtual image is formed at 25cm behind the mirror.**

Solution From the quesion we have,

focal length, $f = -10$cm

image distance, $v = +25$cm

object distance $u = ?$

Using the equation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{25} + \frac{1}{u} = \frac{1}{(-10)}$$

$$\Rightarrow \frac{1}{u} = -\frac{1}{10} - \frac{1}{25} = \frac{-5-2}{50} = \frac{-7}{50}$$

$$\therefore \quad u = -\frac{50}{7}$$

$$\therefore \textit{magnification, } m = \frac{-v}{u} = \frac{-25 \times 7}{-50} = 3.5$$

Example 11.6 **A convex mirror of radius of curvature 4m is used for rear view in an automobile. A person appears to be at 1m behind. What is the actual distance of the person?**

Solution From the question we have

object distacne, $u = ?$

focal length, $f = +\frac{4}{2} = 2$m [(+) ve since the mirror is convex]

image distance, $v = 1$m.

Using the equation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{1} + \frac{1}{u} = \frac{1}{2}$$

$$\Rightarrow \frac{1}{u} = \frac{1}{2} - \frac{1}{1} = \frac{1-2}{2} = -\frac{1}{2}$$

$$\therefore \quad u = -2$$

Hence, the actual distance of the object (person) is 2m.

Try to answer

1. A concentrated image of the Sun can be focussed at 50cm away from a mirror. What is the focal length of the mirror ? [Ans. 50 cm]

2. A concave mirror forms a real image having the same size as the object at a distance of 40cm in front of the mirror. What is the focal length of the mirror? (Ans. 20 cm)

3. An object is placed at a distcance of 50cm in front of a concave mirror of focal length 25cm. Find the image distance. If the object is 10cm high what will be the nature and size of the image ?
[Ans. 50 cm, real inverted, 10 cm high]

4. An object is placed at a distance of 50 cm in front of a convex mirror of focal length 25 cm. Find the image distance. What will be its nature ?
[Ans. 16.67 cm, virtual and erect]

5. An object is placed at a distance of 15 cm in front of a concave mirror of focal length 30 cm. Find the nature and position of the image ?
[Ans. Virtual erect ; 30 cm behind the mirror]

6. An objects is placed at a distance of 15 cm in front of a convex mirror of focal length 30 cm. Find the nature and position of the image.
[Ans. Virtual, erect, 10 cm behind]

11.3 Refraction through plane interface

The bottom of a vessel containing clear water appears to be raised up. When a thick glass slab is placed over some printed matter, the letters appear raised up when viewed through the glass slab. A straight pole inserted slantly in clear water appears to be bent at the surface of water. How can you account for such experiences ?

Light travels in straight line in a uniform transparent medium. When light passes from one medium into another obliquely on the interface its path gets deviated at the interface of the two media. This in known as refraction of light.

Why does light suffer refraction ? The speed of light is different in different media. In vaccum and air (approximately) under normal condition light travels at 3,00,000km per second. In water the speed of light is about 2,25,000 km per second. The medium in which the speed of light is smaller is known as optically denser medium. Thus, water is optically denser than air. When light enters from one medium to another obliquely on the interface, to enable to negotiate the change of speed, the path of the light is bent starting from the interface. Thus refraction takes place.

The ratio of the speed of light in vacuum to the speed of light in a medium i.e. the reciprocal of relative speed of light in a medium to the speed in vacuum is called refractive index of the medium. The ratio of the speed of light in two different media gives the relative refractive index of the second medium with respect to the first medium.

If v_o – represents speed of light in vacuum

v_a – represents speed of light in medium (A)

v_b – represents speed of light in medium (B)

$$\frac{v_o}{v_a} = \frac{1}{\left(\frac{v_a}{v_o}\right)} = \text{refractive index of (A)} = (\eta_A)$$

$$\frac{v_o}{v_b} = \frac{1}{\left(\frac{v_b}{v_o}\right)} = \text{refractive index of (B)} = (\eta_B)$$

$$\frac{v_a}{v_b} = \frac{1}{\left(\frac{v_b}{v_a}\right)} = \text{refractive index of (B) with repect to (A)} = \left[{}_A\eta_B\right]$$

We have,

$$\frac{v_a}{v_b} = \frac{v_a v_o}{v_o v_b} = \frac{\frac{v_o}{v_b}}{\frac{v_o}{v_a}} = \frac{\text{refractive index of (B)}}{\text{refractive index of (A)}}$$

$$\therefore \quad \left[{}_A\eta_B\right] = \frac{\eta_B}{\eta_A}$$

When a ray of light passes from one medium to another the amount of deviation and the sense of deviation of its path are determined by the ratio of the refractive indices of the two media . When a ray of light enters a denser medium the path of the ray is deviated towards the normal on the interface at the point of incidence. When the ray of light is refracted to a rarer medium the path is deviated away from the normal on the interface at the point of incidence.

To understand the phenomenon further let us perform the following activity.

Activity 11.3

Fix a sheet of paper on a drawing board. As shown in the figure 11.6 draw the boundary of a glass slab (ABCD). Remove the glass slab and draw a normal NOM on the side AB at O.

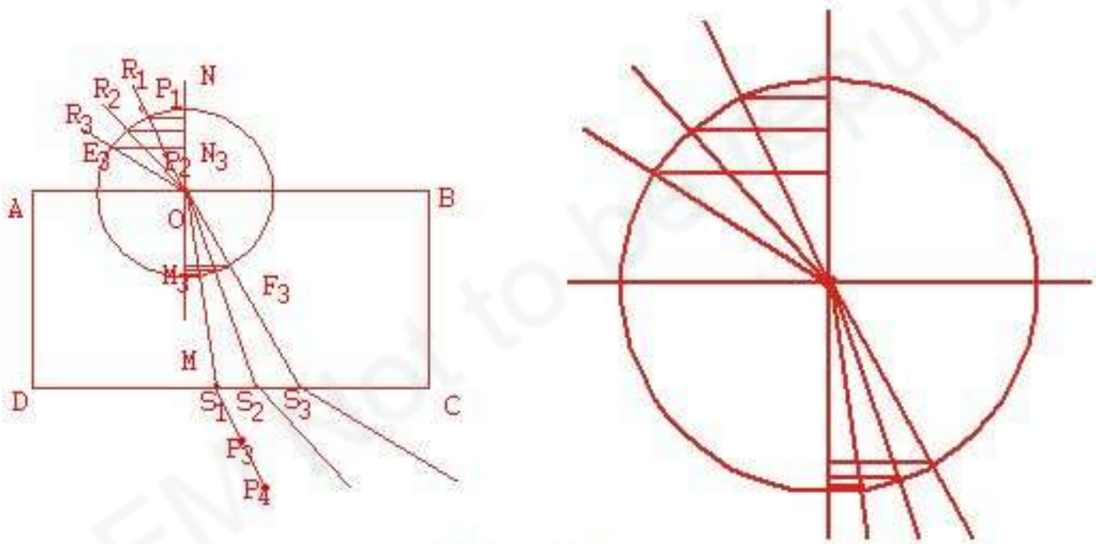


Figure 11.6

Draw a line R_1O making an angle i_1 to the normal ON. Fix two pins P_1 and P_2 upright on the line R_1O. Place the glass slab in the former position.

Look the two pins P_1 and P_2 through the glass slab and fix two pins P_3 and P_4 so that these two pins and the images of the former pins P_1 and P_2 lie on a straight line.

Draw a straight line passing through the two pins P_3 and P_4 meeting the side CD at S_1.

Join OS_1. Now OS_1 is the path of the refracted ray inside the glass slab corresponding to the incident ray R_1O. Thus angle MOS_1 is the angle of refraction r_1.

Observe the path OS_1 is not in the same line as R_1O. It is deviated closer to the normal.

Repeat the same activity using R_2O and R_3O as two more incident rays making angle of incidence i_2 and i_3 to the normal ON. OS_2 and OS_3 are the refracted rays making angle of refraction r_2 and r_3 to the normal respectively.

The incident rays, refracted rays and normal on the refracting surface at the point of incidence lie in the same plane.

Draw a circle of suitable radius with centre O cutting the incident rays at E_1, E_2 and E_3 and refracted rays at F_1, F_2 and F_3.

Draw perpendiculars E_1N_1, E_2N_2 and E_3N_3 from these points on the normal ON also F_1M_1, F_2M_2 and F_3M_3 on the normal OM.

Measure the length of the perpendiculars and find the ratio of $\frac{E_1N_1}{F_1M_1}; \frac{E_2N_2}{F_2M_2}; \frac{E_3N_3}{F_3M_3}$ and compare the results. The ratios are found the same.

What can you conclude from these observations

Here, $\frac{E_1N_1}{F_1M_1} = \frac{E_2N_2}{F_2M_2} = \frac{E_3N_3}{F_3M_3} =$ a constant.

We have, $$\frac{E_1N_1}{F_1M_1} = \frac{\frac{E_1N_1}{OE_1}}{\frac{F_1M_1}{OF_1}} = \frac{\text{Sin}\,i_1}{\text{Sin}\,r_1}$$ [$\because OE_1 = OF_1$ being radii of same circle]

$$\frac{E_2N_2}{F_2M_2} = \frac{\frac{E_2N_2}{OE_2}}{\frac{F_2M_2}{OF_2}} = \frac{\text{Sin}\,i_2}{\text{Sin}\,r_2}$$

$$\frac{E_3N_3}{F_3M_3} = \frac{\frac{E_3N_3}{OE_3}}{\frac{F_3M_3}{OF_3}} = \frac{\text{Sin}\,i_3}{\text{Sin}\,r_3}$$

Thus, we have $$\frac{\text{Sin}\,i_1}{\text{Sin}\,r_1} = \frac{\text{Sin}\,i_2}{\text{Sin}\,r_2} = \frac{\text{Sin}\,i_3}{\text{Sin}\,r_3} = \text{a constant.}$$

The activity gives two results known as the laws of refraction as stated below –

First law of refraction : The incident ray, refracted ray and normal on the refracting surface at the point of incidence lie in a plane.

Second law of refraction : The Sine of the angle of incidence bears a constant ratio to the sine of angle of refraction i.e. $\frac{\text{Sin}i}{\text{Sin}r}$ = a constant. The ratio is also known as refractive index of the second medium with respect to the first medium.

(The ratio is different for different colours (frequencies) of light. Light of different frequencies travel with the same speed in vaccum, however they travel with different speed in other media. In refraction different colours deviate through different angles corresponding to the same angle of incidence).

The ability of a medium to refract light depends upon the refractive index of the medium. It is also expressed in terms of optical density. A medium with larger refractive index is optically denser. Light travels with less speed in denser medium.

Successive Refraction

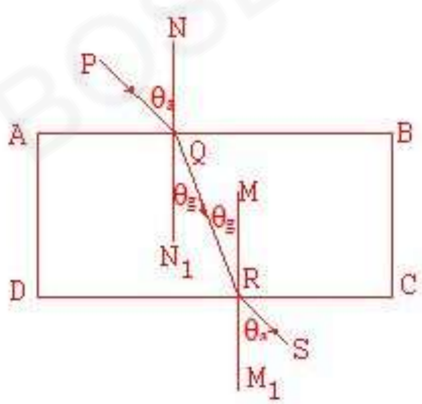


Figure 11.7

Let us study a ray of light PQRS passing through a glass slab ABCD with parallel refracting surfaces AB and DC and placed in air. Fig 11.7.

For the refraction at the first interface AB

θ_a – angle of incidence

θ_g – angle of refraction

$\therefore \frac{\text{Sin}\theta_a}{\text{Sin}\theta_g} = {}_a\eta_g$ (refractive index of glass with respect to air)

Since, AB and DC are parallel to each other the angle of incidence at the interface DC will be equal to the angle of refraction at AB. Thus the refraction at DC is just the reverse to that at AB.

For the refraction at the second interface DC.

$$\frac{\text{Sin}\theta_g}{\text{Sin}\theta_a} = {}_g\eta_a \text{ (refractive index of air with respect to glass)}$$

From these two refraction we can conclude that ${}_a\eta_g = \dfrac{1}{{}_g\eta_a}$

Thus, refractive index of a medium (A) with respect to another medium (B) is the reciprocal of the refrative index of (B) with respect to (A).

Apparent raising of the bottom of a vessel containing water

The bottom of a vessel containing water is apparently raised up. How is it ? Let us consider a point (P) at the bottom Fig. 11.8. A ray PA from the point meets the water surface normally.

It suffers no deviation and travels along AC. (As the angle of incidence is zero). Another ray PB meets the refracting surface at an angle of incidence θ_w. It is refracted away along BD making an angle of refraction θ_a. Here, $\theta_a > \theta_w$. The refracted rays BD and AC meet at Q producing backwards. Thus, the rays emitted from P appear to be emitted from Q, which is the virtual image of P. All the points at the level of P will appear to be at the level of Q. Thus the bottom appears raised up.

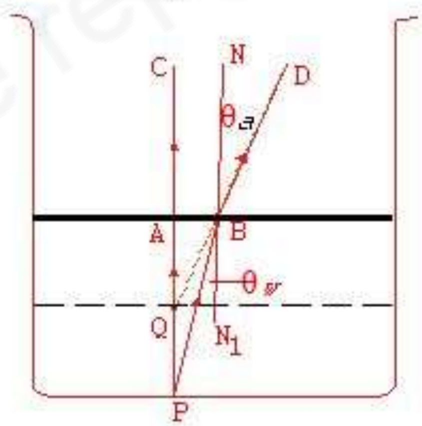


Figure 11.8

Now, PA is the real depth and QA is the apparent depth of the bottom.

With reference to the figure 11.8 the refractive index of water with respect to air, ${}_a\eta_w = \dfrac{\text{Sin}\theta_a}{\text{Sin}\theta_w}$

$$= \frac{\text{SinAQB}}{\text{SinAPB}} = \frac{\frac{AB}{QB}}{\frac{AB}{PB}} \quad \text{[Since } \angle AQB = \theta_a \text{ and } \angle APB = \theta_w \text{]}$$

$$= \frac{PB}{QB} = \frac{PA}{QA} \quad \text{[When B is close to A } \; PB = PA \; \; QB = QA.\text{]}$$

$$= \frac{\text{real depth}}{\text{apparent depth}}$$

Example 11.7 **A fish appears to be at a depth of 0.5m from the surface of water. Find the real position of the fish if refractive index of water is 1.33.**

Solution From the question we have, real depth = ?

Apparent depth = 0.5m

refractive index, η =1.33

Using the relation,

$$\text{refractive index, } \eta = \frac{\text{real depth}}{\text{apparent depth}}$$

$$\text{We have, } 1.33 = \frac{\text{real depth}}{0.5}$$

$\therefore$ real depth = 1.33 × 0.5 = 0.665m.

Refraction from denser to rarer medium

When a ray of light enters a rarer medium from a denser one the path of the ray is deviated away from the normal. Hence angle of refraction is greater than the corresponding angle of incidence. When the angle of incidenc is increased the angle of refraction also increases correspondingly. For a particular angle of incidence the angle of refraction is 90^0. That is, the ray emerges at the grazing angle along the interface. The angle of incidence for which the angle of refraction is 90^0 is called **critical angle** (figure 11.9). What will happen when the angle of incidence is increased beyond critical angle ? The ray will not suffer refraction. The ray will be reflected back completely (totally) obeying the laws of reflection. The phenomenon of reflection of light approaching from a denser medium towards a rarer medium, at the interface of the two media is called total internal reflection.

Two conditions to obtain total internal reflection are :

(i) The ray must approach a rarer medium from a denser one.

(ii) The angle of incidence must be greater than the corresponding critical angle.

Refractive index of the denser medium is equal to the reciprocal of the sine of the critical angle.

$$\text{i.e. } \eta = \frac{1}{\text{Sin C}}$$

Assuming

Refractive index of glass = 1.52 the critical angle of glass with respect to air (vacuum) is given by

$$\text{Sin C} = \frac{1}{\eta} = \frac{1}{1.52} = 0.6579 = \text{Sin}\,(41.1)^0 \quad \therefore \ C = 41.1^0$$

When the angle of incidence is greater than 41.1^0 the ray will suffer internal reflection.

In the case of diamond the refractive index is very high. It is 2.42. For diamond critical angle with respect to air (vacuum) is given by

$$\text{Sin C} = \frac{1}{2.42} = 0.4132 = \text{Sin}\,(24.4)^0$$

Hence, $C = (24.4)^0$

When a ray of light enters diamond it suffers a number of internal reflections inside diamond. The angle of incidence inside easily exceeds the critical value 24.4^0 hence total internal reflection occurs successively inside diamond and it is found exceptionally bright.

Table 11.2 Absolute refractive index of some material media

Material medium	Refractive index	Material medium	Refractive index
Air	1.0003	Rock salt	1.54
Ice	1.31	Flint glass	1.65
Water	1.33	Ruby	1.71
Kerosene	1.44	Sapphire	1.77
Crown glass	1.52	Diamond	2.42

N.B. Optically denser medium may not always possess greater mass density.

Try to answer

1. In which medium will light travel faster water or kerosene ?
2. If the refractive index of glass is 1.5 what will be the apparent thickness of a glass plate of 1.5cm thick ?

11.4 Refraction Through Thin Lenses

Have you ever seen an object through a clean bottle of water ? The object appears distorted. Have you seen an object through a small water drop? The object appears bigger. Some spectacle lenses can concentrate the light from the sun at a point. The point gets heated, sometimes it catches fire. These experiences are related with lens.

What is a lens ? A lens is a transparent medium bounded with two spherical surfaces. [or, a plane surface and a spherical surface.]

There are two types of lenses. They are (i) Convex lens and (ii) Concave lens.

Convex lens – It is the type of lens in which the central portion is thicker than the peripheral portion. It always converge or tends to converge any beam of light passing through it. So, this type of lens is called as converging lens.

Concave lens – It is the type of the lens in which the central portion is thinner than the peripheral portion. When a beam of light passes through this type of lens, it always tends to diverge the beam of light. So, it is called as diverging lens.

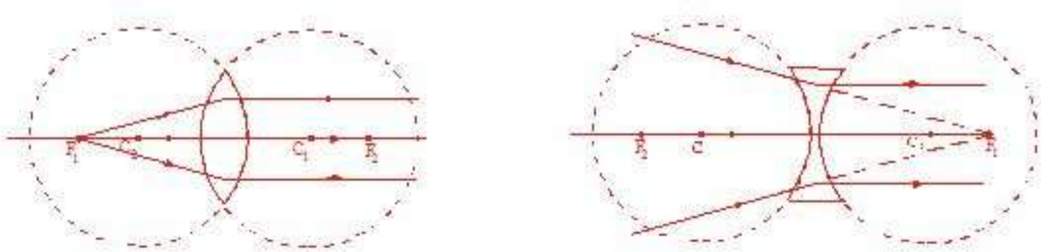
Terms associated with thin lenses

Principal axis – It is the straight line passing through the two centres of curvature of the two surfaces of the lens.

Principal section – It is a section of the lens obtained with a plane passing through the principal axis. In a diagram a lens is represented by its principal section.

Optical centre (O) – It is a point on the principal axis of the lens. Any ray passing through this point does not suffer deviation.

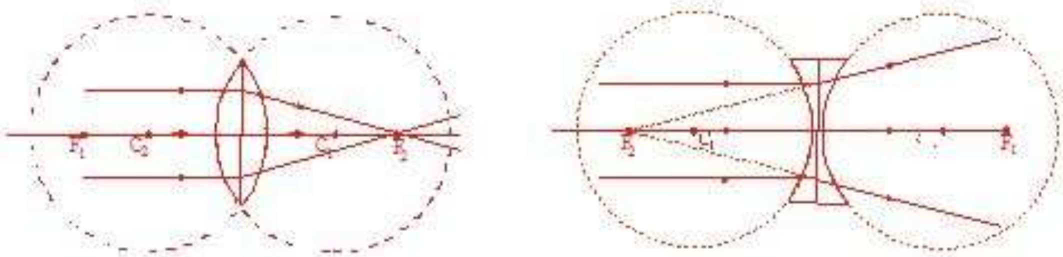
First principal focus (F_1) – It is a point on the principal axis. The rays diverging from this point in the case of convex lens or the rays converging towards this point in the case of concave lens, are refracted by the lens parallel to the principal axis.



(a) *(b)*

Figure 11.10

Second principal focus (F_2) – It is a point on the principal axis. The rays incident on the lens parallel to the principal axis after refraction actually converge to this point or appear to diverge from this point.



(a) *(b)*

Figure 11.11

Focal length (f) – It is the distance of either first principal focus or second principal focus from the optical centre.

Image formed by lens

To locate the position of the image of an extended object, placed on the principal axis using ray diagram you can follow the following steps.

Step I Draw the principal section of the lens showing the position of optical centre (O), first principal focus (F_1) and second principal focus (F_2) on the principal axis. (distance of F_1 and F_2 from O will be equal).

Step II From the top of the object placed on the principal axis conveniently on the left side of the lens trace the path of any two of the following rays.

(i) The ray passing through the optical centre O. It does not suffer any deviation.

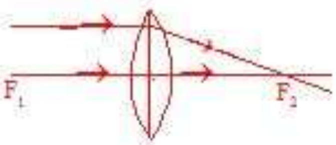
(ii) The ray incident parallel to the principal axis. It is refracted through the second principal focus (F_2) in the case of convex lens. In the case of concave lens it is refracted as if it emerges from the second principal focus (F_2).

(iii) The ray incident on the lens through first principal focus (F_1) in the case of convex lens or incident towards the first principal focus (F_1) in the case of concave lens. It is refracted parallel to the principal axis.

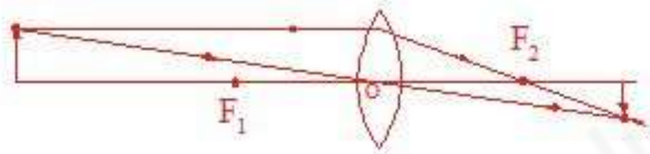
Step III Find out the point where the two refracted rays intersect actually or intersect producing backward. It is the image of the point on the top of the object.

Step IV Draw a perpendicular from the point on the principal axis. The perpendicular represents the image of the extended object.

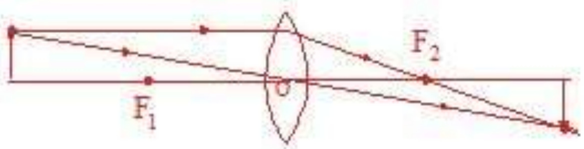
The following ray diagrams show the image formed by the convex lens when the object is placed at different distances. From the diagrams study the position, nature, and size of the image.



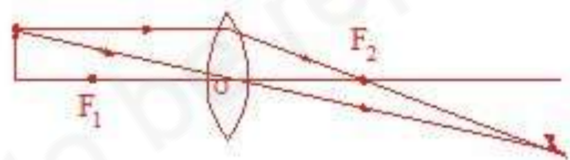
(a) object placed at infinity



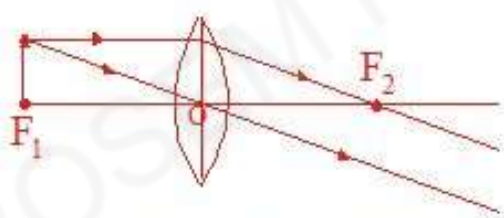
(b) object placed at a distance greater than 2f



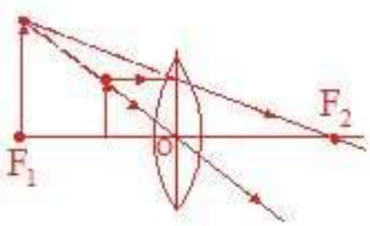
(c) object placed at a distance equal to 2f



(d) object placed at a distance less than2f and greater than f



(e) object placed at a distance equal to (f)



(f) object placed at a distance less than f

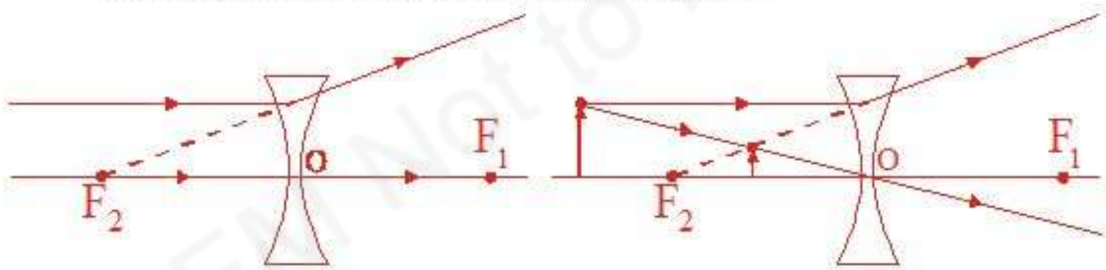
Figure 11.12

The position, nature and size of the image formed by a convex lens when the object is placed at different distances are summarised in the following table.

Table 11.3

Position of the object	Position of the image	Nature of image	Size of the image
At infinity	At the principal focus (F_2)	Real and inverted	highly diminished
At a distance >2f	At a distance greater than (f) and less than 2f	Real and inverted	diminished
At a distance = 2f	At a distance equal to 2f	Real and inverted	same size
At a distance < 2f and greater than f	At a distance greater than 2f	Real and inverted	Magnified
At focus	At infinity	Real and inverted	Infinitely magnified
At a distance < f	On the same side as the object.	Virtual and erect	Magnified

Ray diagrams of the image formed by concave lens :



(a) Object placed at infinity ***(b) Object placed between infinity and O***

Figure 11.13

From these diagrams we can conclude that concave lens always forms virtual, erect and diminished image for real object.

Lens formula

The image distance(v) formed by a lens depends upon the object distance (u) and focal length (f). Their relation is given by the formula

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

While using the formula we shall follow a sign convention similar to the one used for spherical mirror. In the case of lens all measurements are taken from the optical centre of the lens. According to this convention focal length of a convex lens is positive and that of a concave lens is negative.

Magnification – The ratio of the size of the image to the size of the object is called magnification(m). It is also related to the image distance (v) and the object distance (u). The relation is given by

$$\text{Magnification } (m) = \frac{\text{height of the image } (h_i)}{\text{height of the object } (h_o)} = \frac{\text{image distance}(v)}{\text{object distance}(u)}$$

$$\text{i.e } m = \frac{h_i}{h_o} = \frac{v}{u}$$

Power of lens

The converging or diverging ability of a lens is called power of the lens. This ability depends upon the value of focal length. Larger the focal length, power of the lens is less. Power of a lens is measured by the reciprocal of the focal length.

$$\text{Power, } P = \frac{1}{f}$$

When the focal length is expressed in metre the power is expressed in dioptre(D). One dioptre is the power of a lens whose focal length is 1 metre. Thus, $1\text{D} = 1\text{m}^{-1}$.

Example 11.8 **An object 3cm high is placed at a distance of 20cm from a convex lens of focal length 12cm. Find the position, nature and size of the image.**

Solution From the question we have

object distance, $u = (-)\ 20\text{cm}$

focal length, $f = (+)\ 12\text{cm}$.

Image distance, $v = ?$

By the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

We have

$$\frac{1}{v} - \frac{1}{(-20)} = \frac{1}{12}$$

$$\Rightarrow \frac{1}{v}+\frac{1}{20}=\frac{1}{12}$$

$$\Rightarrow \frac{1}{v}=\frac{1}{12}-\frac{1}{20}=\frac{5-3}{60}=\frac{2}{60}=\frac{1}{30}$$

$$\therefore\ v=30\text{cm}$$

magnification, $m=\frac{v}{u}=\frac{30}{-20}=-1.5$

$$\frac{h_i}{h_o}=-1.5\ \therefore\ h_i=-1.5\times 3=-4.5\text{cm}$$

Therefore, the image is formed at a distance of 30cm on the positive side i.e. on the other side of the lens. The image will be inverted and real. The size of the image is 4.5cm.

Example 11.9 **An object is placed at a distance of 10cm from a convex lens of focal length 15cm. Find the position, nature and magnification of the image.**

Solution From the questions we have

object distance, $u=(-)\ 10\text{cm}$

focal length, $f=(+)\ 15\text{cm}.$

Image distance, $v=?$

By the formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

We have,

$$\frac{1}{v}-\frac{1}{-10}=\frac{1}{15}$$

$$\Rightarrow \frac{1}{v}+\frac{1}{10}=\frac{1}{15}$$

$$\Rightarrow \frac{1}{v}=\frac{1}{15}-\frac{1}{10}=\frac{2-3}{30}=\frac{-1}{30}$$

$$\therefore\ v=-30\text{cm}$$

magnification, $m=\frac{v}{u}=\frac{-30}{-10}=+3$

The image is formed at a distance of 30cm on the (–)ve side i.e. on the same side as the object. The magnification is +3. The image is erect and virtual.

Example 11.10 Find the image position of an object kept at a distance of 4cm from a concave lens of focal length 12cm. What is the magnification as well ?

Solution From the question we have
object distance, $u = (-)\,4\text{cm}$
focal lenth, $f = (-)\,12\text{cm}$.
image distance, $v = ?$

By the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{v} - \frac{1}{-4} = \frac{1}{-12}$$

$$\Rightarrow \frac{1}{v} + \frac{1}{4} = \frac{-1}{12}$$

$$\Rightarrow \frac{1}{v} = \frac{-1}{12} - \frac{1}{4} = \frac{-1-3}{12} = \frac{-4}{12} = \frac{-1}{3}$$

$$\therefore \; v = -3\text{cm}$$

magnification, $m = \frac{v}{u} = \frac{-3}{-4} = 0.75$

The image is formed at a distance of 3cm on the (–)ve side that is on the same side as the object. The magnification is (+)ve 0.75. The image is erect and virtual.

Try to answer

1. A lens can focus an image having the same size as the object on a screen 1m away from the lens. What is the focal length of the lens ?
2. An object is seen magnified through a lens. What is the type of the lens convex or concave ?
3. An object is seen diminished through a lens. What is the type of lens – convex or concave ?

(Numerical problems)

4. An object is placed at a distcance of 50cm in front of a convex lens of focal length 25cm. Find the image distance. If the object is 10cm high what will be the nature and size of the image ? [Ans. 50 cm, real inverted, 10 cm high]

5. An object is placed at a distance of 50 cm in front of a concave lens of focal length 25 cm. Find the image distance. What will be its nature ?

   [Ans. 16.67 cm, virtual and erect]

6. An object is placed at a distance of 15 cm in front of a convex lens of focal length 30 cm. Find the nature and position of the image ?

   [Ans. Virtual erect ; 30 cm on the same side as the object]

7. An objects is placed at a distance of 15 cm in front of a concave lens of focal length 30 cm. Find the nature and position of the image.

   [Ans. Virtual, erect, 10 cm on the same side as the object]

11.5 Human Eye and Defects of Vision

The human eye consists of a crystalline convex lens. The lens forms the image of the object (in front of the eye) on the retina. Retina contains a number of light sensitive nerves. The nerves carry the information of the image, formed on it to the brain. Then sensation of sight occurs. Only when the image is formed on the retina distinctly the object is seen clearly.

Can you see an object when it is placed at different distance ? Yes, we can see the object, placed within a wide range of distance. How is it possible ? A lens having fixed focal length can form the image of an object only at a fixed position. If the lens in the human eye has a fixed focal length, it will be able to focus the image on the retina for the object placed at a fixed position only. The eye lens can change its focal length. With the help of ciliary muscles the curvature of the eye lens can be changed. When the eye lens becomes thicker its focal length is reduced. To enable to focus the image on the retina focal length of the eye lens is adjusted. The ability of the eye lens to adjust its focal length is called **power of accommodation**. If the object is brought much closer, the eye lens may not be able to adjust its focal length any more to enable to focus the image on the retina. The nearest point upto which the eye can see is known as least distance of distinct vision (or near point). For normal eye the least distance of distinct vision is 25cm. When the eye lens is in the thinnest condition (normal condition) its principal focus lies on the retina (in the case of normal eye). The image of the object at infinity can be focussed on the retina. Thus, the far point of normal eye is infinity.

Try to read a printed page by holding it closer and closer. At what distance is it most comfortable ? Can you read upto what distance ? If you bring the printed page still closer what sensation do you feel ? Certainly you will feel a strain sensation in your eye.

Defect of vision

Can you read what is written on the blackboard of your class room from the back bench ? If not check your eye sight. When you read the book do you read with strained eye ? Perhaps you have seen some old persons reading books or newspaper keeping at arms length. Sometimes, the eye may gradually lose its power of accommodation. In such conditions, the vision becomes blurred due to refractive defect of the eye.

For a normal eye the range of vision is from 25cm to infinity. When an eye cannot see distinctly and comfortably the objects within the normal range (that is, between 25cm and infinity) the eye is said to have refractive defect of vision.

There are four common refractive defects of vision. They are (i) myopia or nearsightedness, (ii) hypermetropia or farsightedness, (iii) presbyopia or loss of accommodaton, and (iv) astigmatism or loss of horizon.

(i) Myopia or Nearsightedness

The eye suffering from this defect cannot see clearly the far off objects but can see distinctly the objects nearby. The far point of the defective eye is less than infinity and near point also is less than 25cm. The defect is due to either (i) the eye ball is elongated or (ii) the eye lens becomes thicker making its normal focal length too short. In such a situation the image of the distant object is formed in front of the retina Figure 11.14(a). This type of eye defect is corrected by using a concave lens of proper focal length Figure 11.14(c).

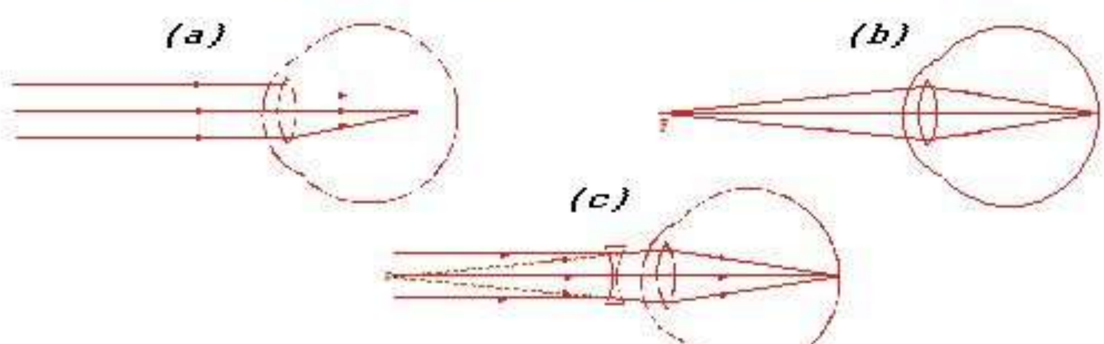


Figure 11.14

[The focal length of the concave lens is equal to the distance of the far point (F) of the defective eye Figure 11.14(b)]

(ii) Hypermetropia or Farsightedness

The eye suffering from this defect can see distant objects clearly but cannot see nearby objects distinctly. The near point of such defective eye is farther away from the normal near point i.e. 25cm. This defect may arise due to (i) shortening of eye ball length or (ii) normal focal length of the eye lens is too long. In such situation, the image of the distant object would be formed behind the retina Fig.11.15(a) if the eye lens is not adjusted by accomodation. To see the distant object the eye lens is adjusted by accommodation Figure 11.15(b). When the object is brought nearer, the eye lens is adjusted accordingly. But the ability to adjust the focal length by accommodation is exhausted when the object reaches a near point (N) which is greater than 25cm, the near point of normal eye Figure 11.15 (c). Hence the hypermetropic eye cannot see clearly objects nearer than N, which is beyond 25cm.

This defect can be rectified by using a converging or convex lens of suitable focal length Figure 11.15 (e).

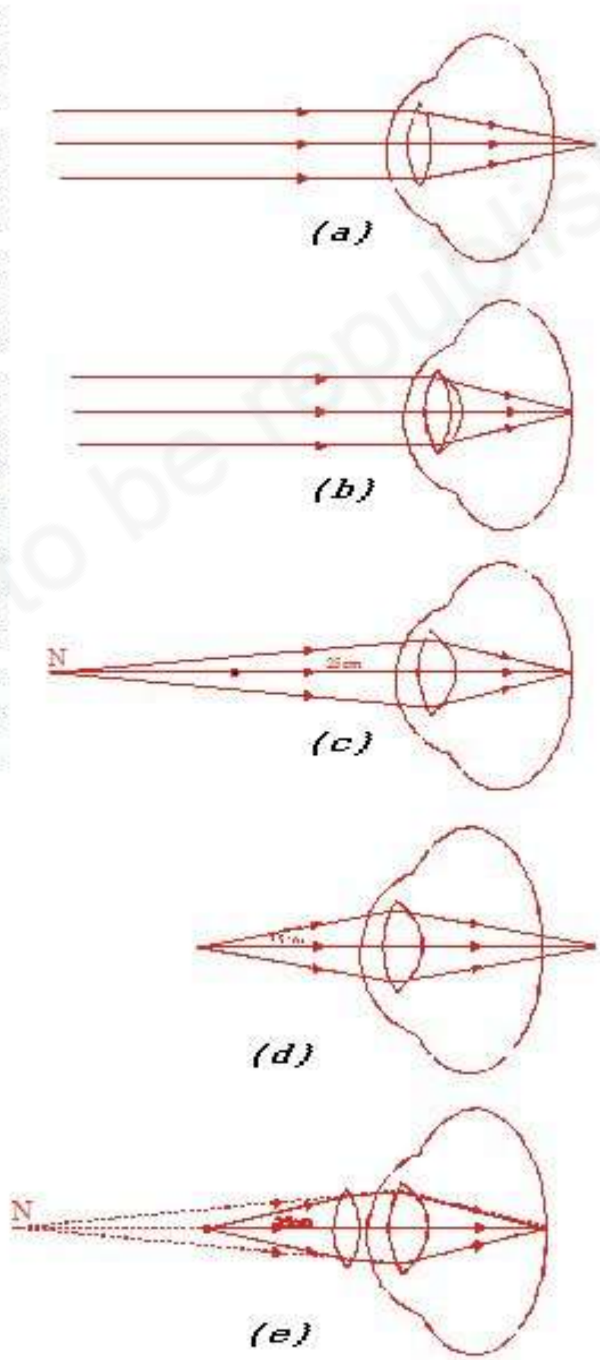


Figure 11.15

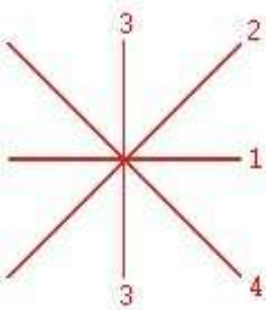
(iii) Presbyopia or Loss of accommodation

Usually with ageing the flexibility of the eye lens diminishes and hence power of accommodation of the eye decreases.

Sometimes, the eye may suffer from both myopia and hypermetropia. Such defect is known as presbyopia. The eye has a short range of vision. The near point recedes away and far point becomes close. Such defect can be rectified using bi-focal lens. A common type of bi-focal lens consists of both concave and convex lenses. The upper portion consists of a concave lens, it is used for distant vision. The lower portion is of a convex lens. It is used for near vision.

(iv) Astigmatism or Loss of horizon

An eye suffering from this defect cannot see all the directions– horizontal or vertical equally well simultaneously. The defect is due to the irregular curvature of the eye lens. The vertical and horizontal curvature of the eye lens are different. Such a defect can be removed using suitable cylindrical lens. To test astigmatism yourself do the following activity.



Figure

Activity 11.4

Draw four lines 1 – 1, 2 – 2, 3 – 3, 4 – 4 as shown in the diagram Figure 11.16 passing through a point with equal intensity.

Look the lines with the eye (left or right) which you are going to test. If all the lines appear equally intense the eye is not astigmatic.

If a particular line is most intense and its perpendicular line is least intense the eye is most likely astigmatic.

Rotate the diagram through 90^0. Does the most intense and least intense lines interchange ? If yes further testing with expert may be required.

Try to answer

1. An eye feels comfortable in reading the book keeping at a distance of 15cm. What is the defect ? What type of lens will be used to rectify the defect ?
2. A defective eye cannot see distinctly the object beyond 1m clearly. What is the defect ? What is the power of the lens required to rectify the defect ?

11.6 Dispersion of Light

We have seen the spectacular colours in a rainbow. How is a rainbow formed ? How could the white light of the sun gives us various colours of a rainbow ?

Light consisting of a number of components with different frequencies or wavelengths is called polychromatic or composite light. Light consisting of a single wavelength is called monochromatic light.

Solar light is a polychromatic or composite light. Splitting of a composite light into its constituent colours is known as dispersion of light.

A glass prism can split white light into its constituent colours. A prism is a transparent medium having two refracting faces inclining at certain angle. When a ray of light is passed through a prism, the ray always suffers deviation. To understand how white light is splitted by a prism let us perform the following activity.

Activity 11.5

- Prepare a narrow slit in a sheet of card board.
- With the help of a plane-mirror a beam of solar light is passed through the slit.
- Take a glass prism and allow the light to pass through the prism.
- Turn the prism slowly until the light that comes out of it falls on a nearby screen.

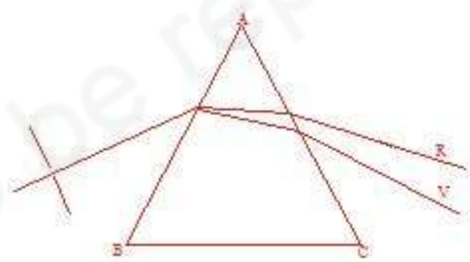


Figure 11.17

- What do you observe ? You will find a beautiful band of colours. Observe the sequence of the colour.

You will find that violet colour is deviated the most and red the least. If you see minutely you will find the sequence of the colours as – Violet, Indigo, Blue, Green, Yellow, Orange and Red. The acronym VIBGYOR will help you to remember the sequence of colours. The colour-band is called the spectrum.

When refraction takes place through the first refracting surface of a prism violet colour is deviated most and red colour is deviated least. Other colours are deviated in between the two extreme range. In the refraction through the second refracting surface also deviation takes place in the same sense and hence different colours are deviated further producing the colour spectrum more distinct. But in the case of glass slab the opposite refracting surfaces are parallel to each other. In this case, the composite light is splitted into its constituent

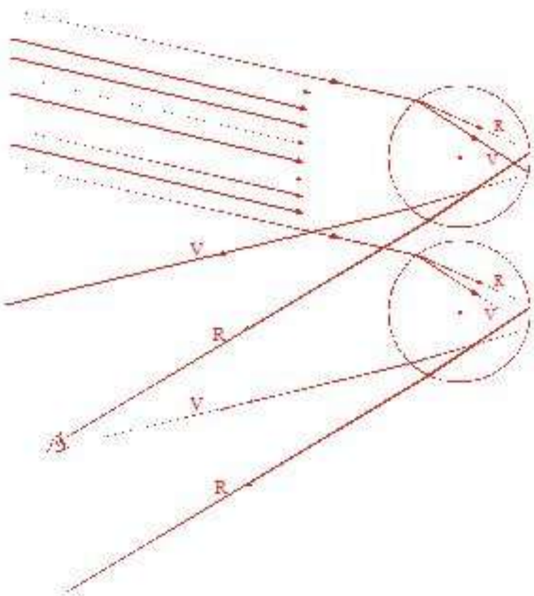


Figure 11.18

colours when refraction takes place through the first surface. When the rays are refracted through the second surface the rays emerge without any deviation from the direction of the incident ray. Splitted rays of different colours corresponding to adjacent incident rays combine to form composite emergent rays. Only the extreme sides of the beam appear coloured. Thus a glass slab cannot cause dispersion of light.

When do you see a rainbow ? It is a natural spectrum appearing in the sky. It is caused by dispersion of sunlight by tiny water droplets, present in the atmosphere. To see a rainbow the sun will be at your backside. A rainbow is always formed in a direction opposite to that of sun. The water droplets act like small prisms. They refract the sunlight, disperse, then internally reflected. Finally the reflected rays emerge out of the raindrop (actually suffering refraction). Due to the dispersion of light and internal reflection, different colours reach the observer's eye Figure 11.18.

Can you create a rainbow on a sunny day for your friend ?

Try to answer

1. In the morning in which direction may you observe a rainbow ?

11.7 Phenomena caused by refraction in atmosphere

Some phenomena caused by refraction in atmosphere are accounted below :

(A) Advance Sunrise and delayed Sunset

Do you know the Sun is visible to us about 2 minutes before the actual sunrise? The sunset is also delayed by about 2 minutes. The day gets elongated by about 4 minutes. The rays of the solar light coming from space undergo refraction as they penetrate the atmosphere of the earth. Further, the density of the atmosphere decreases with altitude. Thus, as the ray travels from top of the atmosphere to the surface of the earth the density of the air medium gradually increases. As a result the path of the ray is slightly, curved and the rising sun which is actually lying below the horizon appears to be a little raised and becomes visible Figure 11.19. Because of this the sun is visible slightly before it actually rises and slightly after it sets. Also the setting sun appears slightly oval in shape rather than being circular. This is due to unequal refraction of light coming from the upper and lower portion of the sun's disc.

Figure 11.19

(B) Twinkling of Stars

The twinkling of star is also due to the refraction caused by the atmosphere. There are always irregular currents of hot air in the atmosphere. This causes the refractive index of the atmospher vary continually. As a result the position of the star appears to fluctuate to an observer on earth. Further, when a sudden current of hot air crosses the line of vision, the light from the star suddenly gets deflected away and the star is temporarily lost from view. Thus the stars twinkle.

The planets and the moon do not twinkle because they are much nearer to the earth and so do not behave like a point source. Further, they appear bright. Because of the reasons they do not twinkle.

(C) Scattering of light

Atmosphere contains not only air particles, but also some more minute particles like – smoke particles, tiny water droplets, dust particles, The interaction of light wave with these tiny particles gives rise to several spectacular phenomena in nature. Blue colour of sky, reddening of the sun at sunrise and sunset are some interesting phenomena. The path of a beam of light passing through a true solution is not visible. However, its path become visible through a colloidal solutions where the size of the particles is relatively larger. When a beam of light strikes such fine particles the path of the beam is visible as diffusely reflected rays reach our eye. The phenomenon of diffused reflection is called scattering of light.

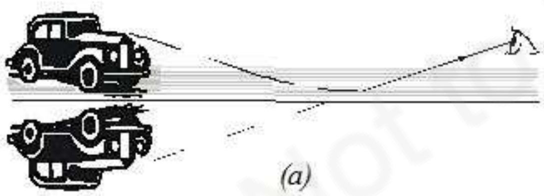
Tiny particles can diffuse the light of shorter wavelength more effectively and light ray of longer wavelength are transmitted undisturbed. Blue light has shorter wavelength than red light. The molecules of air and other fine particles have the size more effective in scattering light of shorter wave lengths at the blue. The red light has a wavelength of about 1.8 times greater than that of blue light. Thus, when sunlight passes through the atmosphere the fine particles in air scatter the blue colour (shorter wavelengths) more strongly than red. The scattered blue light enters our eye. Thus we see the sky blue.

If the earth had not atmosphere, there would not have any scattering, then the sky would have looked dark.

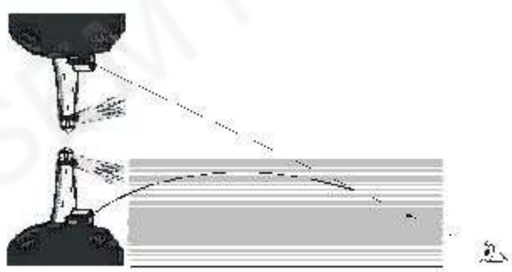
Red light is not scattered or least scattered by the air and suspended particles in the atmosphere. It can penetrate through the air easily with least disturbance. So, red light is used in danger signal.

During sunrise and sunset the light rays from the sun passes through thicker layers of air and larger distance in the earth's atmosphere before reaching our eye. Almost violet and blue part of the solar light are scattered away on the way leaving only the red portion undisturbed. Therefore, the light that reaches our eye is of longer wavelengths. This gives rise to the reddish appearance of the sun.

At noon the sun is at overhead. Light from the sun would travel relatively shorter distance, so only a little portion of the blue and violet colours are scattered and the sun still appears white.



(a)



(b)

Figure 11.20

(D) Mirages

When different layers of the atmosphere are at different temperatures the layers will have different optical density. Many strange phenomena may occur – an object on the street may appear inverted as if reflection occurs on a water surface on the street Figure 11.20(a). A Ship or light house may appear floating in the sky in cold polar region. Such strange phenomena are known as mirages.

On a hot sunny day the layer of the atmosphere just above the road may become very hot and may have least optical density. Overlying layers of air are relatively cold. As we go up higher and higher the layer are optically denser and denser.

The rays from the top of an object on the street suffer refraction consecutively increasing angle of incidence layer after layer. At certain lower layer the angle of incidence may surpass the critical angle. Then the rays will be reflected back internally. To the observer an inverted image of the object will be seen.

In the cold polar region the optical density of the different layers of air decreases as we go higher and higher. Hence rays from the object on the surface of the sea after consecutive refraction are internally reflected back from a layer above. Hence the object is seen hanging in the sky Figure 11.20(b).

POINTS TO REMEMBER

i. Light travels rectilinearly.
ii. Regular reflection can cause the formation of image.
iii. Irregular reflection cannot cause the formation of image.
iv. The image formed by a plane mirror is laterally inverted.
v. Concave spherical mirror can form both real and virtual images depending upon the position of object.
vi. Convex spherical mirror can form only virtual diminished image.
vii. Speed of light is different in different media. Hence when light travels from one medium to another its path is deviated.
viii. The amount and sense of deviation depend upon the relative optical density of the media.
ix. Optical denser medium may not always possess greater mass density.
x. Apparent raising of the bottom of a vessel containing water is due to refraction.
xi. Lens is a transparent medium bounded with two spherical surfaces.
xii. Convex lenses have converging ability while concave lenses have diverging ability.
xiii. The converging or diverging capacity is known as power of a lens.
xiv. Human eye consists of a convex lens, whose focal length can be adjusted.
xv. Refractive defects of vision can be rectified using lens of suitable nature and focal length.
xvi. The range of vision of normal eye is from 25cm to infinity.

xvii. Splitting of composite light into its constituent colours is known as dispersion of light.

xviii. Dispersed pattern of a composite light is spectrum.

xix. Rainbow is formed by dispersion, internal reflection and refraction of solar light.

EXERCISE

1. What are the properties of the principal focus of a concave mirror ?

2. The image formed by a concave mirror is observed to be real, inverted and larger than the object. Where should be the position of the object ?

3. You are given three mirrors– convex, concave and plane appearing identical. How can you identify them without touching ?

4. Name a mirror that can give an erect and enlarged image of an object.

5. Name a mirror that can give an erect and diminished image of an object.

6. Can a convex mirror form a real image of a real object ?

7. Which spherical mirror is used for shaving ?

8. Why do we prefer a convex mirror as a rear-view mirror in vehicles ?

9. The radius of curvature of a spherical mirror is 40cm. What is its focal length ?

10. A concave mirror produce three times magnified real image of an object placed at 20cm in from of it. Where is the image formed ?

11. You are given a concave mirror, a scale and a screen. How will you determine the height of a tree ?

12. A ray of light travelling in air enters obliquely into water. Does the light ray bend towards the normal or away from the normal ? Why ?

13. Light enters from air to glass having refractive index 1.5. What is the speed of light in the glass ? The speed of light in vaccum is 3×10^{8} ms^{-1}.

14. What is refraction of light ? Illustrate with example.

15. What is refractive index of a medium ?

16. Refractive indices of Kerosene and crown glass are 1.44 and 1.52 respectively. In which medium will light propagate faster and how much faster ?

17. Which one is optically denser water of refractive index 1.33 or Kerosene of refractive index 1.44 ?

18. What is total internal reflection ?

19. What is critical angle ? How is it related to the refractive index ?
20. A convex lens forms a real and inverted image of a needle at a distance of 40cm from it. Where is the needle placed in front of the convex lens if the size of the image is equal to that of the object ? Also, find the power of the lens.
21. Define 1 dioptre.
22. Find the power of a concave lens of focal length 50cm.
23. What is meant by power of accomodation of the eye ?
24. When an object is placed before a lens the lens forms a virtual image for any position of the object. Is the lens convex or concave ?
25. Name four common defects of vision. Give the causes and remedial measure.
26. A person has to use concave lens in his spectacle. Which defect of vision is he suffering from ?
27. What type of lens is used to correct (a) myopia and (b) hypermetropia ?
28. Distinguish between real image and virtual image.
29. Convex mirrors are used as side mirror in motorcycles. Explain how they are useful.
30. Why is a convex lens called converging lens ?
31. Why can you not see an object clearly if it is placed very close to your eye ?
32. A person with a myopic eye cannot see objects beyond 2m distinctly. What should be the type of corrective lens used to restore proper vision?
33. A student has difficulty of reading the black board while sitting in the last bench. What could be the defect ? How can it be corrected ?
34. What are the far point and near point of the human eye with normal vision ?
35. What is dispersion of light ?
36. Explain the reason of twinkling the star.
37. Why does the Sun appear reddish during sunset in the month of February and March particularly?
38. To an astronaut outside the atmosphere how would the sky appear ?
39. Why do we see distant object very small ?
40. Explain the reason of advance sunrise and delayed sunset.

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CHAPTER

12

SOURCES OF ENERGY

We have learnt in the previous class that the total energy during a physical or a chemical process is conserved. Why, then, do we talk so much about the energy crisis ? The question can be answered if we recall what else we learnt about energy. We have also learnt that energy exists in different forms and one form of it can be converted to another. Let us consider some examples. If we drop a metallic plate from a height, the loss in potential energy is converted mostly into sound energy, when it hits the ground. If we light a candle, the chemical energy of the wax is converted to heat and light energies on burning. Besides, some other products are also obtained on burning. Since, the total energy during a chemical or physical change remains the same – can we put together the heat and light generated along with the products of the reaction during the burning of candle to get back the chemical energy in the form of wax ?

In another example, suppose 400ml of water at 75^0 C is kept in a room whose temperature is 25^0 C (say). The temperature of water will come to 25^0 C by losing its heat content. Is there any way of collecting the heat lost to the surrounding and making the water hot once it was cooled down ?

In the above examples we will see that energy in the usable form is dissipated to the surroundings in less usable form. That is why, we are not able to perform endless activities without thinking about the energy resources, for any process.

Hence, to do work, we use source of energy. The energy so consumed cannot be used again.

12.1 What are the various Sources of Energy ?

In our day-to-day life we use energy from various sources for doing different works. We use petrol to run cars, scooter and motor cycles etc. We also use diesel to run buses, trucks, water pump, electric generators etc. We use electricity for lighting our houses and streets. We also use energy in our muscles to perform physical works such as household works, running, cycling etc. Try to recognise the different forms of energy with which we are using in day-to-day life, as an activity.

Activity 12.1

1. List four forms of energy that you use from morning, when you wake up, till you reach school.
2. From where do we get these forms of energy ?
3. Can we call them as sources of energy ?

The muscular energy required for carrying out physical work, the electrical energy needed for using electric appliances and the chemical energy required for cooking food, for running different vehicles are obtained from different sources. Sometimes, we need to know how to select the suitable source for obtaining the required energy in its suitable form. To understand the above facts, let us try to perform the following activity.

Activity 12.2

1. Examine the various options that we should have when we choose a fuel for cooking our food.
2. What are the criteria for categorising a good fuel.
3. Would your choice be different if you live (A) in a forest ? (B) in a remote village on a mountain or island ? (C) in town or city? (D) five hundred years ago ?
4. How are the factors different in each of the cases ?

After studying the above two activities, one can see that the particular fuel or source of energy we select for performing some work depends on a number of factors. For example, while selecting a fuel for any purpose we should ask ourselves the following relevant questions. The questions are –

(i) How much heat does the fuel release on burning ?
(ii) Does it produce a lot of smoke on burning ?
(iii) Does it produce poisonous material on burning ?
(iv) Is it readily and abundantly available ?

12.2 Selection of Fuel

The selection of fuel depends on the need of the consumers. Local conditions and personnel liking also influence the consumer in the selection of the fuel. Besides, selection of fuel depends on the work to be done. Would we choose one fuel for cooking and another for heating the room in winter or cold season ?

Thus a good source of energy would be one

(i) Which would do a large amount of work by burning unit volume or unit mass of it,

(ii) be easily accessible or available in plenty,

(iii) be easy to transport and handle,

(iv) be easy to store i.e. it should need less space for storage, and

(v) be economical

Try to answer

1. What is a good source of energy ?
2. What are the characteristics of a good fuel ?

12.3 Conventional Sources of Energy

The simplest, earliest and the most common use of energy by man has been in the form of the energy stored in muscles of his body. The next use of energy by man was in the form of fire. In ancient times wood was the most common source of heat energy. Man next learnt to harness the energy of moving water and wind (i.e. the moving air). The energy so obtained was used for limited activities. Try to find out some of these uses. Next, the exploitation of coal as a source of heat and other forms of energy made the industrial revolution possible. Increasing industrialization has resulted to a better quality of human life all over the world. As a result, the global demand for energy is at a tremendous rate. The growing demand for energy was met on a larger scale by the fossil fuels – coal and petroleum. For India coal is the backbone of national economy and is a source of energy in key industries like railways, steel and thermal power plants. Our technologies were also developed for using coal and petroleum.

But the fossil fuels (coal and petroleum) were formed over millions of years ago on the earth and there are only limited resources because of the finite size of the earth.

Fossil fuels are preserved in the earth's crust as remains of animals and plants. The main fossil fuels are (i) coal (ii) petroleum and (iii) natural gas. Thus, the fossil fuels are non-renewable sources of energy. So we need to conserve them. Experts are of the opinion that if we were to continue consuming these sources of energy at the present alarming rates, we would soon run out of these sources of energy. In order to avoid this, alternate sources of energy were explored by scientists. However, we still continue to be largely dependent on fossil fuels for most of our energy requirements. The situation can be understood from the pie-chart given in figure 12.1.

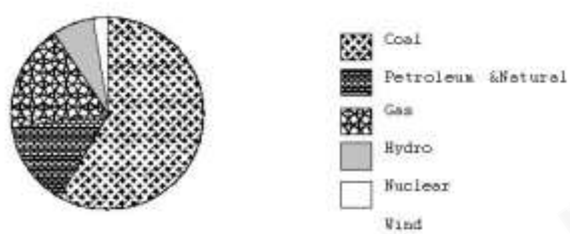


Figure 12.1

The burning of fossil fuels has many disadvantages since the end products of combustion enter into the air. We learnt in class IX, about the air pollution caused by burning of coal or petroleum products. These are mainly oxides of carbon, hydrogen, nitrogen and sulphur, which are acidic oxides. These oxides introduced in the atmosphere are the cause of acid rain which affects our water and soil resources. The unburnt particles of carbon and hydro carbons also enter into the atmosphere. These substances deteriorate the quality of air and the air is said to be polluted. Breathing in such air is harmful. In addition to the problem of air pollution, recall the green house effect, caused by excessive release of carbon dioxide.

Now-a-days, the pollution caused by burning of fossil fuels can be somewhat reduced by increasing the efficiency of the combustion process. This is done by using various techniques to reduce the escape of harmful gases and ashes into the surroundings. Fossil fuels are used directly in gas stoves and vehicles. Moreover, the major fuels used for generating electricity are fossil fuels, inspite of pollutions caused by burning them.

Let us think over for a while – how would our lives change if we could no longer get electricity ? The amount of electricity consumed by each individual in a country is one of the parameters to measure the growth of the country.

Potential energy of a water body stored at a height is another traditional source of energy. Hydel power plants convert the potential energy into electricity. The natural water reservoir or water falls which could be used for this plant is very few. So, hydro-power plants are associated with dams. High rise dams are constructed on the river to collect water in larger reservoirs. The water from the higher level is allowed to run down through a pipe. The potential energy in the stored water is changed into kinetic energy. This kinetic energy is used to move the turbine of the generator. Thus electricity is produced.

The reservoir would be refilled when there is rain. It is a natural process of water cycle. Thus hydro-power plant is a renewable source of energy.

Construction of big dams have certain problems. Large areas of agricultural land and human habitation are to be sacrificed as they get submerged. Large eco-systems are destroyed when submerged under the water. When the vegetation are submerged they rot under anaerobic condition and give rise to large amount of methane which is also a green house gas.

12.4 Improvements in the Technology for using Conventional Sources of Energy

About 80% of the energy consumed by the rural mass in India is based on biomass. The material contained in the bodies of plants and animals is called biomass. When plants die, their biomass can be used as fuel for domestic purposes. In our homes, we burn wood in the traditional Chullas which have poor efficiency of about 8 percent only. At the same time it leads to health hazards from the smoke coming out due to incomplete combustion. The above problems are overcome in smokeless Chullas which allow better combustion and have better efficiency. The smoke, at the same time is removed through chimney attached to it. Charcoal is also used as fuel for domestic and industrial purposes. Charcoal is made by burning wood in a pit where the supply of air is insufficient. In doing so, volatile matters in the wood are drawn off leaving behind a residue black in colour. This black residue is charcoal. Charcoal is mainly carbon.

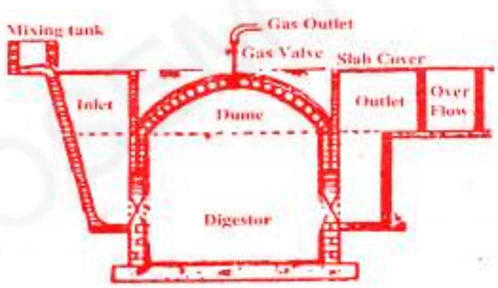
Dried animal dung cakes are also used as domestic fuels in rural areas. When they burn with insufficient supply of air a lot of smoke is produced. This leads to air pollution. At the same time animal dung contains a lot of nutrients vital to soil. It is, therefore, unwise to burn animal dung cakes directly. In order to save the vital nutrients from the animal dung for use in agriculture and to reduce the air pollution to some extent, bio-gas plants have now been designed and are used in rural and some sub-urban house-holds.

The wastes from animals and plants, what we called as biomass can be degraded easily by anaerobic organisms in absence of air but with water. In this process, organic manure which is better than the dry cattle dung and mixture of gases such as methane, carbon dioxide, hydrogen, hydrogen sulphide are produced. The gas mixture is called the biogas. Biogas mainly contains methane about 65 to 75 percent. It is an excellent fuel. It burns without smoke, leaving no residue like ash in wood, charcoal and coal burning. Its heating capacity is high. Bio-gas is also used for lighting. By converting biomass into biogas heating efficiency is increased by about 20 percent.

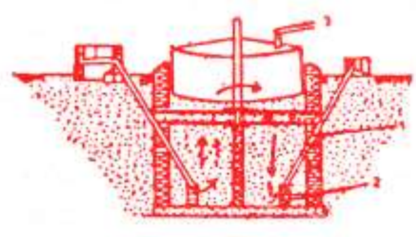
The slurry left in the plant after the gas is withdrawn is rich in phosphorous and nitrogen compounds and is a good quality manure.

Taking due considerations of the above advantages, Khadi and village industries Corporation and other government agencies actively promote the construction of biogas plants. In a country like India having largest cattle population, there is tremendous scope for community size biogas plants which can meet a large percentage of domestic energy needs in the rural areas. This would reduce pressure on chemical fertilizers, stress on forest and other fossil fuels.

There are two types of biogas plants. They are fixed dome type and floating gas holder type.



Fixed dome



Floating gas holder

Figure 12.2

In both the types, thin semiliquid mixture of animal dung and water is put into the plant. Human excreta can also be added in the mixture. The biogas so produced is drawn off through pipes for use at specific points. For continuous supply of it, the plant needs regular supply of biomass. In big cities where underground sewage facilities exist, sewage gas – a mixture of methane and carbon dioxide may be collected. Out of this mixture methane gas may be separated out for using as fuel.

12.5 Alternative or Non-Conventional Sources of Energy

Our life -style is changing. We are using machines to do more and more work for us. Our demand for energy increases day by day. Our basic requirements are also increased. So, we need to look for more and more sources of energy. To develop the technology for using the available or known source of energy more efficiently and to look to new sources of energy are two main areas to pay our attention. Any new source of energy we seek to exploit would need specific devices developed with that source in mind. We shall now look at some source of energy that we seek to tap and the technology designed to capture and store energy from that source.

Solar Energy

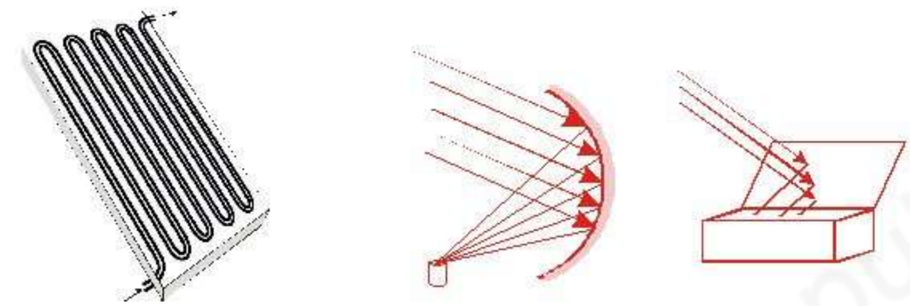
We are receiving the energy from the sun in the form of light energy and heat energy. The quantity of solar energy reaching the earth's upper atmosphere has been estimated at about 1.39 $kJ/m^2/s$. The total solar energy of all wavelengths received per unit time by a surface of unit area oriented normally to the Sun's rays at the top of the earth's atmosphere is called **Solar constant**. Thus, the solar constant is 1.39 $kJ/m^2/s$. It has been calculated that energy received over the total surface of the earth amounts to 3.57×10^{14} kJ/s, roughly 20,000 times larger than the current global energy consumption. The energy is absorbed by numerous atmospheric particles. The total incoming radiation may be divided into direct radiation and diffused or indirect radiation resulting from scattering in the atmosphere and earth's surface. The maximum influx on the average is about 4 to 7 kWh/m^2. The heat that we feel in sunlight is mainly due to the presence of infra-red wavelength in sunlight and it heats up the land and water on the surface of earth. How can you tap this huge amount of energy ? To understand it a little more let us perform the following activity.

Activity 12.3

1. Take two bottles of the same capacity.
2. Paint one white and the other black (or wrap one with white paper and the other with black paper)
3. Fill both the bottles with the same quantity of water.
4. Place the bottles in direct sunlight for an hour.
5. Touch the bottles. Which one is hotter ?

Can you think of ways in which this finding could be used in your daily life .

A black surface absorbs more heat as compared to a white surface. Solar cookers and solar water heaters are designed using this principle. A solar cooker may have solar heat collector. Solar collectors may be divided into two types – (i) Concentrating or focussing type and (ii) flat or non-focussing type.



(a) Solar water heater *(b) Solar collector (concentrating type)* *(c) Solar collector (flat reflector type)*

Figure 12.3

The reflector is made of foils of aluminium or almuminised plastics or strips of mirror and the pot used of cooking may be of aluminium or stainless steel. The outer surface of the cooker is coated with lamp black or nickel black. Solar cookers are covered with glass plate to trap the heat more by green house effect also.

These devices are useful only at certain times during the day, when there is sunshine.

Solar energy can be used to generate electricity

Heat produced by the sun's rays can be used to generate electricity indirectly. In this process, solar energy is used to heat a liquid of low boiling point. The resulting vapour is made to turn turbines which are connected to generators. One such example is Abhimanyu solar pump developed at the National Physical Laboratory, New Delhi, which can generate 1 kW of electricity. At present the use of these engines is rather limited.

In another way, sunlight can be used to generate electricity with the help of light sensitive cells known as solar cells or solar batteries. Such devices are also called photo voltaic devices. These cells are used most often in space vehicles and artificial satellites to power their electrical devices and electronic instruments.

Solar batteries were developed for the first time by the scientists of the Bell Telephone Laboratories, America. Now-a-days, Central Electronics Limited (CEL), India has developed solar batteries. It is made up of a number of cells. Each cell consists of a wafer of pure silicon, to which certain impurities have been doped. In other words, they are solid state semi-conductor devices which convert solar energy directly into D C (direct current) electrical energy. Because of limitations on the maximum voltage and current of a single solar cell a number of solar cells are connected in series and then arranged in parallel resulting to a mixed grouping of cells. Such a combination is known as panel. The panel is finally covered with glass in order to protect the cells from the atmosphere and dust. To use the electricity during the night time and on cloudy days when there is no direct sunshine, the electrical energy is stored in accumulators or secondary batteries. The stored electrical energy is used again in the night or in cloudy periods. This system is very much useful in remote unelectrified villages.

Wind Energy

Figure 12.5

Wind is nothing but the air in motion. The movement of air is also due to the convection current set up in the atmosphere on account of non-uniform heating of the earth's surface by the sun. There are both horizontal and vertical motions of air. What we call wind is mainly the horizontal movement of the air near the earth's surface. We are primarily interested in it.

Earlier wind power was used for propulsion of ships or directly converted into mechanical energy to lift water, to grind corn and for agricultural uses. For the use of wind power to generate electricity, the kinetic energy of the wind is to be converted into some convenient form of mechanical motion which in turn will drive the shaft of an electric generator. For the purpose there is a wind turbine mounted upon a tower Figure 12.5. The kinetic energy of the wind is used to provide rotatory motion of the wind turbine which can be used to do work. The other equipments like gear boxes, speed control devices, safety devices and electrical generators may be mounted on the tower. The diameter of the turbine and height of the tower are designed to suit the wind velocity in the region of installation and the power requirement. It is known that at higher points above the earth's surface, the wind is steady and has greater velocity.

The power available from the wind depends on :

(i) the area of the blade circle, **(ii)** density of the air, and **(iii)** cube of the wind velocity.

The output of a single wind mill is quite small and cannot be used for commercial purpose. Therefore, a number of wind mills are erected over a large area, which is known as wind energy farm. The energy output is coupled together to get electricity on a commercial scale.

The merits of using wind energy are :

(i) It is an environment friendly effort.

(ii) No recurring expenses for energy production required.

The limitations in harnessing wind energy are :

(i) Wind energy farms can be established only at selected places where wind blows for the greater parts of a year with a speed higher than 15km/h to maintain the required speed of the turbine.

(ii) Establishment of wind energy farm requires large area of land.

(iii) There should be enough back up facilities like storage cells.

(iv) Initial cost of establishment of the farm is quite high.

(v) Since the equipments are exposed outside, they need proper maintenance.

It is estimated that nearly 45,000 MW of electrical power can be generated if India's wind potential is fully exploited. The largest wind energy farm in India is located at Kanyakumari in Tamil Nadu. It generates 380 MW of electricity. In the case of Denmark wind energy, from a vast network of wind mills, claims more than 25% of the total electricity used in the country.

Energy from the Sea

Tide is a natural phenomenon occurring periodically on the sea. It creates the difference of water level on the sea. Thus Tidal energy is developed. Can you think how to tap the energy there ? Sea water is never at rest. Sea water has a huge amount of kinetic energy. Would it be possible to tap the energy associated with sea wave?

The water at the surface of sea or ocean is heated by the sun while water in the deeper section is relatively cold. This difference in temperature is exploited to obtain energy in ocean thermal energy conversion plants. The difference of temperature is about 20^0 C at the depth of 2km. The heat in the surface water is used to boil a volatile liquid like ammonia. The vapour of the liquid are then used to run the turbine of generator. Cold water from the depth is used to condense the vapour again to liquid.

The potent energy of the sea is quite large, but efficient commercial exploitation is yet to be worked out.

Geothermal Energy

Have you heard about hot springs ? Sometimes the molten rocks in the deeper regions of earth's crust are pushed up and trapped in certain regions as hot spots. When underground water comes in contact with the hot spot steam is generated. Some of the hot water and steam may find outlets at the surface. They are found in the form of hot spring. Still a large amount of steam remains trapped in the rocks. When the steam is rooted through a pipe to a turbine of a generator, electricity can be produced. The site where such energy can be exploited on the commercially viable project is very limitted. There are a number of power plants based on geothermal energy operational in New Zealand and United States of America.

Nuclear Energy

What is nuclear energy ? The energy released during nuclear reaction is called nuclear energy. There are two types of nuclear reactions. They are (i) nuclear fission and (ii) nuclear fusion. In nuclear fission the nucleus of a heavy atom (such as uranium, plutonium or thorium) is splitted into two lighter nuclei with the help of slow moving neutron. In this process a huge amount of energy is released. The sum of the masses of the product nuclei is less than the mass of the original nucleus. The mass lost is converted into energy. In nuclear reactors the amount of energy released is controlled and used to run the turbine of electric generator.

In nuclear fusion two energetic light nuclei fuse together to make a heavy nucleus with the release of huge amount of energy. In this process also the lost of mass of the interacting nuclei is responsible for the production of the huge amount of energy. Nuclear fusion is responsible for the energy in the sun and the star. To control the fusion reaction for the production of electricity for our use is yet to achieve. Still, nuclear energy cannot be used in large scale on the following grounds (problems). Storage and disposal of spent or used fuel is a major problem. Harmful radiation from the nuclear waste cause damage to the human body and environment. Improper nuclear-waste storage and disposal result in environmental contamination. Further, there is a risk of accidental leakage of nuclear radiation. The high cost of installation is also an additional problem.

We have studied various sources of energy either conventional or non-conventional. Exploiting any source of energy disturbs the environment in some way or the other. We always choose the source depending upon the following factors –

(a) the ease of extracting energy from the source.

(b) the economics of extracting energy from the source.

(c) efficiency of the technology available.

(d) the environmental damage that would be caused by using the source.

POINTS TO REMEMBER

i. Muscular energy, electrical energy, chemical energy etc. are obtained from different sources.

ii. Energy from wood, fossil fuel, hydel power plants are conventional sources of energy.

iii. Improvement in the technology of using conventional sources of energy is highly needed.

iv. Use of solar energy, wind energy, tidal energy, geothermal energy etc. are non-conventional sources of energy.

v. While selecting a fuel we have to consider the easiness of extracting energy from the source, cost of extraction, efficiency of technology available and impact on environment.

EXERCISE

1. What is a good source of energy ?

2. What is a good fuel ?

3. If you could use any source of energy for heating your food, which one would you use and why ?

4. What kind of mirror – concave, convex or plain would be best suited for use in a solar cooker? Why ?

5. What is geothermal energy ?

6. Can any source of energy be pollution free ? Give reason in support of your answer.

7. Name two energy source that you would consider to be renewable. Give reasons for your choice.

8. Give the name of two energy sources that you would consider to be exhaustible. Give reasons for your choice.

9. What are the qualities of an ideal source of energy ?

10. What are the advantages of using a solar cooker ? Are there places where solar cookers would have limited utility ?

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