UNIT

4

ELECTRICITY

4.1 Introduction

Student, have a look at the drawing room of your house. You will see the appliances like television, fan, tube light etc. Now if you look at your kitchen you will find the appliances like refrigerator, microwave oven, mixer etc. If you peep into your study room you may see the instruments like computer, air conditioning machine. In all these appliances, the common thing is that they all are operated by electricity (electical energy). Now imagine that the electrictiy fails in our house ! Our situation will be worse. The electricity empowers the places like schools, offices, industries, hospitals etc. In modern age, the electrical energy among the different forms of energy has more importance in creating luxurious lives for human beings. Electrical energy can easily be stored as well as it can be easily transformed into other forms of energy.

In the present chapter, we shall study the concept of physical quantities like electric current, electric potential, resistance etc. Also we shall get some information about electrical energy and its uses.

Firstly, we shall know about the foundation stone of electricity namely an electric charge.

4.2 Electric Charge

We have studied in Standard 8 that the small pieces of papers can be attracted by a plastic comb after combing through dry hair. Similarly, the attractive force results when a glass rod rubbed with a silk and a plastic rod rubbed with a fur. In this process, the charges resulting on the glass and plastic rod are of opposite type. During the friction, the glass rod acquires positive charges while the plastic rod acquires negative charges.

Thus, the electric charges are of two types : Positive electric charge (proton) and negative electric charge (electron). Electric charge is an intrinsic property of electron and proton like mass, which is difficult to define.

In SI unit system, charge is measured in coulomb (C). Conventionally electric charge of proton is considered positive and the electric charge of electron to be negetive. But their magnitudes are the same.

Charge on proton e = 1.6×10^{-19}C

Charge on electron e = -1.6×10^{-19}C

During the interaction among the electric charges, repulsive force is exerted between two like charges (e.g. electron-electron or proton-proton) and the attractive force is exerted between two unlike charges (e.g. electron-proton). The magnitude of electric force between the charges can be calculated from the law devised by French Scientist Charles Coulomb which you will study in Standard 12.

4.3 Electric Current

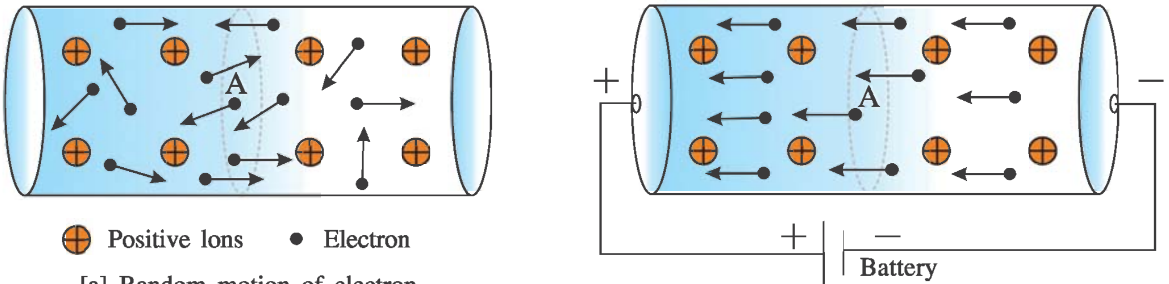
We are familiar with the flow of water. The quantity of water flowing in the river is called water current. Similarly, the amount of charge flowing through the conductor (e.g. Copper wire) is known as electric current.

In atoms, the electrons move around the nucleus whereas the protons remain binded. In the atoms of metallic materials, under the normal circumstances the attractive force between the valence electrons (electrons of the outermost orbit) and the nucleus (positive electric charge) is comparatively very small.

During the formation of metallic materials, these electrons get separated from their parent atoms and move in a random manner. Such electrons are known as 'Free electrons.'

Such free electrons are responsible for the conduction of electric current. Metallic materials like copper, silver and aluminium have plenty of such free electrons. The conduction of an electric current can easily take place in such materials. So they are called "Conductors." The materials like rubber, glass, plastic do not have free electrons so the conduction of electric current through them is not possible. So they are called "Insulators."

In Figure 4.1 (a), the random motion of free electrons in a conducting wire is shown. The motion of electrons is uniform in all the directions. Now think about any one cross-section A which is perpendicular to this conducting wire. In any given interval of time, the number of electrons moving to the right side of cross-section equals to that moving to the left, so that the net quantity of electric charge passing through cross-section is zero. Therefore, the electric current is not formed even though there is a motion of free electrons in conducting materials. As shown in Figure 4.1 (b), if the energy is provided to the conducting wire through the battery, the flow of free electrons can be obtained in a conducting wire from negative terminal to positive terminal of battery. Thus, the net quantity of electric charge passing through the cross-section A does not remain zero and the electric current is said to be formed in a conductor.



[a] Random motion of electron

[b] Electron current

Fig. 4.1 Electric current in a conductor

Earlier, scientists believed that the electric current results only due to the motion of positive charges, so the direction of motion of positve electric charges, was considered as the direction of electric current. But after the invention of an electron by J.J. Thomson (1856-1940), it was to know that the electric current in the conductors results due to the motion of electrons. At present, we also take the direction of electric current in the direction of motion of positive electric charge which is known as conventional electric current. Thus, the direction of conventional electric current is oppsite to the direction of flow of electrons.

After this primary explanation we shall define electric current.

"Electric current means rate of flow of an electric charge."

That means, the net quantity of an electric charge flowing through any cross section of conductor is defined as electric current.

$$\text{Thus, electric current} = \frac{\text{Quantity of electric charge}}{\text{time}}$$

If Q is the amount of electric charge passing through any cross section of conductor in time t,

$$I = \frac{Q}{t} \qquad \text{... ... ... (4.1)}$$

Thus from above equation (4.1), if the quantity of electric charge equals to one coulomb passing through the conductor in one second, the electric current of one ampere (1A) is said to flow through the conductor.

In SI system, the unit of electric current is coulomb/second (C/s). In the name of French Scientist Andre Ampere, it is also represented in Ampere (A)

The small units of electric current are milliampere mA and microampere (μA)

$$1 \text{ mA} = 10^{-3} \text{ A}$$

$$1 \ \mu\text{A} = 10^{-6} \text{ A}$$

The electric current flowing through the conductor is measured by an instrument called 'Ammeter.'

If the number of electrons passing through the cross-section of conductor in time t equals to n, then the quantity of charge passing through the cross-section will be

$Q = ne$

Equation (4.1) can also be represented as

$$I = \frac{ne}{t} \qquad \text{... ... ... (4.2)}$$

where $e = 1.6 \times 10^{-19}$ C, charge of an electron.

Illustration 1 :

If an electric bulb burns on 0.5 A current for 1 hour, how much electric charge will pass through it ? ($e = 1.6 \times 10^{-19}$ C)

How many electrons will pass through it ?

Solution : I = 0.5 A, t = 1 Hour = 3600 s

From equation (4.1)

$$Q = I \times t$$
$$= 0.5 \times 3600$$
$$= 1800 \text{ C}$$

From $Q = ne$

no of electron passing through the bulb

$$n = \frac{Q}{e}$$
$$= \frac{1800}{1.6 \times 10^{-19}}$$
$$= 1125 \times 10^{19} = 1.125 \times 10^{22} \text{ electrons}$$

Illustration 2 :

While connecting a torch with battery, an electric current of 64 mA flows through the bulb. If this torch glows for 10 min, how may electrons will pass through the bulb ?

(charge of electron = e = 1.6×10^{-19} C)

Solution : $I = 64$ m A $= 64 \times 10^{-3}$A, $t = 10$ min $= 10 \times 60 = 600$ s, $e = 1.6 \times 10^{-19}$ C

Electric current $I = \dfrac{ne}{t}$

No of electrons $= \dfrac{I \times t}{e}$

$$n = \frac{64 \times 10^{-3} \times 10 \times 60}{1.6 \times 10^{-19}}$$
$$= 24000 \times 10^{16}$$
$$n = 24 \times 10^{19} \text{ electrons.}$$

4.4 Electric Potential and Electric Potential Difference

Electric Potential : We have seen that the flow of electric charge is necessary to obtain an electric current. How can this electric charge be made to flow in a conductor ?

To understand this, we shall first understand the flow of water.

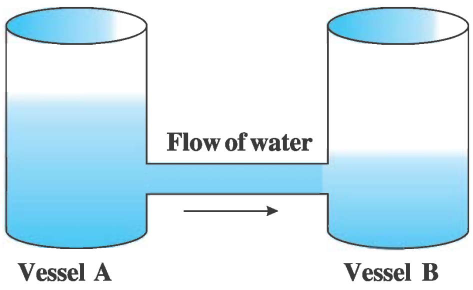


Fig. 4.2 Flow of water

As shown in Figure 4.2, pour more amount of water in vessel A and less amount of water in vessel B. Now when these vessels are connected through a tube, the water flows from vessel A to vessel B.

Here, the water pressure is more in vessel A and the water pressure is less in vessel B.

Thus due to the pressure difference, the water flows through the tube.

In the similar way, if we produce the electrical potential difference, then the electric current can be obtained. This difference in the electric potential is known as electric potential difference. We shall discuss electric potential first.

On bringing some electric charge near any other charge, an attractive or repulsive force exerts on it. Thus, the work is to be done against this force keeping a charge in equilibrium and to move another near or far from it. This work is stored in the form of potential energy. This work done on the charge is called as an electric potential. Electric potential is defined as under :

"The work required to bring the unit positive charge from infinity to any point against the electric force is known as electric potential at that point."

$$\text{Electric potential} = \frac{\text{Work done (W)}}{\text{Electric charge (Q)}}$$

Electric potential is represented in voltage in the memory of Italian Scientist Alexandro Volta. Its symbol is V.

$$\therefore V = \frac{W}{Q}$$

The SI unit of electric potential is joule/coulomb or volt (V).

Electric potential difference :

In practice, electric potential has no importance, but changes in electric potential are important which are defined as under :

"The electric potential difference between any two points A and B in an electric field means the work done to bring the unit positive charge from point A to B against the electrical force."

$$\text{Electric potential difference (V)} = \frac{\text{Work to be done (W)}}{\text{Electron charge (Q)}}$$

$$\therefore V = \frac{W}{Q}$$

Electrical potential difference, in general, is known as voltage. Its SI Unit is joule/coulomb or volt.

If the work done to bring 1 coulomb electric charge from one point to other is 1 joule, then the potential difference between these two points is called 1 volt.

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

The electric potential difference is measured with the device called **voltmeter.** The voltmeter is connected in parallel across two points of which the potential difference is measured.

Now, we shall understand from the activity that how potential difference is produced from the battery.

Activity : 1

Volta's Cell :

As shown in Figure 4.3, take solution of dilute sulphuric acid (H_2SO_4) in a beaker. Dip one copper plate and another zinc plate in the solution in such a way that they do not touch each other. These two plates get electrically charged due to the process between these two plates and the solution. The positive charge at copper plate and negative charge at zinc plate get deposited. Thus electric potential difference is produced between two plates. Positive charge plate is called positive pole of battery or anode and the negatively charged plate is called negative pole of battery or cathode. Such simple battery was invented by Italian Scientist Alexandro Volte (1745-1827). Therefore it is also known as Volta's cell.

Now connect a small bulb between these two poles of a battery. See what happens.

You will see that the bulb will light up. Here the electrons leaving negative terminal of battery move towards positive pole of battery by forming an electric current in the bulb. The bulb lights up due to this electric current. Thus, in bulb the electron flows from negative to positive pole. But the direction of conventional current is opposite to flow of electron, so it is said that it flows from positive toward negative pole of battery.

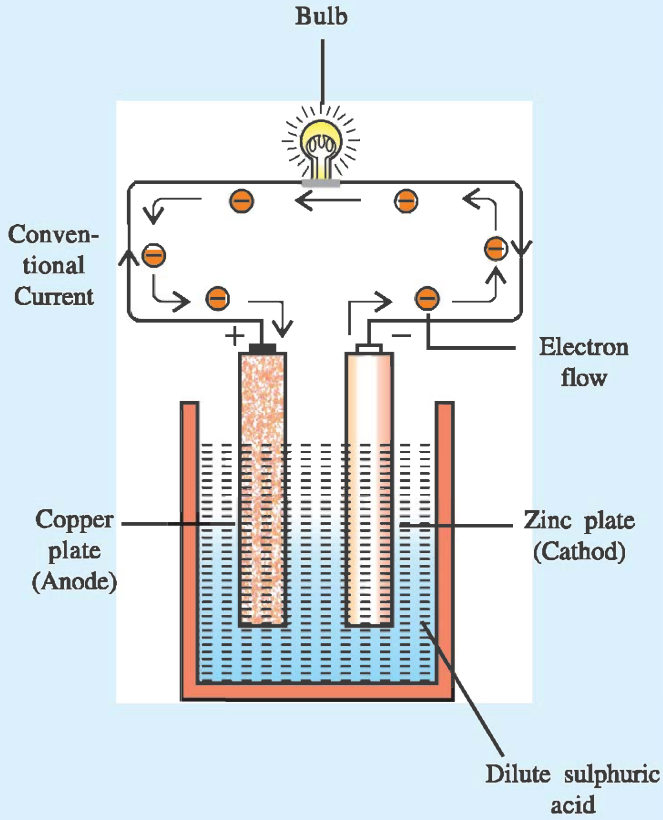


Figure 4.3. : Volta's electric cell

The electrons deposited at anode go back to cathode by taking energy form chemicals and enter the conductor. Thus, the function of battery is to give energy to electrons continuously and to flow the electric current continusly by keeping them in motion.

Thus, volta's cell converts chemical energy into electrical energy. By connecting more than one batteries in series the large electric potential is obtained and large amount of current is obtained in a conductor

Illustration 3 :

How much work is to be done to take 2 C electric charge form the potential of 6 V to the potential of 12 V ?

Solution : Q = 2 C

Electric potential difference V = 12 V − 6 V = 6 V

$$\text{Now} \quad V = \frac{W}{Q}$$

$\therefore$ Work W = VQ = 6 × 2 = 12 J

4.5 Electric Circuit and Symbols

When electrical components such as battery, key, bulb, etc are connected through a conducting wire, then such an arrangement is called electric circuit. The electric bulb glows due to the formation of close loop of circuit. In the following Figure 4.4, electric circuit is shown by representing electrical components with their symbols :

The useful symbols for electric circuit are given in the following Table 4.1

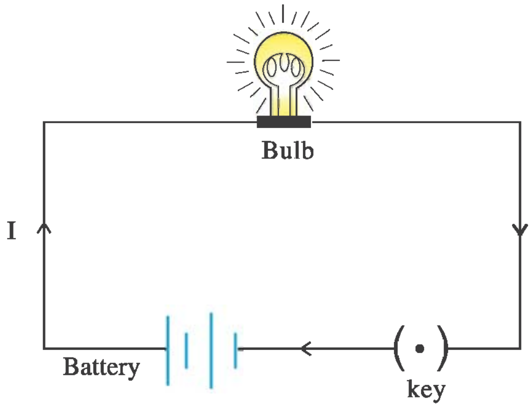
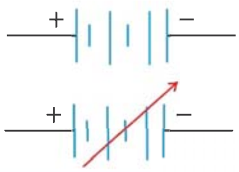
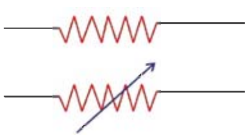
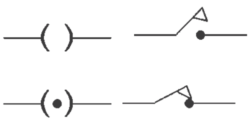
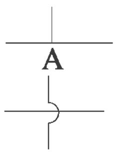
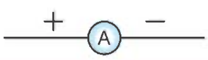
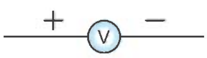


Figure 4.4 Simple electric circuit

Table 4.1 Some useful symbols for electric circuit

No.	Component	Symbol	Description
1.	Electric cell		Gives electrical energy to circuit
2.	Battery (Combination of electric cells)		Gives electrical energy to circuit Variable battery whose voltage value can be changed as per need
3.	Resistance		Provides resistance in the path of electric Current Variable resistor
4.	Key		Key (When open) Key (When closed) It is used to switch on or off.
5.	Connection of conducting wire		Two conducting wires connected at A Two wires passing above each other but not connected.
6.	Galvanometer		Device to detect the presence of electric current
7.	Ammeter		Device to measure an electric current
8.	Voltmeter		Device to measure electric potential difference

4.6 Ohm's Law

Is there a relation between the current (I) passing through the conductor and the potential difference (V) resulting across two ends ? German scientist George Ohm (1789-1854) derived the relation between current (I) and voltage (V) which is known as ohm's law. Perform the following activity to understand this relation.

Activity : 2

For this activity, take 0.5 meter long nichrome wire, four to five batteries of 1.5 V, Voltmeter, Ammeter and key.

As shown in Figure 4.5, first connect nichrome wire (Nichrome is an alloy of nickel, chromium, manganese and iron) with 1.5v battery and ammeter. Now connect the voltmeter between its two ends.

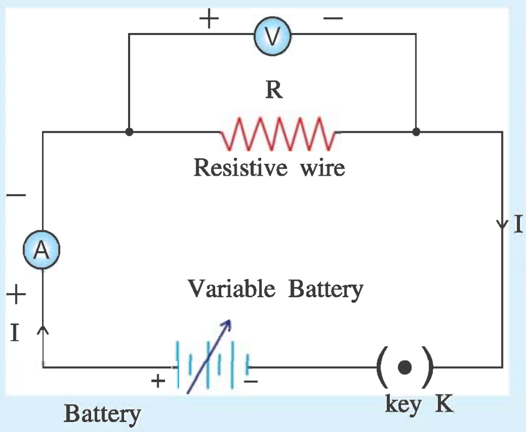


Fig. 4.5 Electric circuit for ohm's law

This experiment can also be perfomed by connecting bulb instead of nichrome wire. Now when the key is on, the electric current will flow through the wire. Measure the magnitude of the current in ammeter and the potential difference across its two ends in voltmeter and note in the observation table. Now connect two batteries instead of one and note the magnitudes of current (I) and voltage (V). In this way, repeat the experiment by connecting three batteries and there after four batteries.

Observation table :

Number	No of Batteries	Voltage across two ends of wire (V)	Current flowing through wire (I)	V/I
1	1			
2	2			
3	3			
4	4			

Now, from the observations, draw the graph of I versus V. What is the type of this graph ?

This graph will be a straight line passing through the origin (Figure 4.6).

The following points are concluded from the graph :

(i) The electric current in the conductor increases in same proportion with the increase in voltage.

(ii) I – V graph is a straight line.

(iii) The ratio of V and I remains constant every time.

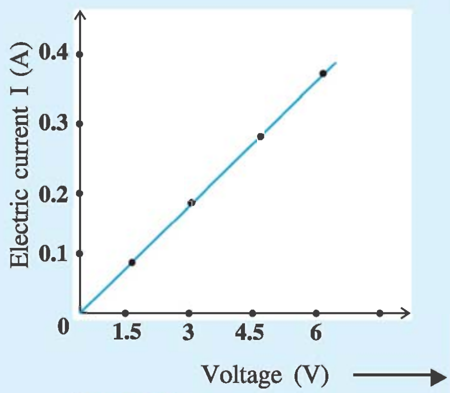


Fig. 4.6 Graph of I versus V

From this type of experiment, Ohm deduced the relation between electric current (I) and voltage (V) which is termed as Ohm's Law. It is stated as under.

Ohm's Law : "In the definite physical situation the electric current flowing through the conductor is directly proportional to the potential difference applied across it.

That means, $I \propto V$

It is also written as, $V \propto I$

$\therefore V = IR$

Where the proportionality constant R represents the resistance of the circuit.

From above equation,

$$\text{Resistance (R)} = \frac{\text{Voltage (V)}}{\text{Electric current (I)}}$$

The SI unit of resistance is volt/ampere which is known as 'ohm'. Its symbol is Ω(omega).

$\therefore$ 1 ohm = 1 volt / 1 ampere

When 1 volt potential difference is applied across the conductor and 1 ampere current flows through it then resistance of the conductor is said to be 1Ω.

The symbol —/\/\/\/\/— is used to represent the resistance in the electrical circuits.

The resistance of substance depends upon the kind of substance and its physical situation (e.g. temperature). In metallic substance, the resistance increases with the increase in temperature. In a conductor, the free electrons collide with the positive ions during their motion so that their motion gets opposite. Thus, the motion of electrons means the motion of electric current get opposed which is called resistance of conductor (R).

The metallic substance such as Copper, Aluminium have less resistance. Therefore, we use the copper wire as a conducting wire. The resistance of insulators is very large. The alloys like nichrome are used to make resistive wires. The resistors used in instruments like TV, Radio etc are made from the mixture of carbon and graphite.

Illustration 4 :

If an electric bulb connected to 220 V line draws an electric current of 0.5 A, then what will be the resistance of filament of a bulb ?

Solution : I = 0.5 A, V = 220 V

According to ohm's law, $R = \frac{V}{I} = \frac{220}{0.5} = 440\ \Omega$

Illustration 5 :

When an electric heater is applied 120 V, an electric current of 2 A passes through it. If the heater is applied 240 V, how much electric current will flow through it ? What will be the resistance of the coil of a heater ?

Solution : $V_1 = 120$ V, $I_1 = 2$ A, $V_2 = 240$ V, $I_1 = ?$

Resistance of heater coil $R = \frac{V_1}{I_1} = \frac{120}{2} = 60\ \Omega$

Now, according to Ohms' law, $R = \frac{V_2}{I_2}$

$$\therefore I_2 = \frac{V_2}{R} = \frac{240}{60} = 4\ A$$

4.7 Resistivity

Activity : 3

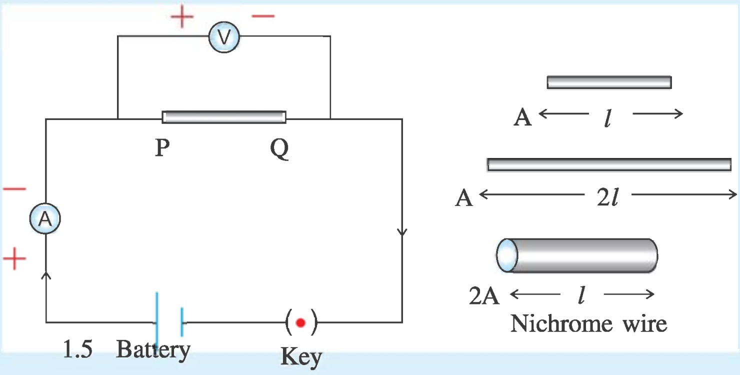


Fig. 4.7. The effect of resistance on its size.

(i) As shown in the Figure 4.7, connect the resistance wire (nichrome wire) of cross section (A) and length *l* (e.g. 0.5 m) in the circuit between the points P and Q. Now measure the current (I) and voltage (V) by closing a key and determine the resistance R_1 from equation R = V/I.

(ii) Now connect the resistive wire of cross section A and length 2*l* (1m) in the circuit and determine its resistance as R_2.

(iii) In the same way take the resistive wire having cross-sectional area 2A and length *l* and determine its resistance as R_3.

Give your conclusions about R_1, R_2 and R_3.

In the activity, you will get $R_2 = 2\ R_1$.

In this case, the area of cross section of wire is double, so its resistance is doubled. Now, for the resistance R_3, you will get $R_3 = \frac{R_1}{2}$. In this case, the length of wires *l* is the same, but the area of cross section of the third wire is twice compared to that of the first one. Therefore, its resistance to be obtained is half to that of R_1.

Thus, the magnitude of resistance depends upon the type and also on size of material.

The resistance of any conduction substance is directly proportional to length and inversely proportional to area of cross section of the substance.

If the length of conductor and its area of cross-section are represented as l and A respectively then,

$$R \propto l, \quad R \propto \frac{1}{A}$$

$$\therefore R \propto \frac{l}{A} \qquad \therefore R = \rho \frac{l}{A}$$

Here, ρ is called the resistivity of conducting material. From above equation $\rho = R\frac{A}{l}$

$$\text{The unit of } \rho = \frac{\text{Unit of resistance} \times \text{Unit of area}}{\text{Unit of length}}$$

$$= \frac{\Omega \times m^2}{m} = \Omega m$$

Table 4.2 represents resistance of some metals, semi-metals and insulators :

Table 4.2 Resistivity of some substances (at 20°C)

Type	Substance	Resistivity ρ (Ωm)
Metals	Aluminium	2.63×10^{-8}
	Copper	1.62×10^{-8}
	Silver	1.6×10^{-8}
	Iron	10×10^{-8}
	Tungsten	5.2×10^{-8}
Alloys	Manganin	44×10^{-6}
	Nichrome	100×10^{-6}
Insulators	Glass	$10^{10} - 10^{14}$
	Rubber (Hard)	$10^{13} - 10^{16}$
	Diamond	$10^{12} - 10^{13}$
	Paper (dry)	10^{12}

It is clear from Table 4.2 that the resistivities of conductors and alloys are less whereas it is very large for insulators. The resistivity of elements such as silicon (Si) and germanium (Ge) is more than conductors but less than insulators. So they are called semiconductors. Such elements are widely used in the fabrication of electronic components.

Illustration 6 : The resistance of a resistive wire having length l and area of cross-section A is 4 Ω. If the length of same type of wire is $l/2$ and the area of cross-section 2A, what will be the resistance of wire ?

Solution : For the first wire, $R = \rho \frac{l}{A}$, for the second wire, $R' = \rho' \frac{l'}{A'}$ From $l' = \frac{l}{2}$ and A' = 2A

$$\therefore R = \rho \frac{l/2}{2A} = \frac{1}{4} \rho \frac{l}{A} = \frac{1}{4} \times R = \frac{1}{4} \times 4 = 1\Omega$$

Illustration 7 :

The resistance of copper wire of length 2 m and 1.7 × 10^{-6} m^2 area of cross-section is 20×10^{-2} Ω. What is its resistivity ?

Solution : $l = 2$ m, $A = 1.7 \times 10^{-6}$ m^2, $R = 2 \times 10^{-2}$ Ω

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

$$\therefore \rho = \frac{R \times A}{l} = \frac{2 \times 10^{-2} \times 10^{-6}}{2} = 1.7 \times 10^{-8}\ \Omega m$$

4.8 Combination of Resistance

Students, have you seen your pocket radio from inside ? You will see the various resistors connected together in a complex manner. These resistors magnitude in the instrument (radio) control the current in the different circuits. For this, sometimes large magnitude and sometimes small magnitude of resistance are required. To get the desired magnitude of resistance, we connect some resistors in series or in parallel or in series and parallel both. Here we shall study about series and parallel connection of resistors.

(1) Series connection of resistors :

The resistors are connected across two points in the circuit in such a way that the current flowing through each resistor is the same and only one path is availble for it to flow, then the resistors are said to be connected in series.

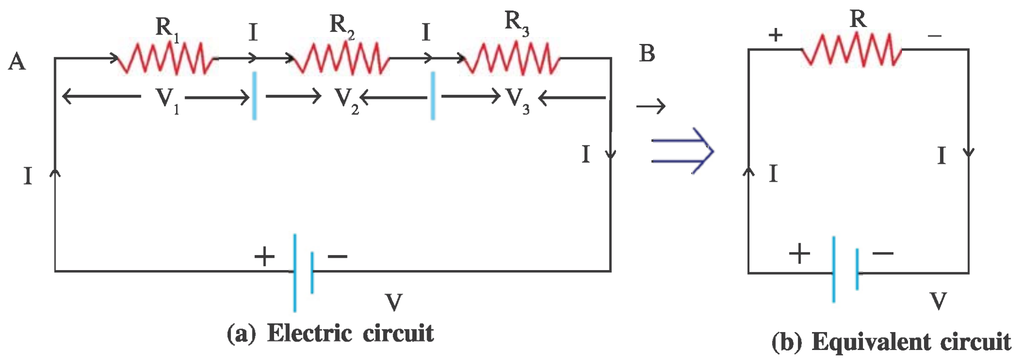


Fig. 4.8 Series connection of resistors

In figure 4.8(a), three resistors R_1, R_2 and R_3 are connected in series across the points A and B.

Here, current (I) flowing through each of the resistors R_1, R_2 and R_3 is the same, but the total voltage of the battery V is divided according to the resistance values.

If the voltage drops across R_1, R_2 and R_3 are V_1, V_2 and V_3 respectively then,

$$V = V_1 + V_2 + V_3 \qquad (4.8.1)$$

Now, if the resistor R instead of these three resistance R_1, R_2 and R_3 is connected in such a way that the current flowing through the circuit remains the same, then R is called equivalent resistance of the circuit. (Fig. 4.8 (b)).

For an equivalent resistor $V = IR$ (4.8.2)

According to Ohm's law,

R_1 voltage drops across, $V_1 = IR_1$ (4.8.3)

R_2 voltage drops across $V_2 = IR_2$ (4.8.4)

R_3 voltage drops across $V_3 = IR_3$ (4.8.5)

From (4.8.3), (4.8.4) and (4.8.5) $IR = IR_1 + IR_2 + IR_3$

$$\therefore \ R = R_1 + R_2 + R_3 \qquad (4.8.6)$$

From this we say that the equivalent resistor R can be obtained by the summation of all the resistors connected in series.

We shall note some important points about the series connection.

(1) In this type of connection, the current flowing through each resistance is the same.

(2) The total voltage drops across all the resistors connected in series equals to the sum of voltage drops across each resistor.

(3) The magnitude of equivalent resitance is always greater than the largest resistance.

Illustration 8 :

In order to get the current 0.5 A in the circuit by connecting a bulb of resistance 20 Ω with 12 V battery how much should be the value of resistance connected in series ? What will be the voltage drop across the bulb ?

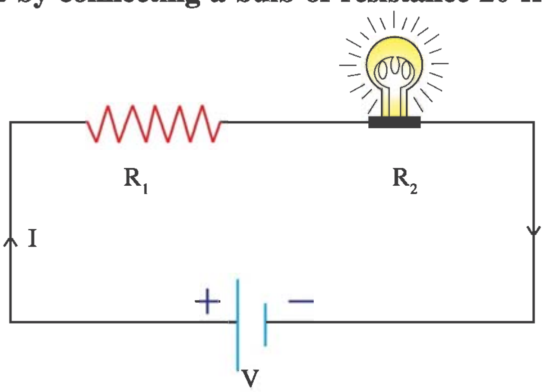


Fig. 4.9

Solution : If the resistance connected in series with bulb is R_1 and resistance of bulb is R_2 then, the circuit will be as shown in Figure 4.9.

$V = 12$ V, $I = 0.5$ A, $R_2 = 20\ \Omega$, $R_1 = ?$

using Ohm's law, $R = \dfrac{V}{I} = \dfrac{12}{0.5} = 24\,\Omega$

Here, bulb and R_1 are in series, therefore equivalent resistance

$R = R_1 + R_2$ ... ... (1)

Substituting the value of R and R_2 in equation (1)

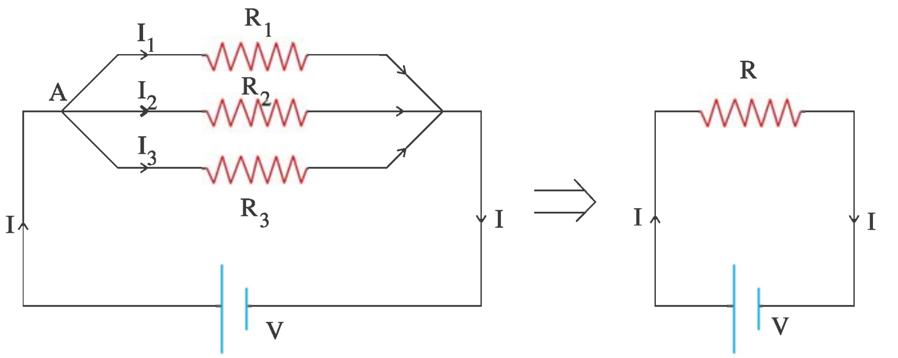
$$24 = 20 + R_2$$

$$\therefore \ R_2 = 24 - 20 = 4\ \Omega$$

The voltage drop across the bulb, $V_2 = I\,R_2 = (0.5)\,(4) = 2$ V

(2) Parallel connection of resistors :

When more than one resistances are connected across two points in the circuit such that more than one path are available for the current to flow and the voltage drops across two ends of each resistor are same, then the resistors are said to be connected in parallel between these two points.



(a) Electric circuit **(b) Equivalent circuit**

Fig. 4.10 Parallel connection of resistors

As shown in Figure 4.10(a), three resistors R_1, R_2 and R_3 are shown connected parallel across A and B. Here, one end of resistors are connected at common point A and the other ends are connected at another common point B. The electric current I at point A is divided into three parts. The current flowing through each resistor depends upon their resistance values.

Suppose the current flowing through resistors R_1, R_2 and R_3 are I_1, I_2 I_3 respectively, then the total electric current is equal to the electric current flowing through the circuit.

$$\therefore\ I = I_1 + I_2 + I_3 \qquad (4.8.7)$$

In parallel connection of resistors, the voltage drop across every resistor is equal to battery voltage V.

Therefore, according to Ohm's law,

$$I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad \text{and } I_3 = \frac{V}{R_3}$$

from equation (4.8.7) $I = \dfrac{V}{R_1} + \dfrac{V}{R_2} + \dfrac{V}{R_3}$

Now, if one such resistor R instead of three resistors R_1, R_2 and R_3, is connected across the battery, the current flowing through the circuit will be same as I (Fig. 4.10 (b))

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

$$\therefore\ \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\therefore\ \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad (4.8.8)$$

Here, R is called the equivalent resistance of parellel connection of three resistors.

We shall note the following points for the parallel connection of resistors :

1. The reciprocal of equivalent resistance R is equal to the sum of reciprocal of individual resistors.

2. The voltage drop across each resistor remains the same.

3. The sum of the current flowing through each resistor equals to total current flowing through the circuit.

4. The magnitude of equivalent resistance is always smaller than the smallest resistance.

Illustration 9 :

The three resistors are connected in parallel with the 30 V battery. The electric current of 7.5 A flows through circuit from battery. If the values of two resistors are 10 Ω and 12 Ω, determine the value of the third resistor.

Solution : $V = 30$ V, $I = 7.5$ A, $R_1 = 10\ \Omega$, $R_2 = 12\ \Omega$, $R_3 = ?$

The equivalent resistance of circuit $R = \frac{V}{I} = \frac{30}{7.5} = 4\ \Omega$

Now, R_1, R_2 and R_3 are connected in parallel.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\therefore \frac{1}{R_3} = \frac{1}{R} - \frac{1}{R_1} - \frac{1}{R_2}$$

$$= \frac{1}{4} - \frac{1}{10} - \frac{1}{12} = \frac{15-6-5}{60} = \frac{1}{15}$$

$\therefore R_3 = 15\ \Omega$

Illustration 10 :

For the circuit shown in Figure 4.11, determine the equivalent resistance between A and B. Also find the current flowing from the battery.

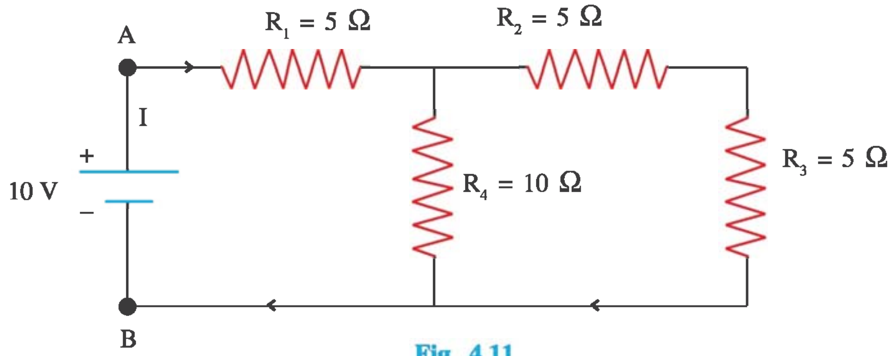


Fig. 4.11

Solution :

As shown in Figure 4.12 (a), R_2 and R_3 are connected in series, their equivalent resistance

$R' = R_2 + R_3$

$= 5 + 5$

$= 10\ \Omega$

Now R' is parallel with R_4 (Figure 4.12 (b)) Equivalent resistance,

$$\therefore \frac{1}{R''} = \frac{1}{R_4} + \frac{1}{R'}$$

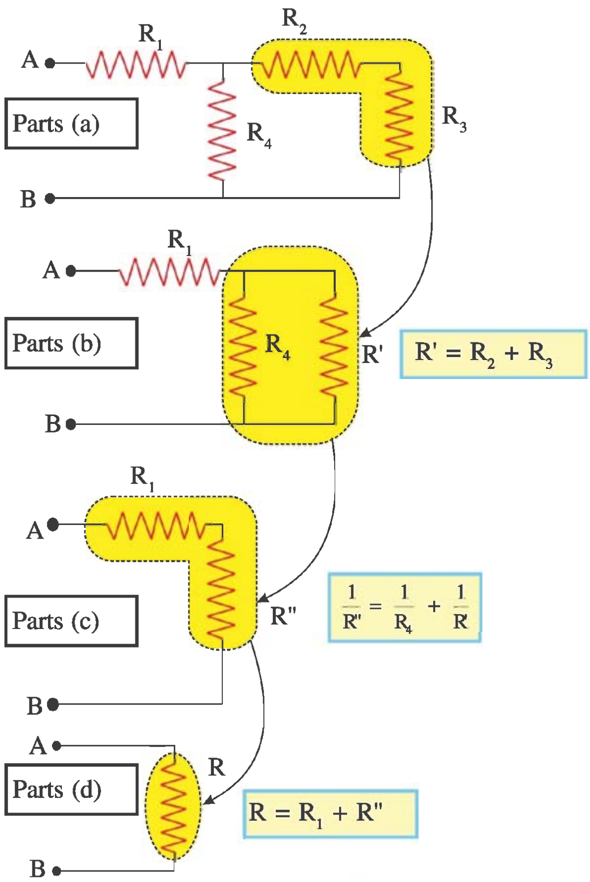


Fig. 4.12

or

$$R'' = \frac{R_4 \times R'}{R_4 + R'}$$

$$= \frac{10 \times 10}{10 + 10}$$

$$= 5\ \Omega$$

Now R'' and R_1 are connected in series (Figure 4.12 (c)). Equivalent resistor across A and B,

$$R = R'' + R_1$$

$$= 5 + 5$$

$$= 10\ \Omega$$

The current flowing from the battery,

$$I = \frac{V}{R} = \frac{10\,V}{10\,\Omega} = 1\,A$$

Illustration 11 :

Determine the equivalent resistance between points A and B in the circuit :

Solution : First of all, R_1 and R_2 are in series.
$R' = R_1 + R_2 = 3 + 3 = 6\ \Omega$

Similarly R_3 and R_4 are in series

$R'' = R_3 + R_4 = 3 + 3 = 6\ \Omega$

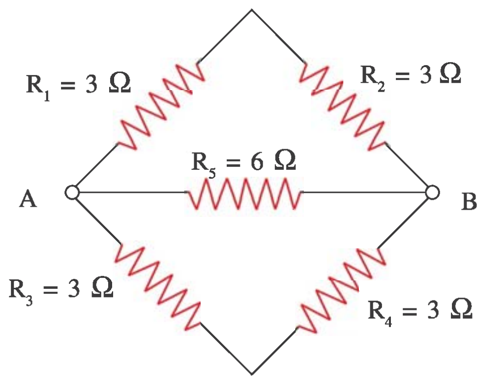


Figure : 4.13

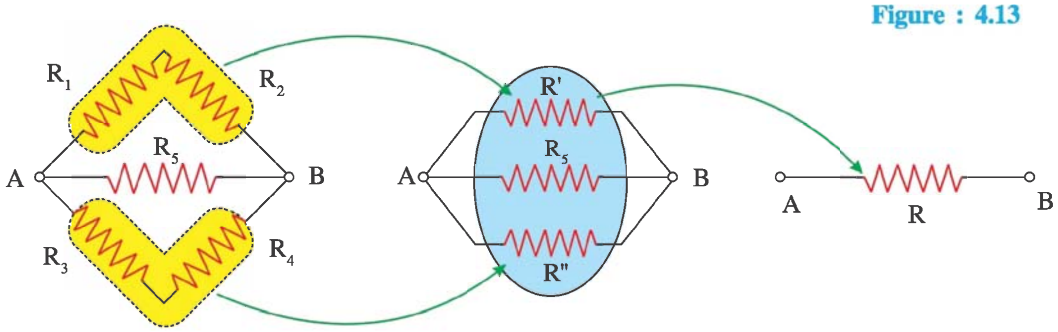


Fig. 4.14

Now, R_5, R' and R" are parallel between A and B

$$\therefore \frac{1}{R} = \frac{1}{R_5} + \frac{1}{R'} + \frac{1}{R''}$$

$$\therefore \frac{1}{R} = \frac{1}{6} + \frac{1}{6} + \frac{1}{6} = \frac{3}{6} = \frac{1}{2} \qquad \therefore R = 2\ \Omega$$

(3) Merits and demerits of series and parallel connections of resistors :

The total resistance of the circuit increases by connecting the resistors in series hence, the current decreases. Thus, to control the current in the circuit, series connection of resistors is useful. Moreover, the fuse is connected in series with 230 V AC mains as well as in electrical appliance and in the domestic electric connection. Therefore, whenever short circuit occurs in any electrical appliance, the fuse wire melts and stops electric current. As a result, damage of the electrical appliance can be prevented.

If the electrical appliances are connected in series, the applied voltage is divided, e.g. the three bulbs operating on 240 V when connected in series each gets 80 V. They cannot give the light efficiently because of this less voltage. In series connection, if fault occurs in one appliance or the circuit breaks, the current does not flow in the circuit and all other appliances stop working, e.g. if one of the 3 bulbs get fused, other bulbs do not light up.

But if these three bulbs are connected in parellel with 240 V supply, all the three bulbs get same voltage. If any one bulb gets fused, the current continues to flow through other two bulbs and they will work. Thus in the parallel connection break up does not occur. In our house, the appliances such as fan, bulb light, TV, refrigerator etc are connected in parallel with 240 V AC mains line. The equivalent resistance in the parallel connection of resistor decreases, hence, more current can be obtained.

4.9 Heating Effect of Electric Current

When we pass the electric current in the bulb, our experience says that after a while it becomes hot. In the same way, by flowing an electric current through electrical appliances like iron or heater, the heat is produced. Here, electrical energy is converted into heat energy which is known as heating effect of an electric current. In the same way the electrical energy is transformed into heat energy due to the resistance.

Electrical energy :

Suppose the electric current is flowing through some resistor (R). To flow this current continuously the battery has to provide energy to every electric charge. Now, the work required to keep the charge Q in motion by the battery of voltage V is,

$$W = VQ$$

From the definition of the electric current,

$$Q = I\,t$$

$$\therefore \quad W = V\,I\,t$$

According to Ohm's law, $V = I R$

$$\therefore W = (IR)(I)(t)$$

$$\therefore W = I^2Rt$$

Thus, the current flowing through a resistor R for time t is I, the electrical energy consumed to be W which is converted into heat energy.

$$\therefore \text{Heat energy (H)} = I^2Rt$$

The obove equation is called **Joule's Law.**

Thus the energy produced in a resistor is,

(1) directly proportional to the square of current passing through it.

(2) directly proportional to the resistance for a given current.

(3) directly proportional to the time t for a given current and resistance.

The SI unit of an electrical energy or heat energy is joule (J).

The thermal effect of an electrical current is used in many instruments used in a daily life. e.g. electric heater, electric iron, water heater, toaster, oven etc. Though in some other appliances like fan, computer, generator, electric motor etc, the heat generated due to the electric current is useless.

Electrical power :

"Electrical power means the rate of electric energy." That means the electrical energy consumed (or heat generated) in unit time is defined as an electric power.

It is denoted as symbol P.

$$\therefore \quad P = \frac{\text{Electrical energy consumed}}{\text{Time}}$$

$$= \frac{W}{t} = \frac{I^2 Rt}{t}$$

$$\therefore \quad P = I^2 R \qquad (4.9.1)$$

$$\text{or} \quad P = I V \quad (\because I R = V) \qquad (4.9.2)$$

$$\text{or} \quad P = \frac{V^2}{R} \quad (\because I = \frac{V}{R}) \qquad (4.9.3)$$

The SI unit of power is joule/second or watt (W).

If 1 A current flows through the circuit from 1V battery, the power consumed to be 1W.

From equation (4.9.2)

$$1 \text{ watt} = 1 \text{ volt} \times 1 \text{ ampere}$$

$$= 1 \text{ VA}$$

Practical unit of electrical energy :

According to definition of electrical power,

$$P = \frac{W}{t}$$

$\therefore$ $W = P \times t$

$\therefore$ 1 joule = 1 watt × 1 second

The unit 'watt sec' is smaller for electrical energy, so in practice a unit kilo watt hour (kWh) is used.

1 kWh = 1000 watt × 3600 second

$\therefore$ 1 kWh = 3.6×10^6 joule

The electricity which you use in your house for domestic purpose is calculated in kWh. It is called "unit."

$\therefore$ 1 unit = 1 kWh = 3.6×10^6 joule

When 1000 W bulb is on for 1 hour, the energy consumed is equal to 1 unit.

Illustration 12 :

The 5 A current flows through an electric iron. If the resistance of electric iron is 44 Ω then how much energy will be consumed in 5 minutes ?

Solution : I = 5 A; R = 44 Ω, t = 5 min = 5 × 60 = 300 s

Electrical enerey $W = I^2 R t$

$= (5)^2 (44) (300) = 330000 = 3.3 \times 10^5$ J

Illustration 13 :

A bulb is marked 220 V, 100 W, what will be the resistance of this bulb ? What will be the current passing through it when connected across 220 V supply ?

Solution : V = 220 V, P = 100 W, R = ? I = ?

From $P = \frac{V^2}{R}$, $R = \frac{V^2}{P}$

$$= \frac{220 \times 220}{100} = 484\ \Omega$$

From P = V I

$$I = \frac{P}{V} = \frac{100}{220} = 0.45 \text{ A}$$

Illustration 14 :

In a house, if three bulbs of 100 W, 60 W and 40 W are used 2 hours per day, how many units of electrical energy will be consumed in 30 days ?

Solution : Evergy consumed per sec P = 100 W + 60 W + 40 W

= 200 W

$\therefore$ Energy consumed per day = P × t

= 200 × 2 × 3600 W

= 144×10^4 W

$$= \frac{1440 \times 10^3}{1000 \times 3600}$$

$$= 0.4 \text{ kWh}$$

$\therefore$ Energy consumed in 30 days W $= 0.4 \times 30$

$= 12$ kWh

Now, 1 unit = 1 kWh

$\therefore$ Energy consumed in 30 days = 12 kWh = 12 units

4.10 Chemical Effect of An Electric Current

The chemical reaction is responsible to get the electrical current means the chemical energy is converted into electrical energy by the battery. Then, can electrical energy be used for the chemical reaction ? Can electric current pass through any chemical ? To understand this let us perform the following activity :

Activity : 4

Take two carbon rods (You may get the rods from the core part of a used up dry cell by breaking it.) Now dip these rods in to a beaker filled with dist. water. Connect small bulb, 12V battery and a key to these rods. What happens when the key is on ? Has the bulb glown ? You may have seen that bulb does not glow. Do not worry, now add some salt into water (or take a tap water instead of distilled water)

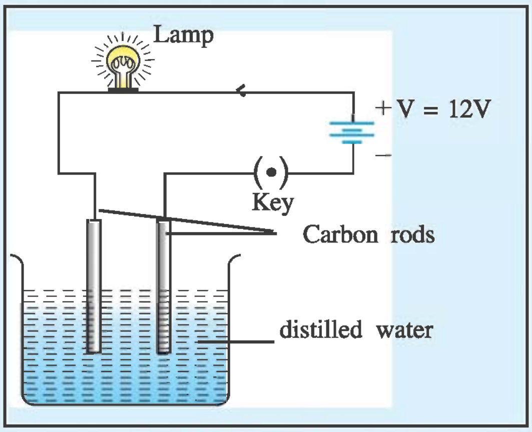


Fig. 4.15 Electric current through water

Now you can see that the bulb glows. Thus distilled or highly pure water does not conduct electricity. When a normal water which we use daily is conductor of electricity (That is why we should not touch the electric switch with the wet hand or foot). The solutions that conduct electricity are called "electrolytes." In the electrolytes, the electric current flows due to positive and negative ions.

Electroplating

You must have seen the metallic ornaments which are gold plated so as to look like real gold. The metals may be even copper plated or silver plated. This is carried through a process known as electroplating. To understand this, take a solution of copper sulphate ($CuSO_4$) in a beaker. In this solution, the iron spoon which is to be electro-plated and a copper plate are taken as electrodes and are connected with battery and key as shown in Figure 4.16. Pass the current in circuit for some time, you will observe that Cu is plated on metallic spoon. How did this happen ?

Here copper sulphate ($CuSO_4$) is taken as an electrolyte. On passing the current through this solution, it is decomposed into Cu^{+2} and SO_4^{2-} ions. As Cu^{+2} ion is positively charged, so it moves towards negative terminal i.e. metal spoon and deposits on iron spoon. Thus on iron spoon the plating takes place. Though there is no scarcity of Cu atoms because the copper atoms go into the solution from positive terminal i.e. copper plates, the above process is called electro-plating.

By the method of electropating, the layers such as copper, nickel and chromium are coated on the things of iron in order to protect them against rusting and to keep them shining.

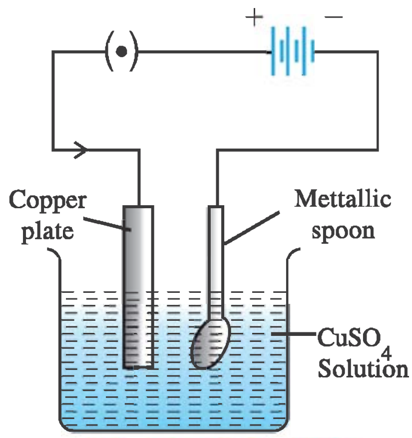


Fig. 4.16 Electroplating

Faradays laws of electrolysis :

On passing the electric current through the electrolytic solution, negative ions move towards positive terminal and the positive ions move towards negative terminal. The process of separating the ions is called electrolysis.

Michael Faraday (1791-1867), studied it in detail and gave two rules to calculate how much metal is deposited on the electrode in the process of electrolysis.

Faraday's First Law :

The mass of the substance (metal) deposited at cathode on passing the electric current through electrolytic solution is proportional to charge passing through it. $m \propto Q$

Faraday's Second Law :

For a given amount of current passed, the masses of different elements deposited on cathode is proportional to their chemical equivalent (e). Chemical equivalent of any atom is the ratio of atomic mass and its valency. $\left(\frac{m_1}{m_2} = \frac{e_1}{e_2}\right)$

What have you learnt ?

- **Electric charge :** Electric charge is an intrinsic property of electrons and protons situated in atom. Electric charges are of two types : (1) Positive electric charge and (2) Negative electric charge.
- **Electric current :** The net amount of electric charge flowing through any cross-section of conductor in unit time is known as an electric current.

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

  The unit of an electric current is ampere (A).

  The direction of conventional electric current is opposite to that of flow of electrons in the conductor.
- **Electric Potential :** The work required to bring the unit positive charge from infinity to any point in the electric field is known as electric potential at that point.

- **Electric Potential Difference :** The electric potential difference between any two points A and B in the electric field means work done to take unit positive charge from A to B against electrical force.

$$V = \frac{W}{Q}$$

The unit of electric potential and electric potential difference is J/C or volt.

- **Ohms' Law :** In the definite physical condition, the current passing through the conductor is proportional to the applied electric potential difference across the conductor ($1 \alpha V$)

In the form of formula, $V = I R$ or $R = \frac{V}{I}$.

R is the resistance of conductor and its unit is Ω.

- The resistance of conductor depends upon the kind of material and its dimensions.

$R = \rho\frac{l}{A}$ where ρ = resistivity of material, l = length of resistive wire,

A = Area of cross-section of resistive wire

- **Series connection of resistors :** Connecting the resistors R_1, R_2, R_3..., R_n in series, their equivalent resistance will be $R = R_1 + R_2 ..... + R_n$.

In the series connection of resistors, the current flowing through each resistor is the same, but the potential difference across each resistor is different (voltage drops).

- **Parallel connection of resistance :** Connecting the resistance R_1, R_2, R_3..., R_n in parallel their equivalent resistance will be $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}$

In this type of connection, the voltage drop across each resistor remains the same, where as the current flowing through them is different.

- **Elctrical Energy :** The energy consumed on passing the current (I) through the resistance (R) conductor for some difinite time (t) is $W = I^2 Rt = \frac{V^2}{R}t = V I t$.

The unit of electric energy is joule. Its conventional unit in practice is kWh or unit.

- **Electrical Power :** The electrical energy consumed in unit time is difined as an electric power (P). Its unit is watt. $P = \frac{W}{t} = I^2R = \frac{V^2}{R}$

- **Electroplating :** The process of depositing of one metal on another metal using the chemical effect of electric current is called electroplating.

The object on which the metal to be deposited is connected with negative terminal and the metal which is to be deposited is connected with the positive terminal of battery.

EXERCISE

1. Select the proper choice from the given multiple choices :

(1) The SI unit of electric charge is ......

(A) ampere (B) volt (C) watt (D) coulomb

(2) What number of electrons will be there in 1.6 C charge ?

(A) 10^{17} (B) 10^{18} (C) 10^{19} (D) 10^{20}

(3) $1\mu A$ = ---------- mA.

(A) 10^{-16} (B) 10^{-3} (C) 10^{3} (D) 10^{6}

(4) Which of the following materials has more number of free electrons ?

(A) Copper (B) Glass (C) Rubber (D) Iron

(5) According to Ohm's law,

(A) The resistance increases with the increase in current.

(B) The resistance increases with the increase in voltage.

(C) The current increases with the increase in voltage.

(D) The resistance and current both increase with the increase in voltage.

(6) The formula for an electric current is --------.

(A) $I = Q\,t$ (B) $I = \frac{Q}{t}$ (C) $I = \frac{t}{Q}$ (D) $I = Wt$

(7) The amount of 2 A electric current is passed for 1 minute through one conducting wire. How much total electric charge will pass through this wire ?

(A) 2 C (B) 30 C (C) 60 C (D) 120 C

(8) In an electrical appliance, the electric current of 4.8 A is passed, then the number of electrons passing through it in one second will be -----------

(A) 0.33×10^{19} (B) 3.3×10^{19} (C) 3×10^{19} (D) 4.8×10^{19}

(9) Which of the following formula represents the voltage ?

(A) $\frac{\text{Work}}{\text{Current} \times \text{Time}}$ (B) $\frac{\text{Work} \times \text{Time}}{\text{Current}}$

(C) Work × electric charge (D) Work × electric charge × time

(10) The unit of electric potential difference is --------

(A) J (B) J/C (C) J C (D) C/J

(11) If the work is to be done to take 3 C electric charge from one point to another point is 15 J, what will be the potential difference between these two points ?

(A) 3 V (B) 15 V (C) 5 V (D) 45 V

(12) The resistance of one conducting wire is 10 Ω. How much electric current will flow by connecting it with a battery of 1.5 V ?

(A) 0.15 mA (B) 1.5 mA (C) 15 mA (D) 150 mA

(13) On which factors does the resistivity of conducting wire depend ?

(A) Length of wire (B) Area of cross-section of wire

(C) Volume of wire (D) Material of wire.

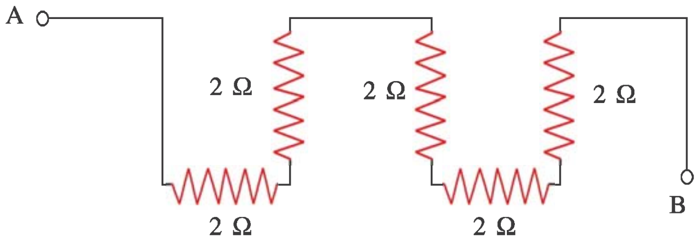
(14) If the five equal pieces of a resistance wire having 5 Ω resistance each is connected in parallel, then their equivalent resistance will be --------

(A) 1/5 Ω (B) 1 Ω (C) 5 Ω (D) 25 Ω

(15) The unit of resistivity of the material is ----------.

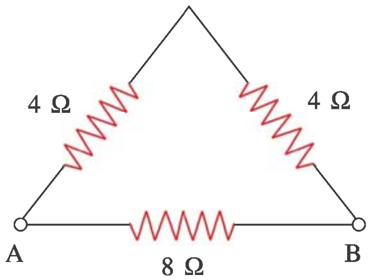
(A) Ω (B) Ω m (C) Ω/m (D) m/Ω

(16) What will be the equivalent resistance between points A and B of the following electric circuit ?



(A) 1 Ω (B) 2 Ω (C) 5 Ω (D) 10 Ω

(17) What will be the equivalent resistance between points A and B of the following electric circuit ?



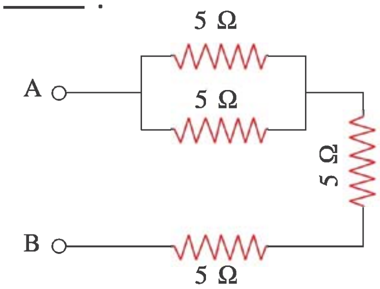
(A) 4 Ω

(B) 8 Ω

(C) 2 Ω

(D) 16 Ω

(18) The equivalent resistance between points A and B in the following electric circuit is ______ .



(A) 2.5 Ω

(B) 5 Ω

(C) 12.5 Ω

(D) 20 Ω

(19) Which physical quantity has a unit of kWh ?

(A) Work (B) Electric power

(C) Electric current (D) Electric potential.

(20) 1kWh = ------------- joule

(A) 3.6×10^{6} (B) 3.6×10^{3} (C) 3.6×10^{-6} (D) 3.6×10^{-3}

(21) An electric heater consumes 1.1 kW power when 220 V voltage applied to it. How much current will be flowing through it ?

(A) 1.1 A (B) 2.2 A (C) 4 A (D) 5 A

(22) What makes the electric current flow through electric solution ?

(A) Only free electrons (B) Only positive ions.

(C) Only negative ions (D) Positive and negative ions.

(23) The distilled water acts as ------ for the electricity.

(A) Conductor (B) Insulator (C) Semiconductor (D) None.

2. Answer the following questions in brief.

1. What is an electric charge ? Give its types and write its unit.
2. What is a free electron ? Explain conducting and non-conducting materials in terms of it.
3. Give the definition of an electric current and define its unit.
4. Give advantages and disadvantages of series and parellel connection of resistors.
5. Write Faraday's laws of electrolysis.

3. Write the answers of following questions :

1. What is an electric potential ? Give the definition and unit of electric potential.
2. Explain the series connection of resistors and derive the formula of equivalent resistance.
3. Explain the parallel connection of resistance and derive the formula of equivalent resistance.
4. Explain electrical energy and derive its formula.

4. Answer the following questions in detail :

1. Draw the figure of voltaic cell and explain its construction. Explain flow of current in conductor through this cell.
2. What is electrolyte ? Describe the experiment showing flow of current in electrolyte.

5. Answer the following questions pointwise :

1. Write Ohm's law. Describe the experiment showing Ohm's law and write its conclusions.
2. What is electroplating ? Explain it with example.

6. Solve the following examples :

1. If 400 mA current flows through the bulb for 1 minute, how many electrons will pass through it ? (**Ans :** 15×10^{19} electrons)

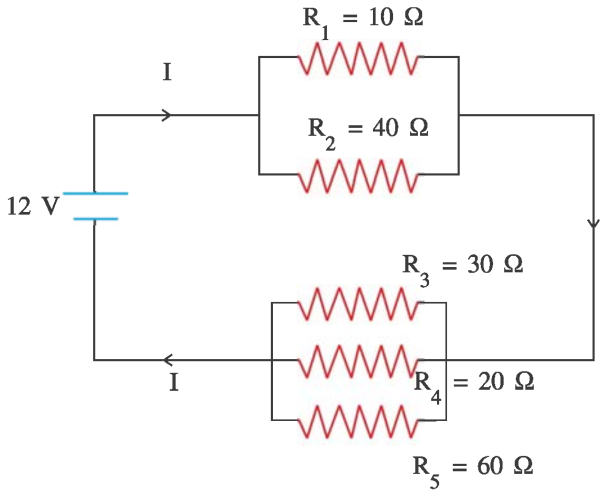
2. The 1800 C electric charge is passing through an electic bulb in one hour. How much current will pass through an electric bulb ? (**Ans :** 0.5 A)

3. The three resistors of resistance 5 Ω, 10 Ω and 30 Ω are connected with a 12 V battery in parallel. Determine (a) total current in the circuit (b) equivalent circuit resistance.

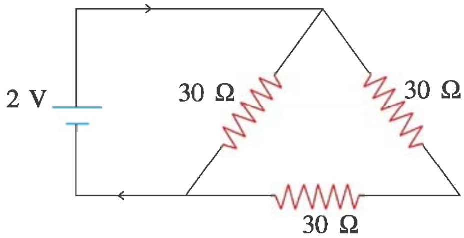
(**Ans :** I = 4 A, R = 3 Ω)

4. As shown in the figure the resitance are connected with a 12 V battery. Determine (a) Equivalent curcuit resistance (b) Current flowing through the circuit.

(**Ans :** (a) R = 18 Ω (b) I = 0.66 A)

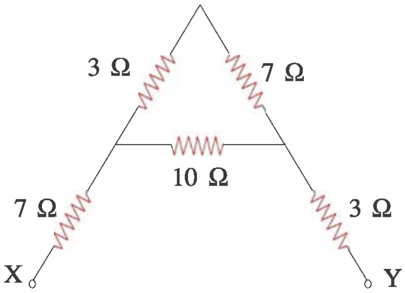


5. Find the electric current in the following circuit :



(**Ans :** 0.1 A)

6. Determine the equivalent resistance between points X and Y in the following circuit.



(**Ans :** 15 Ω)

7. Two lamps of 100 W and 60 W are joined in parallel with 220 V line. How much current will flow through the circuit ? (Ans : 0.73 A)

8. An electric heater consumes 4.4 kW power when connected with a 220 V line voltage then,

(i) Calculate the current passing through the heater.

(ii) Calculate resistance of a heater.

(iii) Calculate the energy consumed in 2 hours.

(**Ans :** (i) 20 A (2) 11Ω (3) 3.168×10^7 W)

UNIT

5

MAGNETIC EFFECTS OF ELECTRIC CURRENT

5.1 Introduction

In the earlier chapter, we have studied the heating and chemical effects of an electric current. In the present chapter, we shall study the magnetic effect of an electric current.

During 1819-20, a science teacher H.C. Oerstead discovered that the magnetic field is produced by an electric current in opposite to that the scientists named Michael Faraday, Andre Ampere etc. had produced an electric current from the magnetic field. It was proved from many experiments that electricity and magnetism are associated with each other. This branch of physics that covers universal study of electricity and magnetism is called electromagnetic or electrodynamics. The electromagnetic principles are widely used in loud speaker, electric motor, magnetic train (maglev), hard disk of computer, communication etc.

In the present chapter, we shall study the characteristics of magnetic field produced by electric current carrying conducting wire, coil, solenoid and the Faraday's experiments induced by magnetic field. In addition, we shall obtain the primary idea about electric motor and electric generator based on the principle of magnetism.

5.2 Magnetic Field and Magnetic Field Lines

Students, you have seen a bar magnet in the laboratory. You have studied about it in the Standard 8.

A bar magnet has two magnetic poles : (1) North pole (N) and (2) South pole (S). When a bar magnet is suspended freely through the string, the pole which becomes steady toward the north pole of an earth is called north pole (N) of a magnet and the other pole is called south pole (S). A repulsive force is resulted on bringing N-N or S-S poles of two different magnets nearer to each other while the attractive force is produced on bringing N-S poles. Magnetism of magnets is maximum at their poles. The magnetic force is represented by a magnetic field.

A magnetic needle experiences deflection when it is placed in the region near a bar magnet. Thus, a magnetic force experienced around the region of a magnet is called a magnetic field of a magnet. The magnetic field lines can be drawn to describe or to study this magnetic field.