9 Current Electricity

(A) ELECTRIC CURRENT

9.1 SOURCES OF DIRECT CURRENT

We are familiar with cells used in a torch to light up its bulb. *The cells are the source of direct current* (abbreviated as d.c.) which lights up the bulb. The current flows from the positive terminal of the cell to its negative terminal* through the bulb of the torch (Fig. 9.1). The magnitude of current given by a cell remains constant for a sufficiently long time. When the cell gets discharged, it stops giving current and becomes useless. We can define direct current (d.c.) as follows:

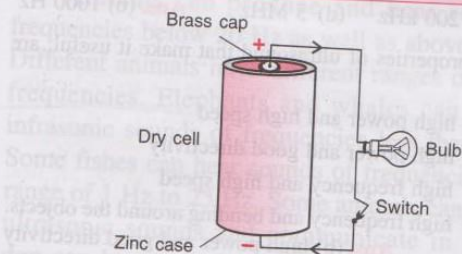*Direct current (d.c.) is a current of constant magnitude flowing in one direction.*

Fig 9.1 A dry cell used to light up a bulb

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* In a dry cell, brass cap projecting out at the centre acts as the positive terminal of the cell and the base of zinc case acts as the negative terminal.

In a cell, chemical energy changes into electrical energy when it sends current in a circuit. A cell basically consists of a vessel containing two conducting rods, called the *electrodes*, at some separation, placed or immersed in a solution (or jelly), called the *electrolyte*.

Kinds of cells : Cells are of *two* kinds :

(1) Primary cells, and

(2) Secondary cells or accumulators.

(1) Primary cells : These cells provide current as a result of *irreversible* chemical reaction. The cells are discarded after use when the entire chemical energy in them has converted into electrical energy. Thus, these are *'use and throw'* type of cells and cannot be recharged. Depending upon the material of electrodes and electrolyte, we have different types of primary cells *e.g.* simple voltaic cell, Leclanche cell, Daniel cell, dry cell, *etc.*

(2) Secondary cells or accumulators : Secondary cells also provide current as a result of a chemical reaction. In these cells, the chemical reaction is *reversible* and so they can be recharged after use. After taking the electrolyte and electrodes in a vessel, the cell is first charged by connecting

it to a direct current source. During charging, electrical energy changes into chemical energy and gets stored in the cell. When cell is used to send current in a circuit, chemical energy changes into electrical energy. These cells can thus be used for a very long period because they can be recharged again and again. Lead (or acid) accumulator and Ni-Fe (or alkali) accumulator are the two types of secondary cells commonly used to provide low as well as high current. We use a number of lead accumulator cells as battery in a car as it is capable of giving high current. Low current rechargeable cells are widely used in toys and mobile phones. These cells are also called storage cells.

Difference between primary cell and secondary cell

Primary cell	Secondary cell
1. Chemical reaction is irreversible.	1. Chemical reaction is reversible.
2. Chemical energy is converted into electrical energy when current is drawn from it.	2. Electrical energy converts into chemical energy when current is passed in it (*i.e.*, during charging), while chemical energy converts into electrical energy when current is drawn from it (*i.e.*, during discharging).
3. It can not be recharged.	3. It can be recharged.
4. Its internal resistance is high.	4. Its internal resistance is low.
5. It is capable of giving weak current only.	5. It can provide low as well as high current.
6. It is light and cheap.	6. It is heavy and costly.
Examples : Simple voltaic cell, Leclanche cell, Daniel cell, dry cell.	*Examples* : Lead (or acid) accumulator, Ni-Fe (or alkali) accumulator, Li-H battery.

9.2 ELECTRIC CURRENT (AS RATE OF FLOW OF ELECTRIC CHARGE)

We have read that when two bodies are rubbed together, they get charged due to transfer of electrons from one body to the other. The body gaining electrons becomes negatively charged while the body loosing electrons gets positively charged. A positively charged body has a deficit of electrons, while a negatively charged body has an excess of electrons. The charges can be made

to flow between them by suitable arrangements. For example, if two charged bodies are joined by a metallic wire, the electrons flow from the body having more electrons, to the body having less electrons. The flow of electrons constitutes an electric current. Thus current flows due to the motion of charges. *The rate of flow of charge gives the magnitude of current.* Thus

Current is the rate of flow of charge across a cross-section normal to the direction of flow of current.

If charge Q flows through the cross-section of a conductor in time t, then

$$\text{Current } (I) = \frac{\text{Charge}(Q)}{\text{time}(t)} \quad \text{...(9.1)}$$

Current is a scalar quantity.

In metals (or conductors), current flows due to the movement of electrons, while in electrolytes, current flows due to the movement of both, the positive and negative ions. An electron carries a negative charge equal to $-e$, where $e = 1\cdot6 \times 10^{-19}$ coulomb, the electronic charge.

If n electrons pass through the cross section of a conductor in time t, then

$$\text{Total charge passed } Q = n \times e$$
$$\text{and current in conductor } I = \frac{Q}{t} = \frac{ne}{t} \quad \text{..(9.2)}$$

Note : In an electrolyte, the current flows due to the movement of both the positive ions (*i.e.*, cations) and negative ions (*i.e.*, anions). In one second, if n_1 positive ions each carrying a charge q_1 move in one direction and n_2 negative ions each carrying a charge q_2 move in opposite direction, the total current will be $I = n_1(+ q_1) - n_2(- q_2)$ $= (n_1q_1 + n_2q_2)$, because direction of current is taken positive in the direction of flow of positive ions, and negative in the direction of flow of negative ions.

Direction of current (conventional and electronic)

Conventionally, the direction of current is taken positive in the direction of flow of positive

charge. Therefore, conventionally, the current will be negative in the direction of flow of electrons. The rate of flow of electrons in a direction is called electronic current in that direction. *The conventional current (or simply current) is in a direction opposite to the direction of motion of electrons.* The magnitude of conventional current is the rate of flow of total charge across the given cross-section.

Unit of current : From relation $I = \dfrac{Q}{t}$

$$\text{Unit of current} = \dfrac{\text{Unit of charge}}{\text{Unit of time}} \, .$$

The S.I. unit of charge is coulomb and S.I. unit of time is second, so the S.I. unit of current is coulomb per second which is called **ampere**. It is denoted by the symbol A. Thus.

$$1 \text{ ampere (A)} = \dfrac{1 \, \text{coulomb (C)}}{1 \, \text{second (s)}} \qquad \dots (9.3)$$

Thus current is 1 A, if the rate of flow of charge is 1 coulomb per second. Since 1 coulomb of charge is carried by $\dfrac{1}{1 \cdot 6 \times 10^{-19}} = 6 \cdot 25 \times 10^{18}$ electrons, therefore if 1 ampere current flows through a conductor, it means that $6 \cdot 25 \times 10^{18}$ electrons pass in 1 second across that cross section of conductor.

Note : Weak current is measured in units milli-ampere (mA) and micro-ampere (μA), where

1 milli-ampere (mA) = 10^{-3} ampere (A), and
1 micro-ampere (μA) = 10^{-6} ampere (A).

9.3 SYMBOLS USED IN CIRCUIT DIAGRAMS

An electric circuit has different electric components connected to a current source. Fig. 9.2 shows some of the electric components which are used in an electric circuit in the laboratory.

The symbols and functions of various electric components are given below.

(1) Source of current : There are *two* types of current sources : (i) alternating current* (a.c.)

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* An alternating current (abbreviated as a.c.) is the current in an element (say, bulb) for which both the magnitude and direction change with time. The current repeats its value after a fixed time. The number of times current repeats its value in one second, is called the frequency of alternating current. The frequency of a.c. obtained from our mains is 50 Hz.
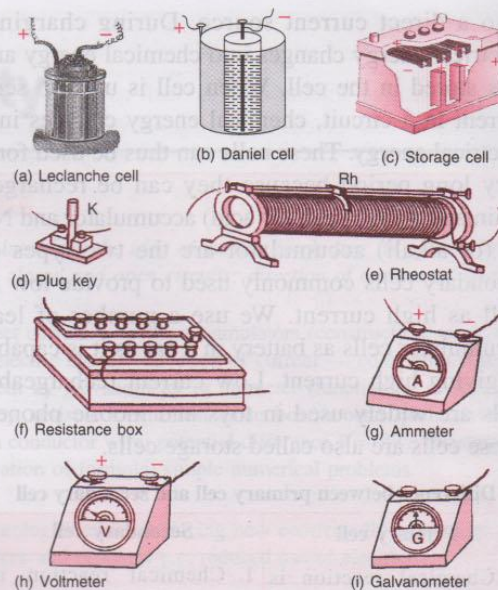

(a) Leclanche cell (b) Daniel cell (c) Storage cell
(d) Plug key (e) Rheostat
(f) Resistance box (g) Ammeter
(h) Voltmeter (i) Galvanometer

Fig. 9.2 Different electric components

source such as mains in our house and a.c. generator, and (ii) direct current (d.c.) source such as a cell or a battery. The purpose of a source of current is to supply electric current (maintain flow of charge) in a circuit. In laboratory, Leclanche cell [Fig. 9.2(a)], Daniel cell [Fig. 9.2(b)] and lead accumulator (storage cell) [Fig. 9.2(c)] are used as direct current sources.

A *d.c. source* (cell) is represented by two vertical lines of unequal lengths. The longer one is marked '+' to represent anode, while the shorter is marked '−' to represent cathode [Fig. 9.3 (a)]. When current is drawn from a cell, it flows from the positive terminal to the negative terminal through the external circuit and from the negative terminal to the positive terminal inside the cell through its electrolyte so as to maintain a continuous flow.

(a) (b) (c)
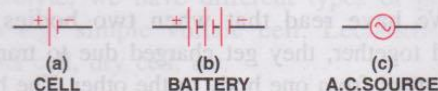CELL BATTERY A.C.SOURCE

Fig. 9.3 Symbolic representation of source of current

When a strong current is needed, either we join a number of cells together in series (cathode of one cell connected to the anode of another cell), to form a *battery* or we use a storage cell.

Fig. 9.3(b) represents the symbol for a battery (using three cells).

An *alternating current* (a.c.) source (mains) is represented by a sine curve (~) within a circle as shown in Fig. 9.3 (c).

(2) Key : It is used to put the current *on* and *off* in a circuit. It may be either a *plug key*, a *switch* or a *tapping key*. Fig. 9.4 shows the symbolic representation of these keys when they are open and when they are closed. A key is usually represented by the symbol K.

In laboratory, generally we use a plug key shown in Fig. 9.2(d). When key is open (*i.e.*, the plug is taken out), the circuit is incomplete and is called an *open circuit*. When key is closed (*i.e.*, the plug is put in), current flows through the circuit and is said to be *closed*. A tapping key is used when current is momentarily needed in the circuit.

When key is open

| (a) | (b) | (c) |
| PLUG KEY | SWITCH | TAPPING KEY |

When key is closed

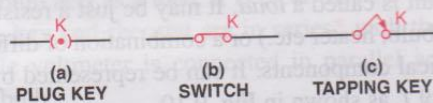| (a) | (b) | (c) |
| PLUG KEY | SWITCH | TAPPING KEY |
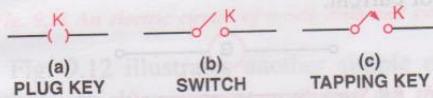
Fig. 9.4 Symbolic representation of different keys

(3) Resistance wire, resistance box, rheostat or variable resistance : A *resistance wire* is generally made from an alloy, called *manganin** and it has a fixed resistance depending upon its length and thickness. It is used as a standard resistance.

A *rheostat* [Fig. 9.2(e)] is a device by which resistance in a circuit can be varied continuously. It is used to adjust the magnitude of current in a circuit by changing the length of resistance wire

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* Manganin is an alloy which is used for preparing wires in a resistance box and rheostat. It is composed of 84% copper, 12% manganese and 4% nickel. The resistance of this wire does not vary much with temperature
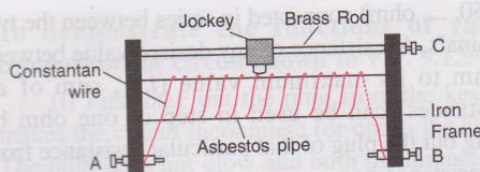

Fig 9.5 Rheostat

included in the circuit. As shown in Fig. 9.5, it consists of an enamelled constantan wire wound in form of a coil (single layer) over an asbestos pipe fitted in an iron frame and provided with a sliding contact (jockey) on a brass rod. It has three terminals A, B and C, out of which two terminals A and B are at the ends of the resistance wire and the third terminal C is at the end of the brass rod connecting the jockey. The enamel of the coiled wire is removed at the places where jockey touches the wire.

The wire between the two terminals A and B provides a fixed resistance equal to the resistance of the entire length of wire. When rheostat is used as a *fixed resistance R*, connections are made with the terminals A and B as shown in Fig. 9.6 (a). Symbol R is used for a fixed resistance.

The main use of a rheostat is as a *smoothly varying resistance*. For this, connections are made between the terminals C and either of the fixed terminal A or B at the end, as shown in Fig. 9.6 (b). The jockey connected to the middle terminal C can be slided and by making its contact at different points, a *variable resistance* can be obtained. The current then enters at the positive terminal A (or B), it flows in the resistance wire of length up to the jockey and then leaves at the terminal C. In order to adjust current of a desired value in the circuit, the jockey of the rheostat is slided to obtain desired resistance. Symbol Rh is used for a variable resistance.
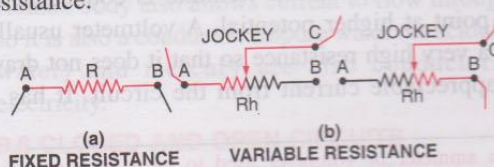

| (a) | (b) |
| FIXED RESISTANCE | VARIABLE RESISTANCE |

Fig. 9.6 Symbolic representation of a rheostat

A *resistance box* [Fig. 9.2(f)] is provided with several standard resistances (say 1, 2, 2, 5, 10, 20,

20, 50, ... ohm) connected in series between the two terminals. A resistance of any desired value between 1 ohm to its maximum value (*i.e.*, sum of all resistances) can be used in step of one ohm by taking out the plug of that particular resistance from the resistance box.

(4) Ammeter : An ammeter [Fig. 9.2(g)] is an instrument used to measure the magnitude of current flowing in a circuit. It is joined in series in a circuit so that the entire current of the circuit passes through it. It is symbolically represented by the letter A enclosed in a circle as shown in Fig. 9.7. The + sign marked at one terminal of it indicates that current must enter it through this terminal. Therefore this terminal is connected to the higher potential terminal of the current source. An ammeter must have a very low resistance so that the resistance of the circuit (or the current to be measured) may not alter when it is joined in the circuit. It has a calitrated dial on which deflection of needle shows the magnitude of current flowing in that circuit.
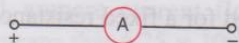

Fig. 9.7 Symbolic representation of an ammeter

Different kinds of ammeter are required to measure alternating current and direct current*.

(5) Voltmeter : A voltmeter shown in Fig. 9.2(h) is used to measure the potential difference between two points of a circuit. It is connected across the two points between which potential is to be measured (*i.e.*, in parallel to the flow of current). It is symbolically represented by the letter V enclosed in a circle as shown in Fig. 9.8. The + sign marked at one terminal of it indicates that current must enter it through this terminal. Therefore this terminal is connected to the point at higher potential. A voltmeter usually has a very high resistance so that it does not draw an appreciable current from the circuit. It has a

calibrated dial on which deflection of needle shows the potential difference across the points of circuit in between which voltmeter is connected.
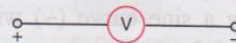

Fig. 9.8 Symbolic representation of a voltmeter

Different kinds of voltmeter are required to measure alternating and direct potential difference*.

(6) Galvanometer : A galvanometer [Fig. 9.2(i)] is used when we want to detect the presence of very weak current in an electric circuit or to know only the direction of flow of current in a circuit. It does not measure the magnitude of current in a circuit. It is joined in a circuit in series just like an ammeter. It is symbolically represented by the letter G enclosed in a circle as shown in Fig. 9.9. Current can enter or leave through any of its terminal, therefore no +/– signs are marked at its terminals. It has a dial with zero mark at its centre. The deflection of needle on it shows the presence of current and the direction of deflection indicates the direction of flow of current.

Fig. 9.9 Symbolic representation of a galvanometer

(7) Load : An appliance which is connected in a circuit is called a *load*. It may be just a resistance (*e.g.*, bulb, heater etc.) or a combination of different electrical components. It can be represented by the symbol L as shown in Fig. 9.10.

(a)
BULB

(b)
HEATER
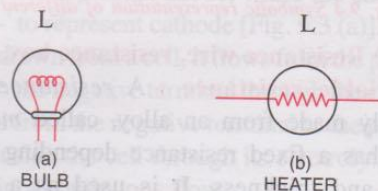
Fig. 9.10 Symbolic representation of a load

(8) Connecting wires : These are the wires used to connect various electrical components. They are made of highly conducting metal such as copper (or aluminium because of its low cost) so that they are of negligible resistance and do not change the resistance of the circuit. A connecting wire may be a thick wire or several fine wires twisted together.

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* An ammeter or voltmeter used to measure alternating current is based on heating effect of current so it has graduations of unequal spacing while meters used to measure direct current is based on magnetic effect of current so it has graduations of equal spacing.

Generally, we use thick insulated copper wire as a connecting wire which is represented in a circuit diagram simply by a line.

9.4 SIMPLE ELECTRIC CIRCUIT

In our daily life, we use a torch in which a cell (or a combination of two or more cells) is connected to a bulb. This is the simplest electric circuit which uses only three components viz cell, bulb and switch. Fig. 9.11 shows a line diagram representing a simple electric circuit containing a cell, a bulb and a switch. As the switch is closed, a current flows through the bulb and the bulb glows. The flow of current stops as the switch is opened. The bulb then ceases to glow.
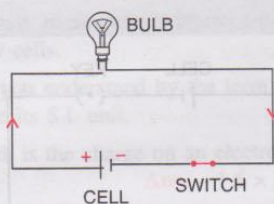

Fig. 9.11 An electric circuit of a cell, bulb and switch

Fig. 9.12 illustrates another simple electric circuit in which various components are the cell, key, rheostat, bulb, voltmeter and ammeter. Here the bulb acts as a load. It is clear that the ammeter, cell, key and rheostat are in series* with the bulb, while voltmeter is connected in parallel across** the bulb.
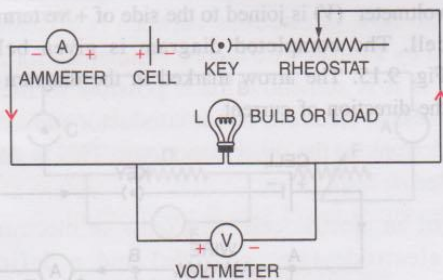

Fig. 9.12 Electrical circuit

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* The electrical components which are joined one after another and through which the same amount of current flows, are said to be in series.

** The electrical components which are joined with their one terminal forming one end and second terminal forming the other end, are said to be in parallel.

To demonstrate the functions of various components of circuit shown in Fig. 9.12.

(i) First take out the plug from the key. This makes the circuit incomplete (or opens the circuit). The bulb does not glow and both the ammeter and the voltmeter read zero since no current flows in the circuit.

(ii) Now insert the plug in the key. The circuit is completed (or closed). The bulb glows and the ammeter reads current in the circuit, while the voltmeter reads potential difference (or voltage) across the bulb.

(iii) Then vary the resistance of the circuit by sliding the variable terminal (or jockey) of the rheostat. The glow of bulb changes as well as the readings of ammeter and voltmeter change. On decreasing the resistance by sliding the jockey to the left, the glow of bulb increases, the readings of ammeter and voltmeter also increase. On increasing the resistance by sliding the jockey to the right, the glow of bulb decreases, the readings of ammeter and voltmeter also decrease.

9.5 INSULATORS AND CONDUCTORS

Insulators : The substances which do not allow current to flow through them, are called *insulators*. They have almost no free electrons and offer a very high resistance to the flow of current. Some examples of insulators are cotton, rubber, plastic, wood, paper, glass, leather, pure water, asbestos, china clay, *etc*.

Conductors : The substances which allow current to flow through them easily, are called *conductors*. All metals such as copper, aluminium, silver, iron, brass and steel are conductors. They have a large number of free electrons and they offer a very small resistance to the flow of current. Human body also allows current to flow through it, so it is also a conductor. Impure water (or acidulated water) and mercury are also conductors of electricity.

9.6 CLOSED AND OPEN CIRCUITS

The path along which current flows, is called a circuit. Current flows only if the circuit is *complete* (or *closed*). If the circuit is *open* (or *incomplete*), current does not flow.

For an electric circuit to be complete, each component of it must pass current through it i.e. it should be conducting. If there is an insulator in the path (or if the circuit is broken), the circuit is incomplete (or open) and the current will not flow through it.

In Fig. 9.13 (a), a bulb is connected between the two terminals A and B of a dry cell by two metal wires. The circuit is complete and the bulb glows. In Fig. 9.13 (b), the circuit from terminal A of the cell to the bulb is broken, so the circuit is incomplete and the bulb does not glow. In Fig. 9.13 (c), terminal

A of the cell is connected to the bulb by a metal wire, while the other terminal B of the cell is connected to the bulb by a thread (insulator), so the circuit is incomplete and the bulb does not glow.
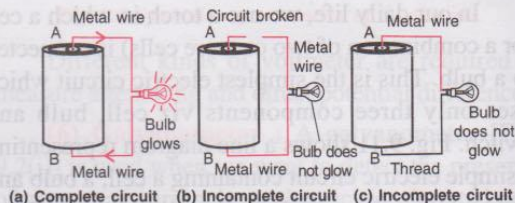

(a) Complete circuit (b) Incomplete circuit (c) Incomplete circuit

Fig. 9.13 Closed and open circuits

EXAMPLES

1. What is responsible for the flow of current through (i) a metallic conductor, (ii) an electrolyte ?

(i) In a metallic conductor, **free electrons** are responsible for the flow of current.

(ii) In an electrolyte, **both the positive and negative ions** are responsible for the flow of current.

2. A conductor carries a current of 0·2 A. (a) Find the amount of charge that will pass through the cross section of conductor in 30 s. (b) How many electrons will flow in this time interval if charge on one electron is $1·6 \times 10^{-19}$ C ?

Given : $I = 0·2$ A, $t = 30$ s

(a)　　　　Charge　= Current × time

or　　　　　$Q = I \times t = 0·2 \times 30 = 6$ **C**

(b) If n electrons flow and e is the charge on one electron, then total charge passed $Q = ne$

∴ $n = \dfrac{Q}{e} = \dfrac{6}{1·6 \times 10^{-19}} = 3·75 \times 10^{19}$

3. You are given a resistance wire AB connected with a cell and a key as shown in Fig. 9.14. You are required to measure the current in the wire AB and potential difference across it. Name the instruments that you would use and draw a labelled diagram to show how are they connected. Also mark the direction of current in each component.
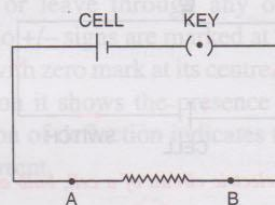
Fig. 9.14 Electrical circuit

To measure current, an **ammeter** is used and to measure the potential difference, a **voltmeter** is used. The ammeter (A) is connected in series with the resistance wire AB and cell, while the voltmeter (V) is connected in parallel across the wire AB. Care is taken that + marked terminal of ammeter (A) and voltmeter (V) is joined to the side of + ve terminal of cell. The completed diagram is given below in Fig. 9.15. The arrow marked in the diagram shows the direction of current.

Fig. 9.15

1. Name *one* d.c. source and *one* a.c. source.

   Ans. d.c. source : cell, **a.c. source :** mains.

2. Distinguish between d.c. and a.c.

3. What is an electric cell ?

4. What transformation of energy takes place when current is drawn from a cell ?

   Ans. Chemical energy changes to electrical energy.

5. Name the constituents of a cell.

   Ans. Two electrodes and an electrolyte in a vessel.

6. State the *two* kinds of cell. Give *one* example of each.

7. What is a primary cell ? Name *two* such cells.
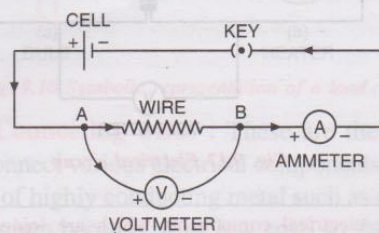
8. What is a secondary cell ? Name *one* such cell.

9. State *three* differences between *primary* and *secondary* cells.

10. What do you understand by the term current ? State and define its S.I. unit.

11. How much is the charge on an electron ?

    Ans. − 1·6 × 10⁻¹⁹ coulomb.

12. *n* electrons flow through a cross section of a conductor in time *t*. If charge on an electron is *e*, write an expression for the current in the conductor.

    Ans. $\frac{ne}{t}$

13. Name the instrument used to control current in an electric circuit. **Ans.** Rheostat

14. In the electric circuit shown in Fig. 9.16, label the parts *A, B, C, D, E,* and *F*. State the function of each part. Show in the diagram the direction of flow of current.
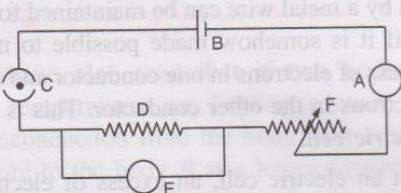
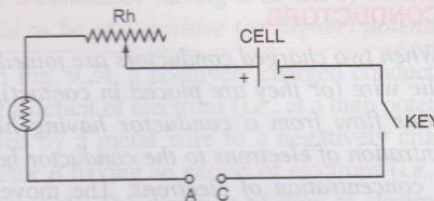

    Fig. 9.16

15. What is the function of a key (or switch) in an electric circuit ?

    Ans. To put on or off current in a circuit.

16. Write symbols and state functions of each of the following components in an electric circuit : (i) key, (ii) cell, (iii) rheostat, (iv) ammeter, and (v) voltmeter.

17. (a) Complete the circuit given in Fig. 9.17 by inserting between the terminals *A* and *C*, an ammeter. (b) In the diagram mark the polarity at the terminals of ammeter and indicate clearly the direction of flow of current in the circuit, when the circuit is complete. (c) Name and state the purpose of Rh in the circuit.

    Fig. 9.17

18. What are conductors and insulators of electricity ? Give *two* examples of each.

19. Select conductors of electricity from the following : Copper wire, silk thread, pure water, acidulated water, human body, glass, mercury.

    Ans. Copper wire, acidulated water, human body and mercury.

20. State *two* differences between a conductor and an insulator of electricity.

21. Distinguish between a closed circuit and an open circuit, with the use of suitable labelled diagrams.

22. Write the condition required for a circuit to be a closed circuit.

Multiple choice type :

1. A cell is used to :
   (a) measure current in a circuit
   (b) provide current in a circuit
   (c) limit current in a circuit
   (d) prevent current in a circuit.

   Ans. (b) provide current in a circuit

2. The unit of current is :
   (a) ampere   (b) volt
   (c) ohm   (d) coulomb.

   Ans. (a) ampere

3. The insulator of electricity is :
   (a) copper   (b) acidulated water
   (c) human body   (d) silk

   Ans. (d) silk

Numericals :

1. A charge 0·5 C passes through a cross section of a conductor in 5 s. Find the current.
   Ans. 0·1 A

2. A current of 1·5 A flows through a conductor for 2·0 s. What amount of charge passes through the conductor ?
   **Ans.** 3 C

3. When starter motor of a car is switched on for 0·8 s, a charge 24 C passes through the coil of the motor. Calculate the current in the coil. **Ans.** 30 A

(A) POTENTIAL DIFFERENCE AND RESISTANCE

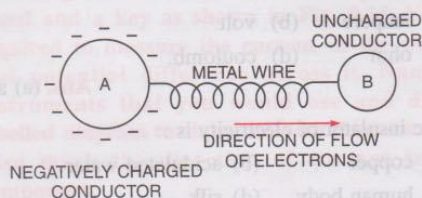## 9.7 FLOW OF ELECTRONS BETWEEN THE CONDUCTORS

When two charged conductors are joined by a metallic wire (or they are placed in contact), free electrons flow from a conductor having higher concentration of electrons to the conductor having lower concentration of electrons. The movement of electrons stops when concentration of electrons in both becomes equal. This can be understood by the following examples.

Examples : **(1)** In Fig. 9.18, a positively charged conductor A is joined by a metal wire to an uncharged conductor B. Electrons move from the uncharged conductor B to the charged conductor A to balance the deficit of electrons in the conductor A. This movement of electrons continues till both the conductors have *equal concentration* of electrons.

POSITIVELY CHARGED CONDUCTOR
UNCHARGED CONDUCTOR
METAL WIRE
DIRECTION OF FLOW OF ELECTRONS
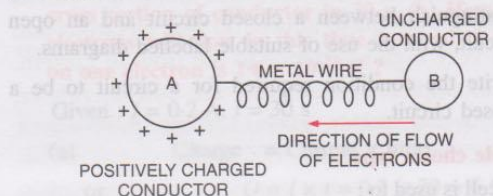
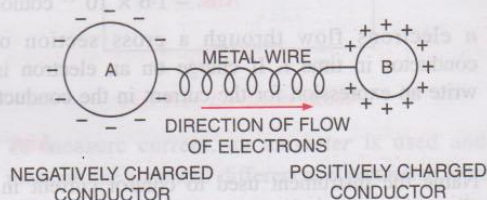*Fig. 9.18 Direction of flow of electrons from an uncharged conductor to a positively charged conductor*

(2) In Fig. 9.19, a negatively charged conductor A is joined by a metal wire to an uncharged conductor B. Electrons flow from the charged conductor A (which has excess of electrons) to the uncharged

NEGATIVELY CHARGED CONDUCTOR
UNCHARGED CONDUCTOR
METAL WIRE
DIRECTION OF FLOW OF ELECTRONS

Fig. 9.19 Direction of flow of electrons from a negatively charged conductor to an uncharged conductor

conductor B (which is neutral). This movement of electrons stops when both the conductors acquire *equal concentration* of electrons.

(3) In Fig 9.20, two charged conductors A and B are joined by a metal wire. Conductor A is negatively charged, while conductor B is positively charged. Electrons flow from the negatively charged conductor A (which has excess of electrons) to the positively charged conductor B (which has deficit of electrons). This flow of electrons continues till there is *equal concentration of* electrons in both the conductors.

METAL WIRE
DIRECTION OF FLOW OF ELECTRONS
NEGATIVELY CHARGED CONDUCTOR
POSITIVELY CHARGED CONDUCTOR

Fig. 9.20 Direction of flow of electrons from a negatively charged conductor to the positively charged conductor

Inference : From above examples, it is clear that the flow of electrons between two conductors joined by a metal wire can be maintained for a long time, if it is somehow made possible to maintain an excess of electrons in one conductor and a deficit of electrons in the other conductor. This is done in an *electric cell.*

In an electric cell, an excess of electrons on one electrode (*i.e.*, cathode) and a deficit of electrons on the other electrode (*i.e.*, anode) is maintained for a sufficiently long time by a chemical reaction within the cell. Thus, *an electric cell works as a source of electrons* and there is a continuous flow of electrons in the external circuit connected with the cell, in a direction from cathode to anode.

9.8 DIRECTION OF THE ELECTRIC CURRENT — CONVENTIONAL AND ELECTRONIC FLOW

It is our common experience that if a body is released from a height, the body always moves from a higher level A (away from the earth) to the lower level B (nearer the earth surface) i.e., from a higher gravitational potential to the lower gravitational potential (Fig. 9.21).

High gravitational
potential
A   A body released from
a height falls down

Low gravitational
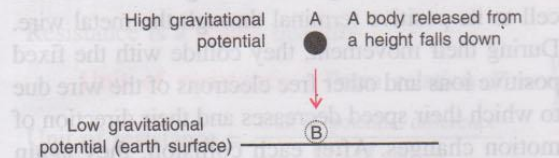potential (earth surface)   B

Fig. 9.21 A freely falling body

Similarly, if two vessels containing water up to different levels are joined together, water flows from the vessel A containing water up to a higher level to the vessel B containing water up to a lower level. This flow of water is due to the difference in hydrostatic pressure (or level of water) in the two vessels and it continues till the level of water is same in both the vessels (Fig. 9.22).
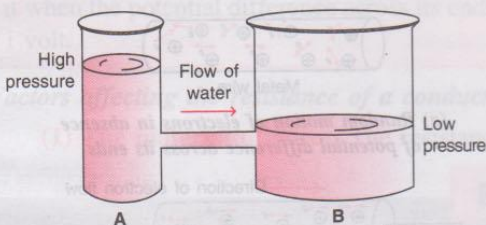
High
pressure
Flow of
water
Low
pressure

A   B

Fig. 9.22 Flow of water in two vessels

We have also read that if two bodies at different temperatures are kept in contact, heat flows by conduction from the body A at a higher temperature to the body B at a lower temperature
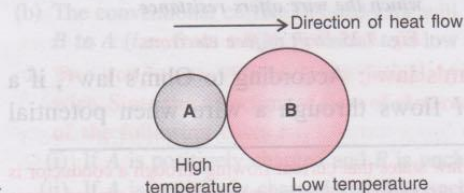
Direction of heat flow

A   B

High
temperature   Low temperature

Fig. 9.23 Flow of heat in two bodies

till both the bodies acquire the same temperature (Fig. 9.23).

In a similar manner, when two charged conductors are joined by a metal wire, the direction of flow of electrons is determined by a quantity called the *electric potential* of the conductor.

> *A conductor having an excess of electrons is said to be at a negative (or lower) potential, while a conductor having a deficit of electrons is said to be at a positive (or higher) potential.*

In Fig. 9.24, a positively charged conductor A having a deficit of electrons (i.e., at a high potential) is joined by a metal wire to a negatively charged conductor B having an excess of electrons (i.e., at a low potential). The direction of flow of electrons is from conductor B to conductor A i.e., from *low potential to high potential*. In keeping with the convention of flow from a higher to a lower level*, *the electric current is said to flow from a body at higher potential to a body at lower potential i.e., in a direction opposite to the direction of flow of electrons.* Thus, *the direction of flow of conventional current is opposite to the direction of flow of electrons.* With this convention, in Fig. 9.18 current flows from A to B while in Fig. 9.19 and 9.20, current flows from B to A (opposite to the flow of electrons).

High potential   Flow of
electrons
Low potential

A   B

Deficiency of electrons
(charged positively)   Flow of
current   Excess of electrons
(charged negatively)
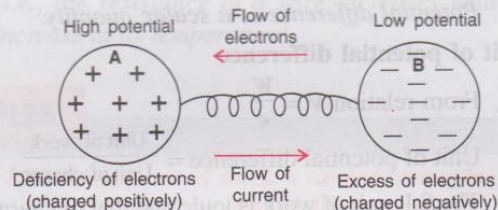
Fig. 9.24 Flow of electrons and flow of current between the two conductors

9.9 ELEMENTARY IDEA ABOUT WORK DONE IN TRANSFERRING CHARGE THROUGH A CONDUCTING WIRE; POTENTIAL DIFFERENCE ($V = W/Q$)

We know that like charges repel and unlike charges attract, therefore to create an excess or deficit of electrons at a point, some work is to be done in

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* Heat flows from a body at a high temperature to a body at a low temperature. Liquid flows from a high level to a low level, so we say that current flows from higher potential to lower potential.

moving the charges (or electrons) against the forces between them. The force between the two charges is zero when they are at infinite separation. Hence quantitatively, potential at a point is measured in terms of work done in bringing a charge q from infinity to that point. If work W' is done in bringing a charge q from infinity to a point, then potential at that point is

$$V = \frac{W'}{q} \qquad ....(9.4)$$

Potential is a **scalar** quantity. Its S.I. unit is joule/coulomb or volt (symbol V).

Similarly the potential difference between two conductors is measured in terms of the work done in transferring the charge from one conductor to the other, through a metallic wire.

> *The potential difference between two conductors is equal to the work done in transferring a unit positive charge from one conductor to the other conductor.*

If work W is done in transferring a test charge q from one conductor to the other, the potential difference between them is

$$V_1 - V_2 = \frac{W}{q} \qquad ...(9.5)$$

*Potential difference is a **scalar** quantity.*

Unit of potential difference

From relation $V = \frac{W}{q}$

$$\text{Unit of potential difference} = \frac{\text{Unit of work}}{\text{Unit of charge}}.$$

The S.I. unit of work is joule and that of charge is coulomb (C), so the potential difference is measured in joule per coulomb which is named as volt (abbreviated as V). Thus

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}} \text{ or } 1 \text{ V} = \frac{1 \text{ J}}{1 \text{ C}}$$

> *Potential difference between two points is said to be 1 volt if work done in transferring 1 coulomb of charge from one point to the other point is 1 joule.*

9.10 ELECTRICAL RESISTANCE

When current flows through a metallic wire, it offers some obstruction called *resistance* to the flow of current through it. Thus we define resistance as :

> *The obstruction offered to the flow of current by a conductor is called its electrical resistance.*

Cause of resistance : A metal wire has free electrons which move in a random manner in absence of any cell connected across it [Fig. 9.25 (a)]. When the ends of the wire are connected to a cell, the electrons start moving from the negative terminal of cell to its positive terminal through the metal wire. During their movement, they collide with the fixed positive ions and other free electrons of the wire due to which their speed decreases and their direction of motion changes. After each collision, they again accelerate towards the positive terminal and suffer collisions with other positive ions and free electrons again. This process continues. As a result, the electrons do not move in bulk with increasing speeds from one end to the other, but they drift towards the positive terminal. This is how a wire offers resistance to the flow of electrons (or current) through it. Fig. 9.25 (b) shows the drift of electrons in a wire. The electrons are shown by dots($\bullet$) and the positive ions are shown as $\oplus$.

(a) Random motion of electrons in absence of potential difference across its ends

(b) Collisions of electrons with the positive ions due to which the wire offers resistance

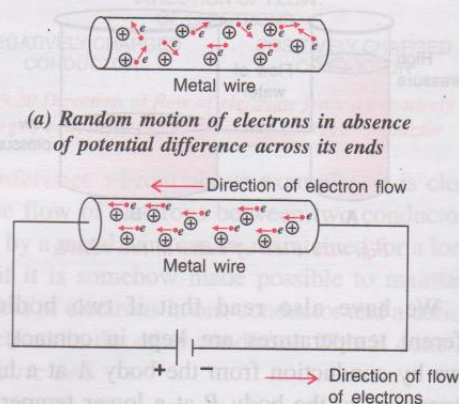**Fig. 9.25 Drift of free electrons**

Ohm's law : According to Ohm's law*, if a current I flows through a wire when potential

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* Ohm's law states that current flowing through a conductor is directly proportional to the potential difference applied across its ends provided its temperature is constant. *i.e.*, $I \propto V$ or $V \propto I$ or $V = IR$ where R is the resistance of conductor.

difference across the ends of the wire is V, the resistance offered by the wire to the flow of current is the ratio of potential difference across it to the current flowing in it. *i.e.,*

Resistance of wire (R)

$$= \frac{\text{Potential difference across the wire } (V)}{\text{Current flowing in the wire } (I)}$$

$$R = \frac{V}{I} \quad \text{or} \quad V = IR \qquad \dots (9.6)$$

Resistance is a **scalar** quantity

Unit of resistance : From relation $R = \frac{V}{I}$,

$$\text{Unit of resistance} = \frac{\text{Unit of potential difference}}{\text{Unit of current}}.$$

The S.I. unit of potential difference is volt (V) and that of current is ampere (A), hence S.I. unit of resistance is volt per ampere which is named as ohm (symbol Ω). Thus,

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}} \text{ or } 1 \Omega = \frac{1 \text{ V}}{1 \text{ A}}$$

The resistance of a conductor is said to be 1 ohm if a current of 1 ampere flows through it when the potential difference across its ends is 1 volt.

Factors affecting the resistance of a conductor

(1) The material of wire : The resistance of a wire depends on the number of collisions which the electrons moving through it suffer with the other electrons and fixed positive ions of the wire. In different materials, the concentration of electrons and the arrangement of atoms are different, therefore, *the resistance of wires of same length, same area of cross section, but of different materials differ depending on their material.* Good conductors having higher concentration of free electrons (such as metals) offer less resistance.

(2) The length of wire : The number of collisions suffered by the moving electrons will be more if they have to travel a longer distance in a wire, therefore, *a long wire offers more resistance than a short wire* (*i.e.,* resistance of a wire $\propto$ length of wire).

(3) The area of cross section of wire : In a thick wire, electrons get a larger area of cross section to flow as compared to a thin wire, therefore, *a thick wire offers less resistance* (*i.e.,* resistance of wire $\propto$ l/area of cross section of wire).

(4) The temperature of the wire : If the temperature of wire increases, ions in it vibrate more violently. As a result, the number of collisions increases and hence the resistance of wire increases (*i.e., the resistance of a wire increases with the increase in its temperature*).

EXAMPLES

1. A conductor AB is joined to a cell with its end A at a low potential and the end B at a high potential. (a) State the direction of flow of electrons in it. (b) What will be the direction of flow of conventional current in the conductor ?

(a) The flow of electrons is from A to B (*i.e.,* from a low potential to a high potential).

(b) The conventional current in conductor will flow from B to A (*i.e.,* from a high potential to a low potential).

2. Two conductors A and B are joined by a copper wire. State the direction of flow of electrons in each of the following cases :

(i) If A is positively charged and B is uncharged.
(ii) If A is negatively charged and B is uncharged.
(iii) If A is positively charged and B is negatively charged.

Ans. (i) B to A (ii) A to B (iii) B to A.

3. What amount of work is needed in moving 2 C charge through a potential difference of 8 V ?

Given : $q = 2$ coulomb, $V = 8$ volt

$\therefore$ Work needed $W = qV = 2 \times 8 = $ **16 J.**

4. A cell is connected to a bulb which develops a potential difference of 12 volt across it. The current in circuit is measured to be 2 ampere. Find the resistance offered by the filament of bulb to the flow of current.

Given : $V = 12$ volt, $I = 2$ ampere.

Resistance of filament of bulb

$$R = \frac{V}{I} = \frac{12 \text{ volt}}{2 \text{ ampere}} = \textbf{6 ohm.}$$

5. Calculate the potential difference across the ends of a wire of resistance 2 Ω when a current of 1·5 A passes through it.

Given : $R = 2\,\Omega$, $I = 1·5\,A$

From Ohm's law, $V = IR$

Potential differences $V = 1·5 \times 2 = \mathbf{3·0\ V}$

6. Calculate the current flowing through a wire of resistance 7·5 Ω connected to a battery of potential difference 1·5 V.

Given : $R = 7·5\,\Omega$, $V = 1·5\,V$

From Ohm's law, $V = IR$

Current in wire $I = \dfrac{V}{R} = \dfrac{1·5}{7·5} = \mathbf{0·2\ A}$

EXERCISE–9(B)

1. Fig. 9.26 below shows two conductors A and B. Their charges and potentials are given in the diagram. State the direction of (i) flow of electrons, and (ii) flow of current, when both the conductors are joined by a metal wire.
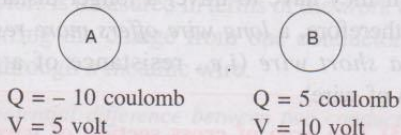

A	B
$Q = -10$ coulomb	$Q = 5$ coulomb
$V = 5$ volt	$V = 10$ volt

Fig. 9.26

Ans. (i) A to B, (ii) B to A

2. How is the direction of flow of current between two charged conductors determined by their potentials ?

Ans. Current flows from high potential to low potential.

3. Explain the concept of electric potential difference in terms of work done in transferring the charge.

4. Define the term potential difference.

5. State and define the S.I. unit of potential difference.

6. 'The potential difference between two conductors is 1 volt'. Explain the meaning of this statement.

7. What do you understand by the term resistance ?

8. Explain why does a metal wire when connected to a cell offer resistance to the flow of current.

9. State and define the S.I. unit of resistance.

10. State Ohm's law.

11. How are the potential difference (V), current (I) and resistance (R) related ? **Ans.** $V = I R$

12. 'The resistance of a wire is 1 ohm'. Explain the meaning of this statement.

13. How is the current flowing in a conductor changed if the resistance of conductor is doubled keeping the potential difference across it the same ?

Ans. Halved.

14. State *three* factors on which the resistance of a wire depends. Explain how does the resistance depend on the factors stated by you.

15. How is the resistance of a wire affected if its (a) length is doubled, (b) radius is doubled ?

Ans. (a) becomes more or twice
(b) becomes less or one-fourth.

16. State whether the resistance of filament of a bulb will decrease, remain unchanged or increase when it glows.

Ans. Increase

17. Name the physical quantities of which the units are : (i) volt, (ii) coulomb, (iii) ohm, (iv) ampere.

Ans. (i) Potential difference (ii) charge
(iii) resistance, (iv) current.

Multiple choice type :

1. Current in a circuit flows :
(a) in direction from high potential to low potential
(b) in direction from low potential to high potential
(c) in direction of flow of electrons
(d) in any direction.

Ans. (a) in direction from high potential to low potential

2. The unit of potential difference is :
(a) ampere (b) volt
(c) ohm (d) coulomb. **Ans.** (b) volt

3. On increasing the resistance in a circuit, the current in it :
(a) decreases (b) increases
(c) remains unchanged (d) nothing can be said.

Ans. (a) decreases

Numericals :

1. In transferring 1·5 C charge through a wire, 9 J of work is needed. Find the potential difference across the wire. **Ans.** 6 V

2. A cell of potential difference 12 V is connected to a bulb. The resistance of filament of bulb when it glows, is 24 Ω. Find the current drawn from the cell.

Ans. 0·5 A

3. A bulb draws current 1·5 A at 6·0 V. Find the resistance of filament of bulb while glowing. **Ans.** 4·0 Ω

4. A current 0·2 A flows in a wire of resistance 15 Ω. Find the potential difference across the ends of the wire. **Ans.** 3·0 V

5. Calculate the potential difference across the ends of a wire of resistance 2 Ω when a current of 1·5 A passes through it.

Given : $R = 2\ \Omega$, $I = 1.5$ A

From Ohm's law, $V = IR$

Potential differences $V = 1.5 \times 2 = \mathbf{3.0\ V}$

6. Calculate the current flowing through a wire of resistance 7·5 Ω connected to a battery of potential difference 1·5 V.

Given : $R = 7.5\ \Omega$, $V = 1.5$ V

From Ohm's law, $V = IR$

Current in wire $I = \dfrac{V}{R} = \dfrac{1.5}{7.5} = \mathbf{0.2\ A}$

EXERCISE–9(B)

1. Fig. 9.26 below shows two conductors A and B. Their charges and potentials are given in the diagram. State the direction of (i) flow of electrons, and (ii) flow of current, when both the conductors are joined by a metal wire.
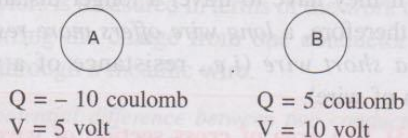
(A)   (B)

Q = – 10 coulomb   Q = 5 coulomb
V = 5 volt   V = 10 volt

Fig. 9.26

Ans. (i) A to B, (ii) B to A

2. How is the direction of flow of current between two charged conductors determined by their potentials ?

Ans. Current flows from high potential to low potential.

3. Explain the concept of electric potential difference in terms of work done in transferring the charge.

4. Define the term potential difference.

5. State and define the S.I. unit of potential difference.

6. 'The potential difference between two conductors is 1 volt'. Explain the meaning of this statement.

7. What do you understand by the term resistance ?

8. Explain why does a metal wire when connected to a cell offer resistance to the flow of current.

9. State and define the S.I. unit of resistance.

10. State Ohm's law.

11. How are the potential difference (V), current (I) and resistance (R) related ? **Ans.** $V = IR$

12. 'The resistance of a wire is 1 ohm'. Explain the meaning of this statement.

13. How is the current flowing in a conductor changed if the resistance of conductor is doubled keeping the potential difference across it the same ?

Ans. Halved.

14. State *three* factors on which the resistance of a wire depends. Explain how does the resistance depend on the factors stated by you.

15. How is the resistance of a wire affected if its (a) length is doubled, (b) radius is doubled ?

Ans. (a) becomes more or twice
(b) becomes less or one-fourth.

16. State whether the resistance of filament of a bulb will decrease, remain unchanged or increase when it glows.

Ans. Increase

17. Name the physical quantities of which the units are :
(i) volt, (ii) coulomb, (iii) ohm, (iv) ampere.

Ans. (i) Potential difference (ii) charge
(iii) resistance, (iv) current.

Multiple choice type :

1. Current in a circuit flows :
(a) in direction from high potential to low potential
(b) in direction from low potential to high potential
(c) in direction of flow of electrons
(d) in any direction.

Ans. (a) in direction from high potential
to low potential

2. The unit of potential difference is :
(a) ampere   (b) volt
(c) ohm   (d) coulomb. **Ans.** (b) volt

3. On increasing the resistance in a circuit, the current in it :
(a) decreases   (b) increases
(c) remains unchanged   (d) nothing can be said.

Ans. (a) decreases

Numericals :

1. In transferring 1·5 C charge through a wire, 9 J of work is needed. Find the potential difference across the wire. **Ans.** 6 V

2. A cell of potential difference 12 V is connected to a bulb. The resistance of filament of bulb when it glows, is 24 Ω. Find the current drawn from the cell.

Ans. 0·5 A

3. A bulb draws current 1·5 A at 6·0 V. Find the resistance of filament of bulb while glowing. **Ans.** 4·0 Ω

4. A current 0·2 A flows in a wire of resistance 15 Ω. Find the potential difference across the ends of the wire. **Ans.** 3·0 V

(C) EFFICIENT USE OF ENERGY

9.11 EFFICIENT USE OF ENERGY

The meaning of efficient use of energy is to reduce the cost and amount of energy used to provide us the various products and services. Energy efficiency can be achieved by adopting more efficient ecofriendly technologies and processes. This results in reduction of (i) the cost of energy and (ii) the emission of green house gases.

Examples : (1) By properly insulating a home, it is possible to maintain a comfortable temperature inside. It will reduce the cost of heating devices in winter and cooling devices in summer.

(2) The use of fluorescent and LED lights or natural skylight instead of traditional incandescent light bulbs, reduces the amount of energy required to attain the same level of illumination.

(3) The use of compact fluorescent lights (CFL) saves 67% energy and they may last 6 to 10 times longer than incandescent lights.

(4) The use of LED (light emitting diode) bulbs for lighting reduces the consumption of energy drastically. It is also helpful in reducing global warming and the harmful effect of mercury used in the fluorescent light.

(5) The modern energy efficient appliances such as refrigerators, freezers, ovens, stoves, dishwashers, dryers, etc. make use of significantly less energy than the older appliances. Nowadays appliances are star rated according of their efficient use of electricity.

(6) A building's location and its surroundings play a key role in regulating its temperature and illumination. Proper placement of windows and skylights and the use of architectural features that reflect light into the building can reduce the need of artificial lighting. White roof systems can save more energy in summers.

(7) The use of advanced boilers and furnaces in industry can save sufficient amount of energy in attaining the high temperature by burning less fuel. Use of such technologies is more efficient and less polluting.

(8) Fuel efficiency in vehicles can be increased by reducing the weight of the vehicle, using advanced tyres and computer controlled engines.

According to the International Energy Agency (IEA), the improved energy efficiency in buildings, industries and transportation could reduce the world's energy need in 2050 by one-third and thus it can help to control global emission of green house gases.

9.12 SOCIAL INITIATIVES

The rapid depletion of energy resources and the adverse environmental impacts of energy use, has led to (i) the efforts to develop energy efficient machines and (ii) the technologies which can reduce energy expenditure and minimize environmental hazards. It has become essential to create awareness amongst the people and build in them the trends of sensitive use of the resources and products so as to reduce the use of electricity. Public awareness can be improved through mass-media and children's participation in compaigns and eco-club activities. Community involvement will surely be effective in reducing the misuse of electricity. The non-government organisations (NGO's) can be used to create social awareness of the sensitive use of the resources.

EXERCISE–9(C)

1. What is meant by efficient use of energy ?
2. State *two* ways to save the energy.
3. How does proper insulation of home save energy ?
4. Which of the following device is most efficient for lighting purpose :
   LED, CFL, Fluorescent tube light, Electric bulb.
5. Give an example to explain that the use of modern eco-friendly technologies is more efficient and less polluting.
6. Describe *three* ways for the efficient use of energy.
7. What social initiatives must be taken for the sensitive use of energy ?

Multiple choice type :

1. The most non-polluting and efficient lighting device is :
   (a) CFL   (b) LED
   (c) Fluorescent light   (d) Electric bulb.
             Ans. (b) LED

2. IEA is the short form of :
   (a) Indian Energy Association
   (b) Indian Eco Academy
   (c) International Energy Agency
   (d) International Eco Academy.
         Ans. (c) International Energy Agency