Contents

SECTION A

FORMAL EXPERIMENTAL PHYSICS

ACTIVITIES IN PHYSICS

Further, the positive plate of the accumulator has to be connected to the positive terminal of the battery charger *i.e.* the battery charger has to force the charging current through the accumulator in the direction opposite to that of the discharging current. It will, then, make H^+ ions to move towards negative plate and SO_4^{--} ions towards the positive plate. The following chemical reactions take place at the two plates :

At the negative plate :

$$PbSO_4 + 2\,H^+ + 2\,e^- \longrightarrow Pb + H_2SO_4$$

At the positive plate :

$$\begin{array}{rcl} PbSO_4 + SO_4^{--} - 2\,e^- & \longrightarrow & PbO_2 + 2\,SO_3 \\ 2\,SO_3 + 2\,H_2O & \longrightarrow & 2\,H_2SO_4 \\ \hline PbSO_4 + 2\,H_2O + SO_4^{--} - 2\,e^- & \longrightarrow & PbO_2 + 2\,H_2SO_4 \\ \hline \end{array}$$

Therefore, during the charging process, $PbSO_4$ at both electrodes is converted back into the spongy lead (Pb) at negative plate and PbO_2 at positive plate. Further, in the reactions during charging, water is consumed and sulphuric acid is produced. As a result, the specific gravity of the sulphuric acid recovers.

Application. Lead accumulators are used to make batteries. Due to low internal resistance, high current can be drawn from such a battery. However, such batteries get damaged, in case they are overdischarged or overcharged. Being delicate and heavy, they are not suitable for use in laboratories.

1.10. EDISON ALKALI CELL

It is also called nickel-iron (Ni-Fe) cell. Its positive plate consists of a number of tubes of perforated steel ribbon wound spirally and held together by steel rings. The tubes are nickel plated. The active material consisting of $Ni(OH)_4$ and flakes of metallic nickel are packed into the nickel plated steel tubes in alternate layers.

The negative plate is made from finely perforated nickeled steel strip, stamped into pockets. The pockets are filled with powdered iron oxide.

The plates are separated from one another by hard rubber strips. The chemical changes during charging and discharging can be represented by the following reversible equation :

$$Ni\,(OH)_4 + KOH + Fe \rightleftharpoons Ni(OH)_2 + KOH + Fe\,(OH)_2$$

The e.m.f. of the fully charged Ni – Fe cell is 1·45 volt and it falls to 1·2 volt on discharging.

This cell is light, portable and does not need special care. It is more durable and robust. Its internal resistance is greater than the lead accumulator but its efficiency is low.

Application. An Edison alkali cell can withstand heavy currents during charging and discharging. It is quite light as compared to a lead accumulator. Although they are costly, yet they are preferred for their use in laboratories.

1.11. BATTERY AND BATTERY ELIMINATOR

Battery. *A series combination of a number of cells is known as a battery.*

As said earlier, lead accumulators are used to make a battery. Six lead accumulators connected in series provide a 12 V battery.

Battery eliminator. It is basically a rectifier. A 6 V battery eliminator provides 6 V d.c. supply from 220 V a.c. mains supply. Some battery eliminators can provide d.c. voltage from 0 – 12 V in steps of 1·5 V. It serves as a good substitute for cells and batteries in the laboratory.

For details, refer to section 10.03.

1.12. ELECTRICAL INSTRUMENTS

The following electrical instruments are usually used in various experiments on electricity :

1. **Resistance coil.** A resistance coil of a standard known resistance is made from the wire of a material such as manganin, constantan (or eureka), german silver, etc. Such materials have low temperature coefficient of resistance *i.e.* resistance of the wire made of such materials practically remains the same with change in temperature.

A calculated length of the wire having the required value of the resistance is enclosed in a small ebonite box. To avoid the inductive effect, the wire is double folded and wound on a reel or wooden bobbin. The two free ends of the wire are soldered to the two binding terminals provided on the top of the ebonite box as shown in Fig. 1.06 (*a*)

In an electric circuit, a resistance is represented as shown in Fig. 1.06 (*b*).

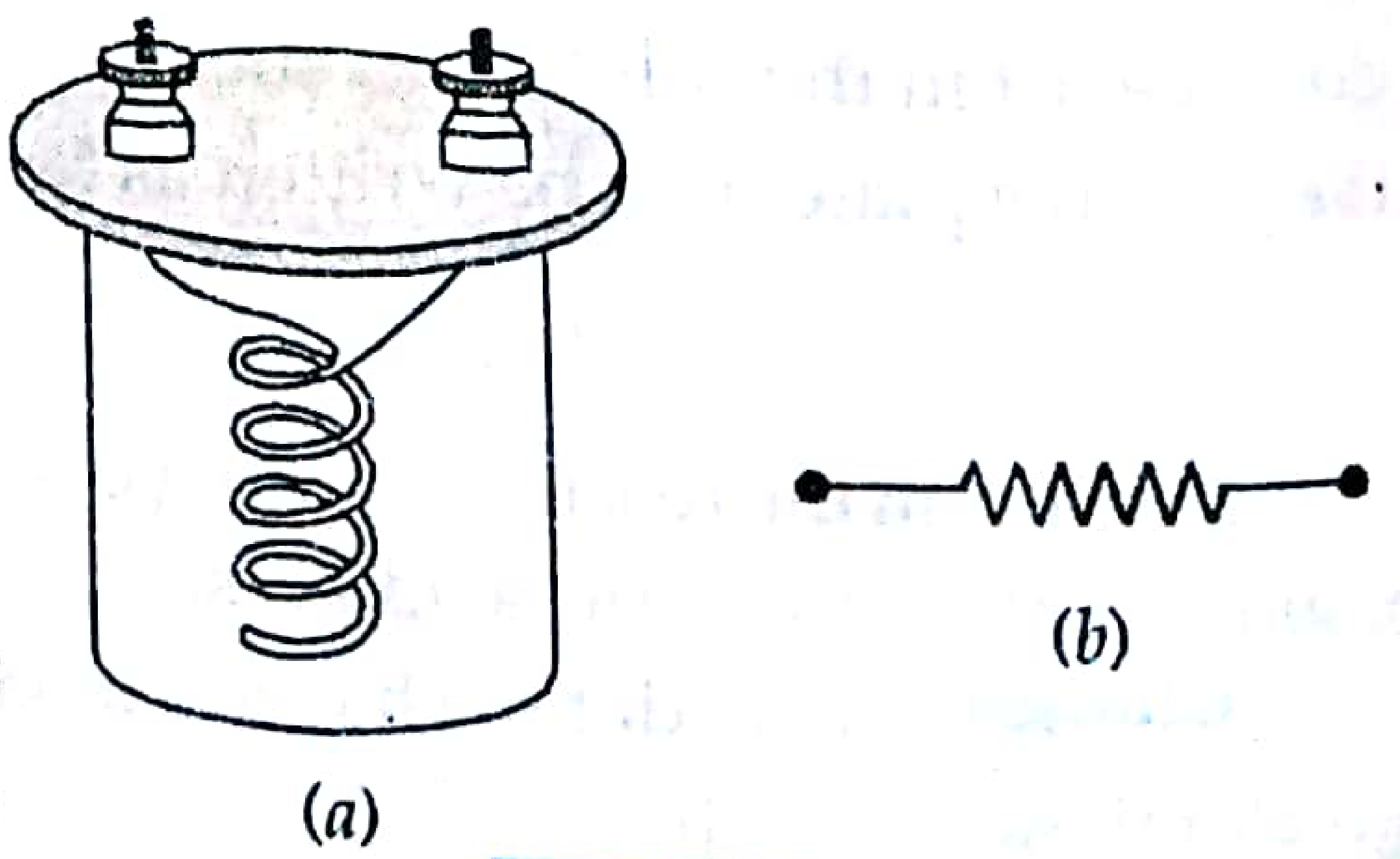
(*a*) (*b*)

Fig. 1.06

2. **Resistance box.** It is an electric device, which is used in electrical circuits to introduce a known value of resistance.

A resistance box contains a set of resistance coils of known values 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1000, 2000, 2000 and 5000 Ω, which are connected in series with each other. The resistance coils are arranged inside a wooden box provided with an ebonite top. A number of thick brass studs are arranged in the form of letter 'U' between two binding terminals on the ebonite top as shown in Fig. 1.07 (*a*). The studs are fixed with a small gap between them and there is a small cylindrical hole between the two adjacent studs. The brass plugs can fit tightly in the cylindrical holes between the studs. The resistance coils are soldered across the gaps between the studs and the value of the resistance of each coil is engraved on the stud near the corresponding gap.

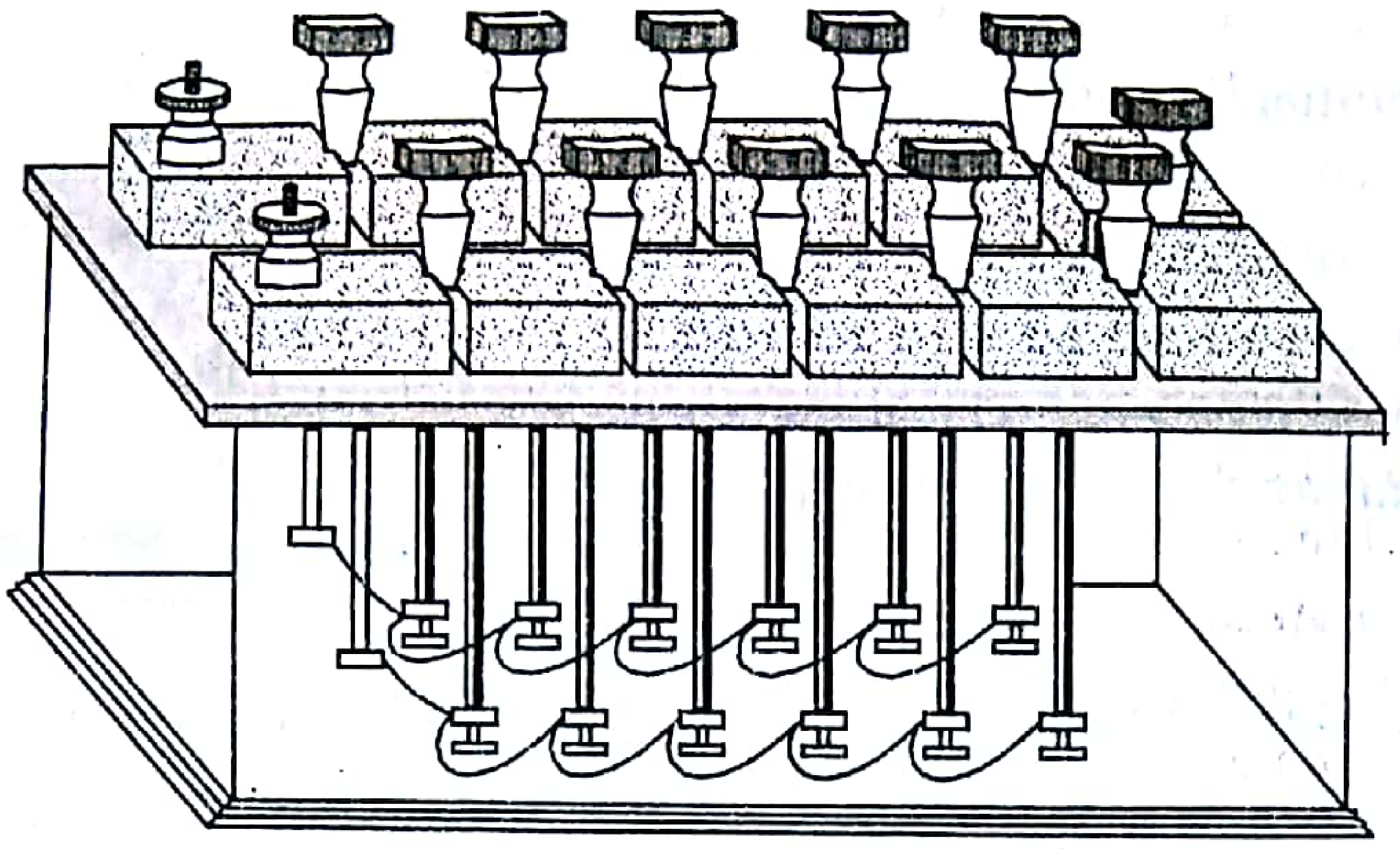
Fig. 1.07 (*a*)

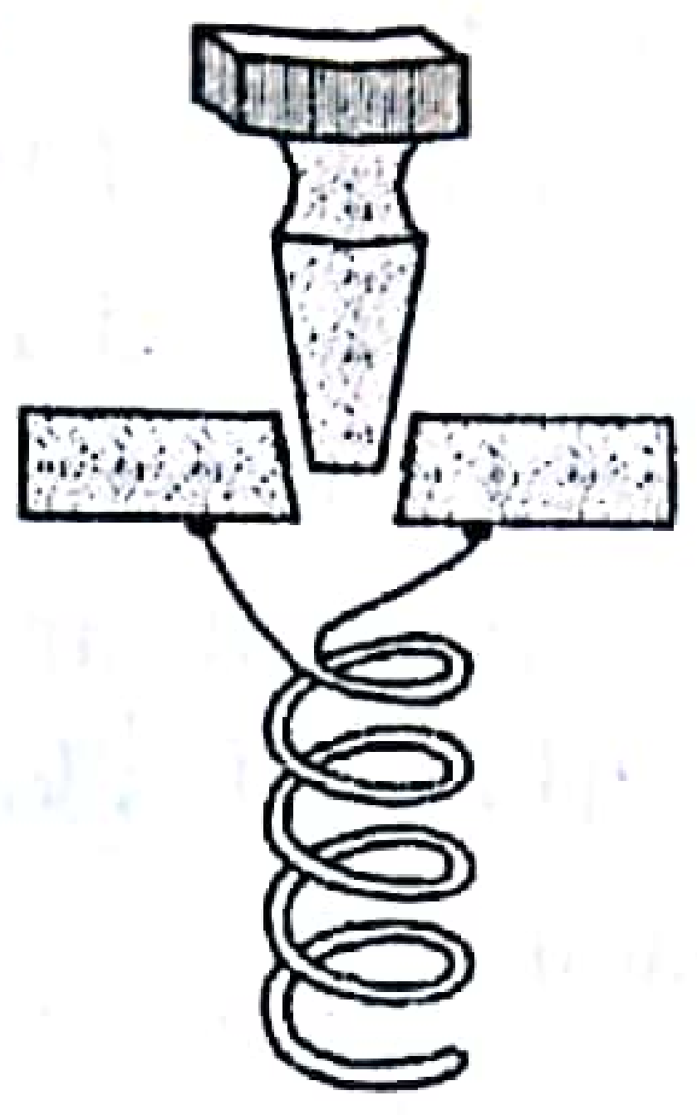
Fig. 1.07 (*b*)

When all the plugs are inserted in the resistance box, no resistance is introduced by the resistance box in the circuit. It is because, the thick brass studs offer a path of practically zero resistance to the current and likewise the resistance coils connected across them are bypassed. When a plug is taken out, the resistance coil across that gap comes in the circuit [Fig. 1.07 (*b*)]. It is because, the current cannot flow through the air gap between the two studs. To introduce a resistance of say, 137 Ω, one will take out the plugs corresponding to the resistance coils of 100, 20, 10, 5 and 2 Ω.

In a resistance box, there is an infinite resistance plug also. It is marked as INF (or ∞) on the brass stud. In fact, there is no resistance coil across the infinite resistance plug. When the infinite resistance plug is taken out, the circuit gets broken. Since no current can flow through the air gap, infinite resistance is said to be introduced in the circuit.

While using a resistance box in an electric circuit, the following precautions must be taken :

(*i*) All the plugs in the resistance box must be made tight in the holes with a screw motion.

(*ii*) The current passed through the resistance box should not be strong. Otherwise, the resistance coils may get burnt.

3. **Rheostat.** It is an electrical device, which is used to vary current in the circuit or for providing varying potential difference.

A rheostat consists of very long resistance wire wound on a porcelain cylinder in the form of a coil. The turns of the resistance wire are well insulated from each other. The two ends of the resistance wire are connected to the binding terminals B_1 and B_2, called the ***base terminals*** [Fig. 1.08 (*a*)]. A slider or Jockey J attached to a thick metallic rod R can slide over the windings of the rheostat. The slider provides a movable contact between the windings of the rheostat and the sliding rod R. There is one binding terminal T fixed at one end of the sliding rod. It is called the ***top terminal.*** The maximum value of the resistance, it can introduce and the maximum current, it can bear are marked on the body the rheostat.

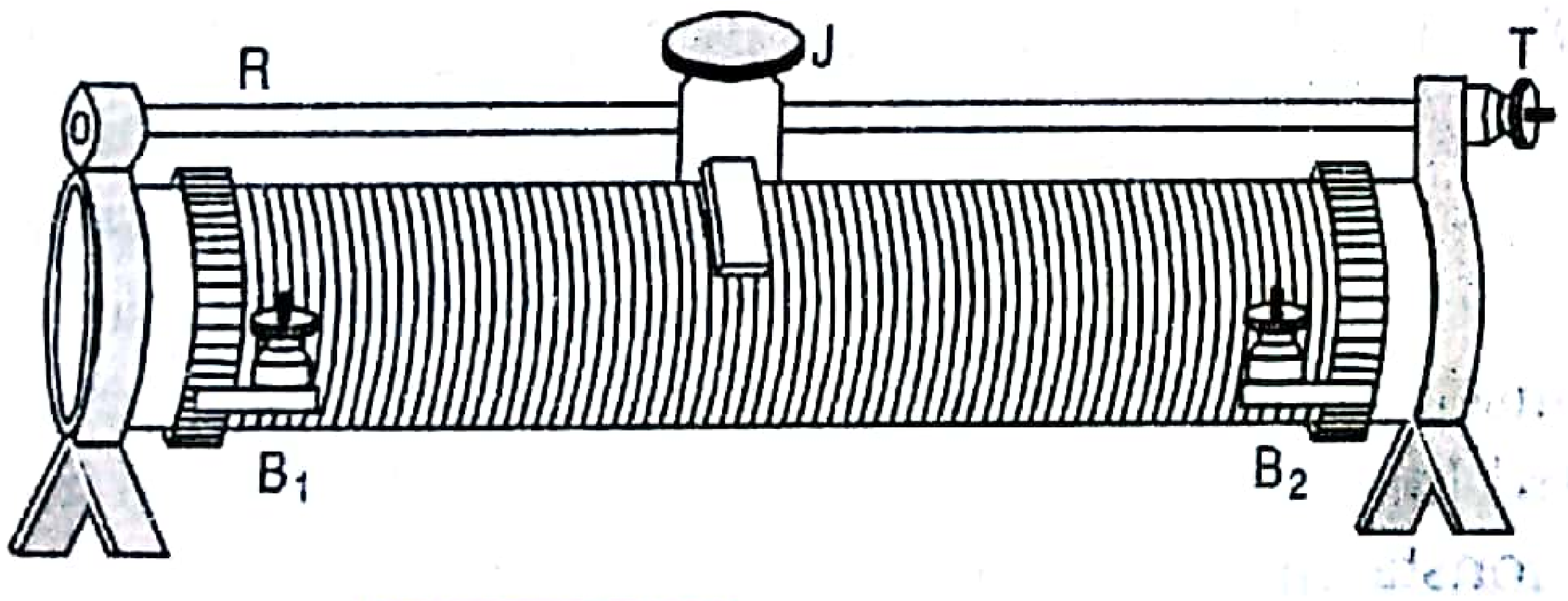

Fig. 1.08 (*a*)

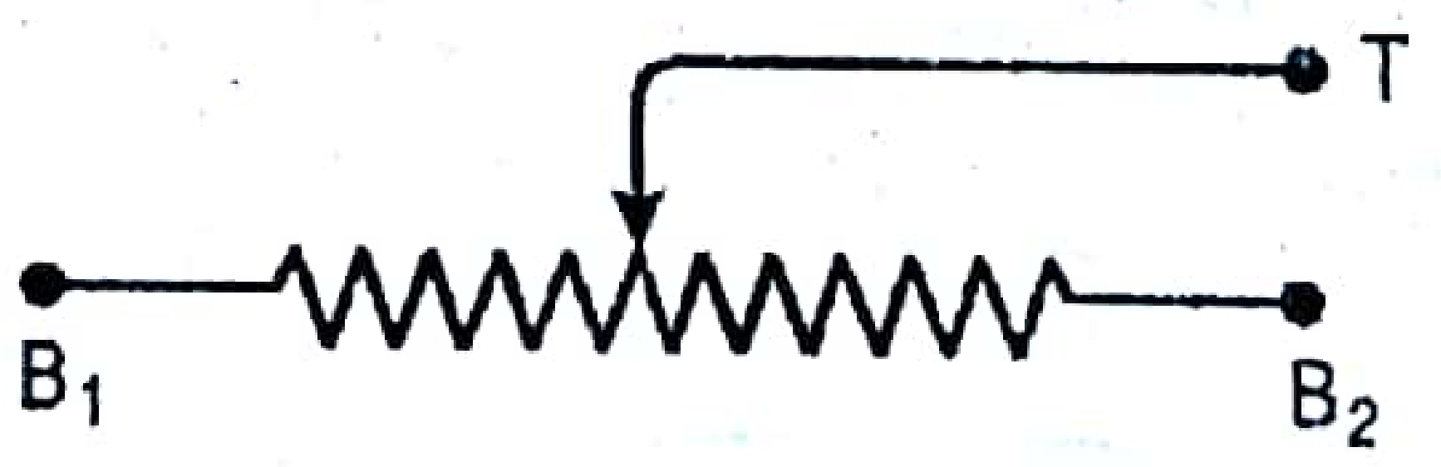

Fig. 1.08 (*b*)

In an electric circuit, the rheostat, is represented as shown in Fig. 1.08 (*b*). A rheostat can be used in an electric circuit for the following purposes :

(*i*) ***To use rheostat for varying current.*** For varying current in an electric circuit, a rheostat is used as a variable resistor. In order to do so, either of the two base terminals (say B_1) and the top terminal T are connected in the circuit. When the slider is moved, the resistance of the wire between the base terminal B_1 and the slider varies and as a result, the current in the circuit also changes.

(*ii*) ***To use rheostat for varying potential difference.*** A rheostat can be used to obtain a varying potential difference from a source of e.m.f. The source of e.m.f. is connected across the base terminals B_1 and B_2 as shown in Fig. 1.09. A uniform potential drop occurs along the entire length of the resistance wire of the rheostat. When the terminals B_1 and T of the rheostat are connected in the circuit, the potential difference proportional to the length of the wire between the terminals B_1 and T provides current in the circuit. The above use of the rheostat is known as the ***potential divider arrangement*** of the rheostat.

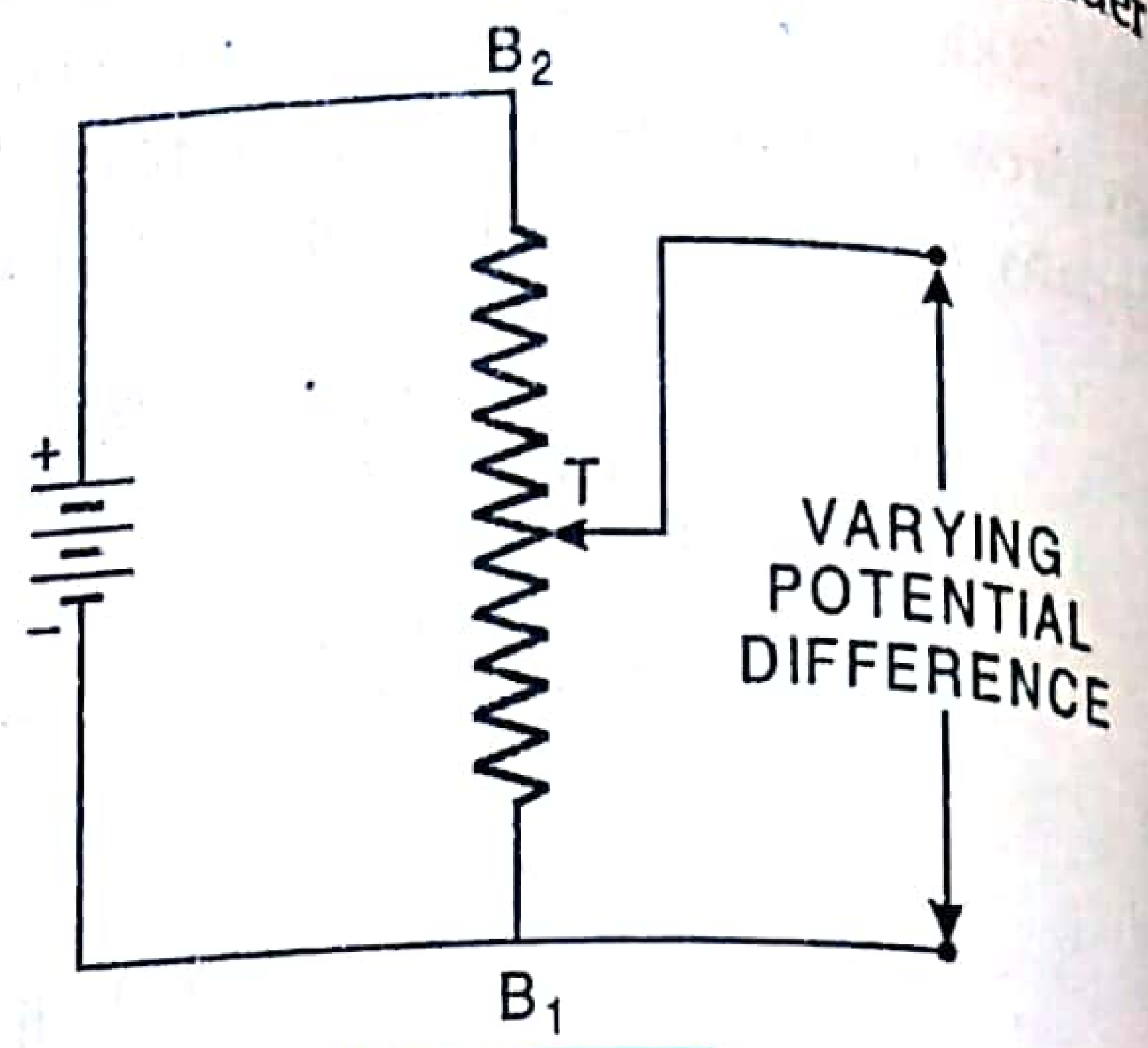

Fig. 1.09

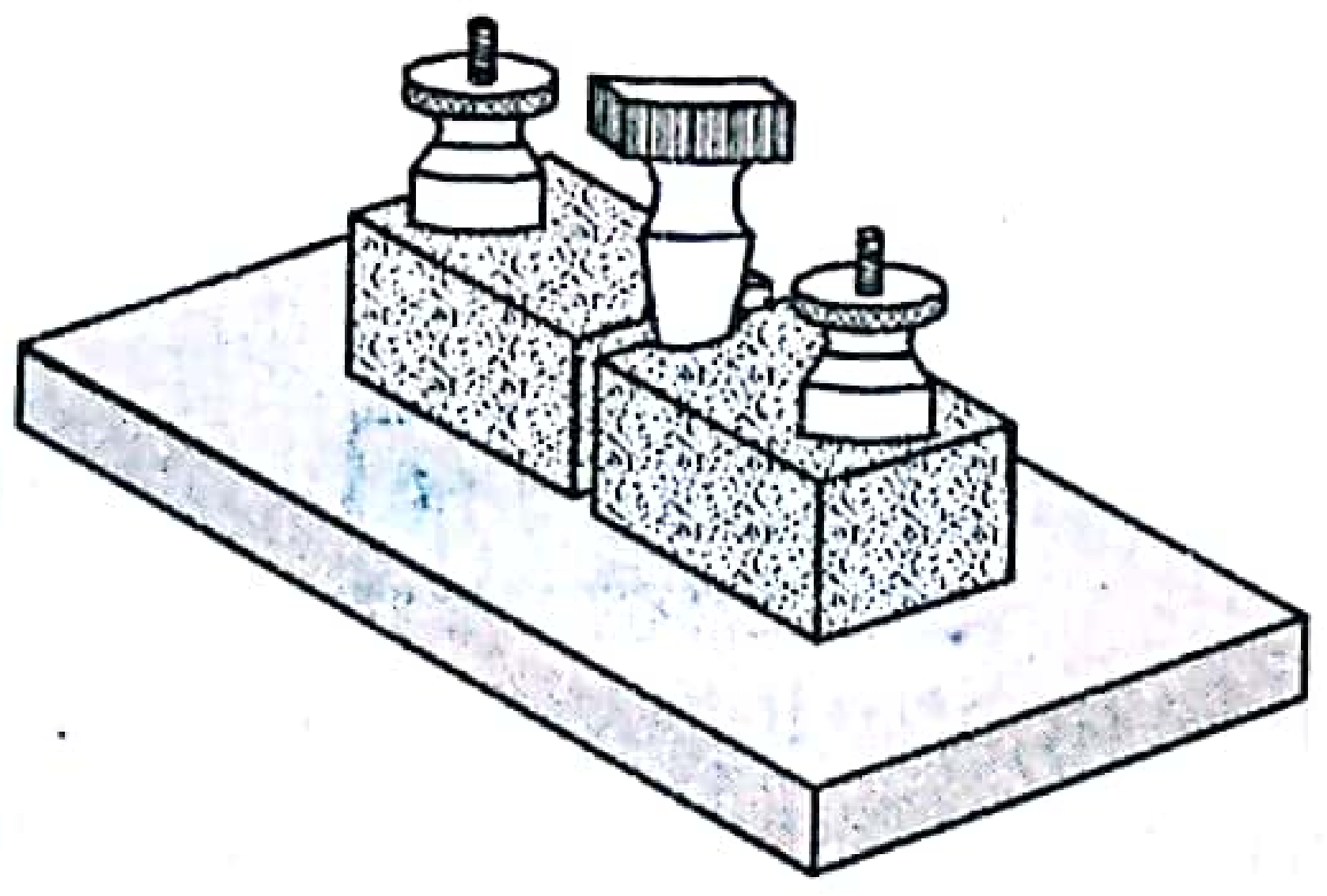

Fig. 1.10

4. **One-way key.** It works as a switch is an electric circuit. A one-way key consists of two thick brass studs fixed on an electric base. The two studs are separated from each other and have a cylindrical hole between them. A brass plug can fit tightly in the cylindrical hole. The brass studs are provided with the binding terminals A and B are shown in Fig. 1.10. The brass plug is inserted in the cylindrical hole, when the circuit is to be closed. When the current in the circuit is to be stopped, the plug is taken out from the key.

5. **Two-way key.** It works as a double switch in an electric circuit.

A two-way key consists of three thick brass studs arranged in the form of letter 'F' on an ebonite base. Each of the two small studs and the long (or main) stud have cylindrical holes, in which brass plugs can tightly fit in. A binding terminal is fixed on each of the three brass studs as shown in Fig. 1.11.

A two-way key is used in an electric circuit, for the following purposes :

(*i*) To connect or disconnect the source of e.m.f.

(*ii*) To obtain current in the circuit from either of the two sources of e.m.f. connected in the circuit.

(*iii*) To make current flow in the different parts of the circuit.

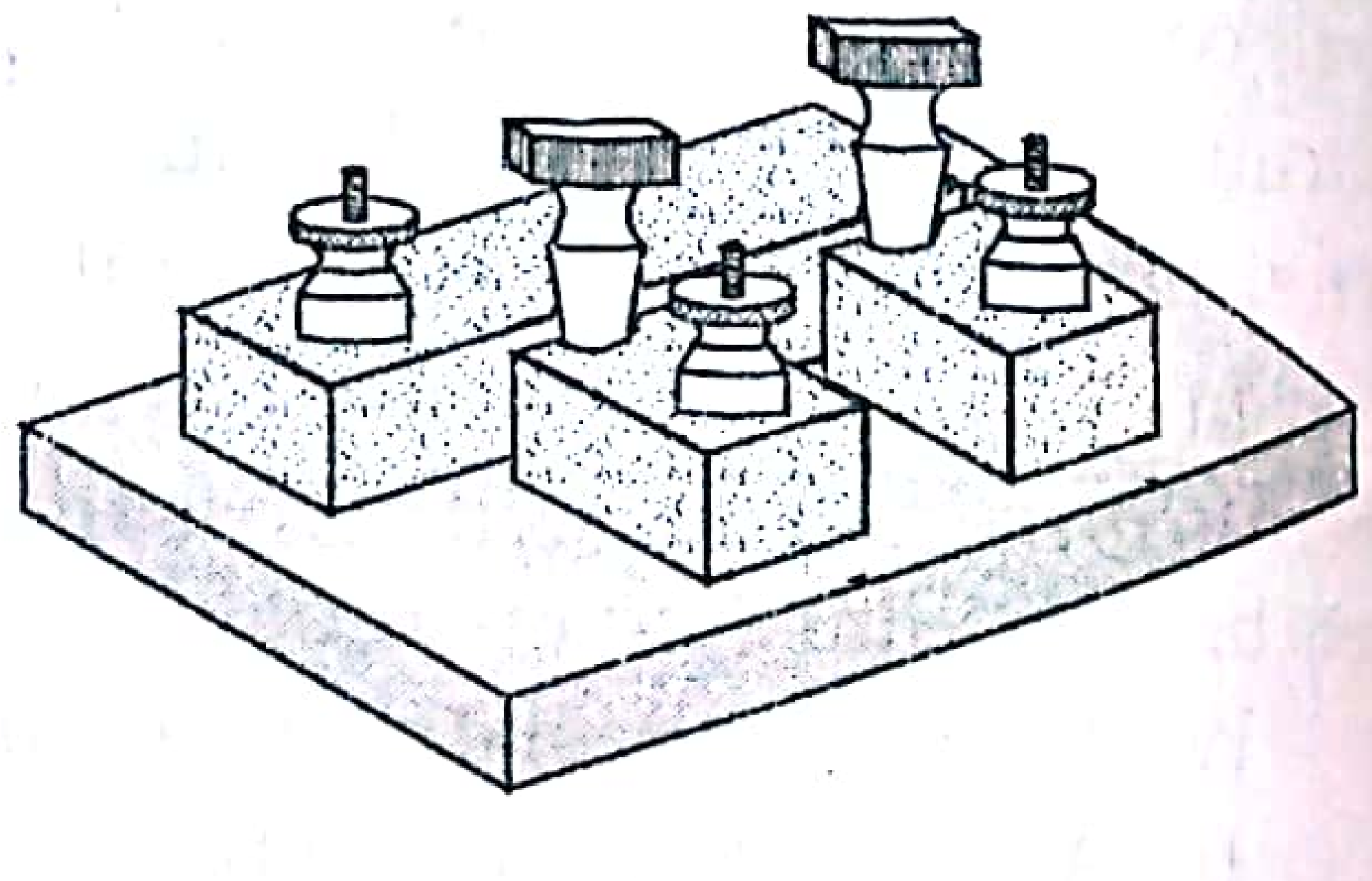

Fig. 1.11

6. **Tapping key.** It works as a temporary switch in an electric circuit. A tapping key consists of a metallic strip, whose one end is fixed firmly to an ebonite base and the free end is provided with a knob.

A small metallic stud is fixed on the ebonite base exactly below the knob of the metallic strip. The metallic stud and the fixed end of the strip are connected to the binding terminals A and B [Fig. 1.12]. When the knob is pressed down the strip comes in contact with the metallic stud and the circuit gets closed. On the other hand, when pressure is released on the knob, the strip no longer remains in contact with the stud. Due to this, the current in the circuit stops. A tapping key is used in an electric circuit, when the circuit is to be closed for a short interval of time.

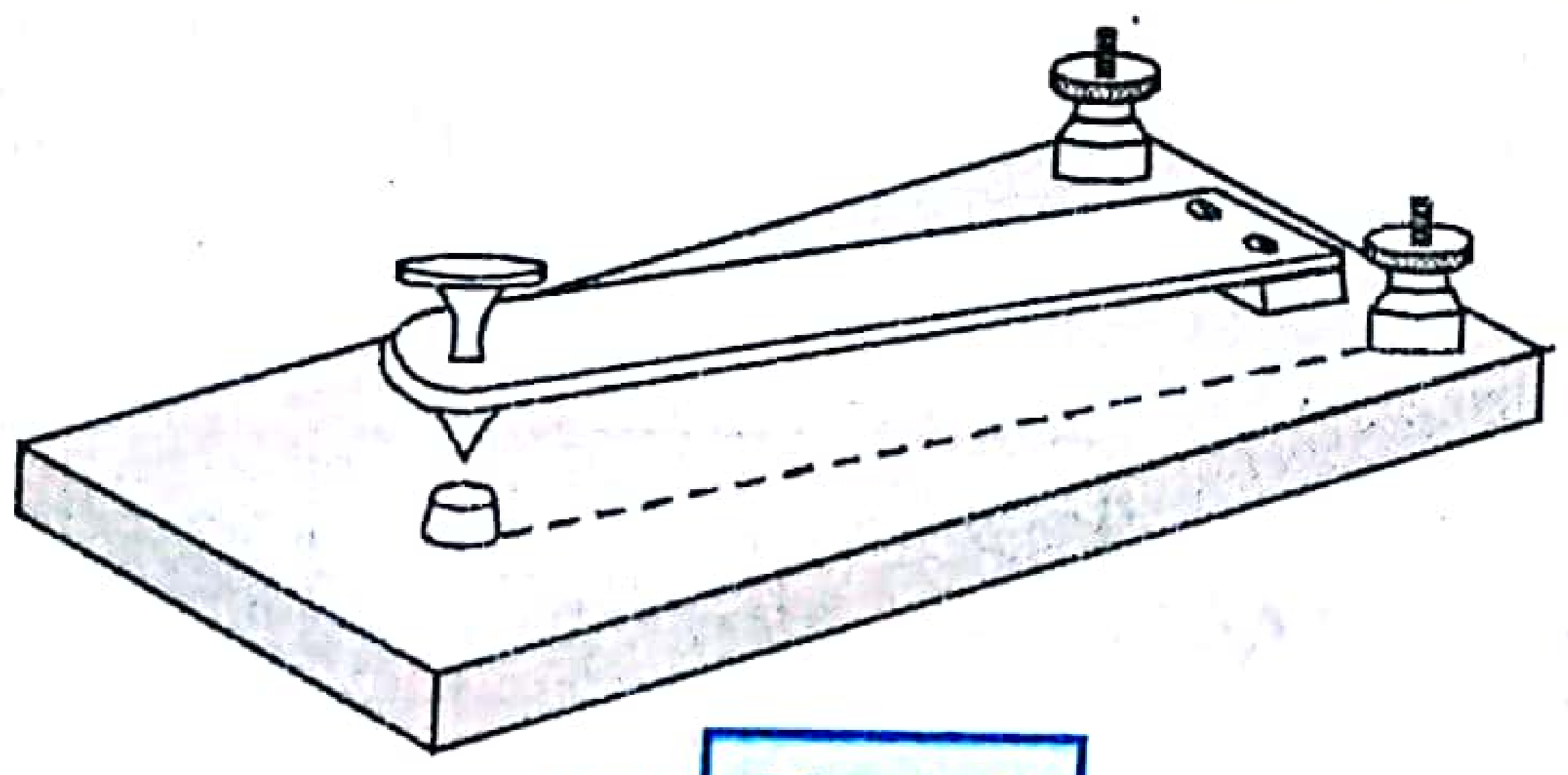

Fig. 1.12

7. **Reversing key.** It is used to reverse the direction of the current in an electric circuit.

A reversing key consists of two thick semi-circular brass strips fixed on an ebonite base. The binding terminals A and B are fixed on the brass strips as shown in Fig. 1.13. An ebonite arm, capable of rotating about a central vertical axis, has binding terminals C and D fixed at its two ends. The metallic brushes connected to the terminals C and D provide sliding contact with the brass strips fixed on the ebonite base.

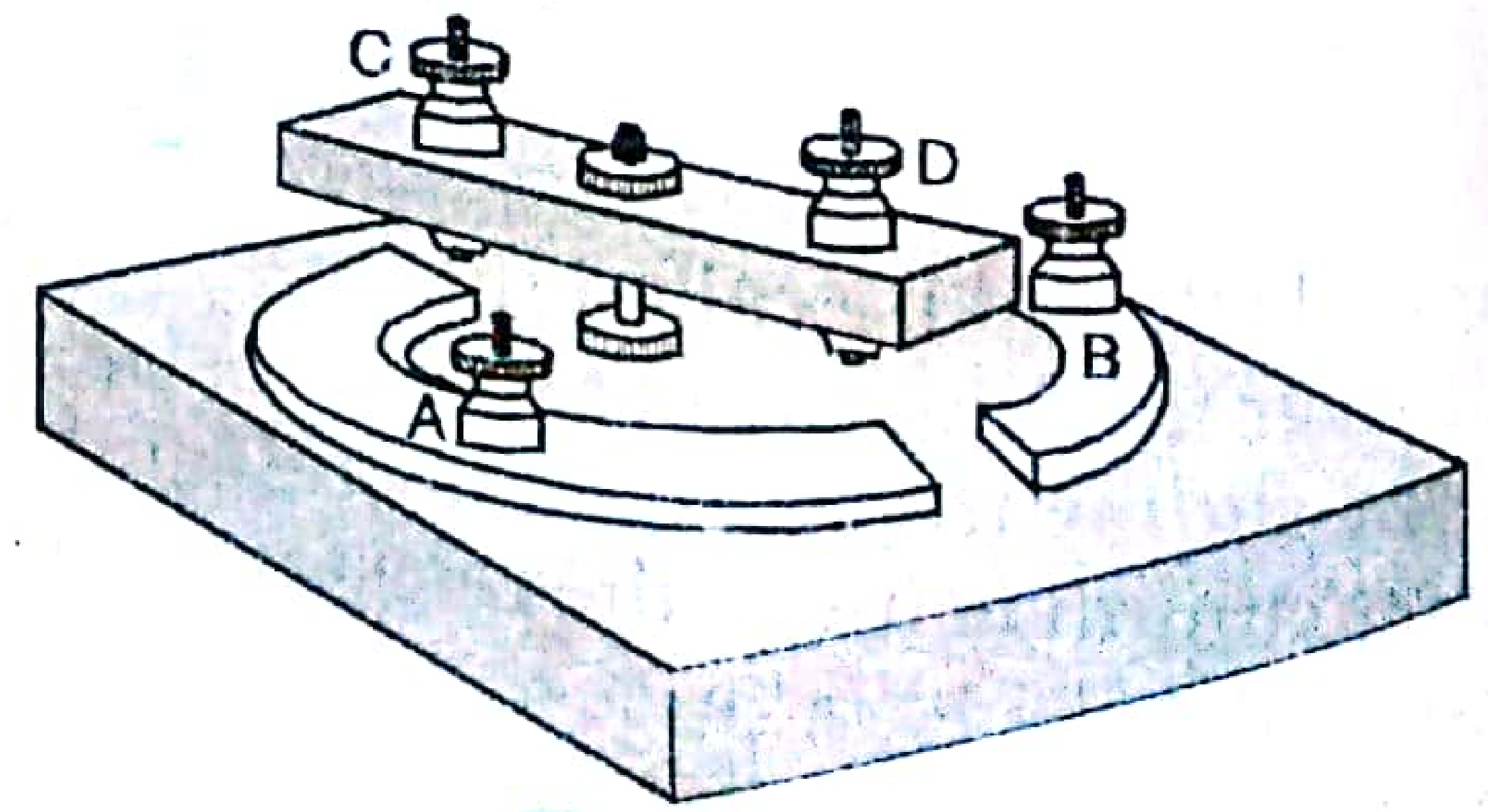

Fig. 1.13

When the source of e.m.f. is connected across the terminals A and B and the remaining part of the electric circuit across the terminals C and D, the current flows through the circuit in one direction. When the ebonite arm is rotated, the contact of terminal C with A and that of D with B get broken and the contact of the terminal C with B and that of D with A is established. As a result of this, the direction of flow of current in the circuit is reversed.

8. **Weston type galvanometer.** It is used for detecting current in an electric circuit.

A Weston type galvanometer is pivoted coil pointer type galvanometer. It consists of a rectangular coil of many turns made from a fine insulated copper wire. It is pivoted between two cylindrical poles of a strong permanent horse shoe magnet NS. A cylindrical soft iron core is fixed inside the coil. The motion of the coil is controlled by two hair springs attached to it. The free ends of the hair springs are soldered to the binding terminals T_1 and T_2 fixed on the bakelite case of galvanometer. An aluminium pointer is attached to the coil, which can move over the scale on either side of the zero mark of the scale. [Fig. 1.14]. The galvanometer is connected is series in the circuit. When current is passed through the galvanometer, the coil experiences a torque, which rotates the coil. It marks the pointer to move over the scale. The deflection of the pointer is proportional to the current passed through the galvanometer.

A galvanometer is a very sensitive instrument. It gives a large deflection even for a small current.

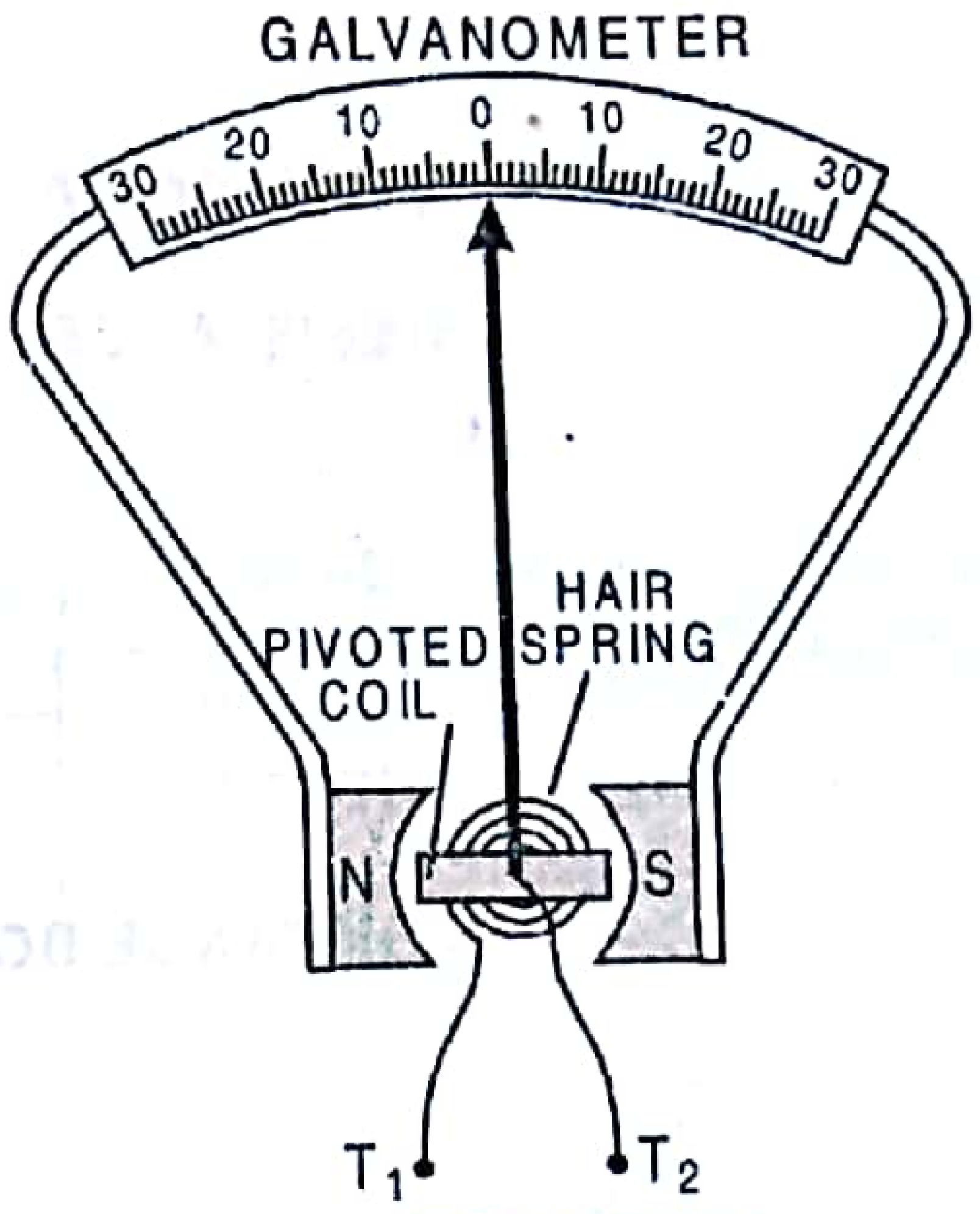

Fig. 1.14

9. **Ammeter.** It is an instrument used for measuring current in an electric circuit.

A galvanometer is low resistance instrument and as such it cannot be used to measure current in an electric circuit. It is because, when even a small current is passed through the galvanometer, it produces a large deflection. In case a large current is passed through the galvanometer, it may get damaged. In order to measure a large current, a galvanometer is converted into an ammeter by connecting a suitable small resistance, in parallel to the coil of the galvanometer as shown in Fig. 1.15. Such a small resistance is known as ***shunt.*** The scale of an ammeter is calibrated so as to read the current directly in ampere. For measuring a small current, ***milliammeter*** or a ***microammeter*** is used.

An ammeter is very low resistance instrument and it is always connected in series in the circuit.

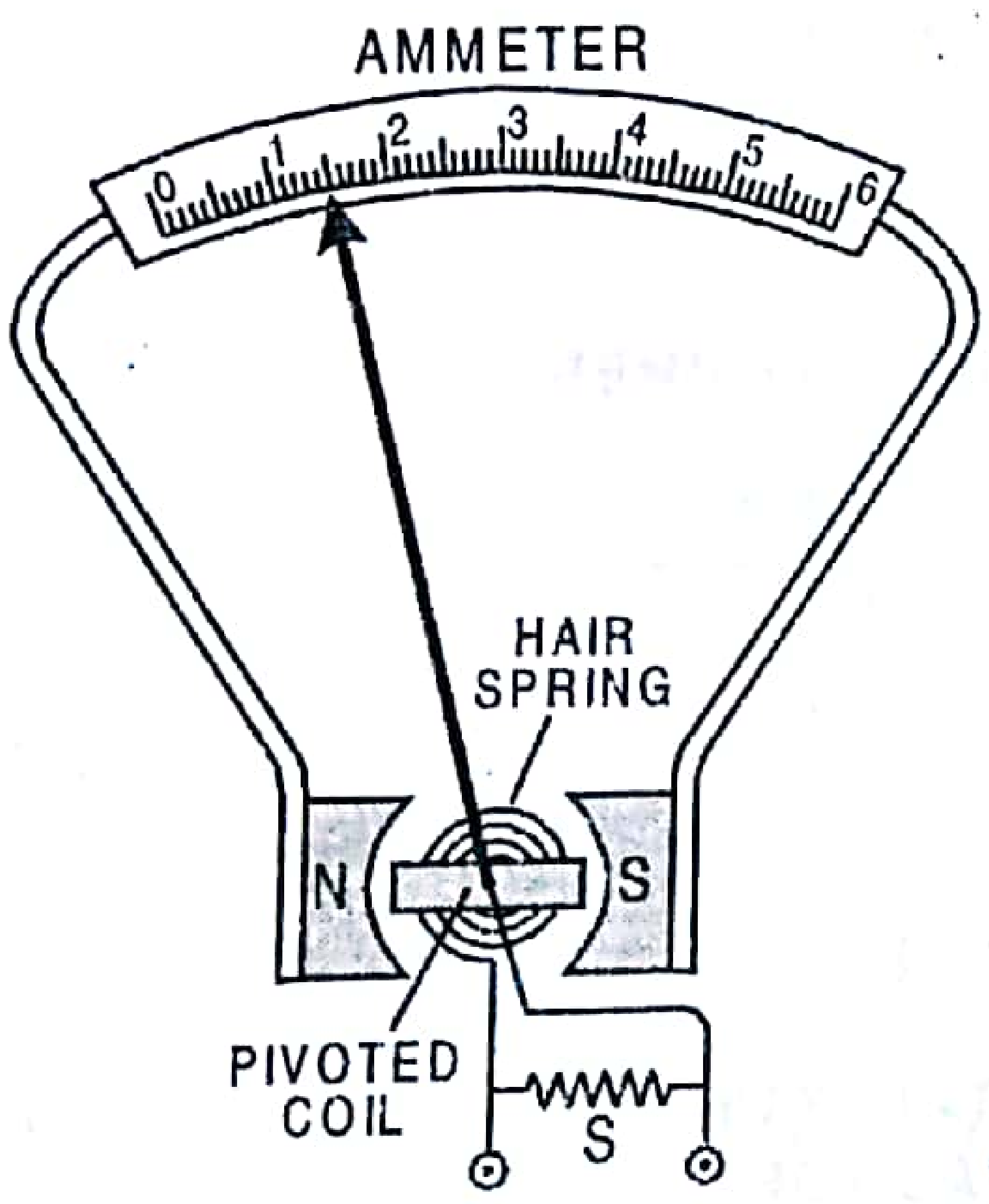

Fig. 1.15

10. **Voltmeter.** It is an instrument used for measuring potential difference across a conductor in an electric circuit.

A galvanometer cannot be used to measure potential difference across a conductor in the circuit. It is because, when a galvanometer is connected across the conductor, due to its low resistance; a large part of the current flows through the galvanometer. As a result, the current flowing through the conductor and hence the potential difference across it, will decrease. In order to measure potential difference across a conductor without causing any change in the value of the potential difference, a galvanometer is converted into a voltmeter. For this, a suitable high resistance R is connected in series to the coil of the galvanometer [Fig. 1.16]. The scale of the voltmeter is calibrated so as to read the potential difference directly in volt. For measuring a small potential difference, a ***millivoltmeter*** or a ***microvoltmeter*** is used.

A voltmeter is very high resistance instrument and it is always connected in parallel to the conductor, across which the potential difference is to be measured.

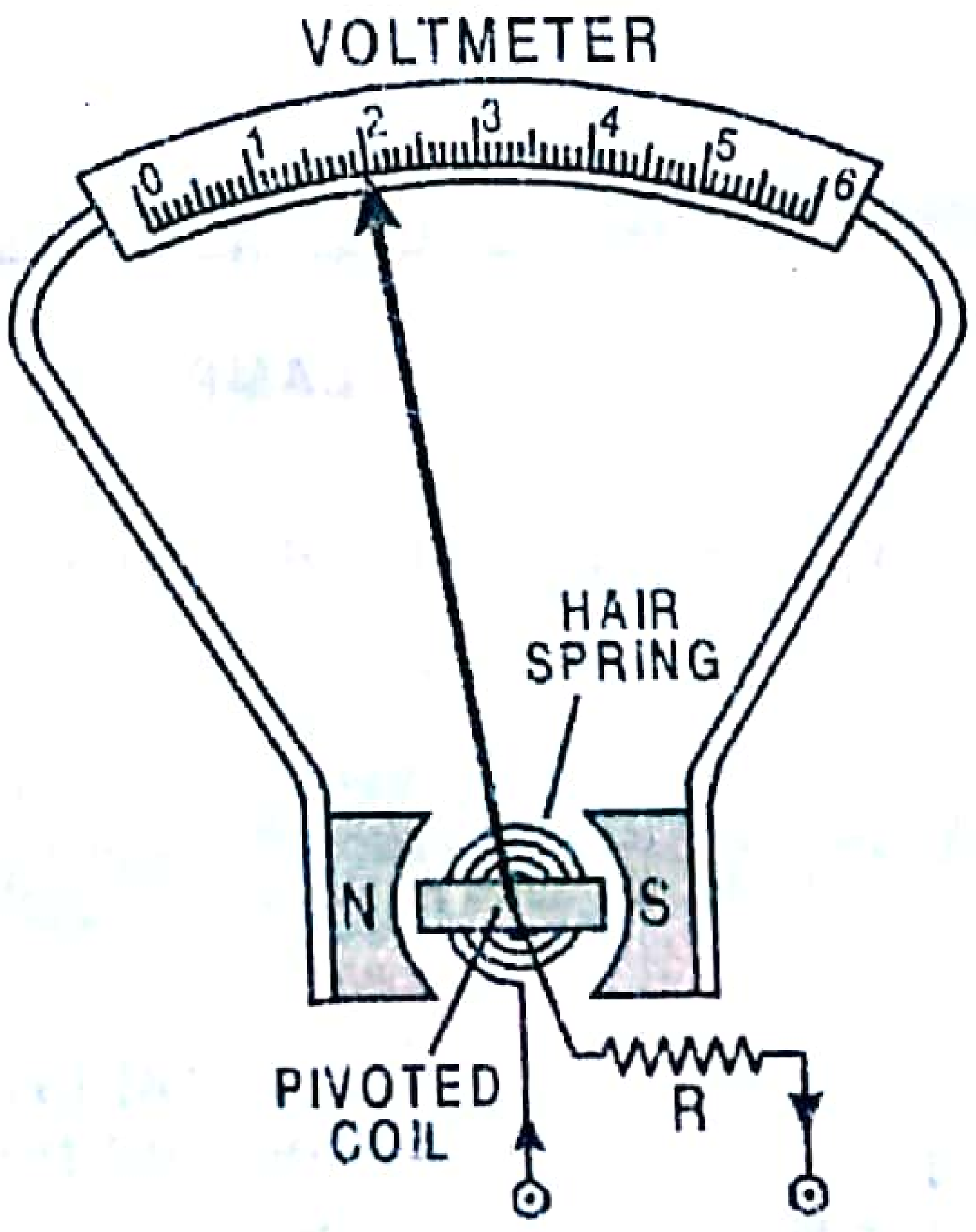

Fig. 1.16

SYMBOLS FOR VARIOUS ELECTRICAL COMPONENTS

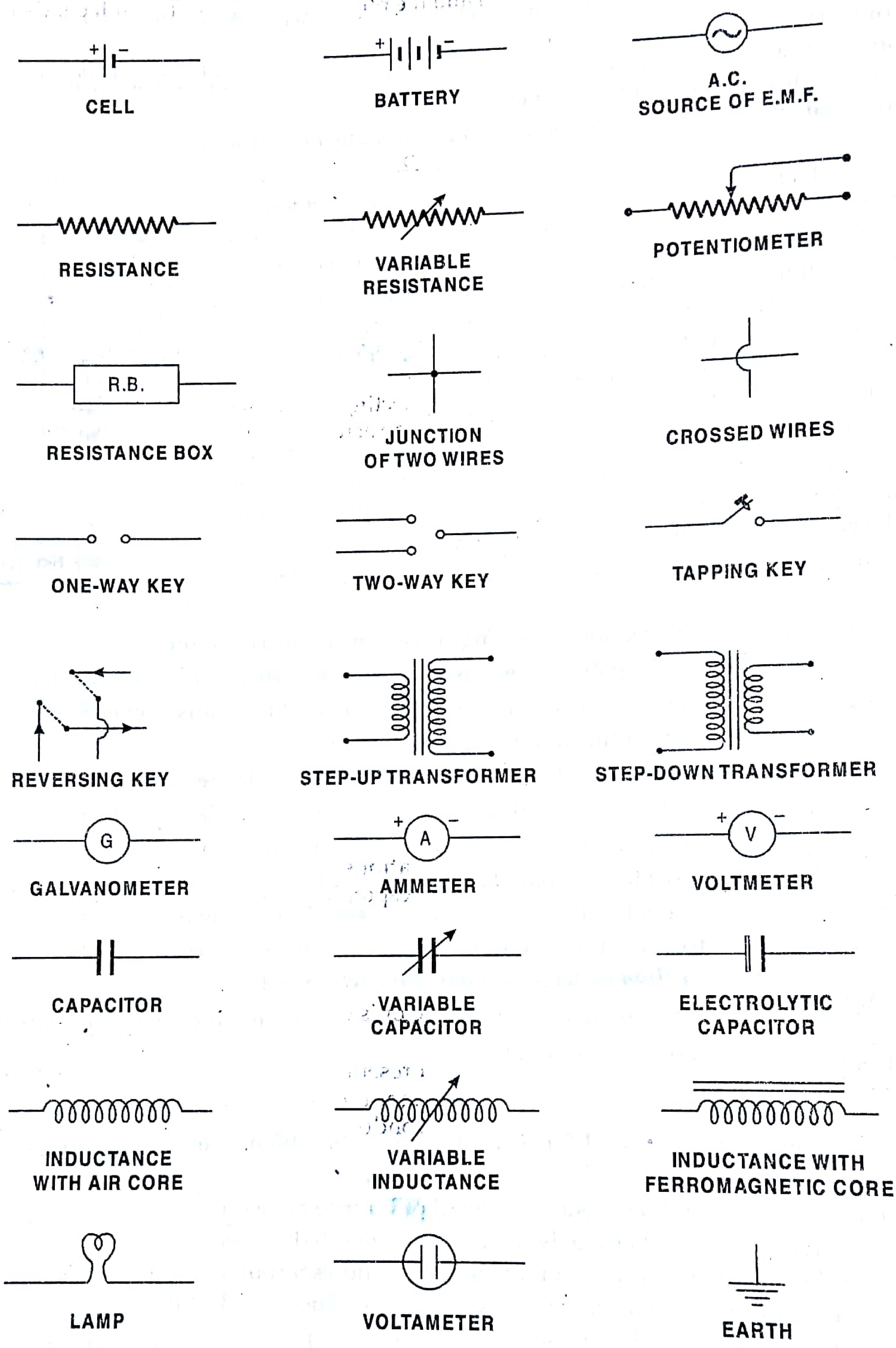

Fig. 1.17

1.13. OHM'S LAW

It is the most fundamental law of electricity and was given by George Simon Ohm in 1828. It states that *the physical conditions (temperature, mechanical strain, etc) remaining unchanged, the current flowing through a conductor is always directly proportional to the potential difference across its two ends.* Mathematically,

$$V \propto I$$

or

$$V = R\,I, \qquad \text{...(1.01)}$$

where the constant of proportionality R is called the ***electrical resistance*** or simply ***resistance*** of the conductor. Its value depends upon the nature of conductor, its dimensions and the physical conditions. It is independent of the values of V and I.

Resistance. *The resistance of a conductor is defined as the ratio of the potential difference applied across the conductor to the current flowing through it.* Mathematically,

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

In SI, the unit of the resistance is **ohm.** It is denoted as Ω.

$$1 \text{ ohm } (\Omega) = \frac{1 \text{ volt (V)}}{1 \text{ ampere (A)}} = 1 \text{ V A}^{-1}$$

The resistance of a conductor is said to be one ohm, if one ampere of current flows through the conductor, when a potential difference of one volt is applied across it.

V.I

1.14. TO STUDY CURRENT VOLTAGE RELATIONSHIP (TO VERIFY OHM'S LAW)

The current voltage relationship can be studied by connecting a resistance coil to a battery and measuring the current passing through it using an ammeter and potential drop across it with the help of a voltmeter [Fig. 1.18]. The current in the circuit is varied during the different observations with the help of the "rheostat". The ratio of the potential difference (V) across the resistance coil and the corresponding current (I) flowing through it are measured for each observation. It will be found that

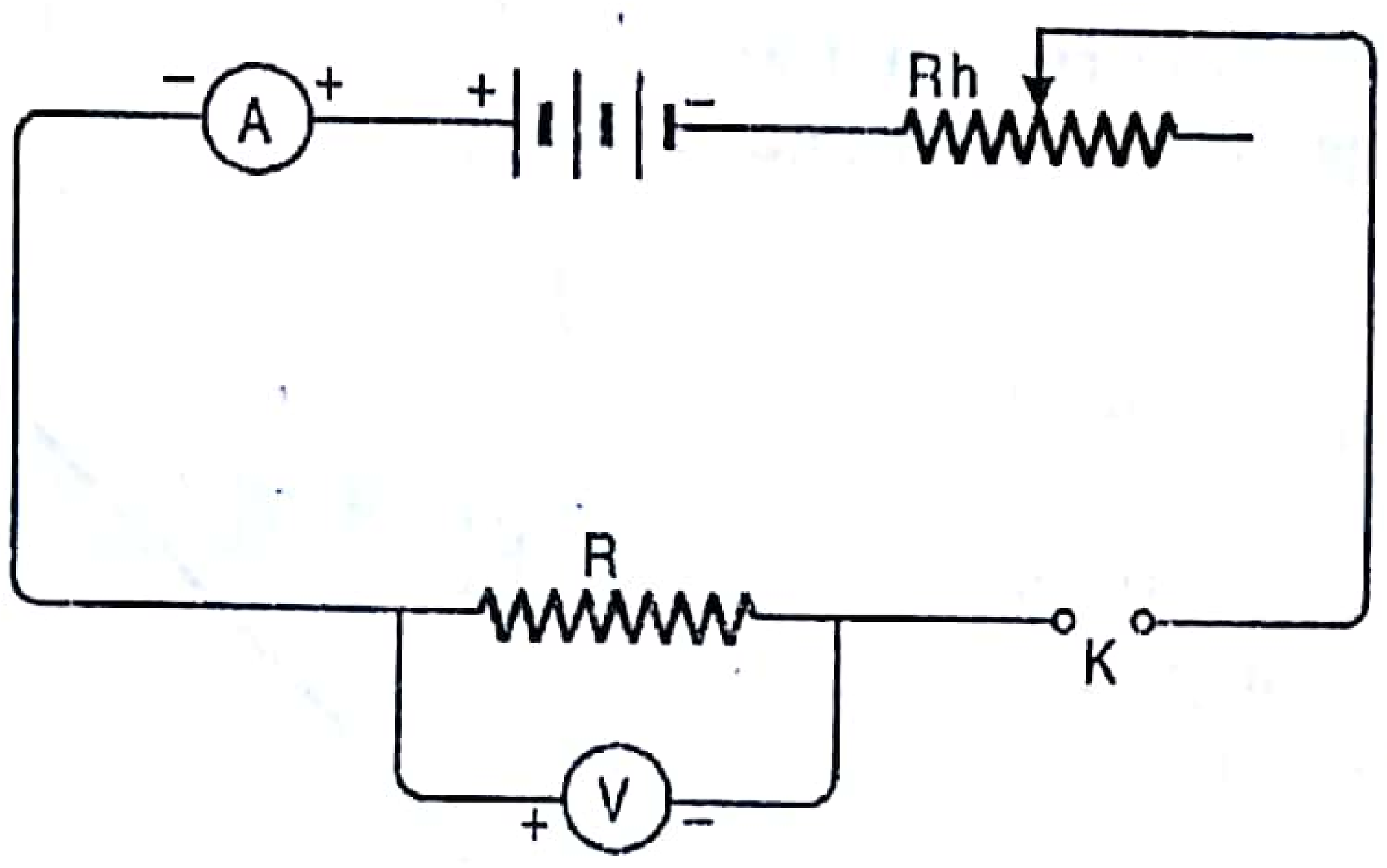

Fig. 1.18

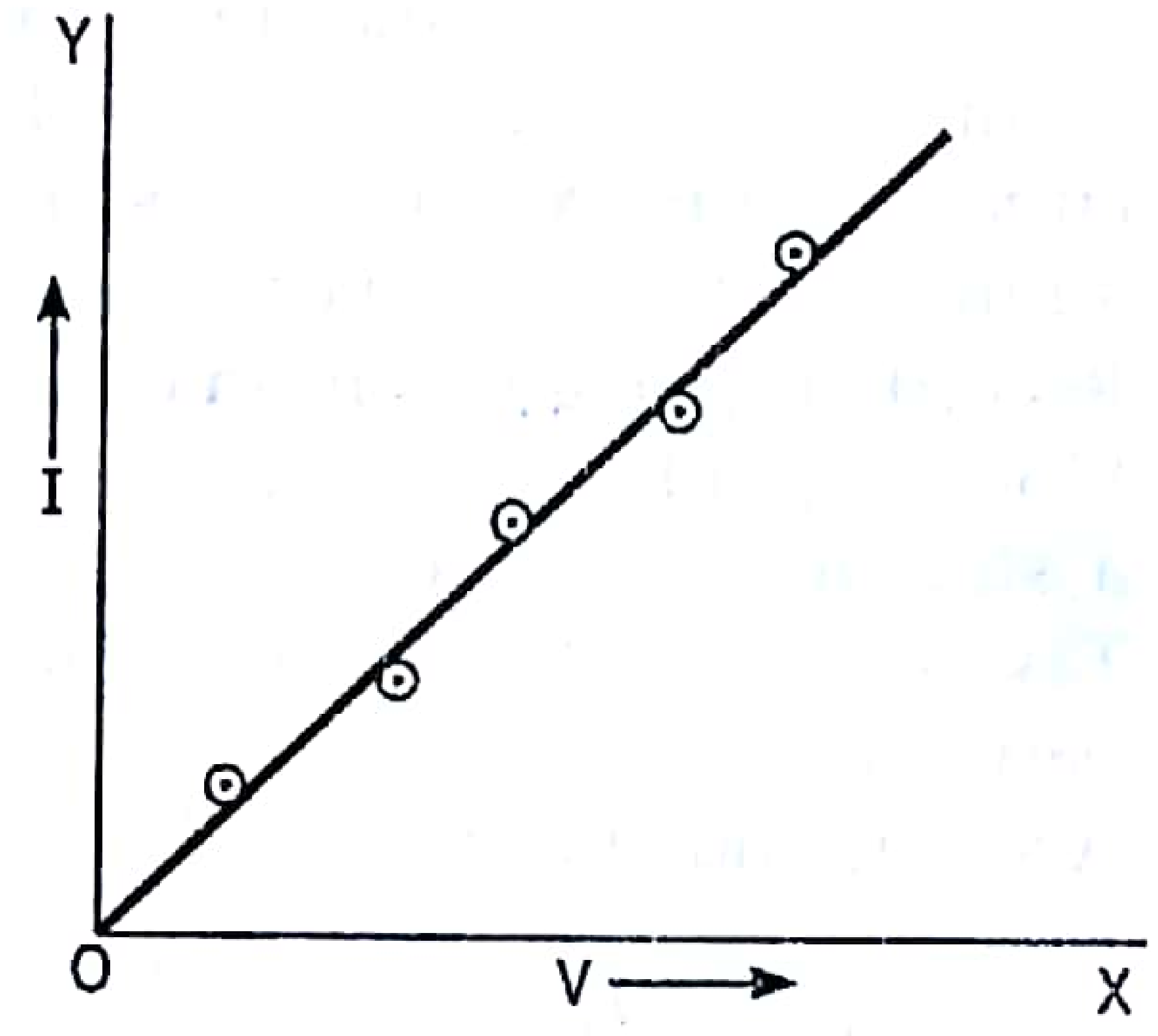

Fig. 1.19

$$\frac{V}{I} = \text{constant}$$

It, then, shows that the current flowing through a conductor is directly proportional to the potential drop across it *i.e.* it verifies Ohm's law.

Further, for the variables V and I, the equation (1.01) represents a straight line. If a graph is plotted between V (along X-axis) and I (along Y-axis), the graph will be a straight line as shown in Fig. 1.19. The straight line graph between V and I shows that the current flowing through a conductor is directly proportional to the potential drop across it.

EXPERIMENT NO. 1

AIM. To determine resistance per cm of a given wire by plotting a graph of potential difference versus current.

Apparatus

A wire of uniform area of cross-section (unknown resistance, whose resistance per cm has to be found), a battery of 2-3 cells, a voltmeter of range 0 – 3 V, an ammeter of range 0 – 1·5 A, a rheostat, a one-way key, connecting wires and a sand paper.

↳ इसलिये से Radio of $\frac{V}{I}$ is always constant in each obser- So, ohm's law is verified

Theory

Refer to sections 1.13.

Formula used

1. The resistance of the wire,

$$R = \frac{V}{I},$$ where V is potential difference across the wire and I, the current flowing through it.

2. The resistance per cm of the wire,

$$r = \frac{R}{l}, \text{ where } l \text{ is length the wire.}$$

Procedure

1. Draw a neat circuit diagram as shown in Fig. 1.18.
2. Arrange the various components of the apparatus in the order as shown in the circuit diagram.
3. Remove the insulation and clean the ends of the connecting wires with the help of sand paper.
4. Take out plug from the one-way key and make neat and tight connections according to the circuit diagram.
   See that the positive terminals of the ammeter and voltmeter are connected to the positive terminal of the battery.
5. Note the least count (value of one division of the scale) of the ammeter and voltmeter. Also note the zero error (if any) for both ammeter and voltmeter.
6. Insert plug in one-way key and adjust the sliding contact of the rheostat so that a small current passes through the resistance coil.
   See that the pointer of ammeter or voltmeter does not lie between two divisions of the scale. Make slight adjustment with the help of rheostat (if required), so that the readings of the both the ammeter and voltmeter are equal to full number of divisions.
7. Note the values of the potential difference (V) from the voltmeter and the current (I) from the ammeter.
8. By moving the sliding contact of the rheostat, change the current in the circuit. By proceeding as in step 6, note the readings of voltmeter and ammeter atleast for five more observations.
9. Record the observations in tabular form.
10. Plot the graph between V (along X-axis) and I (along Y-axis). It will be a straight line as shown in Fig. 1.20.
11. Take two points A and B on the graph. From these two points, draw perpendiculars AC andBD on the V-axis. Also, from the point A, draw AN perpendicular to BD. Then, the resistance of the wire,
$$R = \frac{\Delta V}{\Delta I} = \frac{AN}{BN}$$
12. Cut the resistance wire at the point, where it just leaves the binding terminals of the ammeter and the one-way key. After removing the kinks (if any), stretch it against the metre scale and measure its length (l). Then, the resistance per cm of the wire,
$$r = \frac{R}{l}$$

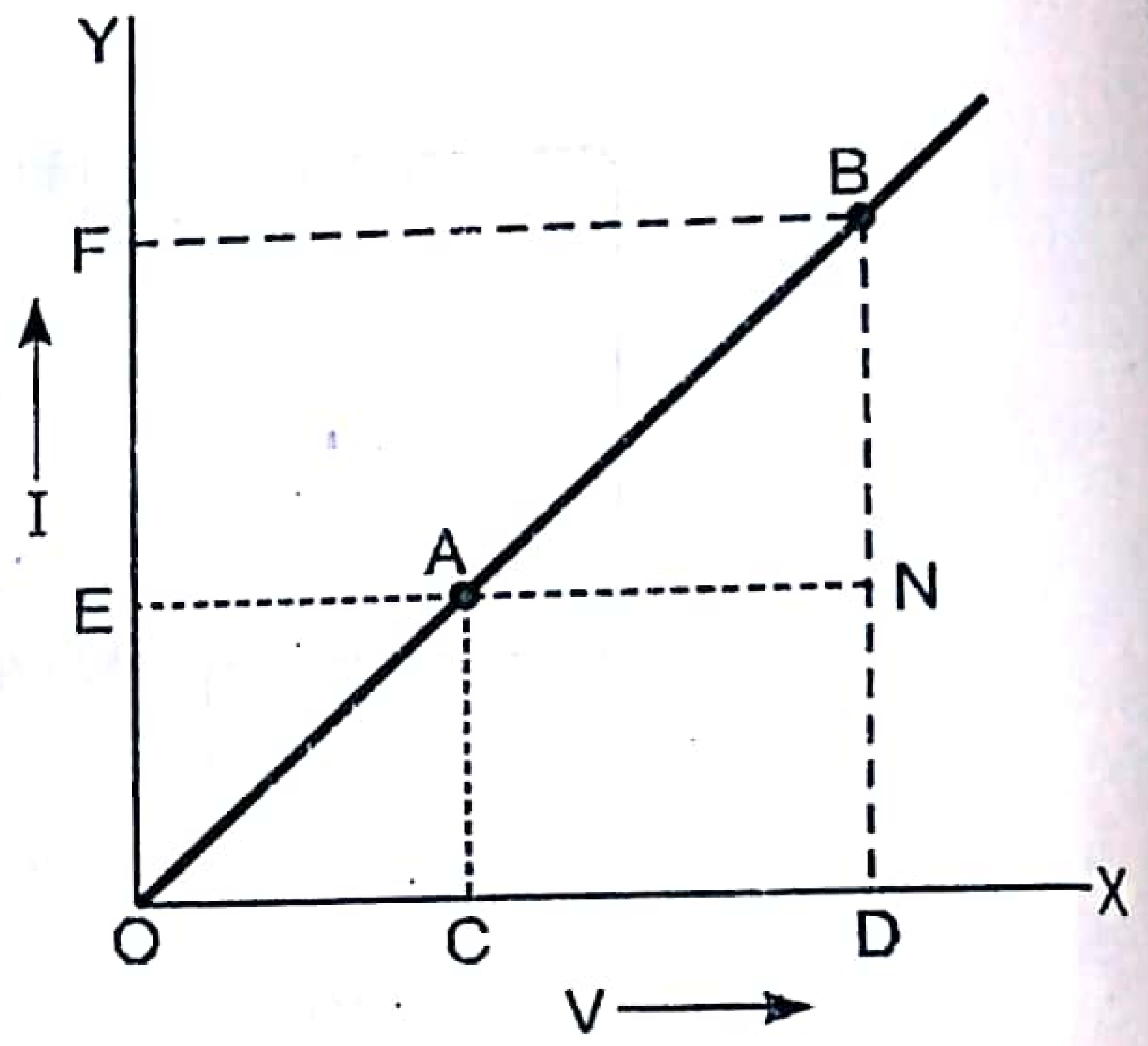

Fig. 1.20

Observations and calculations.

Least count of the ammeter = ... A

Least count of voltmeter = ...V

Zero error (if any) in ammeter, e =...........A

Zero error (if any) in voltmeter, e = ... V

Zero correction for ammeter, $c = -e =$ .... A

Zero correction for voltmeter, $c = -e =$ V

No.	Voltmeter reading		Ammeter reading	
	Observed	Corrected (V)	Observed	Corrected (I)
1.				
2.				
3.				
4.				
5.				
6.				

$\frac{V}{I}$ [illegible]

From the graph shown in Fig. 1.20 :

$$\Delta V = AN = OD - OC = ...V$$

and

$$\Delta I = BN = OF - OE = ...A$$

Therefore, resistance of the wire,

$$R = \frac{\Delta V}{\Delta I} = ...\Omega$$

Length of the wire between the binding terminals of the ammeter and the one-way key,

$$l = \ldots\ldots\text{ cm}$$

Hence, the resistance per cm of the wire,

$$r = \frac{R}{l} = \ldots\ldots\text{ cm}$$

Result

The resistance per cm of the wire, $r = \ldots\ldots\Omega\ \text{cm}^{-1}$

Precautions

1. The ends of connecting wires should be cleaned before making connections.
2. The connections should be neat and tight.
3. The voltmeter and ammeter used should be of proper ranges.
4. The positive terminals of the voltmeter and ammeter should be connected to the positive terminal of the battery.
5. The zero corrections (if any) should be applied to the readings of the voltmeter and ammeter.
6. The plug in the one-way key should be inserted only while taking the observation.

Sources of error

1. The connections may not be tight.
2. The resistance of the connecting wires may not be negligible. To avoid error in this account, thick connecting wires should be used.
3. Due to heating effect of the current, the resistance of the coil may change due to rise in its temperature.

1.15. WHEATSTONE BRIDGE

It is one of the accurate arrangements for measuring the resistance of a conductor.

The four resistances P, Q, R and X are connected to form a quadrilateral. A galvanometer and a tapping key K_1 (called galvanometer key) are connected between the points B and D, while a battery and a one-way key K_2 (called battery key) are connected between the points A and C [Fig. 1.21]. Usually, P and Q, called ***ratio arms***, are known resistances; R is an adjustable resistance (resistance box) and X is the unknown resistance. The value of the resistance R is so adjusted that the galvanometer does not give deflection on pressing the key K_1. It happens so, when the points B and D are at the same potential. In such a case, the bridge is said to be ***balanced.*** For a balanced bridge, it can be proved that

$$\frac{P}{Q} = \frac{R}{X}$$

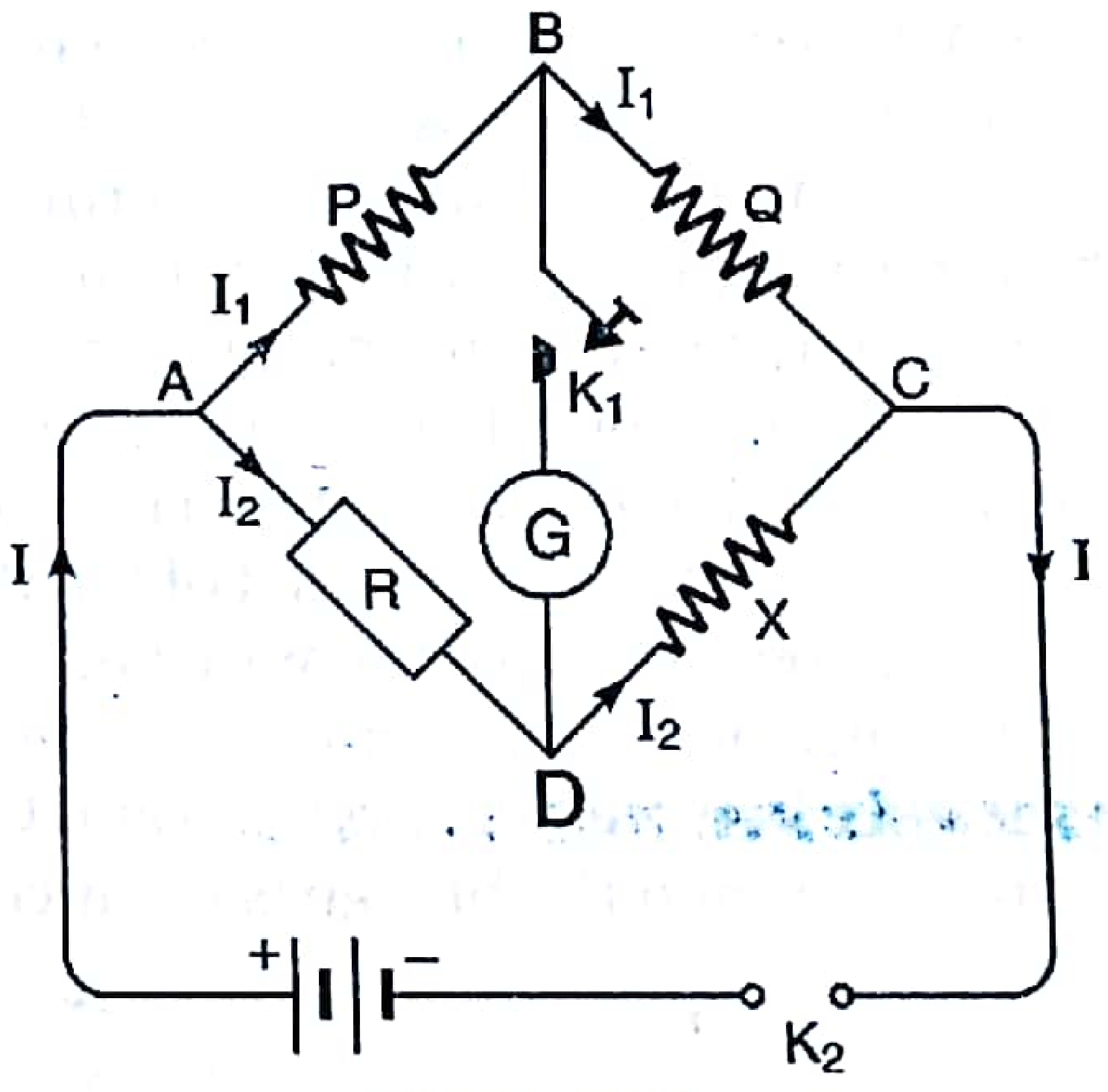

Fig. 1.21

Proof. Let V_A, V_B, V_C and V_D be the electric potentials of points A, B, C and D respectively. Let I be the current in the main circuit. At point A, say current equal to I_1 flows through the resistance P and the remaining current $I - I_1 = I_2$ (say) flows through the resistance R. When the bridge is balanced, the points B and D are at the same potential and therefore no current will flow through the galvanometer *i.e.* current I_1 will flow as such through the resistance Q, while I_2 through X. At point C, the currents through the resistances Q and X add up, so as to send a total current I through the circuit.

Now, potential difference across P *i.e.* $V_A - V_B = I_1 P$ ...(1.02)

Potential difference across Q *i.e.* $V_B - V_C = I_1 Q$ ...(1.03)

Potential difference across R *i.e.* $V_A - V_D = I_2 R$ ...(1.04)

Potential difference across X *i.e.* $V_D - V_C = I_2 X$ ...(1.05)

Since the bridge is balanced, the points B and D are at same potential *i.e.*. $V_B = V_D$. Replacing V_D by V_B in equations (1.04) and (1.05), we have

$$V_A - V_B = I_2 R \quad \text{...(1.06)}$$

and

$$V_B - V_C = I_2 X \quad \text{...(1.07)}$$

From equations (1.02) and (1.06), we have

$$I_1 P = I_2 R \quad \text{...(1.08)}$$

From equations (1.03) and (1.07), we have

$$I_1 Q = I_2 X \qquad \text{...(1.09)}$$

Dividing equation (1.08) by (1.09), we have

$$\frac{P}{Q} = \frac{R}{X} \qquad \text{...(1.10)}$$

The value of the unknown resistance X can be found, as we know the values of P, Q and R. It may be remembered that the bridge is most sensitive, when all the four resistances are of the same order.

Merits of Wheatstone bridge method. The Wheatstone bridge method for measuring an unknown resistance has the following merits over the other methods for measuring the resistance :

1. It is a null method. Therefore, the measurement of resistance made by this method is not affected by the internal resistance of the battery used.
2. As no measurement of current or potential difference is involved, the measurement of resistance is not affected because of the fact that the ammeters and voltmeters in practice are not ideal ones.
3. The value of unknown resistance can be measured to a very high degree of accuracy by increasing the ratio of the resistances in the arms P and Q.

1.16. METRE BRIDGE

A metre bridge can be used to measure an unknown resistance or to compare the values of two unknown resistances or to verify the laws of combination of resistances. It is also known as *slide wire bridge.*

Principle. *It is constructed on the principle of Wheatstone bridge.*

Construction. It consists of a wooden board over which a wire AC made of constantan and one metre in length is stretched between the two end copper strips as shown in Fig. 1.22. A metre scale is also fitted on the wooden board parallel to the length of the wire. Another copper strip is fitted between the two end strips with a small gap between them. A resistance box R is connected across the left gap and the unknown resistance X is connected across the right gap between the strips. The binary terminals are provided over the three copper strips as shown in the figure. One terminal of a sensitive galvanometer is connected to the binary terminal D and the other to a jockey, which can be slided over the wire to balance the bridge. The circuit shown in Fig. 1.22 is now exactly the same as that of the Wheatstone bridge [Fig. 1.21]. The resistance of the wire between the points A and B (the balance point of the bridge) represents the arm P and that of the wire between the points B and C represents the arm Q. Therefore, when the bridge is balanced,

$$\frac{P}{Q} = \frac{R}{X}$$

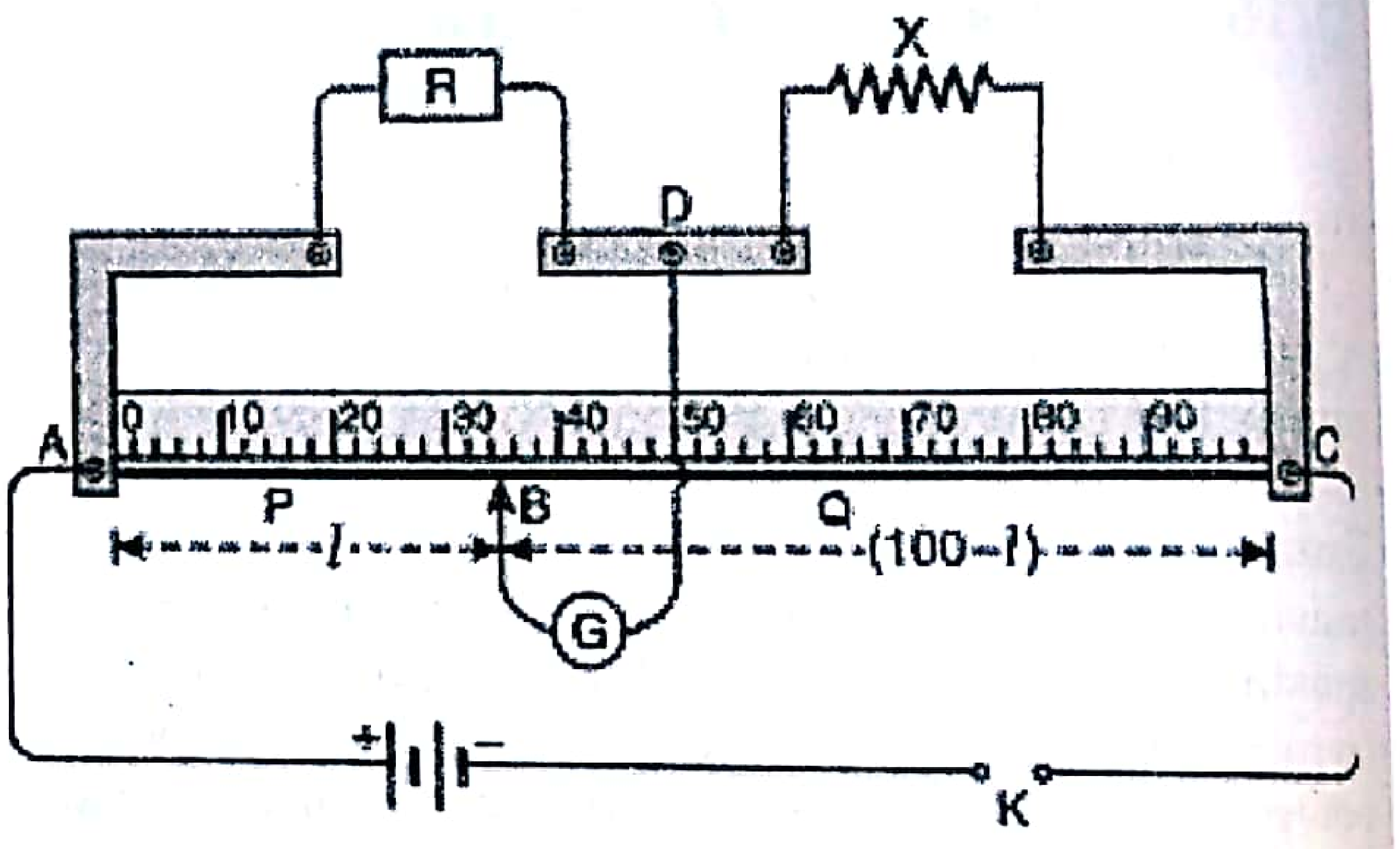

Fig. 1.22

1.17. SPECIFIC RESISTANCE

The resistance of a conductor depends upon the following factors :

(i) It is directly proportional to the length of the conductor i.e.

$$R \propto l$$

(ii) It is inversely proportional to the area of cross-section of the conductor i.e.

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

Combining the above two factors, we have

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

or

$$R = \rho \frac{l}{A}, \qquad \text{...(1.11)}$$

where the constant or proportionality ρ is called *specific resistance* or *resistivity* of the conductor. Its value depends upon the nature of the material of the conductor and its temperature. The equation (1.11) gives the resistance of a conductor in terms of its length, area of cross-section and resistivity of the material.

If $l = 1$ and $A = 1$, then $R = \rho \frac{1}{1}$ or $\rho = R$

Hence, *the specific resistance or resistivity of the material of a conductor is the resistance offered by a wire made of this material having unit length and unit area of cross-section.*

From equation (1.11), we have

$$\rho = R\frac{A}{l} \qquad \text{...(1.12)}$$

From equation (1.12), we have

$$\rho = \text{ohm} \times \frac{\text{metre}^2}{\text{metre}} = \text{ohm metre}$$

Therefore, SI unit of specific resistance is **ohm metre (Ω m).**

1.18. TO FIND SPECIFIC RESISTANCE OF THE MATERIAL OF A WIRE (USING METRE BRIDGE)

To find specific resistance of the material of a given wire, first its resistance is found using a metre bridge.

To find the unknown resistance X of the given wire, it is connected in the right gap of the metre bridge [Fig. 1.22]. A known resistance is introduced in the left gap with the help of resistance box R. By moving the jockey over the wire, the bridge is balanced. Let B be the balance point of the bridge. When the jockey is at the point B on the wire, galvanometer will not show any deflection. The value of R is adjusted so that the balance point lies between 35 cm and 65 cm marks. If the length of the portion of wire AB = l, then length of the portion BC = $100 - l$. The resistance of wire between the points A and B is taken as P and that of the portion between the points B and C is taken as Q. If the wire is of uniform area of cross-section, then

$$P \propto l \qquad \text{and} \qquad Q \propto 100 - l$$

$$\therefore \qquad \frac{P}{Q} = \frac{l}{(100 - l)}$$

From the principle of Wheatstone bridge,

$$\frac{P}{Q} = \frac{R}{X}$$

$$\therefore \qquad \frac{R}{X} = \frac{l}{(100 - l)}$$

$$\text{or} \qquad X = R\frac{(100 - l)}{l} \qquad \text{...(1.13)}$$

Since the values of R and l are known, the value of the unknown resistance of X can be found.

$$\text{Now,} \qquad \rho = X\frac{A}{l} \qquad \text{...(1.14)}$$

If D is the diameter of the wire, then area of cross-section of the wire,

$$A = \frac{\pi D^2}{4}$$

Therefore, equation (1.14) becomes

$$\rho = X\frac{\pi D^2}{4l} \qquad \text{...(1.15)}$$

Measuring the diameter (D) of the wire with the help of a screw gauge and the length (l) of the wire coming out of the binding terminals of the metre bridge with a metre scale, the equation (1.15) can be used to find the specific resistance of the material of the wire.

EXPERIMENT NO. 2

AIM. To find resistance of a given wire using metre bridge and hence determine the specific resistance of its material.

Apparatus

A metre bridge, a Leclanche cell, a resistance box, a galvanometer, a jockey, one-way key, the resistance wire (of which specific resistance is to be determined), a screw gauge, a metre scale, connecting wires and sand paper.

Theory

Refer to sections 1.17 and 1.18.

Section B

FORMAL EXPERIMENTAL PHYSICS

ACTIVITIES IN PHYSICS

Formula used

1. The resistance of the given wire,

$$X = R\frac{(100 - l)}{l},$$

where R is a known resistance (connected in the left gap) and l, the length of the metre bridge wire between zero mark and the balance point.

2. The specific resistance of the material of the wire,

$$\rho = X\frac{\pi D^2}{4L},$$

where D is the diameter of the wire and L, the length of the wire.

Procedure

(a) To measure resistance of the wire :

1. Draw a neat circuit diagram as shown in Fig. 1.22.
2. Arrange the various components of the apparatus in the order as shown in the circuit diagram.
3. Remove the insulation and clean the ends of the connecting wires with the help of sand paper.
4. Take out plug from the one-way key and make neat and tight connections according to the circuit diagram.
   See that the unknown resistance (X) is connected in right gap and the resistance box (R) in the left gap.
5. Take out plug from the resistance box so as to introduce some resistance (say 5 Ω). Insert plug in the one-way key.
6. To check the connections, touch the jockey gently first at the left end and then at the right end of the bridge wire.
   If the galvanometer shows deflection in opposite directions, the connections made are correct.
7. Move the jockey gently over the bridge wire from its left end A to right end C, till a point B is reached, where the deflection in the galvanometer becomes zero. The point B is called ***balance*** or ***null point.***
   The value of R should be so adjusted that the balance point lies between 35 cm and 65 cm marks. If the null point is below 35 cm mark, increase the value of R and vice-versa.
8. Note the position of the balance point B and find the length of the portion AB of the bridge wire. Let it be equal to l. Also note the value of R.
9. By proceeding as in steps 5 to 8, repeat the experiment atleast three times more by changing the value of R in steps of one ohm.
10. Record the observations in the tabular form.
11. Find the mean value of the resistance (X) of the wire.

(b) To measure length of the wire :

12. Cut the resistance wire at the point, where it just leaves the binding terminals of the metre bridge. After removing the kinks (if any), stretch it against the metre scale and measure its length (L).

(c) To measure the diameter of the wire :

13. Find the pitch and least count of the screw gauge. Also find the zero error (if any) of the screw gauge and hence the zero correction.
14. Measure the diameter of the wire in two mutually perpendicular directions *a* and *b* atleast at three different places [Fig. 1.23]. Find the mean observed diameter (D') of the wire.
15. Apply zero correction to find the mean corrected diameter (D) of the wire.

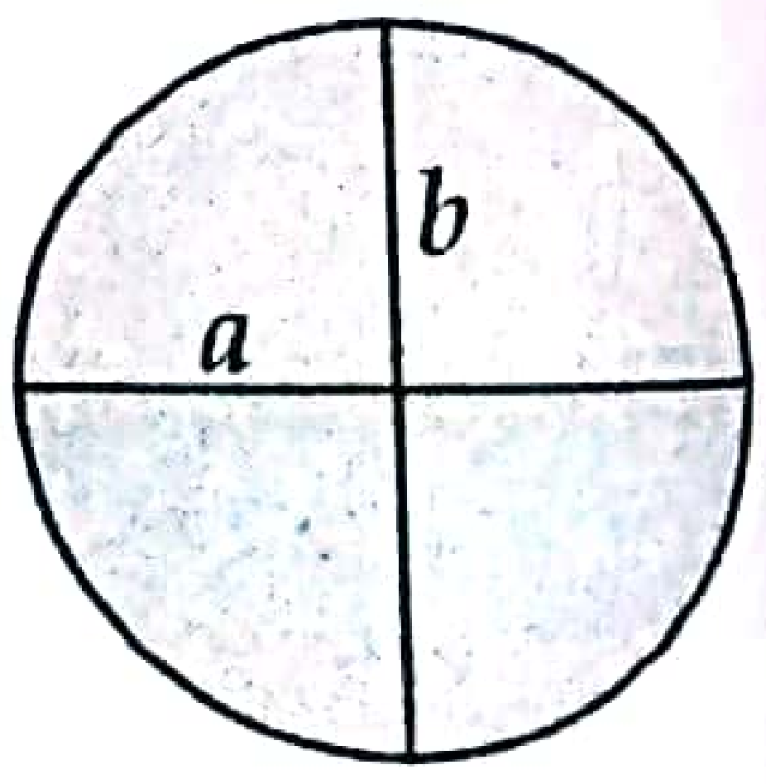

Fig. 1.23

Observations

(a) To measure resistance of the wire :

No.	Resistance from the resistance box, R (ohm)	Length of the bridge wire in arms P and Q		Resistance of the wire, $X = R\frac{(100 - l)}{l}$ (ohm)
		AB (or P) = l	BC (or Q) = 100 − l	
1.				
2.				
3.				
4.				

Mean value of the resistance of wire, X = ...ohm

SECTION A

FORMAL EXPERIMENTAL PHYSICS

1. **Measurement of Resistance**
2. **Measurement of E.M.F. and Internal Resistance**
3. **Conversion of Galvanometer into Ammeter and Voltmeter**
4. **Frequency of a.c. Mains**

ACTIVITIES IN PHYSICS

5. **Inductor**
6. **Use of Multimeter to measure Resistance and Voltage**
7. **Household Wiring**
8. **Assembling an Electric Circuit**
9. **Principle of Potentiometer**

CHAPTER

1

Measurement of Resistance

1.01. SOURCE OF E.M.F. AND FLOW OF ELECTRIC CURRENT

A conductor contains free electrons, which are always in random motion. The flow of free electrons in a definite direction constitutes the electric current through the conductor. It can be achieved by maintaining a difference of electric potential across the two ends of the conductor. This difference in electric potential across the two ends performs work in moving the free electrons through the conductor in a definite direction. Such a device or an arrangement, which can maintain potential difference across a conductor is called the ***source of e.m.f.***

Therefore, *a source of e.m.f. is an arrangement, which supplies energy in some form so as to bring about the movement of free electrons in a conductor in a particular direction.*

When a source of e.m.f. is connected across the two ends of a conductor, its two ends become at different levels of electricity. Due to this, the electric charge (free electrons) starts flowing from one end of the conductor to the other. This charge flow is called flow of ***electric current.***

There are many types of sources of e.m.f. However, we shall restrict our study to ***electrochemical cell*** only.

1.02. ELECTROCHEMICAL CELL

An electrochemical cell or simply a cell is an arrangement, in which chemical reaction takes place at a steady rate, so as to convert chemical energy into electrical energy.

The total amount of electrical energy that can be provided by a cell is limited by the amount of reactants present in the cell.

The electrochemical cells are of two types, namely ***primary cells*** and ***secondary*** or ***storage cells.***

Primary cell. *It is an electrochemical cell, which once discharged, cannot be put to use again by passing electric current from an external source.*

Therefore, when a primary cell gets discharged, the chemicals inside the cell have to be replaced completely. Daniel cell, Leclanche cell and Bunsen cell are examples of primary cells.

Secondary cell. *It is an electrochemical cell, which has to be charged initially by passing electric current from an external source, so as to convert the stored chemical energy into electrical energy.*

On getting discharged, a secondary cell can again be put into use by recharging it. In other words, the chemical reactions, which take place inside a secondary cell, are reversible in nature. Since a secondary cell stores energy when it is charged, it is also called a ***storage cell*** or ***an accumulator.*** Lead acid cell and alkali cells are two commonly used secondary cells.

Advantages of a secondary cell over a primary cell. **1.** A secondary cell can be put to use again and again by recharging it ; while a primary cell once discharged, cannot be recharged.

2. The internal resistance of a secondary cell is less than that of a primary cell. As such, a secondary cell can be used to draw much larger current.

Disadvantages of a secondary cell. **1.** A secondary cell has to be charged first, so as to obtain electrical energy from it. In other words, a secondary cell requires a lot of time before it can be put to use, while a primary cell starts functioning immediately after its construction.

2. The initial cost of a secondary cell is quite large as compared to that of a primary cell.

1.03. PRIMARY CELLS

The different types of primary cells are as listed below :

1. Simple voltaic cell

2. Daniel cell

3. Leclanche cell

4. Leclanche dry cell

1.04 SIMPLE VOLTAIC CELL

It was invented by Allexandro de Volta in the year 1800.

Construction. It consists of a glass vessel containing dilute sulphuric acid as electrolyte. Two rods, one of copper and the other made of zinc, are placed in dilute sulphuric acid as shown in Fig. 1.01 Due to the chemical reactions inside the cell, the zinc rod acquires negative charge and the copper rod positive charge. As a result, a potential difference is established between the copper and the zinc rods. The copper rod is called *positive pole,* while the zinc rod is called *negative pole* or *terminal* of the cell.

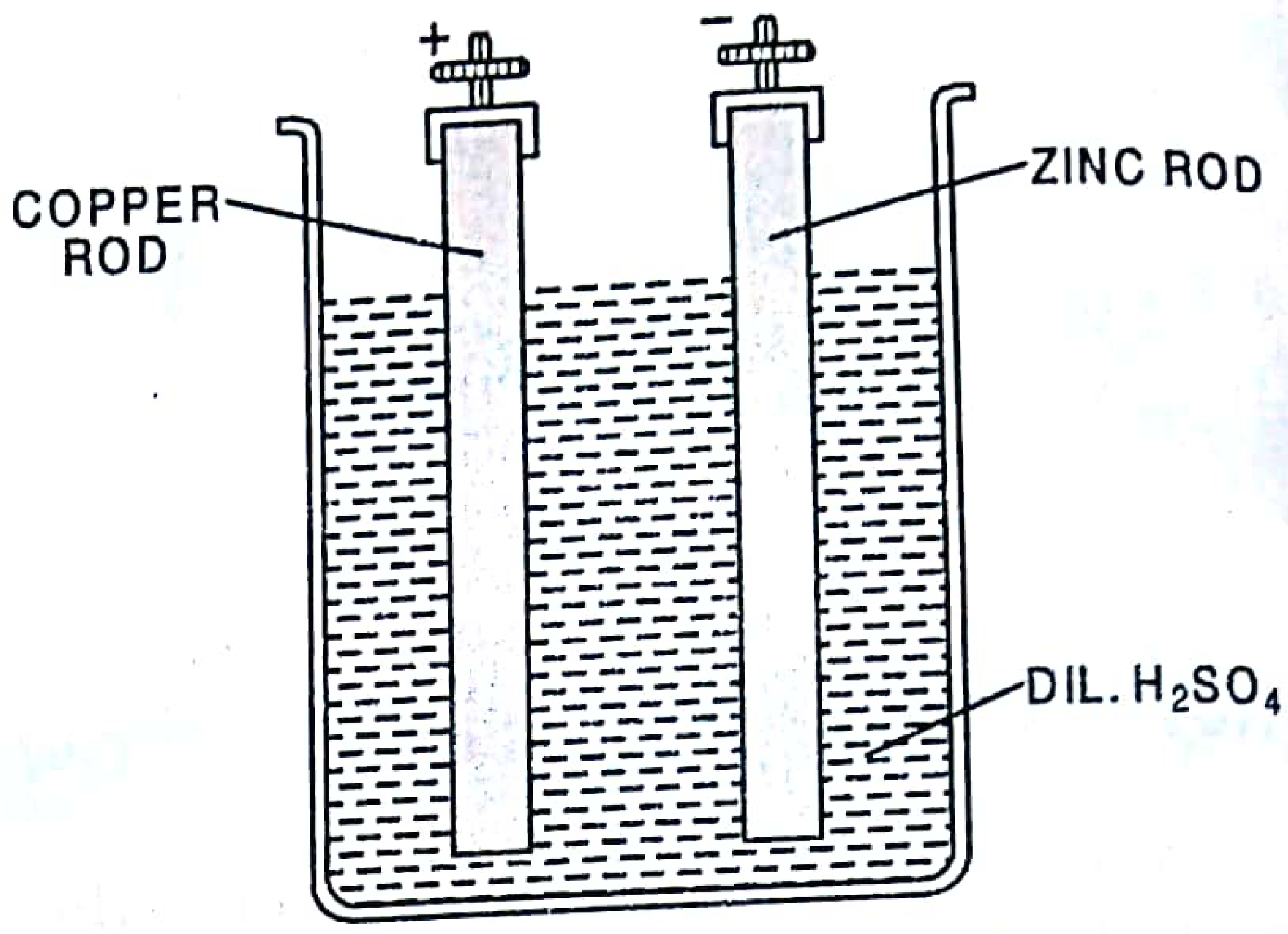

Fig. 1.01

Action. The dilute sulphuric acid dissociates into positive hydrogen ions (H^+) and negative sulphate ions (SO_4^{--}) as given below :

$$H_2SO_4 \longrightarrow 2H^+ + SO_4^{--}$$

When the copper and zinc rods are placed in dilute sulphuric acid, some of the neutral zinc atoms go into the electrolyte as Zn^{++} ions, which are produced as below :

$$Zn \longrightarrow Zn^{++} + 2e^-$$

For each Zn^{++} ion so produced, two electrons ($2e^-$) are left on the zinc rod. As more and more Zn^{++} ions enter the electrolyte, the zinc rod becomes more and more negative. Also the concentration of Zn^{++} ions in the electrolyte goes on increasing. The H^+ ions drift towards the copper rod. On reaching the copper rod, the H^+ ions extract electrons from the rod and form neutral hydrogen atoms. As a result of it, the copper rod acquires positive charge. As more and more H^+ ions discharge at the copper rod, it becomes more and more positive. Due to positive charges building up on the copper rod and negative charge on the zinc rod, the potential difference between the two rods goes on increasing. It continues, till the potential gradient along the electrolyte between copper and zinc rod just restricts the drift of H^+ ions towards the copper rod. The maximum e.m.f. developed in voltaic cell is found to be 1·08 V.

Defects in a voltaic cell

A voltaic cell suffers from the following two defects :

1. *Local action.* The commercial zinc usually contains traces of iron and lead. When such a zinc rod containing impurity atoms of iron and lead is dipped in dilute sulphuric acid, tiny voltaic cells are formed locally on the zinc rod and in these cells, local electric currents are set up. Due to these local currents, zinc is converted into $ZnSO_4$ and is wasted, even when the cell is not in use. This defect in voltaic cell is called local action.

To overcome this defect, the zinc rod is rubbed with mercury. The impurity atoms of iron and lead are insoluble in mercury and hence they get covered with a layer of mercury. On the other hand, zinc forms a mercury amalgam. Due to this, whereas the impurity atoms of iron and lead are no longer exposed to the dilute sulphuric acid, the zinc atoms remain exposed. Thus, on amalgamating the zinc rod, the chemical action inside the cell is sustained without any effect of local action.

2. *Polarisation.* This defect arises due to the formation of a neutral layer of hydrogen gas on the copper rod, when the H^+ ions on reaching the copper rod extract electrons from it and form hydrogen atoms. The layer of hydrogen gas on the copper rod weakens the action of the cell in the following two ways :

(*i*) The layer of hydrogen is a bad conductor of electricity. Due to this, internal resistance of the cell increases.

(*ii*) Due to the formation of a layer of hydrogen gas, H^+ ions moving towards the copper rod are unable to transfer their positive charge on it. As such, H^+ ions set up an electric field from the layer of hydrogen to the zinc rod, which opposes the motion of H^+ ions towards the copper rod. It results in *back electromotive force,* which sends the current in opposite direction and weakens the action of the cell. This defect in the cell is called polarisation. This defect can be removed by brushing off the hydrogen from time to time or by using a depolariser (an oxidising agent), which will convert hydrogen gas into water.

1.05. DANIEL CELL

It was developed by Daniel in the year 1836.

Construction. It consists of copper vessel containing copper sulphate ($CuSO_4$) solution. The copper vessel itself acts as the positive pole of the cell. Inside the $CuSO_4$ solution, a porus pot containing an amalgamated zinc rod and dilute H_2SO_4 acid is placed as shown in Fig. 1.02. Whereas the porus pot prevents the dilute H_2SO_4 and the $CuSO_4$ solution from mixing with each other, it allows the H^+ ions produced in the porus pot to diffuse through its walls into the $CuSO_4$ solution. The amalgamated zinc rod is used in order to avoid the defect of local action from occurring in the cell. The amalgamated zinc rod acts as the negative pole of the cell and both the $CuSO_4$ solution and dilute H_2SO_4 serve as the electrolyte. However, the $CuSO_4$ solution serves as depolariser also.

When the cell functions, the concentration of $CuSO_4$ solution falls. In order to keep the concentration of $CuSO_4$ solution constant, the crystals of $CuSO_4$ are placed on the perforated shelf provided along the walls of the copper vessel.

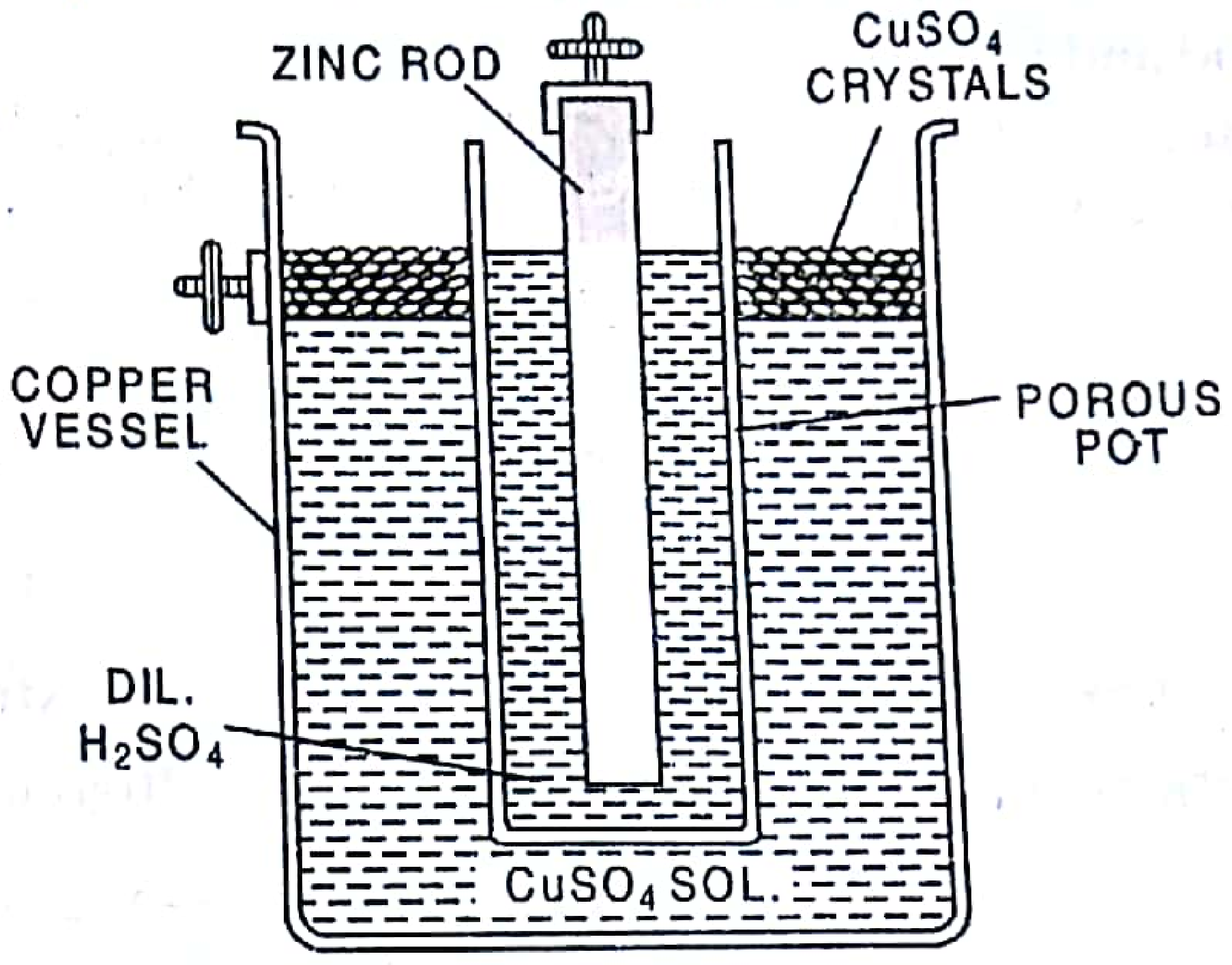

Fig. 1.02

Action. Inside the porus pot, the dilute H_2SO_4 acid dissociates into H^+ and SO_4^{--} ions. As the zinc rod is dipping inside the dilute H_2SO_4 acid, some of the zinc atoms go into the solution as Zn^{++} ions. For each Zn^{++} ion going into the solution, two electrons are left on the zinc rod. As the concentration of Zn^{++} ions in the solution increases, zinc rod becomes more and more negative and the H^+ ions diffuse through the walls of the porus pot into the $CuSO_4$ solution. The reactions taking place inside the porus pot are as below :

$$\begin{array}{rcl} H_2SO_4 & \longrightarrow & 2\,H^+ + SO_4^{--} \\ Zn & \longrightarrow & Zn^{++} + 2\,e^- \\ Zn^{++} + SO_4^{--} & \longrightarrow & ZnSO_4 \\ \hline Zn + H_2SO_4 & \longrightarrow & ZnSO_4 + 2\,H^+ + 2\,e^- \\ \hline \end{array}$$

The formation of $ZnSO_4$ on the porus pot does not affect the working of the cell, until crystals of $ZnSO_4$ are deposited along its walls.

On diffusing out of the porus pot, H^+ ions react with copper sulphate solution as below :

$$2\,H^+ + CuSO_4 \longrightarrow H_2SO_4 + Cu^{++}$$

As the Cu^{++} ions deposit on the copper vessel, it acquires positive charge. Due to building up of the positive charge on the copper vessel and negative charge on the zinc rod, the potential difference between the two poles of the cell goes on increasing. When equilibrium is attained, the cell develops an e.m.f. of 1·1 V.

It may be pointed out that the use of $CuSO_4$ solution makes Cu^{++} ions to discharge at the copper vessel in place of H^+ ions. In case H^+ ions are discharged at the copper vessel, the defect of polarisation would occur due to the production of H_2 gas. Therefore, due to the use of $CuSO_4$ solution, the defect of polarisation is avoided in the Deniel cell. The $CuSO_4$ solution is said to be acting as *depolariser.* However, as the cell works, the concentration of $CuSO_4$ solution falls and this in turn decreases the e.m.f. of the cell. But before this may happen, some $CuSO_4$ crystals from the perforated shelf get dissolved into $CuSO_4$ solution and the concentration of $CuSO_4$ solution recovers to the original value. As the concentration of $CuSO_4$ solution is maintained, the cell provides a steady e.m.f., while in use.

Application. The e.m.f. of Daniel cell is small but it remains fairly constant. Further, its internal resistance also remains steady. In laboratory, it is used in those experiments, where a weak but steady current is required.

1.06. LECLANCHE CELL

It was invented by George Leclanche in the year 1865.

Construction. It consists of glass vessel containing a strong solution of ammonium chloride (NH_4Cl) as the electrolyte. An amalgamated zinc rod dipping in the NH_4Cl solution acts as the negative pole of the cell. The use of amalgamated zinc rod avoids the defect of local action from occurring in the cell. A porus pot containing a carbon rod is placed inside the NH_4Cl solution. The carbon rod acts as the positive pole of the cell. The empty space in the porus pot is filled with manganese dioxide (MnO_2) and charcoal powder [Fig. 1.03]. Manganese dioxide is used as *depolariser.* The use of charcoal powder makes MnO_2 conducting and thus, decreases the internal resistance of the cell.

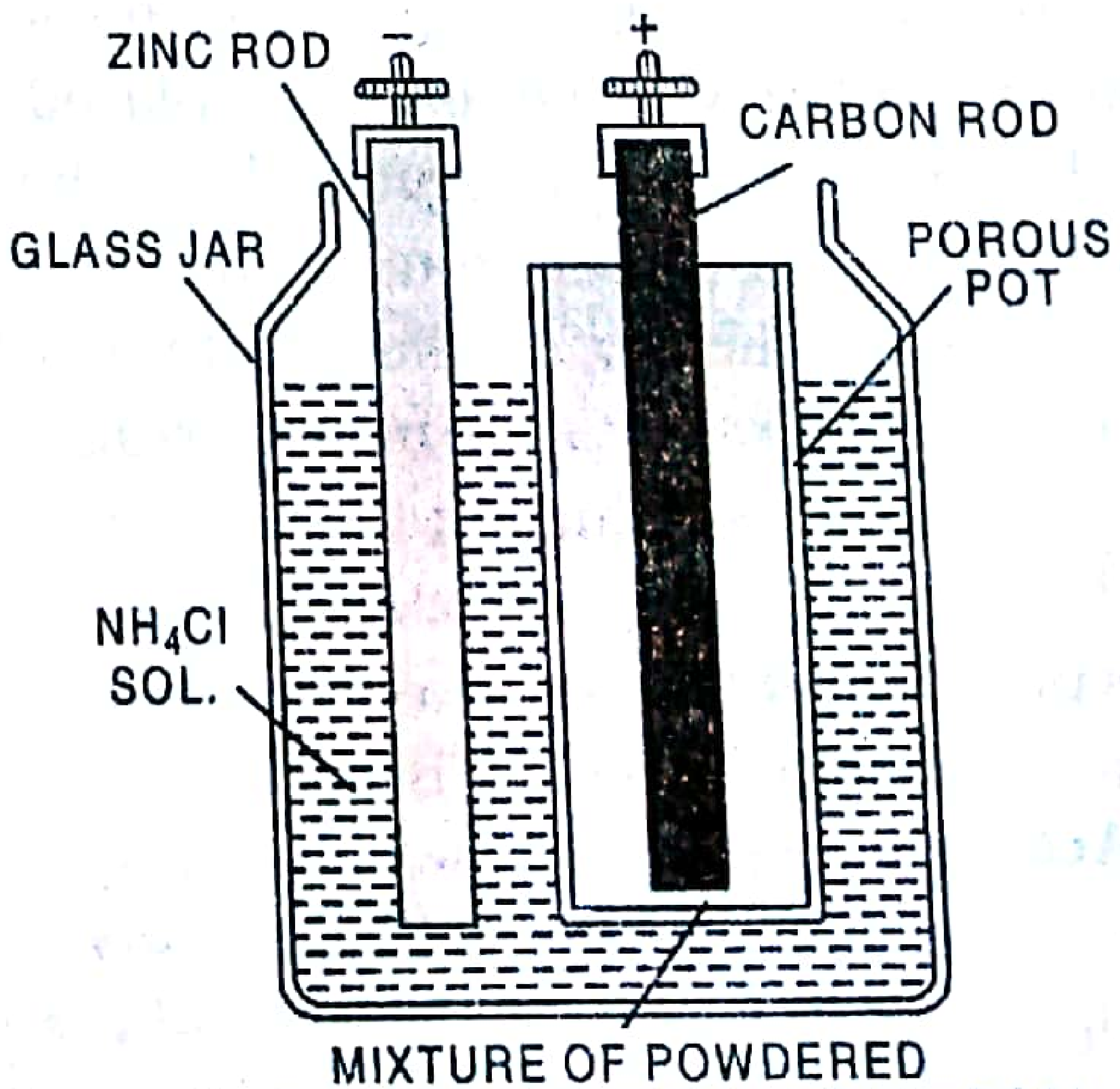

Fig. 1.03

Action. The electrolyte (NH_4Cl solution) dissociates into NH_4^+ and Cl^- ions. As the zinc rod is dipping inside the NH_4Cl solution, some of the atoms go into the solution as Zn^{++} ions. For each Zn^{++} ion so produced, two electrons are left on the zinc rod and hence it becomes negative pole of the cell. The NH_4^+ ions are repelled by Zn^{++} ions and they diffuse into the MnO_2 and charcoal mixture through the walls of the porus pot. Inside the glass vessel, Zn^{++} ions combine with Cl^- ions to form $ZnCl_2$. The reactions taking place inside the glass vessel are as below :

$$\begin{aligned} 2\,NH_4Cl &\longrightarrow 2\,NH_4^+ + 2\,Cl^- \\ Zn &\longrightarrow Zn^{++} + 2\,e^- \\ Zn^{++} + 2\,Cl^- &\longrightarrow ZnCl_2 \\ Zn + 2\,NH_4Cl &\longrightarrow ZnCl_2 + 2\,NH_4^+ + 2\,e^- \end{aligned}$$

On diffusing into porus pot, NH_4^+ ions extract electrons from the carbon rod making carbon rod as positively charged and producing ammonia and hydrogen gas as represented below :

$$2\,NH_4^+ + 2\,e^- \longrightarrow 2\,NH_3 + H_2$$

Whereas the ammonia gas escapes from the cell, hydrogen gas is neutralised by MnO_2 producing manganese trioxide (Mn_2O_3) and water as below :

$$2\,MnO_2 + H_2 \longrightarrow Mn_2O_3 + H_2O$$

It may be pointed out that by converting hydrogen gas into water, MnO_2 prevents hydrogen gas from causing the defect of polarisation in the cell. Therefore, MnO_2 acts as depolariser in Leclanche cell. The e.m.f. of Leclanche cell is nearly 1·5 V.

However, the defect of polarisation is found to occur, if the cell is used continuously. Being a solid depolariser, MnO_2 reacts with the hydrogen gas at a much slower rate, than at which it is liberated. Therefore, after some time, there is partial polarisation due to accumulation of hydrogen gas and e.m.f. of the cell falls.

It is found that if the cell is allowed to rest for some time by switching off the circuit, the e.m.f. of the cell recovers. It is because, during this period, Mn_2O_3 changes back into MnO_2 by taking oxygen from the atmosphere as represented below :

$$2\,Mn_2O_3 + O_2 \longrightarrow 4\,MnO_2$$

Because of this reason, Leclanche cell is used in experiments, where only intermittent supply of electric current is required.

Application. The e.m.f. of a Leclanche cell is large as compared to that of a Daniel cell but it cannot be used continuously. It is because, the polarisation is fast and the action of the depolariser is slow. In laboratory, it is used in those experiments, in which the flow of intermittent current is required.

1.07. DRY CELL

It is a portable form of the Leclanche cell.

Construction. In a dry cell, a moist paste of ammonium chloride and zinc chloride (highly hygroscopic) is used as an electrolyte. Zinc chloride is added to ammonium chloride in order to keep it moistened. The paste of NH_4Cl and $ZnCl_2$ is contained in a small cylindrical zinc vessel, which acts as the negative pole of the cell. A carbon rod fitted with a brass cap is placed in the middle of the zinc vessel. It acts as the positive pole of the cell. The carbon rod is surrounded by a closely packed mixture of MnO_2 and charcoal powder in a muslin bag. While the MnO_2 acts as the depolariser, the charcoal powder reduces the internal resistance of the cell by making MnO_2 electrically conducting. The zinc container and its contents are sealed at the top with pitch or shellac as shown in Fig. 1.04. A small hole is provided at the top, so as to allow ammonia gas formed during chemical reactions to escape the cell.

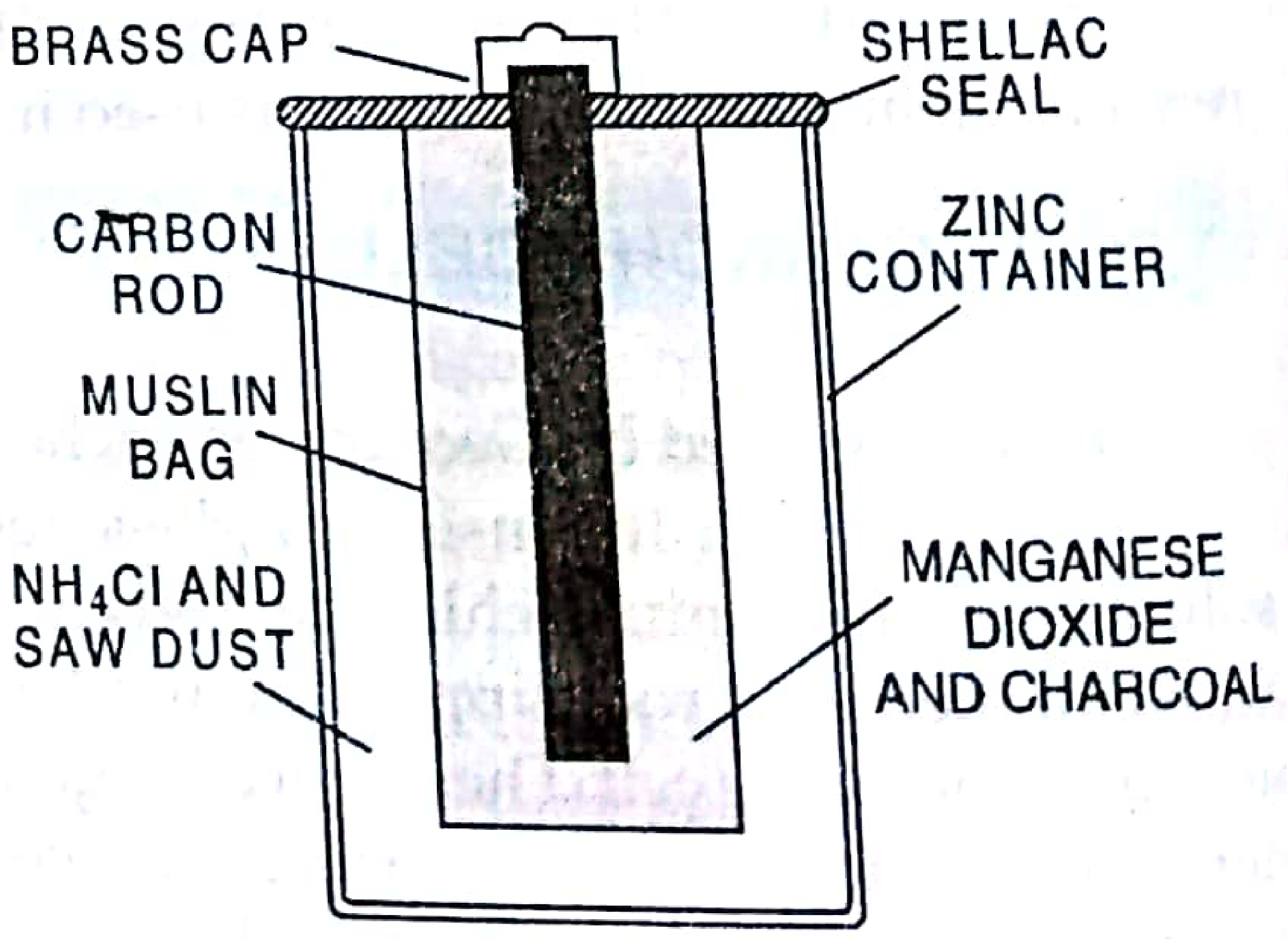

Fig. 1.04

Action. A dry cell is only a modification of a wet Leclanche cell. Therefore, the action of a dry cell as regards the chemical reactions that take place inside the cell, is same as that of the Leclanche cell.

The dry cells are manufactured in different sizes and shapes to suit particular needs. Irrespective of the size of the cell, it has an e.m.f. of the cell which is nearly 1·5 V. Its internal resistance may vary from 0·1 Ω to 10 Ω. Further, an electric current of about 0·25 A can be continuously drawn from a dry cell.

1.08. SECONDARY CELLS

A secondary cell is one in which chemical energy is converted into electrical energy but they do so only when they are charged by passing current through them by some source.

The secondary cells are also called **accumulators** or **storage cells.** These are of two types :

1. Lead acid cell or lead accumulator
2. Edison alkali cell

1.09. LEAD ACCUMULATOR

It is a secondary cell and is the most common type of storage battery used in automobiles. It is also known as the lead acid cell. It was invented by French Physicist, Gaston Plante in the year 1859.

Construction. It consists of a hard rubber, glass or celluloid container containing dilute sulphuric acid as the electrolyte. Each of the two electrodes consists of a set of alternate parallel mesh type perforated plates made of lead. The set of plates to be made the positive pole is filled with a paste of lead dioxide (PbO_2), while the set of plates to be made the negative pole is filled with a paste of spongy lead (Pb). The positive and negative plates are kept separated and insulated from each other by porus separators made of rubber, plastic or glass fibre. This arrangement of positive and negative plates is placed inside the dilute sulphuric acid and connected to the lead terminals provided on the hard and rigid cover of the container [Fig. 10.5].

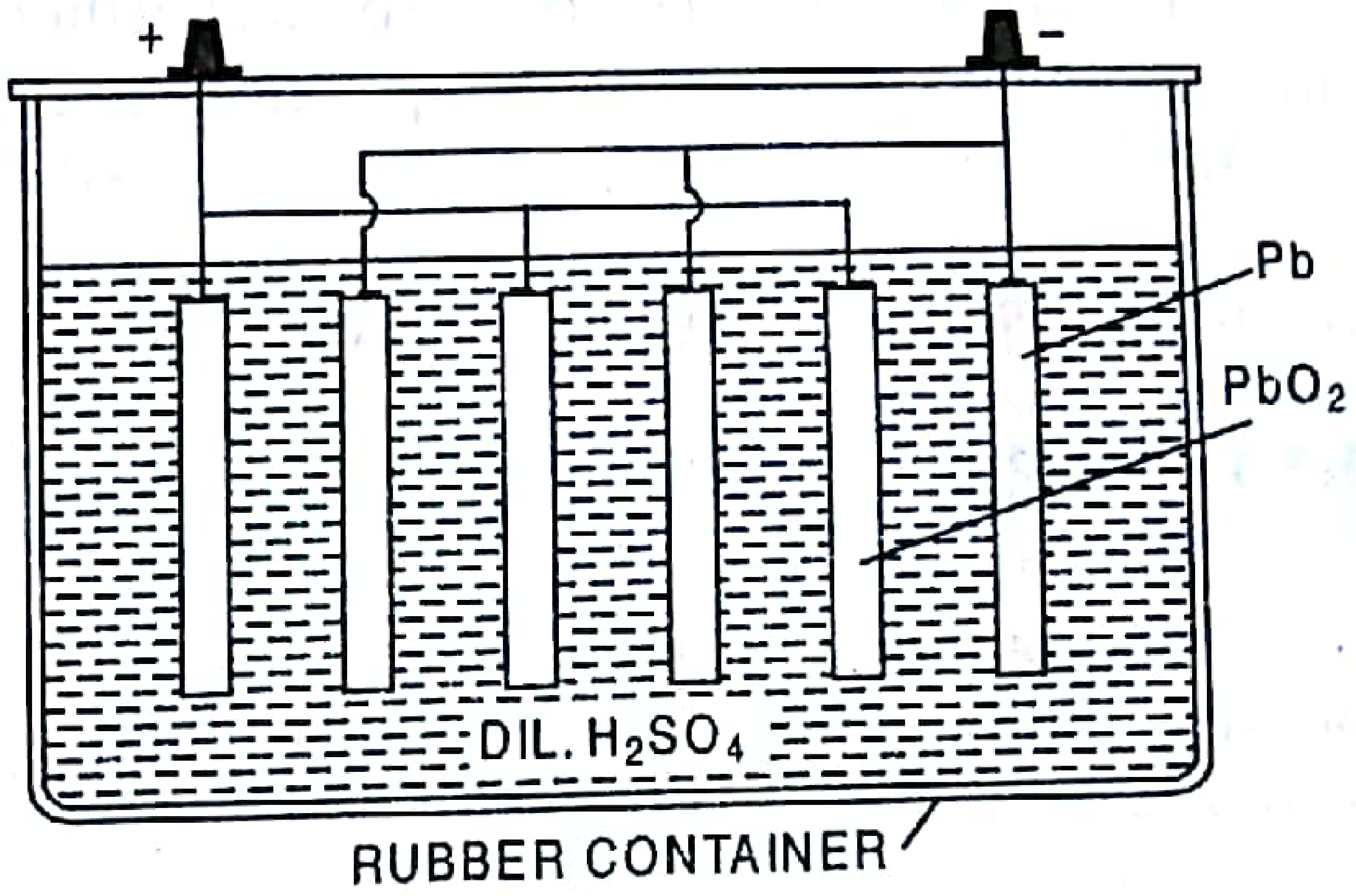

Fig. 1.05

The e.m.f. of each cell of a fully charged lead accumulator is 2·05 V and a lead accumulator of such six cells produces an e.m.f. of nearly 12 V. The specific gravity of the electrolyte (dilute sulphuric acid) in a fully charged lead accumulator is 1·28. However, when discharged, both the e.m.f. of the cell and the specific gravity of the electrolyte fall. Whereas e.m.f. of a cell of the accumulator should not be allowed to fall below 1·8 V, the specific gravity of the electrolyte should not drop below 1·12.

Discharging. When the cell is connected to an external load, it sends current in the circuit and starts discharging. The dilute sulphuric acid dissociates into H^+ and SO_4^{--} ions as below :

$$H_2SO_4 \longrightarrow 2\,H^+ + SO_4^{--}$$

The H^+ ions drift towards the positive plate, while SO_4^{--} ions move towards the negative plate of the accumulator. The chemical reactions take place at the two plates of the accumulators as given below :

At the negative plate :

$$Pb + SO_4^{--} - 2\,e^- \longrightarrow PbSO_4$$

At the positive plate :

$$\begin{array}{lcl} PbO_2 & + & 2\,H^+ + 2\,e^- \longrightarrow PbO + H_2O \\ PbO & + & H_2SO_4 \longrightarrow PbSO_4 + H_2O \\ \hline PbO_2 + H_2SO_4 & + & 2\,H^+ + 2\,e^- \longrightarrow PbSO_4 + 2\,H_2O \end{array}$$

Therefore, during discharging, the material of each plate is converted into $PbSO_4$. The lead sulphate produced in these reactions is in the soft form and is chemically more active than the hard lead sulphate. Further, H_2SO_4 molecules do not exist in the solution as such. As said above, they dissociate into H^+ and SO_4^{--} ions. Therefore, the reaction at the positive plate may be written as below :

$$PbO_2 + 4\,H^+ + SO_4^{--} + 2\,e^- \longrightarrow PbSO_4 + 2\,H_2O$$

Further, in the reactions during discharge, sulphuric acid is consumed and water is formed. As a result, the specific gravity of the sulphuric acid falls.

Charging. In order to charge a lead accumulator, it is connected to a battery charger capable of supplying e.m.f. greater than that of the lead accumulator. While charging an accumulator, a high series resistance is included in the circuit. In the absence of such a resistance, large current flows through the accumulator during charging. Due to this, a non-porus layer of $PbSO_4$ is formed on both the plates, which does not decompose during subsequent charging.