



## TOPIC

## 2

## Direct Current (DC) Electricity

### 2.1 PRIMARY AND SECONDARY CELLS

A Cell or Battery is an electrical component that converts Chemical Energy into Electrical Energy. Both Cell and Battery are the same combination of electrochemical Cells. The Cell is a simple and small unit. Many Cells make up a Battery and therefore, the Battery is called a cluster of Cells. The Cell is relatively small in size than the Battery.

There are mainly two types of Cells. This is briefly discussed below.

#### Primary Cell

In these Cells, electrical energy is generated using an irreversible Chemical reaction. Rechargeable Cells come out slowly. They are very intertwined. Because of the lack of fluid in the Cell, it is also called a dry Cell. Although easy to use, they cannot be reused. In general, they have very high internal opposition.

#### Secondary Cell

Secondary regenerative Cells convert Chemical Energy into electrical Energy and vice versa. They are charged again by the power supply. There is low internal resistance in this Cell. They are relatively inexpensive to use than the main Cell. They cost more than a basic Cell.

#### The Difference Between a Basic and a Secondary Cell

Primary Cells are the only ones that can be charged and need to be discarded after the end of the life span, while Secondary Cells need to be recharged once the charging is complete. Both types of batteries are widely used in a variety of applications and these Cells vary in size and material.

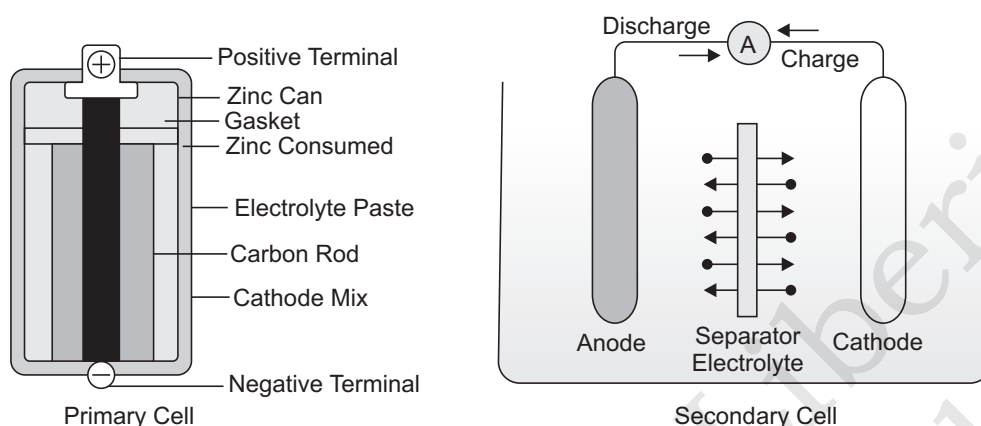


Fig. 2.1

### Difference between Primary and Secondary Cell

S.No.	Primary Cell	Secondary Cell
1.	These cannot be recharged again after getting discharged once.	These can be recharged easily.
2.	These are cheap or low cost.	These are expensive compared to Primary Cell.
3.	These are easy to use.	These are difficult to use in comparison to Primary Cell.
4.	These can be used only once.	These can be used more than once.
5.	In these Cells irreversible reactions occur.	In these Cells reversible reaction occurs.
6.	These have a lower self-discharge rate.	These have a higher self-discharge rate.
7.	These are used in torch and other portable devices as they produce electric current immediately.	These are used in inverters and automobiles.
8.	These Cells don't require regular maintenance and can be disposed of easily after use.	These Cells require regular maintenance.
9.	They have a low or small lifetime.	They have a high lifetime.
10.	Examples of these Cells are dry Cells, Daniel Cells etc.	Examples of these Cells are lead-acid Cell, nickel – iron Cell etc.

## 2.2 FUEL AND SOLAR CELLS

Plants split water into  $\text{H}^+$  and  $\text{O}_2$  using natural *catalysts* that are renewed every 30 minutes. We can already do the same thing very easily using electricity and metal electrodes in a process called *electrolysis* (water splitting) but this is very expensive in both energy and materials cost. To store solar energy in a  $\text{H}_2$  fuel on a large scale to meet the Terawatt challenge, we need to be able to split water with renewable energy or a solar driven process using inexpensive materials. This is indeed what a number of researchers startup and established companies around the world are currently working hard to achieve.

Yet, if  $\text{H}_2$  is a fuel that's storing energy, how do we get the energy back out?

That's easy using fuel cells that produce electricity by doing exactly the opposite of splitting water—reacting  $\text{H}_2$  and  $\text{O}_2$  to form water again as in the animation below that shows the operation of one cell in a fuel cell stack. So fuel cells run by consuming hydrogen, a 'zero-emission' fuel and produce only water and electricity.

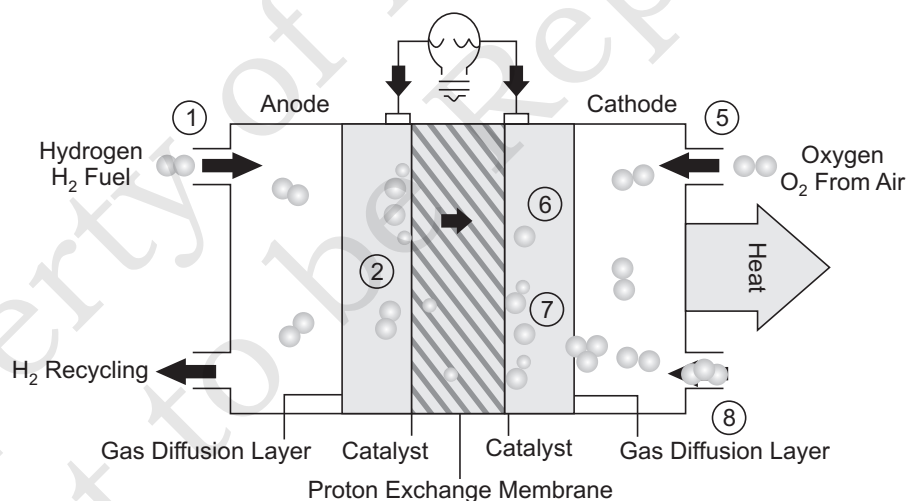


Fig. 2.2

## 2.3 ELECTRIC CURRENT

**(i)** The branch of physics which deals with the motion of charges is called **current electricity**.

In metallic conductors such as silver, copper, aluminium etc., the electrons in the outermost orbits of the atoms are loosely bound to their respective atoms. These electrons can be made easily free. These are known as *free electrons*. Since the electronic current in a conductor is due to the motion of free electrons, therefore, these electrons are also known as *conduction electrons*. In other words, the free electrons act as charge carriers in metallic conductors.

**The flow of free charges in a conductor constitutes electric current.**

### (ii) Electric current

The **electric current** is defined as the charge flowing through any section of the conductor in one second. In other words, it is the rate of flow of electric charge through any section of the conductor.

If the rate of flow of charge is independent of time, then the electric current is said to be steady. In a steady flow of charge, if a charge  $q$  crosses any section of the conductor in time  $t$ , then the current flowing through the conductor is given by,

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

If the rate of flow of charge varies with time, then the current at any time *i.e.*, instantaneous current is given by

$$I = \frac{dq}{dt}$$

where  $dq$  is the extremely small amount of charge crossing any section of the conductor in small time  $dt$ .

If  $n$  be the number of conduction electrons crossing a certain cross-section of the conductor in time  $t$ ,

then 
$$I = \frac{ne}{t} \quad \text{or} \quad n = \frac{It}{e}$$

### (iii) Current-time Graphs

Graph of Fig. 2.3 represents a steady current.

*Steady current is that current which does not vary with time.*

The graphs (a), (b) and (c) of Fig. 2.4 represent varying currents.

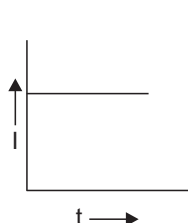


Fig. 2.3

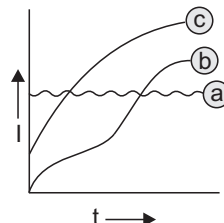


Fig. 2.4

*Varying current is a current whose magnitude varies with time.*

Graph of Fig. 2.5 shows alternating current. *An alternating current is a current whose magnitude changes continuously with time and direction changes periodically.*

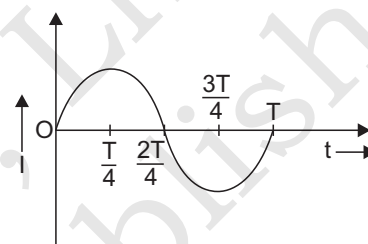


Fig. 2.5

#### (iv) Measurement of Current

In actual practice, the measurement of electric current does not include individual measurements of charge and time. The electric current is generally measured by its magnetic effect, chemical effect, heating effect etc.

#### (v) Convention for the Direction of Current

In the year 1820, Ampere put forward a **convention for the direction of electric current**. According to this convention, *the direction of electric current is the direction in which a positive charge would move under the action of an electric field*. In a metallic conductor, the positive charges cannot move. The electric current is wholly due to the movement of the negative charges *i.e.*, free electrons. *But a negative charge moving in one direction is equivalent to an equal amount of positive charge moving in the opposite direction*. So, the direction of conventional current in a metallic conductor is opposite to that in which the free electrons move (Fig. 2.6).



Fig. 2.6. Direction of current

## 2.4 SI UNIT OF ELECTRIC CURRENT

The **SI unit** of electric current is **ampere (A)**.

The **current** flowing in a conductor is said to be one ampere if one coulomb of charge flows across any of its cross-section in one second.

$$\therefore 1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

One ampere may also be defined as that constant current which when flowing in two straight parallel conductors of infinite length and of negligible cross-sectional area and placed one metre apart in vacuum would produce between these conductors a force equal to  $2 \times 10^{-7}$  newton per metre of length.

**Example 1:** Calculate the number of electrons crossing a given cross-section in 1 second to constitute a current of 1 A.

**Solution:**  $I = \frac{q}{t} = \frac{ne}{t}$

or  $I = \frac{n}{t} \times 1.6 \times 10^{-19} \quad \text{or} \quad \frac{n}{t} = 6.25 \times 10^{18} \text{ s}^{-1}$

**Example 2:** A current of 0.50 ampere is passing through a  $\text{CuSO}_4$  solution. How many  $\text{Cu}^{++}$  ions will be deposited on cathode in 10 second?

**Solution:** Current,  $I = 0.50 \text{ A}$  ; Time,  $t = 10 \text{ s}$

Each  $\text{Cu}^{++}$  ion carries charge of two protons. If  $n$  be the number of copper ions, then charge,

$$q = n \times 2e$$

Now,  $I = \frac{q}{t} \quad \text{or} \quad q = It \quad \text{or} \quad n \times 2e = It$

or  $n = \frac{It}{2e} = \frac{0.50 \text{ A} \times 10 \text{ s}}{2 \times 1.6 \times 10^{-19} \text{ C}} = 1.5625 \times 10^{19}$

## 2.5 OHM'S LAW

**Statement.** Physical conditions such as temperature, mechanical strain etc., remaining the same, the electric current flowing through a conductor is directly proportional to the potential difference across the two ends of the conductor.

Imagine a conductor through which a current  $I$  is flowing and let  $V$  be the potential difference between the ends of the conductor. Then, according to Ohm's law,

$$V \propto I \quad \text{or} \quad V = RI$$

where the constant of proportionality  $R$  is called the resistance of the conductor.

Since the current  $I$  is proportional to the potential difference  $V$  therefore the graph between  $V$  and  $I$  is a straight line (Fig. 2.7).

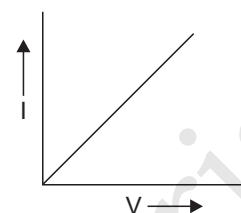


Fig. 2.7. V-I graph for an Ohmic conductor

**Example 3:** In a discharge tube, the number of hydrogen ions (i.e., protons) drifting across a cross-section per second is  $1.0 \times 10^{18}$ , while the number of electrons drifting in the opposite direction across another cross-section is  $2.7 \times 10^{18}$  per second. If the supply voltage is 230 V, what is the effective resistance of the tube?

**Solution:** 
$$I = \frac{(1.0 \times 10^{18} + 2.7 \times 10^{18}) \times 1.6 \times 10^{-19}}{1} \text{ A} = 0.592 \text{ A}$$

$$\text{Resistance, } R = \frac{V}{I} = \frac{230}{0.592} \Omega = 388.5 \Omega$$

**Example 4:** A copper bar carrying 1000 A has a potential drop of 1 mV along 10 cm of its length. What is the resistance per metre of the bar?

**Solution:** 
$$R = \frac{V}{I} = \frac{10^{-3}}{1000} \Omega = 10^{-6} \Omega$$

$$\text{Resistance/metre} = \frac{10^{-6} \times 100}{10} \Omega \text{ m}^{-1} = 10 \mu\Omega \text{ m}^{-1}$$

## 2.6 ELECTRICAL RESISTANCE

(i) The **resistance** of conductor is the opposition offered by the conductor to the flow of electric current through it.

We know that, 
$$R = \frac{ml}{ne^2 A \tau} \quad \text{or} \quad R = \frac{m}{ne^2 \tau} \times \frac{l}{A} \quad \text{or} \quad \boxed{R = \rho \frac{l}{A}}$$

where  $\rho \left( = \frac{m}{ne^2 \tau} \right)$  is called the **specific resistance** or **electrical**



**resistivity of the material of the conductor.** Both  $n$  and  $\tau$  depend on the nature of material of the conductor. So,  $\rho$  depends on the nature of material of the conductor and not on the dimensions of the conductor.

**(ii) Factors affecting resistance.** The resistance of a conductor is *directly proportional to the length* of the conductor, provided other factors remain unchanged.

The resistance of a conductor is *inversely proportional to the cross-sectional area* of the conductor, provided other factors remain unchanged.

The resistance of a conductor also depends upon the *nature of material* and *temperature* of the conductor.

**(iii) Units.** We know that,  $R = \frac{V}{I}$

So, the resistance of a conductor is the ratio between the potential difference  $V$  across the ends of the conductor and the electric current  $I$  flowing through the conductor.

The **SI unit** of resistance is **ohm**. It is denoted by the symbol  $\Omega$ .

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

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

One **international ohm** is the resistance of a column of mercury of length 106.3 cm and having an area of cross-section 1 sq. mm at  $0^\circ\text{C}$ .

1 international ohm = 1.0006495 ohm.

Larger units of resistance are called kilo ohm and mega ohm.

1 kilo ohm = 1000 ohm and 1 mega ohm =  $10^6$  ohm

The smaller unit of resistance is micro ohm. 1 micro ohm =  $10^{-6}$  ohm

**(iv) Dimensional formula.**

$$\begin{aligned} R &= \frac{V}{I} = \frac{\text{Work done}}{\text{Charge}} \times \frac{1}{\text{Current}} \\ &= \frac{\text{Work done}}{\text{Current} \times \text{Time} \times \text{Current}} \end{aligned}$$

$$[R] = \frac{[\text{ML}^2\text{T}^{-2}]}{[\text{A}^2\text{T}]} = [\text{ML}^2\text{T}^{-3}\text{A}^{-2}]$$



## 2.7 ELECTRICAL RESISTIVITY (SPECIFIC RESISTANCE)

(i) **Definition and explanation.** We know that

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

$$\rho = R.$$

This leads us to the following definition of resistivity.

The **resistivity** of a material is the resistance of a conductor of this material of unit length and unit cross-sectional area. The shape of the cross-section is immaterial.

The **resistivity** of a material may also be defined as the resistance of a unit cube of that material.

Those substances which have **low resistivity** are conductors of electricity. Metals belong to this category. Conductors are used for transporting electric current without appreciable loss of energy.

Those substances which have **high resistivity** are non-conductors of electricity *i.e.*, insulators. When we do not want electric current to flow between two points, then an insulating material such as glass, mica or bakelite is put between those two points. These materials are used to avoid electric shocks.

(ii) **Factors affecting resistivity.** We know that,  $R = \left[ \frac{m}{ne^2\tau} \right] \frac{l}{A}$

Also,  $R = \rho \frac{l}{A}$ . Comparing,  $\rho = \frac{m}{ne^2\tau}$

It follows from here that the resistivity of the material of a conductor depends upon the following factors :

(a) Resistivity is inversely proportional to  $n$  *i.e.*, the number of free electrons per unit volume. But the value of  $n$  depends upon the nature of the material. So, the resistivity of a conductor depends upon the nature of material of the conductor.

(b) Resistivity is inversely proportional to  $\tau$  *i.e.*, the average relaxation time of the free electrons in the conductor.  $\tau$  decreases with rise of temperature. So, resistivity increases with the increase in temperature of the conductor.

The free electron density and the relaxation time are different for different materials. So, the resistivity for different materials is different.

(iii) **Unit.**  $R = \rho \frac{l}{A}$  or  $\rho = \frac{RA}{l}$

The SI unit of  $\rho$  is  $\frac{\text{ohm metre}^2}{\text{metre}}$  or ohm metre i.e.,  $\Omega \text{ m}$ .

(iv) **Dimensional formula**

$$\rho = \frac{RA}{l} ; \quad [\rho] = \frac{[ML^2T^{-3}A^{-2}][L^2]}{[L]} = [ML^3T^{-3}A^{-2}]$$

## 2.8 ELECTRICAL CONDUCTANCE

The reciprocal of resistance is called **conductance**. It is denoted by  $G$ .

$$G = \frac{1}{R} = \frac{A}{\rho l}$$

The SI unit of conductance is **ohm<sup>-1</sup>** ( $\Omega^{-1}$ ) or **mho** or **A V<sup>-1</sup>** or **siemen (S)**.

## 2.9 ELECTRICAL CONDUCTIVITY

As the name suggests, the conductivity of a material is its ability to conduct electric current. It is a measure of the ease with which the current flows through a conductor.

**Electrical conductivity is defined as the reciprocal of resistivity.**

It is denoted by  $\sigma$ .

$$\sigma = \frac{1}{\rho} \quad \text{or} \quad \sigma = \frac{ne^2\tau}{m}$$

The SI unit of conductivity is ohm<sup>-1</sup> metre<sup>-1</sup> ( **$\Omega^{-1} \text{ m}^{-1}$** ) or mho metre<sup>-1</sup> or siemen metre<sup>-1</sup> ( **$\text{S m}^{-1}$** ).

$$[\sigma] = \frac{[L^{-3}][AT]^2[T]}{[M]} ; \quad [\sigma] = [M^{-1}L^{-3}T^3A^2]$$

**Example 5:** A nichrome wire of resistivity ' $\rho$ ' is stretched to make it 10% longer. What is the percentage change in its resistance?

**Solution:** We have,  $l' = l + \frac{10}{100} l = l + 0.1 l$

$$= 1.1 l \quad \text{or} \quad \frac{l'}{l} = 1.1.$$

Since volume is to remain unchanged,

$$\therefore A'l' = Al \quad \text{or} \quad \frac{A'}{A} = \frac{l}{l'} = \frac{1}{1.1}$$

$$R' = \rho \frac{l'}{A'} = \frac{\rho(1.1l)(1.1)}{A} = (1.1)^2 R = 1.21 R$$

$$\text{Now,} \quad \frac{R' - R}{R} \times 100 = \frac{1.21 R - R}{R} \times 100 = 21\%$$

## 2.10 SERIES COMBINATION OF RESISTORS

**Resistors are said to be connected in series if the same current flows through each resistor when some potential difference is applied across the combination.**

When resistors are connected in series between two points, they provide a single path between the two points.

It is possible to find a single resistor which could replace series combination of resistors in any given circuit and leave unaltered the potential difference between the terminals of the combination and the current in the rest of the circuit. The resistance of this single resistor is called the **equivalent resistance** of the combination.

If  $R_s$  be the equivalent resistance and  $V_{ab}$  the potential difference between the terminals  $a$  and  $b$  of the network, then

$$V_{ab} = IR_s \quad \dots(1)$$

where  $I$  is the current flowing in the network.

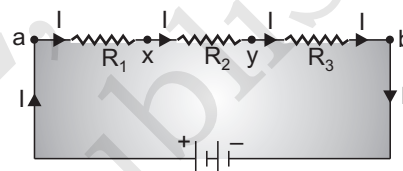
When the resistors are connected in series, the current in each must be the same and equal to the line current  $I$ .

$$\therefore V_{ax} = IR_1, V_{xy} = IR_2 \text{ and } V_{yb} = IR_3$$

$$\text{Now,} \quad V_{ax} + V_{xy} + V_{yb} = IR_1 + IR_2 + IR_3 = I(R_1 + R_2 + R_3)$$

$$\text{But} \quad V_{ax} = V_a - V_x, V_{xy} = V_x - V_y \text{ and } V_{yb} = V_y - V_b$$

$$\begin{aligned} \therefore V_{ax} + V_{xy} + V_{yb} &= V_a - V_x + V_x - V_y + V_y - V_b \\ &= V_a - V_b = V_{ab} \end{aligned}$$



**Fig. 2.8.** Series combination of resistors

$$\begin{aligned} \therefore V_{ab} &= I(R_1 + R_2 + R_3) \\ \text{or } IR_s &= I(R_1 + R_2 + R_3) & [\text{From Eqn. (1)}] \\ \text{or } R_s &= R_1 + R_2 + R_3 \end{aligned}$$

This relation can be generalised for any number of resistances connected in series. So, if  $n$  resistances are connected in series, then their equivalent resistance is given by

$$R_s = R_1 + R_2 + R_3 + \dots + R_n \quad \text{or}$$

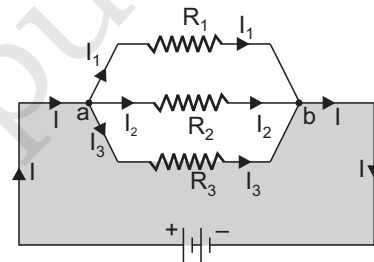
$$R_s = \sum_{i=1}^{i=n} R_i$$

**Conclusion.** *The equivalent resistance of any number of resistors in series is equal to the sum of their individual resistances.*

## 2.11 PARALLEL COMBINATION OF RESISTORS

**Resistors are said to be connected in parallel if the potential difference across each of them is the same and is equal to the applied potential difference.**

Figure 2.9 shows three resistors of resistances  $R_1$ ,  $R_2$  and  $R_3$  connected in parallel. Each resistor provides an alternative path between the two terminals  $a$  and  $b$  of the network. Let  $R_p$  be the equivalent resistance of the network.



**Fig. 2.9.** Parallel combination of resistors

$$V_{ab} = IR_p \quad \dots(1)$$

Since the resistors are connected in parallel therefore the potential difference between the terminals of each must be the same and equal to  $V_{ab}$ . If  $I_1$ ,  $I_2$  and  $I_3$  are the currents in resistances  $R_1$ ,  $R_2$  and  $R_3$  respectively, then

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

Charge is delivered to the terminal  $a$  by the line current  $I$  and removed from  $a$  by the currents  $I_1$ ,  $I_2$  and  $I_3$ . So, no charge accumulates at  $a$ .

$$\therefore I = I_1 + I_2 + I_3 \quad \text{or} \quad I = \frac{V_{ab}}{R_1} + \frac{V_{ab}}{R_2} + \frac{V_{ab}}{R_3}$$

or

$$\frac{I}{V_{ab}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

But

$$\frac{I}{V_{ab}} = \frac{1}{R_p} \quad [\text{From Eqn. (1)}]$$

$$\therefore \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

This relation can be generalised for any number of resistances connected in parallel. So, if  $n$  resistances are connected in parallel, then

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

or

$$\frac{1}{R_p} = \sum_{i=1}^n \frac{1}{R_i}$$

**Conclusion.** For any number of resistors connected in parallel, the reciprocal of the equivalent resistance is equal to the sum of the reciprocals of their individual resistances.

## 2.12 DISTRIBUTION OF ELECTRIC CURRENT IN TWO PARALLEL RESISTANCES

Consider two resistances  $R_1$  and  $R_2$  connected in parallel. The current  $I$  will be divided into two parts at the terminal  $x$ . Suppose current  $I_1$  flows through  $R_1$  and current  $I_2$  flows through  $R_2$ . The currents  $I_1$  and  $I_2$  combine at  $y$  to give the original current  $I$ . If  $R$  be the total resistance between  $x$  and  $y$ , then

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{or} \quad R = \frac{R_1 R_2}{R_1 + R_2}$$

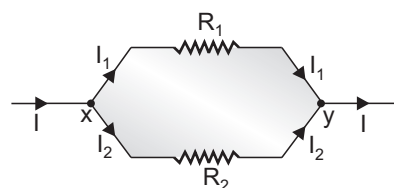


Fig. 2.10. Distribution of current

If  $V$  be the potential difference between  $x$  and  $y$ , then

$$V = IR = \frac{IR_1R_2}{R_1 + R_2}. \quad \text{Now, } I_1 = \frac{V}{R_1} = \frac{IR_2}{R_1 + R_2} \quad \dots(1)$$

$$\text{Similarly, } I_2 = \frac{IR_1}{R_1 + R_2} \quad \dots(2)$$

Dividing (1) by (2), we get,

$$\frac{I_1}{I_2} = \frac{IR_2}{R_1 + R_2} \times \frac{R_1 + R_2}{IR_1} \quad \text{or} \quad \boxed{\frac{I_1}{I_2} = \frac{R_2}{R_1}}$$

**Conclusion.** The currents divide themselves in the inverse ratio of resistances.

**Example 8:** Find the strength of current flowing through the circuit shown in Fig. 2.11.

**Solution:** In the given network,  $4\ \Omega$  and  $1\ \Omega$  are in series. This gives  $5\ \Omega$ . So, the given circuit may be redrawn as shown in Fig. 2.12.

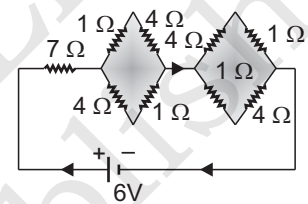


Fig. 2.11

$$\begin{aligned} \text{Now, } R &= (7 + 2.5 + 2.5)\ \Omega \\ &= (7 + 5)\ \Omega = 12\ \Omega \\ \text{Current, } I &= \frac{V}{R} = \frac{6}{12}\ \text{A} \\ &= \frac{1}{2}\ \text{A} = \mathbf{0.5\ A} \end{aligned}$$

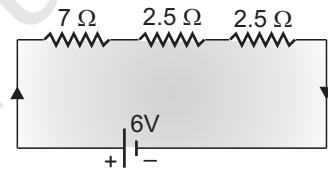


Fig. 2.12

## 2.13 TEMPERATURE DEPENDENCE OF RESISTANCE

We know that

$$R = \frac{m}{ne^2\tau} \times \frac{l}{A}$$

For a given conductor,

$$\boxed{R \propto \frac{1}{\tau}}$$

When a metallic conductor is heated, the atoms in the metal vibrate with greater amplitude and frequency about their mean positions. Due to increase in thermal energy, the thermal velocities of the free electrons also increase. Consequently, the number of collisions between free electrons and atoms increases. This reduces the relaxation time  $\tau$  and increases the value of resistance  $R$ .

The resistance  $R_t$  of a metallic conductor at temperature  $t^\circ\text{C}$  is given by

$$R_t = R_0(1 + \alpha t + \beta t^2)$$

where  $\alpha$  and  $\beta$  are constants whose values vary from metal to metal. If  $t$  is not sufficiently large, then

$$R_t = R_0(1 + \alpha t)$$

where  $\alpha$  is called the temperature coefficient of resistance of the material of the conductor.

*The temperature coefficient of resistance is defined as the change in resistance per unit resistance at  $0^\circ\text{C}$  per degree rise of temperature.*

Strictly speaking,  $\alpha$  is defined with respect to  $0^\circ\text{C}$ . The value of  $\alpha$  is different at different temperatures. Temperature coefficient of resistance **averaged over the temperature range**  $t_1^\circ\text{C}$  to  $t_2^\circ\text{C}$  is given by,

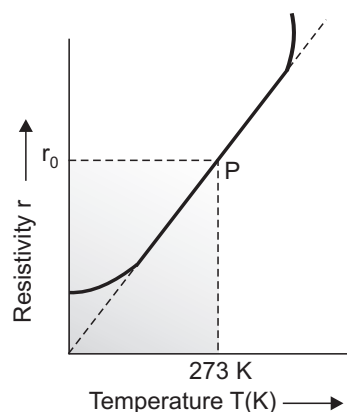
$$\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$$

For **metals**, (silver, copper),  $\alpha$  is positive i.e., the resistance increases with increase in temperature. For most of the pure metals, the value of  $\alpha$  is of the order of  $\frac{1}{273}^\circ\text{C}^{-1}$ .

## 2.14 TEMPERATURE DEPENDENCE OF RESISTIVITY

**(i) Metallic Conductors.** We know that  $\rho = \frac{m}{ne^2\tau}$  ... (1)

Resistivity is inversely proportional to relaxation time. When the temperature of a metallic conductor is increased, the relaxation time is decreased on account of increased atomic vibrations. Thus, resistivity of all metallic conductors increases with increase of temperature. At ordinary temperatures, the resistivity of most of the metals increases linearly with temperature.



**Fig. 2.13.** Variation of resistivity with temperature



$$\rho_T = \rho_0[1 + \alpha(T - T_0)]$$

where  $\rho_0$  is the resistivity at a reference temperature  $T_0$ ,  $\rho_T$  is the resistivity at temperature  $T$ . The factor  $\alpha$  is the temperature coefficient of resistivity.

At low temperatures, the temperature-dependence of resistivity is non-linear. At low temperatures, the resistivity increases as a higher power of temperature.

Graph (Fig. 2.14) shows the variation of resistivity of metallic conductors with temperature. The graph is a straight line over a limited range of temperature. The point P on the linear portion of the graph may be taken as the reference point. The temperature corresponding to this point is 273 K and resistivity is  $\rho_0$ .

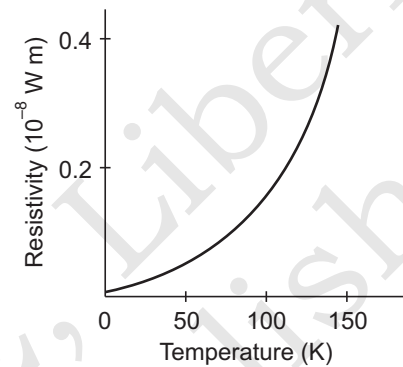


Fig. 2.14. Variation of resistivity of copper with temperature

Fig. 2.14 shows the resistivity of copper as a function of temperature  $T$ .

## 2.15 ELECTROMOTIVE FORCE OF A CELL

Electromotive force (emf) of a cell is the potential difference between the two terminals of the cell in an open circuit (when no current is drawn from the cell).

It is due to the emf of the cell that the cell drives the charge round the circuit. So, emf of a cell may also be defined as under :

*Electromotive force (emf) of a cell is the energy supplied by the cell to drive a unit charge round the complete circuit. It is denoted by  $\epsilon$ .*

The SI unit of  $\epsilon$  is joule/coulomb i.e., volt.

The emf of a cell is said to be one volt if one joule of work is performed by the cell to drive one coulomb of charge round the circuit.

## 2.16 TERMINAL POTENTIAL DIFFERENCE OF A CELL

*The terminal potential difference of a cell is the difference of potentials between the terminals of the cell when the cell is in closed circuit i.e., when current is drawn from the cell. It is denoted by  $V$ .*

**Note:** Both emf and potential difference have the same units.

## 2.17 COMPARISON OF EMF AND POTENTIAL DIFFERENCE

1. The difference of potentials between the two terminals of a cell in an open circuit i.e., when no current is drawn from the cell is known as the electromotive force (emf) of the cell. On the other hand, the potential difference is the difference of potentials between any two points in a closed circuit.

2. The emf is independent of the resistance of the circuit. However, the potential difference between any two points of a circuit is proportional to the resistance between those two points.

3. The term 'emf' is used only for the source of emf. The 'potential difference' is measured between any two points of the electric circuit.

4. The emf is greater than the potential difference between any two points of a circuit. However, when the cell is being charged, the potential difference between its two terminals is larger than the emf of the cell.

## 2.18 INTERNAL RESISTANCE OF A CELL

*The opposition offered by the electrolyte of the cell to the flow of electric current through it is called the internal resistance of the cell.* It is generally denoted by  $r$ . The value of internal resistance for a freshly prepared cell is low. However, as the cell is used more and more, its internal resistance goes on increasing.

The internal resistance of a cell depends upon the following factors :

**(i)** Larger the *separation between the electrodes* of the cell, more the length of the electrolyte through which current has to flow and consequently a higher value of internal resistance.

**(ii)** Greater the *conductivity* of the electrolyte, lesser is the internal resistance of the cell. So, the internal resistance depends upon the nature of the electrolyte.

**(iii)** The internal resistance of a cell is inversely proportional to the common area of the electrodes dipping in the electrolyte.

**(iv)** The internal resistance of a cell also depends upon the nature of the electrodes.

**(v)** The internal resistance of a cell increases with the decrease in temperature of the electrolyte.

## 2.19 CIRCUIT EQUATION

Consider a cell of emf  $\varepsilon$  and internal resistance  $r$  connected to an external resistance  $R$  as shown in Fig. 2.15. Let a constant current  $I$  flow through the circuit.

Using definition of emf,

$\varepsilon$  = Work done by the cell in carrying a unit charge along the closed circuit

= Work done in carrying a unit charge from A to B against the external resistance  $R$  + Work done in carrying a unit charge from B to A against the internal resistance  $r$

$\varepsilon = V + V'$ , where  $V = IR$  and  $V' = Ir$

$\therefore \varepsilon = IR + Ir = I(R + r)$

or

$$I = \frac{\varepsilon}{R + r}$$

This relation is called circuit equation.

**Example 10:** Two cells  $\varepsilon_1$  and  $\varepsilon_2$  in the given circuit diagram have an emf of 5 V and 9 V and internal resistance of 0.3  $\Omega$  and 1.2  $\Omega$  respectively.

Calculate the value of current flowing through the resistance of 3  $\Omega$ .

**Solution:** Net emf = 9 V – 5 V = 4 V

$$\text{Total resistance} = 0.3 + 1.2 + 4.5 + \frac{6 \times 3}{6 + 3} = 8 \Omega$$

$$\text{Current through the circuit, } I = \frac{4}{8} = 0.5 \text{ A}$$

Current through the 3  $\Omega$  resistance

$$= \frac{6 \times 0.5}{6 + 3} = \frac{1}{3} \text{ A} = \mathbf{0.33 \text{ A}}$$

**Example 11:** Three identical cells, each of emf 4 V and internal resistance  $r$ , are connected in series to a 6  $\Omega$  resistor. If the current flowing in the circuit is 1.5 A, calculate (a) internal resistance of each cell and (b) the terminal voltage across each cell.

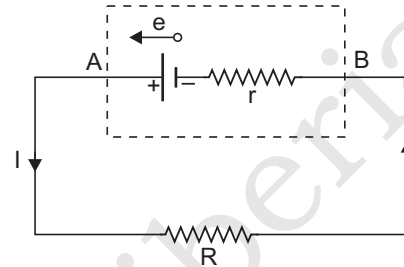


Fig. 2.15

**Solution:** (a) Total emf =  $3 \times 4 \text{ V} = 12 \text{ V}$

Total resistance =  $6 + 3r$

Using circuit equation,

$$1.5 = \frac{12}{6 + 3r} \text{ or } r = \frac{2}{3} \Omega = \mathbf{0.67 \Omega}$$

$$(b) V = \varepsilon - Ir = \left( 4 - 1.5 \times \frac{2}{3} \right) \text{ volt} = \mathbf{3 \text{ V}}$$

## 2.20 KIRCHHOFF'S LAW

While discussing an electrical network, we shall proceed on the assumption that the emfs are constant and that the steady conditions have been reached in the network so that the currents are also constant. **The general problem is to calculate currents in terms of emfs and resistances.** There are two famous rules to solve this kind of problem. These rules were first developed by Gustav Robert Kirchhoff in the year 1842 and are known after him as Kirchhoff's rules or Kirchhoff's laws. **These laws are simply the expressions of conservation of electric charge and of energy.** These laws may be stated as follows :

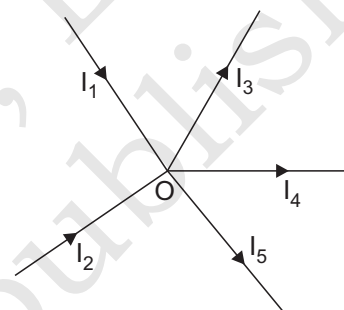


Fig. 2.16. Kirchhoff's current law

### 1. Kirchhoff's first law or Kirchhoff's Current Law or Junction Rule

It is stated as follows :

**"In any electrical network, the algebraic sum of currents meeting at a junction is always zero."**

$$\Sigma I = 0$$

When applying this law, we adopt the following **sign convention** :

*"The currents directed towards the junction are taken as positive while those directed away from the junction are taken as negative."*

Consider a number of conductors meeting at junction O and carrying currents  $I_1, I_2, I_3, I_4$  and  $I_5$ . Applying Kirchhoff's current law to the network shown in Fig. 2.16, we get

$$I_1 + I_2 - I_3 - I_4 - I_5 = 0 \quad \text{or} \quad I_1 + I_2 = I_3 + I_4 + I_5$$

This leads us to the following alternative way of stating the law :

**"The sum of the currents flowing towards a junction is equal to the sum of currents leaving the junction."**

The charges cannot accumulate at a junction. The number of charges that arrive at a junction in a certain time must leave the junction in the same time. This is in accordance with the conservation of charge which is the basis of Kirchhoff's current law.

**Problem. Apply Kirchhoff's first law to the junctions A, B and C of the electrical network shown in Fig. 2.16.**

<b>Solution.</b>	For junction A	:	$I_6 - I_1 - I_2 = 0$
	For junction B	:	$I_1 - I_3 - I_5 = 0$
	For junction C	:	$I_2 + I_5 - I_4 = 0$

## 2. Kirchhoff's Second Law or Kirchhoff's Voltage Law or Loop Rule

It is stated as follows :

**"The algebraic sum of all the potential drops and emfs along any closed path in a network is zero."**

Kirchhoff's second law expresses the conservation of energy i.e., the net change in the energy of a charge after the charge completes a closed path must be zero. When applying this law, we adopt the following **sign convention**.

In applying the second law, we have to keep in mind that **the potential falls along the direction of current in a current path. It rises along a path from negative terminal to the positive terminal. While the 'potential fall' is taken as negative, the 'potential rise' is taken as positive.**

The product of current and resistance will be taken as negative when we traverse in the direction of the conventional current.

The emf is taken as negative when we traverse from positive to the negative terminal of the cell through the electrolyte. The emf will naturally be taken as positive when we traverse from negative to the positive terminal of the cell.

Keeping in mind this sign convention, let us now apply Kirchhoff's second law to the paths marked 1, 2 and 3 in Fig. 2.17.

For path 1,  $-R_1 I_1 - R_5 I_5 + R_2 I_2 + \varepsilon_2 = 0$

For path 2,  $-R_3 I_3 + R_4 I_4 + R_5 I_5 = 0$

For path 3,  $-R_2 I_2 - R_4 I_4 - R_6 I_6 + \varepsilon_1 - \varepsilon_2 = 0$

or

$$\varepsilon_1 - \varepsilon_2 = R_2 I_2 + R_4 I_4 + R_6 I_6$$

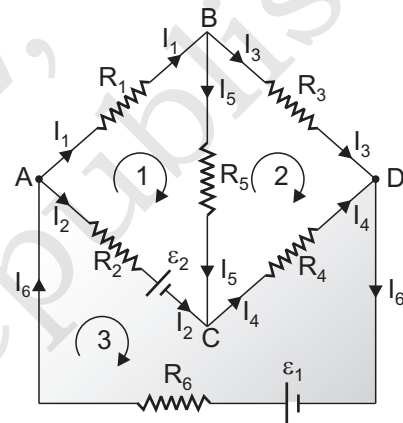


Fig. 2.17. Kirchhoff's voltage law

In general,  $\sum \varepsilon = \sum IR$

A practical rule to follow in finding the currents in a network having  $n$  junctions is to apply the first law to  $(n - 1)$  junctions only because once the law is satisfied for  $(n - 1)$  junctions, it is automatically satisfied for the remaining junction. Kirchhoff's second law must be applied to as many closed paths as required in order for each conductor to be part of a path at least once.

The following guidelines will help with the problem of signs while applying Kirchhoff's second law :

(i) Choose any closed loop in the network and designate a direction (clockwise or counter clockwise) to traverse the loop.

(ii) Go around the loop in the designated direction, adding emfs and potential differences. An emf is counted as 'positive' when it is traversed from negative to positive and 'negative' when from positive to negative. An  $IR$  term is counted as negative if the resistor is traversed in the same direction as the assumed current, positive if in the opposite direction.

## 2.21 COMPARISON OF KIRCHHOFF'S FIRST AND SECOND LAWS

1. While first law is in accordance with the law of conservation of charge, the second law is in accordance with the law of conservation of energy.
2. The first law is applicable to both open and closed circuits. The second law is applicable to closed circuit.
3. According to first law,  $\sum I = 0$ .  
According to second law,  $\sum \varepsilon = \sum IR$ .

**Example 14:** Use Kirchhoff's rules to determine the value of current  $I_1$  flowing in the circuit shown in the figure.

**Solution:** Using Kirchhoff's first law at junction E,

$$I_3 = I_1 + I_2 \quad \dots(i)$$

In loop ABCDA, using Kirchhoff's second law

$$80 - 20I_2 + 30 I_1 = 0 \quad \text{or} \quad 2I_2 - 3I_1 = 8 \quad \dots(ii)$$

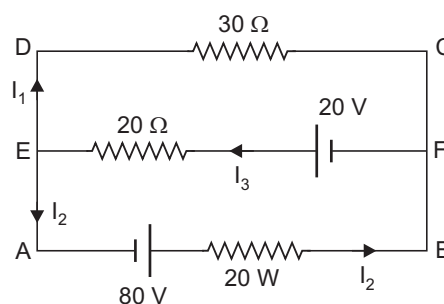


Fig. 2.18



In loop ABFEA, we get

$$80 - 20 I_2 + 20 - 20 I_3 = 0$$

$$\text{or} \quad I_2 + I_3 = 5 \quad \dots(iii)$$

Putting the value of  $I_3$  in (iii), we have

$$I_2 + (I_1 + I_2) = 5$$

$$\text{or} \quad 2I_2 + I_1 = 5 \quad \dots(iv)$$

Solving equations (ii) and (iv), we get

$$I_1 = -\frac{3}{4} \text{ A} = -0.75 \text{ A}$$

The negative sign indicates that the direction of current is opposite to that shown in the circuit diagram.

## 2.22 WHEATSTONE BRIDGE (Simple Application of Kirchhoff's Laws)

It is an arrangement of four resistances used for measuring one of them in terms of the other three. It was devised by Sir Charles F. Wheatstone, a British physicist in 1833. It is in his honour that the arrangement is known as Wheatstone bridge.

Fig. 2.19 represents Wheatstone's bridge circuit where P, Q, R and S are connected to form a mesh. A battery of emf  $\varepsilon$  is connected between the junctions A and C through a key  $K_B$  called the battery key. A galvanometer of resistance G is connected between the terminals B and D through a key  $K_G$  called galvanometer key. *It is always the battery key which is closed first and then the galvanometer key.*

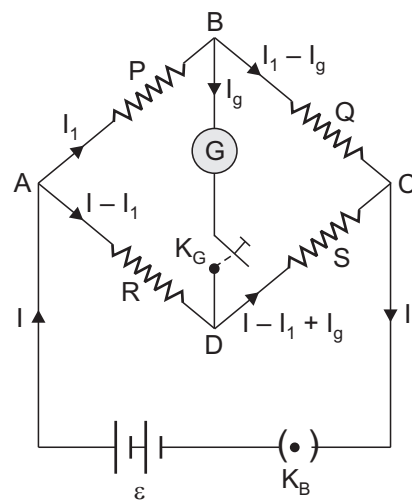
The currents through the various branches are indicated in Fig. 2.19. In order to reduce the number of unknowns at the outset, Kirchhoff's first rule is used at every junction.

Applying Kirchhoff's voltage law to the mesh ABDA, we get

$$-I_1 P - I_g G + (I - I_1) R = 0 \quad \dots(1)$$

Again, applying Kirchhoff's voltage law to the mesh BCDB, we get

$$-(I_1 - I_g) Q + (I - I_1 + I_g) S + I_g G = 0 \quad \dots(2)$$



**Fig. 2.19.** Wheatstone bridge



The resistances P, Q, R and S are so adjusted that the galvanometer gives zero deflection. This would be possible if B and D are at the same potential and therefore, no current would flow through the galvanometer i.e.,  $I_g = 0$ . In this situation, the Wheatstone bridge is said to be **balanced**.

Substituting  $I_g = 0$  in equations (1) and (2), we get

$$-I_1P + (I - I_1)R = 0 \quad \dots(3)$$

and

$$-I_1Q + (I - I_1)S = 0 \quad \dots(4)$$

Rewriting (3) and (4), we have

$$I_1P = (I - I_1)R \quad \text{and} \quad I_1Q = (I - I_1)S$$

Dividing,

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

This is the condition for the Wheatstone bridge to be balanced. Clearly, if three resistances are known, the fourth one can be calculated.

**Example 16:** The galvanometer, in each of the two given circuits, does not show any deflection. Find the ratio of the resistors  $R_1$  and  $R_2$ , used in these two circuits.

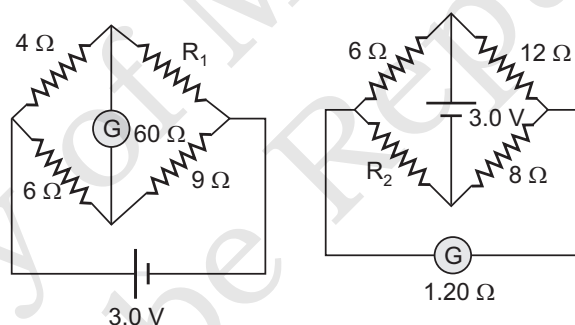


Fig. 2.20

**Solution:** For the first circuit, we have (from the Wheatstone bridge balance condition),

$$\frac{4}{R_1} = \frac{6}{9} \quad \text{or} \quad R_1 = 6 \, \Omega$$

For the second circuit, the interchange of the positions of the battery and the galvanometer does not change the Wheatstone bridge balance condition.

$$\therefore \frac{6}{12} = \frac{R_2}{8} \quad \text{or} \quad R_2 = 4 \, \Omega$$

$$\text{Now, } \frac{R_1}{R_2} = \frac{6}{4} = \frac{3}{2}$$

## 2.23 THERMAL EFFECT OF CURRENT AND JOULE'S LAW

**The heating of a conductor by the flow of an electric current through it is called Joule heating.** It is an irreversible process. If the direction of current in a resistor is reversed, the resistor would not be cooled. It would again show heating effect.

Joule's law of heating may be stated as follows :

The heat produced in a conductor due to flow of current in it is proportional to square of current, resistance of conductor and the time for which current flows.

In 1841, Joule stated that when a current  $I$  is made to flow through a passive or ohmic resistance  $R$  for time  $t$ , heat  $Q$  is produced such that

$$Q = I^2 R t$$

This equation is called **Joule's law of heating**. It is clear that the amount of heat developed in a passive resistance by the passage of steady electric current through it is proportional to

(i) the square of the electric current (ii) the resistance of conductor (iii) the time for which the current flows.

## 2.24 ELECTRICAL ENERGY AND POWER

(i) **Electrical energy** is the total work done by an electric current in a given time. It is equal to the total energy consumed in an electric circuit in a given time.

Consider a conductor AB through which a steady current  $I$  is flowing from A to B [Fig. 2.21]. Let  $V_A$  and  $V_B$  be the potentials at the ends A and B respectively of the conductor.

Since current flows from A to B,  $\therefore V_A > V_B$ .

The electrons move from B to A. They enter B at potential  $V_B$  and leave A at potential  $V_A$ .

The electric potential at a point is the potential energy per unit charge at that point.

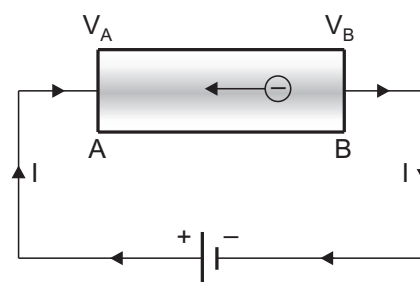


Fig. 2.21

Potential energy of an electron at B =  $(-e) V_B$

Potential energy of an electron at A =  $(-e) V_A$

Since  $V_A$  is greater than  $V_B$ , therefore, the electrons entering B possess more potential energy than those leaving A. But their kinetic energies are the same because their drift velocities are equal. So, the electrons lose potential energy while passing from B to A.

Let  $n$  be the number of electrons entering B and leaving A in time  $dt$ . If  $e$  be the charge on electron, then charge flowing through AB in time  $dt$ ,  $dq = ne$ .

$$\text{Current, } I = \frac{dq}{dt} = \frac{ne}{dt} \quad \text{or} \quad n = \frac{Idt}{e}$$

Loss in potential energy of electrons in time  $dt$ ,

$$dW = \frac{Idt}{e} [(-e) V_B - (-e) V_A] = Idt (V_A - V_B) = Idt V_{AB}$$

where  $V_{AB}$  is the potential difference between A and B.

This energy appears as heat energy. In general, if a current of  $I$  ampere flows through a wire of resistance  $R$  ohm for  $t$  second when the potential difference between the ends of the wire is  $V$  volt, then the electrical energy is given by :

$$W = VIt \text{ joule}$$

$$\text{But } V = IR \text{ (Ohm's law)}$$

$$\therefore W = I^2 R t \text{ joule}$$

1 calorie of heat is equivalent to 4.2 joule work. So, the heat  $Q$  produced in the wire is given by

$$Q = \frac{W}{4.2} = \frac{VIt}{4.2} \text{ cal} = \frac{I^2 R t}{4.2} \text{ cal} = \frac{V^2 t}{4.2 R} \text{ cal} = 0.238 I^2 R t \text{ cal}$$

$$\approx 0.24 I^2 R t \text{ cal}$$

which is Joule's law of heating.

(ii) **Electric power** is the rate at which work is done by an electric current.

The electric power of an appliance is the rate of consumption of electric energy.

Energy consumed in time  $t$ ,  $W = VIt$  joule

$$\text{Electric power, } P = \frac{W}{t} = \frac{VIt}{t} \text{ joule s}^{-1} \text{ or } W$$

or

$$P = VI$$

or

$$P = I^2 R$$

or

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

(iii) **Units of power.** If  $V$  is measured in volt and  $I$  in ampere, then  $P$  is measured in watt.

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

The power expended is said to be one watt when a current of one ampere flows under a potential difference of one volt.

A bigger unit of power is kilowatt.  $1 \text{ kW} = 1000 \text{ W}$

$$\text{Power in kilowatt} = \frac{V \text{ in volt} \times I \text{ in ampere}}{1000}$$

The power of an electrical appliance is generally expressed in kilowatt.

The engineering unit of power is 'horse power (hp)'.  $1 \text{ hp} = 746 \text{ W}$

(iv) **Commercial unit of electrical energy.** The commercial unit of electric energy is kilowatt hour or Board of Trade Unit (**kWh or B.O.T.U.**). It is defined as the amount of work done when a power of one kilowatt is consumed for one hour.

$$\begin{aligned} 1 \text{ kWh} &= 1 \text{ kW} \times 1 \text{ hour} \\ &= 1000 \text{ W} \times 3600 \text{ s} = 1000 \text{ J s}^{-1} \times 3600 \text{ s} \\ &= 3.6 \times 10^6 \text{ J} = 3.6 \times 10^{13} \text{ erg} \quad [\because 1 \text{ J} = 10^7 \text{ erg}] \end{aligned}$$

**Note.** The watt-hour-meter placed on the premises of every consumer records the electrical energy consumed.

## REVIEW EXERCISE

### A. MULTIPLE CHOICE QUESTIONS (MCQs)

- The mean free path of electrons in a metal is  $4 \times 10^{-8} \text{ m}$ . The electric field which can give on an average 2 eV energy to an electron in the metal will be in unit of  $\text{V m}^{-1}$   
 (a)  $8 \times 10^7$  (b)  $5 \times 10^{-11}$  (c)  $8 \times 10^{-11}$  (d)  $5 \times 10^7$
- A quantity  $X$  is given by  $\epsilon_0 L(\Delta V/\Delta t)$  where  $\epsilon_0$  is permittivity of free space,  $L$  is length,  $\Delta V$  is potential difference and  $\Delta t$  is time interval. The quantity  $X$  is same as  
 (a) resistance (b) charge (c) voltage (d) current

3. The temperature coefficient of resistance of the material of a wire is 0.001 per °C. Its resistance at 300 K is 1 ohm. At what temperature will the resistance of the wire be 2 ohm ?  
(a) 781 K (b) 1027 K (c) 1054 K (d) 1327 K
4. Dimensions of resistance in an electrical circuit, in terms of dimension of mass  $M$ , of length  $L$ , of time  $T$  and of current  $I$ , would be :  
(a)  $ML^2T^{-2}$  (b)  $ML^2T^{-1}I^{-1}$  (c)  $ML^2T^{-3}I^{-2}$  (d)  $ML^2T^{-3}I^{-1}$
5. Three resistors 1 W, 2 W and 3 W are connected to form a triangle. Across 3 W resistor, a 3 V battery is connected. The current through 3 W resistor is  
(a) 0.75 A (b) 1 A (c) 2 A (d) 1.5 A
6. The density of copper is  $9 \times 10^3 \text{ kg m}^{-3}$  and its atomic mass is 63.5 u. Each copper atom provides one free electron. Estimate the number of free electrons per cubic metre in copper.  
(a)  $10^{19}$  (b)  $10^{23}$  (c)  $10^{25}$  (d)  $10^{29}$
7. A colour coded carbon resistor has the colours orange, blue, green and silver. Its resistance value and tolerance percentage respectively are  
(a)  $36 \times 10^5 \text{ W}$  and 10% (b)  $36 \times 10^4 \text{ W}$  and 5%  
(c)  $63 \times 10^5 \text{ W}$  and 10% (d)  $35 \times 10^6 \text{ W}$  and 5%
8. The dimensions of 'resistance' are same as those of ..... where  $h$  is the Planck's constant,  $e$  is the charge.  
(a)  $\frac{h^2}{e^2}$  (b)  $\frac{h^2}{e}$  (c)  $\frac{h}{e^2}$  (d)  $\frac{h}{e}$
9. If a wire is stretched to make it 0.1% longer, its resistance will  
(a) increase by 0.05% (b) increase by 0.2%  
(c) decrease by 0.2% (d) decrease by 0.05%
10. If 400 W of resistance is made by adding four 100 W resistance of tolerance 5%, then the tolerance of the combination is  
(a) 20% (b) 5% (c) 10% (d) 15%
11. The resistance of a 10 m long wire is 10 W. Its length is increased by 25% by stretching the wire uniformly. Then the resistance of the wire will be  
(a) 12.5 W (b) 14.5 W (c) 15.6 W (d) 16.6 W  
(e) 18.6 W
12. Two identical conductors maintained at same temperature are given potential differences in the ratio 1 : 2. Then the ratio of their drift velocities is  
(a) 1 : 2 (b) 3 : 2 (c) 1 : 1 (d)  $1 : 2^{1/2}$

- 13.** A resistor has the following colour code, sequentially from the left:  
Black Brown Orange Red and Black.  
What is the resistance of the resistor ?  
(a) 13 Ohm (b) 1300 Ohm  
(c) 130 Ohm (d) 13000 Ohm.
- 14.** A coil has resistance 25.00 ohm and 25.17 ohm at 20°C and 35°C respectively. What is the temperature coefficient of resistance ?  
(a)  $4.545 \times 10^{-4}/^{\circ}\text{C}$  (b)  $4.545 \times 10^{-3}/^{\circ}\text{C}$   
(c)  $4.545 \times 10^{-2}/^{\circ}\text{C}$  (d)  $4.545 \times 10^{-5}/^{\circ}\text{C}$ .
- 15.** The number of electrons per second flowing through any cross-section of the wire carrying current of 1 ampere is  
(a)  $3.12 \times 10^{16}$  (b)  $1.6 \times 10^{18}$  (c)  $6.25 \times 10^{16}$  (d)  $3.12 \times 10^{18}$   
(e)  $6.25 \times 10^{18}$

## B. FILL IN THE BLANKS

- Two batteries of emfs 2 V and 1 V of internal resistances 1 W and 2 W respectively are connected in parallel. The effective emf of the combination is .....
- A battery of emf 8 V with internal resistance 0.5 W is being charged by a 120 V dc supply using a series resistance of 15.5 W. The terminal voltage of the battery is .....
- The resistances in the four arms of a Wheatstone network in cyclic order are 5  $\Omega$ , 2  $\Omega$ , 6  $\Omega$  and 15  $\Omega$ . If a current of 2.8 A enters the junction of 5  $\Omega$  and 15  $\Omega$ , then the current through 2  $\Omega$  resistor is .....
- A galvanometer connected with an unknown resistor and two identical cells in series each of emf 2 V shows a current of 1 A. If the cells are connected in parallel, it shows 0.8 A. Then the internal resistance of the cell is .....
- The percentage error in measuring resistance with a metre bridge can be minimised by adjusting the balancing point close to .....

## C. VERY SHORT ANSWER TYPE QUESTIONS

- The storage battery of a car has an emf of 12 V. If the internal resistance of the battery is 0.4  $\Omega$ , what is the maximum current that can be drawn from the battery ?
- A battery of emf 10 V and internal resistance 3  $\Omega$  is connected to a resistor. If the current in the circuit is 0.5 A, what is the resistance of the resistor ? What is the terminal voltage of the battery when the circuit is closed ?

3. At room temperature ( $27.0^{\circ}\text{C}$ ), the resistance of a heating element is  $100\ \Omega$ . What is the temperature of the element if the resistance is found to be  $117\ \Omega$ , given that the temperature coefficient of the material of the resistor is  $1.70 \times 10^{-4}\ ^{\circ}\text{C}^{-1}$ .
4. A silver wire has a resistance of  $2.1\ \Omega$  at  $27.5^{\circ}\text{C}$ , and a resistance of  $2.7\ \Omega$  at  $100^{\circ}\text{C}$ . Determine the temperature coefficient of resistance of silver.
5. A storage battery of emf  $8.0\ \text{V}$  and internal resistance  $0.5\ \Omega$  is being charged by a  $120\ \text{V}$  dc supply using a series resistor of  $15.5\ \Omega$ . What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit?

#### D. SHORT ANSWER TYPE QUESTIONS

1. (a) Three resistors  $1\ \Omega$ ,  $2\ \Omega$  and  $3\ \Omega$  are combined in series. What is the total resistance of the combination?  
 (b) If the combination is connected to a battery of emf  $12\ \text{V}$  and negligible internal resistance, obtain the potential drop across each resistor.

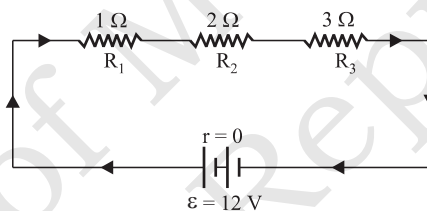


Fig. 2.22

2. In a potentiometer arrangement, a cell of emf  $1.25\ \text{V}$  gives a balance point at  $35.0\ \text{cm}$  length of the wire. If the cell is replaced by another cell and the balance point shifts to  $63.0\ \text{cm}$ , what is the emf of the second cell?
3. The number density of free electrons in a copper conductor is  $8.5 \times 10^{28}\ \text{m}^{-3}$ . How long does an electron take to drift from one end of a wire  $3.0\ \text{m}$  long to its other end? The area of cross-section of the wire is  $2.0 \times 10^{-6}\ \text{m}^2$  and it is carrying a current of  $3.0\ \text{A}$ .
4. A negligibly small current is passed through a wire of length  $15\ \text{m}$  and uniform cross-section  $6.0 \times 10^{-7}\ \text{m}^2$ , and its resistance is measured to be  $5.0\ \Omega$ . What is the resistivity of the material at the temperature of the experiment?
5. Two wires of equal length, one of aluminium and the other of copper, have the same resistance. Which of the two wires is lighter? Hence explain why aluminium wires are preferred for over-head power cables.



( $\rho_{\text{Al}} = 2.63 \times 10^{-8} \Omega \text{ m}$ ,  $\rho_{\text{Cu}} = 1.72 \times 10^{-8} \Omega \text{ m}$ , Relative density of Al = 2.7, of Cu = 8.9)

### E. LONG ANSWER TYPE QUESTIONS

- Two batteries, each of emf  $E$  and internal resistance  $r$ , are connected in parallel. The current from this combination is sent through an external resistance  $R$ . For what value of  $R$ , maximum power will be obtained? What will be this maximum power?

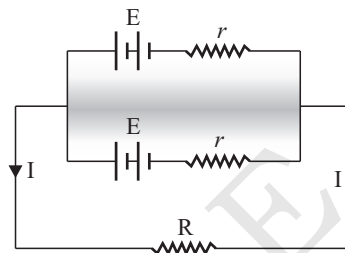


Fig. 2.23

- Three equal resistances, each of  $R$  ohm, are connected as shown in Fig. 2.24. A battery of emf 2 V and internal resistance  $0.1 \Omega$  is connected across the circuit. Calculate the value of  $R$  for which the heat generated in the circuit is maximum?

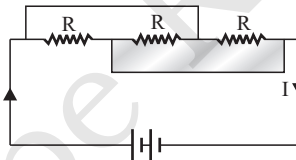


Fig. 2.24

- A heater is designed to operate with a power of 1000 W in a 100 volt line [Fig. 2.25]. It is connected to two resistances of  $10 \Omega$  and  $R \Omega$ . If the heater is now operating with a power of 62.5 W, calculate the value of  $R$ .

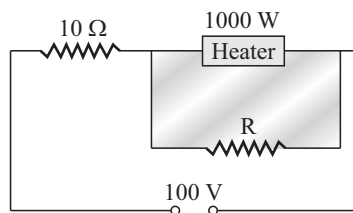


Fig. 2.25

4. Determine the current in each branch of the network shown in figure.

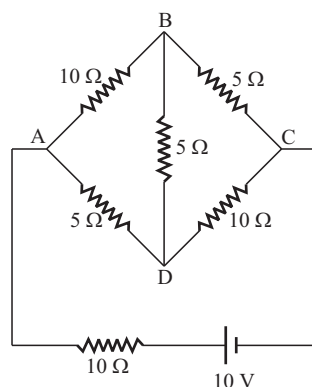


Fig. 2.26

5. (a) In a metre bridge shown the figure, the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of  $12.5\ \Omega$ . Determine the resistance of X. Why are the connections between resistors in a Wheatstone or metre bridge made of thick copper strips?
- (b) Determine the balance point of the bridge if X and Y are interchanged.
- (c) What happens if the galvanometer and cell are interchanged at the balance point of the bridge? Would the galvanometer show any current?

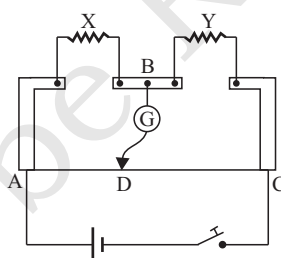


Fig. 2.27