Chapter 10

Current Electricity

Learning Objectives: After studying this chapter, the learner should be able to;

- **-describe electric current and types of current; AC and DC.**
- **-define resistance, combination of resistances; series and parallel.**
- **-state Ohm’s law, Kirchhoff’s law and their applications**

Electric current is the rate of flow of charge passing through a conductor.

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

where I = the electric current,q = charge,t = time taken

The direction of current is the **direction of flow of positive charge** i.e. opposite to the direction of flow of electron.

SI unit: Ampere (A)

$$1 \text{ ampere (A)} = \frac{1 coulomb}{1 sec}$$

One Ampere:

The current flowing through the conductor is said to be of one ampere if one coulomb of charge flows through the conductor in one second.

Potential Difference (V)

It is the difference in electric potential between two points in an electric circuit i.e. the work that has to be done in transferring unit positive charge from one point to other.

$$V = \frac{Work}{charge}$$

Unit: Volts (V)

One Volt:

It is defined as energy consumption of one joule per electric charge of one coulomb.

OHM'S LAW- It states that the current flowing through a conductor is always directly proportional to the potential difference between the two ends if the physical condition (temperature, pressure etc.) of the conductor remains constant".

$$V \alpha \ I$$

$$V = R I$$

where R is a constant and is called electric resistance.

The value of R depends upon

n**ature, dimension and temperature** of the conductor.

Thus, If a graph is drawn between current (I) and the potential difference (V) it will be a straight line for a conductor

RESISTANCE (R)

The opposition to the flow of electric current in an electric circuit is called resistance.

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

SI unit of R is ohms.

Symbol: Ohms (Ω)

One Ohm:

One ohm is the resistance of conductor in which a current of one ampere flows through it when the potential difference of one volt is maintained between its two ends.

Specific Resistance

The resistance of a conductor depends on following factors:

(i) The resistance of a given conductor is directly proportional to its length i.e. $R \propto l$ ....(1)

ii) The resistance of a given conductor is inversely proportional to its area of cross-section. $R \propto \frac{1}{A}$ ....(2)

By combining equation (1) and (2), we get

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

where ρ (rho) is a constant and known as specific resistance or resistivity of the material. The resistivity of a material does not depend on its length or thickness. It depends on the nature of the material.

If l = 1 m and A = 1 m^2 then from above equation

$$\rho = R$$

Thus resistivity of the material is the resistance of a conductor having unit length and unit area of cross- section.

Units: Ohm-m (Ωm)

Conductivity

It is the degree to which an object conducts electricity. This is the reciprocal of the resistivity,

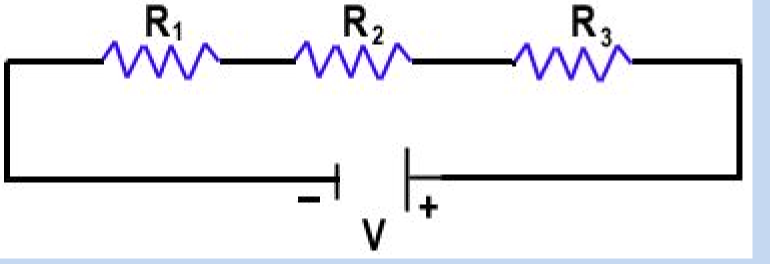
$$\sigma = \frac{1}{\rho}$$

Where, σ is the conductivity and ρ is the resistivity of the conductor.

Unit: Siemens per meter or mho per meter

Resistance in Series combination:

Resistances are connected in series when they are joined end to end so that the same quantity of electricity must flow through each resistance.



1. The total voltage drop is the sum of the individual voltage drops across individual resistances.
2. The current in each resistance is the same and is equal to current in circuit.

$$V = V_1 + V_2 + V_3$$

$$V = IR$$

$$V_1 = IR_{1,} V_2 = IR_{2,} V_3 = IR_3$$

$$IR = IR_1 + IR_2 + IR_3$$

$$R = R_1 + R_2 + R_3$$

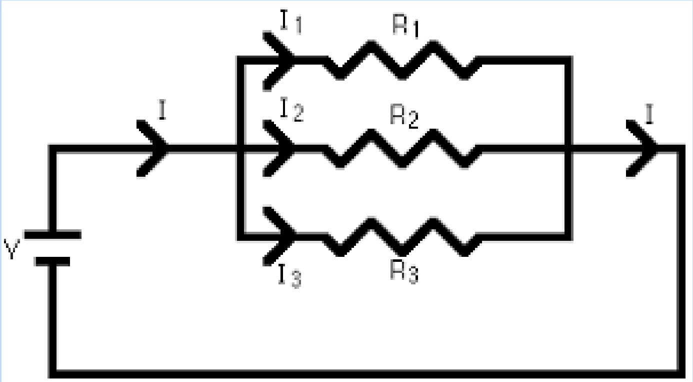
Conclusion: The total internal resistance of the battery is the sum of the individual internal resistances.

Resistance in Parallel combination:

Resistance are said to be connected in parallel when they are joined such that current is divided between the cells.

NOTE:

1. **The emf of the battery is the same as that of a single resistance**
2. **The current in the external circuit is divided equally among the resistances.**



$$I = I_1 + I_2 + I_3$$

$$I = \frac{V}{R}; I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, I_3 = \frac{V}{R_3}$$

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

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

Conclusion: The reciprocal of the total internal resistance is the sum of the reciprocals of the individual internal resistances.

THERMAL EFFECT OF CURRENT

Joule's Law:

When an electric current is passed through a conducting wire, the electrical energy is converted into heat energy. This effect is called 'heating effect of electric current'.

$$Q = I^2 R t$$

Q is in Joule, I in Amp, R in ohm and t in sec.

$$Q = \frac{I^2 R t}{J}$$

Q is in Calorie, I in Amp, R in ohm and t in sec.

Cause of Heating Effect of Current:

When a battery is connected to the ends of a conductor, electric field is set up. The free electrons move in the direction opposite to the field. They undergo collision with the positive ions and atoms of the conductor. The average kinetic energy of vibration of the ions and the atoms increases and hence the temperature increases.

Applications of Heating Effect of Current

The heating effect of current is used in various electrical heating appliances such as electric bulb, electric iron, room heaters, geysers, electric fuse etc

HEATING EFFECT OF ELECTRIC CURRENT

Derivation of Formula- To calculate the heat produced in a conductor, consider current I is flowing through a conductor of resistance R for time t. Also consider that the potential difference applied across its two ends is V.

Now, total amount of work done in moving a charge q from point A to point B is given by: $W = q \times V$ ------------------ (1)

Now, we know that charge = current x time

or $q = I \times t$

and $V = I \times R$ (Ohm's law)

Putting the values of q and V in equation (1), we get

$W = (I \times t) \times (I \times R)$ or $W = I^2Rt$

Now, assuming that all the work done is converted into heat energy we can replace symbol of 'work done' with that of 'heat produced'. So,

$H = W = I^2Rt$

Electric Power:

Electric power is the rate at which work is done by an electric current.

$P = V I$ $\quad$ $P = I^2 R$ $\quad$ $P = V^2 / R$

SI unit of power is ‘watt’.

Other units are ‘kW’ and ‘hp’.

1 kW = 1000 W $\quad$ 1 hp = 746 W

Electric Energy:

Electric energy is the total work done by an electric current in a given time.

$E = V I t$ $\quad$ $E = I^2 R t$ $\quad$ $E = V^2 t / R$

Commercial Unit of Electric Energy is kWh or B.O.T.U.

1 kWh = 3.6×10^6 Joule

Electric Fuse:

Electric fuse is a protective device used in series with an electric circuit or an electric appliance to save it from damage due to overheating produced by strong current in the circuit or appliance.

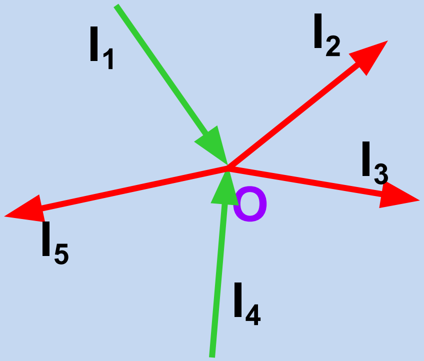
Fuse is generally made of alloy of 63% tin and 37% lead.

It has high resistance and low melting point.

KIRCHHOFF'S LAWS:

I Law or Current Law or Junction Rule:

The algebraic sum of electric currents at a junction in any electrical network is always zero.



$$I_1 - I_2 - I_3 + I_4 - I_5 = 0$$

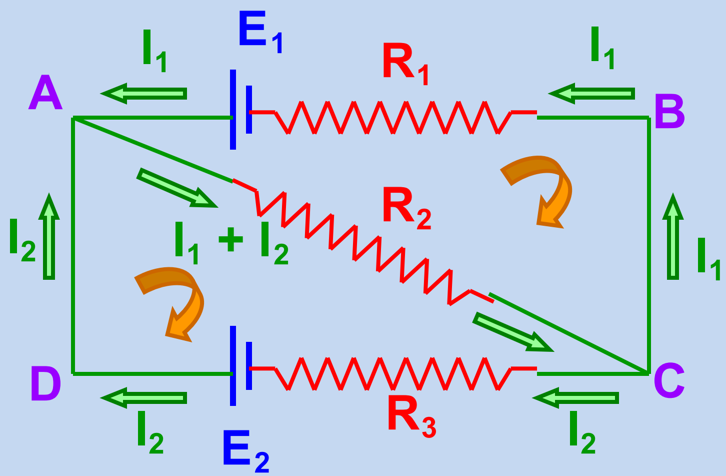
Sign Conventions:

1. **The incoming currents towards the junction are taken positive.**
2. **The outgoing currents away from the junction are taken negative.**

Note: The charges cannot accumulate at a junction. The number of charges that arrive at a junction in a given time must leave in the same time in accordance with conservation of charges.

II Law or Voltage Law or Loop Rule:

The algebraic sum of all the potential drops and emf's along any closed path in an electrical network is always zero.



Loop ABCA:

$$- E_1 + I_1.R_1 + (I_1 + I_2).R_2 = 0$$

Loop ACDA:

$$- (I_1 + I_2).R_2 - I_2.R_3 + E_2 = 0$$

Sign Conventions:

1. **The emf is taken negative when we traverse from positive to negative terminal of the cell through the electrolyte.**
2. **The emf is taken positive when we traverse from negative to positive terminal of the cell through the electrolyte.**

The potential falls along the direction of current in a current path and it rises along the direction opposite to the current path.

3. **The potential fall is taken negative.**
4. **The potential rise is taken positive.**

Note: The path can be traversed in clockwise or anticlockwise direction of the loop.

EXERCISE

Fill in the blanks

1) The resistance of the wire is inversely proportional to ....

2) The formula of Specific resistance of a wire is ....

3) Product of voltage and current is known as ....

4) SI unit of electric potential is ....

5) SI unit of resistance is ....

6) The reciprocal of Conductance is ....

7) SI unit of specific resistance is ....

Short answer question

1. What is Electric current?
2. Define Resistance.
3. Define Specific resistance.
4. What is Conductance?
5. Explain Alternating current and Direct current.
6. Explain ohm’s law.
7. Write short note on electric power.
8. Explain Kirchhoff laws.
9. If a wire is stretched to double of its length. What will be the new resistivity?