Current Electricity

Ohms Law, Circuits and Cells

Synopsis

1. Electric Current

a) Net charge flowing across the cross section of the conductor in one second is called electric current.

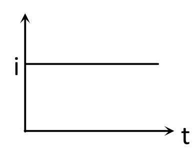
$i = Q / t$ or $Q = it$

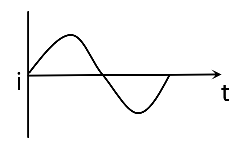
b) S.I. unit of current is ampere

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

c) The current flowing through a conductor is said to be one ampere when one coulomb of charge passes through it in one second.

d) If 6.25×10^{18} electrons pass across the cross-section of a conductor in one second, the strength of the current flowing across the conductor is one ampere.





2. Drift velocity (V_d)

a) The average velocity of the charge is called as Drift velocity (V_d).

b) Drift velocity is the average velocity and not instantaneous velocity of the charge.

$$i = AV_d \rho_c$$

Where A is area of cross section of the conductor; V_d is drift velocity; ρ_c is charge per unit volume.

$$i = AV_d ne$$

Where n is number of electrons per unit volume. Drift velocity per unit field is termed as **mobility** (μ).

$$\mu = \frac{V_d}{E}$$

3. Two terminologies are used for current regarding the direction of flow. They are

   i) **Electronic Current:** Here the direction of this current is taken as the direction in which the electrons are transferred.

   ii) **Conventional Current:** The direction of this current is taken as opposite to that of electronic current.

4. a) Free electrons are charge carriers in metals.

   b) Positive and negative ions are charge carriers in liquids.

   c) Positive ions and electrons are charge carriers in gases.

   d) Holes and electrons are charge carriers in semiconductors.

5. The current in different situations is calculated as follows:

   a) **Due to translatory motion of charge :** If n particles, each of charge q passes through a given area in time t seconds then **i** = $\frac{nq}{t}$

   b) **Due to rotatory motion of charge :** If a point charge q is moving in a circle of radius r with speed v, constant frequency f and time period T then **i** = $\frac{q}{t} = \frac{e}{T} = qf = \frac{qv}{2\pi r}$

6. AC and DC

   a) If the magnitude and direction of current does not vary with time. It is known as direct current DC.

   b) If a current is periodic i.e. magnitude varies periodically and polarity reverses after each half cycle, it is known as alternating current (AC).

7. **Ohm's law:** At constant temperature, the current (i) flowing through a conductor is directly proportional to the potential difference (V) between its ends.

   $V \alpha i$ or $V = iR$ where R is the electrical resistance of the conductor

   a) Ohm's law is not a universal law.

   b) Conductors which obey Ohm's law are called **ohmic** (or) **linear conductors**. **Ex**. metals.

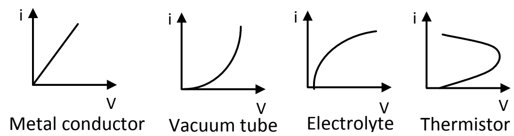
   c) The graph between V and I for ohmic conductor is straight line passing through the origin.

d) Conductors which do not obey Ohm's law are called **Non ohmic** (or) **Non linear conductors**.

Ex: Carbon compounds, electrolytes, transistors, diodes, semiconductors, discharge tubes, Thermionic valves, vacuum tubes.

e) The graph between V and i for non ohmic resistance is a curve

f)



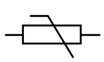
8. **Thermistor**

a) It is a thermal resistor.

b) It is a heat sensitive non ohmic device.

c) Made of semiconductor compounds as oxides of nickel, iron, cobalt and Cu.

d) It is enclosed in a capsule with an epoxy surface.

e) Symbol is   or

f) One type of thermistor has high positive temperature co-efficient (PTC) of resistance.

g) Another type of thermistor has high negative temperature co-efficient (NTC) of resistance.

h) (i) NTC thermistor is used as resistance thermometer for measuring low temperatures of the order of 10 K.

(ii) High resistance at low temperature makes it possible to measure low temperature very accurately.

i) Thermistors one in the form of beads, discs or rods to which a pair of platinum wires are provided at leads.

j) A tiny bead form thermistor serves as thermometer and can measure temperature changes of the order as small is 10^{-3} K.

k) Thermistor used in measuring the rate of energy (power) in a mino wave beam.

l) Thermistor used in radio circuits to avoid sudden and large surge of current.

m) Thermistor is used as thermostat.

9. **Resistance**

a) The property by virtue of which a conductor opposes the flow of charge in it is known as resistance.

b) It is measured as the ratio between potential difference between the ends of the conductor and current flowing in the conductor ⇒ R= V/i.

c) SI unit of resistance is Ohm.

1 ohm = 1 volt / 1 amp

d) Ohm is the resistance of a conductor through which a current of 1 ampere flows when the potential difference between its ends is 1 volt.

e) Dimensions formula R is $ML^2T^{-3}I^{-2}$.

f) For good conductors resistance is very low and for insulators or bad conductors it is high.

10. **Conductance**

a) The reciprocal of resistance is known as conductance ⇒ G = 1 /R.

b) SI unit of G is siemen (S) (or ohm^{-1} or mho)

c) Conductance decreases on increasing temperature

11. **Dependence of Resistance**

a) Resistance of a conductor is directly proportional to its length and inversely proportional to its area of cross section.

$R \propto \frac{\ell}{A} \Rightarrow R = S\frac{\ell}{A}$ or $\rho \frac{\ell}{A}$

Here S or ρ is known as resistance or specific resistance

$R = \frac{\rho\ell}{\pi r^2}$ Where r is radius of cross section.

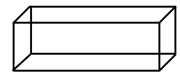
b) $R = \frac{\rho l}{A} = \frac{\rho l^2}{V} = \frac{\rho V}{A^2} = \frac{\rho m}{A^2 d} = \frac{\rho l^2 d}{m}$

c) Resistance does not depend on current and potential difference.

Through resistance of a linear conductor is independent of applied voltage, for a given body it is not unique and depends on length and area of cross section. (i.e. how the potential difference is applied)If ℓ,b, h denote length, breadth and thickness of a slab, (ℓ>b>h), $R_{max} = \frac{\rho\ell}{bh}$ and $R_{min} = \frac{\rho h}{\ell b}$

12. **Specific Resistance**

a) It is equal to resistance of the conductor of unit length and unit area of cross section.



b) R α $\frac{\ell}{A}$ or R= $\frac{s\ell}{A}$ or s = $\frac{RA}{\ell}$

c) S.I. unit : Ohm – meter

d) It depends only on the material of the conductor and temperature.

e) It is independent of dimensions of the conductor.

f) For silver and copper specific resistance is small

g) For Nichrome, constantan, Manganin it is large.

13. **Conductivity: (or) specific conductance (σ)**

a) It is reciprocal of resistivity. $\sigma = \frac{1}{s} = \frac{\ell}{RA}$

b) S.I unit : siemen / m

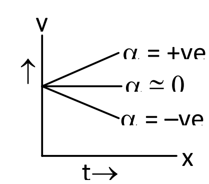
c) For insulators $\sigma = 0$

d) For perfect conductors, σ = infinity

14. **Temperature co-efficient of resistance (α)** :

a) It is defined as the change in specific resistance (or resistance) per 1°C rise of temperature to the original specific resistance (or resistance) at 0°C.

b) $\alpha = \frac{\rho_t - \rho_0}{\rho_0 t}$



c) $\alpha = \frac{R_t - R_0}{R_0 t}$

c) $\rho_t = \rho_0(1 + \alpha\Delta t)$ … (1)

d) $R_t = R_0 (1 + \alpha\Delta t)$ … (2)

ρ_0 and R_0 are the specific resistance and resistance at 0°C,

ρ_t and R_t are the corresponding values at t° C

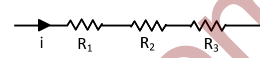
.e If R_1 and R_2 are resistances at t_1°C and t_2°C then

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

f) For small temperature variation, $\rho_T = \rho_{T_o}[1 + \alpha(T - T_o)]$ where ρ_{T_o} and ρ_T are the resistivities at temperatures T_o and T respectively and α is a constant for a given material and is called the temperature coefficient of resistivity.

$$\alpha = \frac{1}{\rho} \cdot \frac{d\rho}{dT}$$

15. **Series Connection**



i) Current is the same through all the resistors

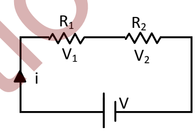
ii) Total p.d. = sum of individual p.d.s across each resistor.

iii) Individual p.d. is directly proportional to individual resistor.

iv) Total resistance is greater than the greatest individual resistance.

v) Total resistance = sum of the individual resistances.

$R = R_1 + R_2 + R_3 + \ldots\ldots.$



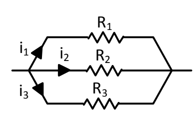
vi) Two resistances in series:

a) The total resistance $R_S = R_1 + R_2$ b) $V_1 = \frac{VR_1}{R_1 + R_2}$

c) $V_2 = \frac{VR_2}{R_1 + R_2}$ d) $i = \frac{V_1}{R_1} = \frac{V_2}{R_2}$

vii) A **conductor and Semi conductor** are connected in series. If the resistance of the combination is same at all temperatures then $R_1 \alpha_1 = R_2 \alpha_2$ where R_1, R_2 are resistances of conductor and semi conductor.

16. **Parallel Connection**



i) Potential difference remains the same across each resistor.

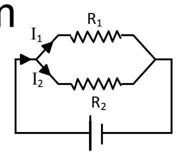
ii) Total current=sum of the individual currents.

iii) Individual currents are inversely proportional to the individual resistances.

iv) Effective resistance is less than the least individual resistance.

v) When a number of conductors are connected in parallel, the reciprocal value of the resultant resistance is equal to the sum of the reciprocal values of the individual resistances.

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



vi) Two resistances in parallel

a) The total resistance $R_P = \frac{R_1R_2}{R_1+R_2}$

b) $I_1 = \frac{IR_2}{R_1+R_2}$

c) $I_2 = \frac{IR_1}{R_1+R_2}$; $V = I_1R_1 = I_2R_2$

If R_S and R_P be the resultant resistance of resistances R_1 and R_2, when connected in series and parallel then

$R_1 = \frac{1}{2}\left(R_S + \sqrt{R_S^2 - 4R_SR_P}\right)$ $R_2 = \frac{1}{2}\left(R_S + \sqrt{R_S^2 - 4R_SR_P}\right)$

If n equal resistances each of resistance R are connected to form triangle (or) Square (or) Polygon then effective resistance between any two adjacent corners is $R^1 = \left(\frac{n-1}{n}\right)R$.

When twelve identical resistors each of resistance R Ω are connected in the form of a skeleton cube, the effective resistance across

(i) the ends of a side is (7r/12)Ω,

(ii) the opposite vertices on the same face is (3r/4)Ω and

(iii) the diagonally opposite vertices is (5r/6)Ω̃

17. **Electrical power**

The rate at which work is done in maintaining the current in electric circuit

Electrical power

$P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}$ watt (or) joule / sec

18. **Electrical Energy**

The electric energy consumed in a circuit is defined as the total work done in maintaining the current in an electric circuit for a given time.

Electrical Energy = Vt = Pt = $I^2Rt = \frac{V^2t}{R}$

S.I. unit of electric energy is joule

Where

1 Joule=1watt× 1 sec = 1 volt × ampere × 1 sec

$1 Kwh = 1000 Wh = 3.6 \times 10^6 J$

19. Bulbs connected in Series

If Bulbs (or electrical appliances) are connected in series, the current through each resistance is same. Then power of the electrical appliance $P \propto R$ & $V \propto R \left[\because P = i^2Rt\right]$

i.e. In series combination; the potential difference and power consumed will be more in larger resistance.

When the appliances of power are in series, the effective power consumed (P) is $\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + ...$ i.e. effective power is less than the power of individual appliance.

If 'n' appliances, each of equal resistance 'R' are connected in series with a voltage source 'V', the power dissipated 'Ps' will be $Ps = \frac{V^2}{nR}$.

20. **Bulbs connected in parallel**

1) If Bulbs (or electrical appliances) are connected in parallel, the potential difference across each resistance is same. Then $P \propto \frac{1}{R}$ and $I \propto \frac{1}{R}$.

i.e. The current and power consumed will be more in smaller resistance.

When the appliances of power $P_1, P_2, P_3....$ are in parallel, the effective power consumed (P) is $P = P_1 + P_2 + P_3 + ...$

i.e. the effective power of various electrical appliance is more than the power of individual appliance.

If 'n' appliances, each of resistance 'R' are connected in parallel with a voltage source 'V', the power dissipated 'Pp' will be

$$P_P = \frac{V^2}{(R/n)} = \frac{nV^2}{R}$$

$$\frac{P_P}{P_S} = n^2 \text{ (or) } P_P = n^2 P_S$$

This shows that power consumed by 'n' equal resistances in parallel is n^2 times that of power consumed in series if voltage remains same.

In parallel grouping of bulbs across a given sources of voltage, the bulb of greater wattage will give more brightness and will allow more current through it, but will have lesser resistance and same potential difference across it.

For a given voltage V, if resistance is changed from 'R' to $\left(\frac{R}{n}\right)$, power consumed changes from 'P' to 'nP' $P = \frac{V^2}{R}$ where $R' = \frac{R}{n}$, then $P' = \frac{V^2}{(R/n)} = \frac{nV^2}{R} = np$.

Filament of lower wattage bulb is thinner that of higher wattage bulb i.e. filament of 60 watt bulb is higher than that of 100 watt bulb.

If 'I' is the current through the fuse wire of length 'l', radius 'r', specific resistance 'P' and 'Q' is the rate of loss of heat per unit area of a fuse wire, then at steady state,

$I^2R = QA$ Or $\frac{I^2P\ell}{\pi r^2} = Q \times 2\pi r \times \ell$

$I^2 = \frac{2\pi^2 Q}{P} r^3 \Rightarrow I \propto r^{3/2}$

Hence current capacity of a fuse is independent of its length and various with its radius as.

If t_1, t_2 are the time taken by two different coils for producing same heat with same supply, then

If they are connected in series to produce same heat, time taken $t = t_1 + t_2$

If they are connected in parallel to produce same heat, time taken is $t = \frac{t_1 t_2}{t_1 + t_2}$.