# CURRENT ELECTRICITY

## 1. State and explain Ohm's law

This law states that, ***the current flowing through a conductor is directly proportional to the potential difference between the ends of the conductor. Provided temperature and other physical conditions of the conductor remaining constant***"

$$I \propto V$$

$$I = \frac{1}{R} V$$

$$\boldsymbol{V = IR}$$

## 2. Define (a) Drift velocity (b) Mobility of electrons

**Drift velocity:** The average velocity with which free electrons get drifted towards the positive end of conductor under the influence of an external electric field is called drift velocity.

**Mobility:** It is defined as the ratio of magnitude of drift velocity per unit electric field.

$$\mu = \frac{|v_d|}{E}$$

## 3. Derive an expression for Drift velocity in terms of electric field and relaxation time.

The average velocity of the electrons due to *random motion in the conductor* will be zero.

This velocity is given by $u_{av} = 0$

When a potential difference V is applied between the ends of the conductor, it produces an electric field E.

It exerts force on the electron in the opposite direction, therefore electron accelerates in the opposite direction. $a = \frac{-F}{m} = \frac{-eE}{m}$

And The average time between successive collisions is denoted by $\tau$ and is given by

$$t_{av} = \tau = \frac{t_1+t_2+t_3+\cdots t_N}{N}$$

Consider, v = u + at

$$V_d = 0 + \frac{-eE}{m}\,.\,\tau$$

$$\therefore\ \boldsymbol{v_d = -\frac{eE}{m}\tau}$$ → This is the expression for drift velocity.

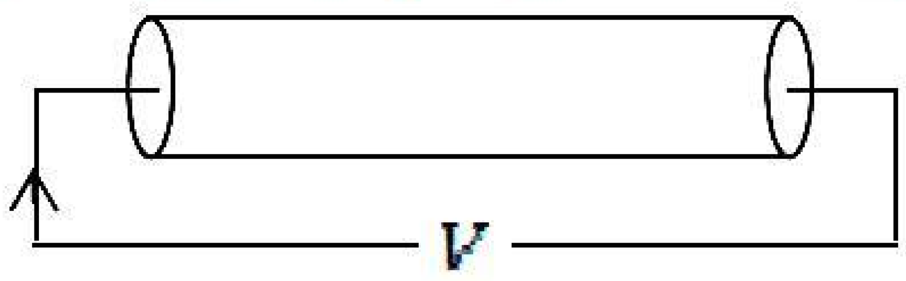
## 4. Write the Limitations of Ohm's law

The limitations of Ohm's law are

1) The variation between Current and Potential difference is non linear.
2) The relation between Current and Potential difference is non unique.
3) Ohm's law is not applicable for semiconductors.

## 5. Derive the vector form of ohm's law $\vec{j} = \sigma\,\vec{E}$

## Or Derive an expression for equivalent form of Ohm's law.




Let I be the current in the conductor due to the potential difference $V$ across the conductor, then according to ohm's law

$$V = IR \ \ldots\ldots\ldots\ldots\text{(i)}$$

The electric field $E$ produced in the conductor is given by

$$E = \frac{V}{L}$$

$$\therefore V = EL \ \ldots\ldots\ldots\ldots\text{(ii)}$$

From (i) and (ii) we get

$$EL = IR$$

$$EL = I \times \rho\frac{L}{A} \qquad (R = \rho\frac{L}{A})$$

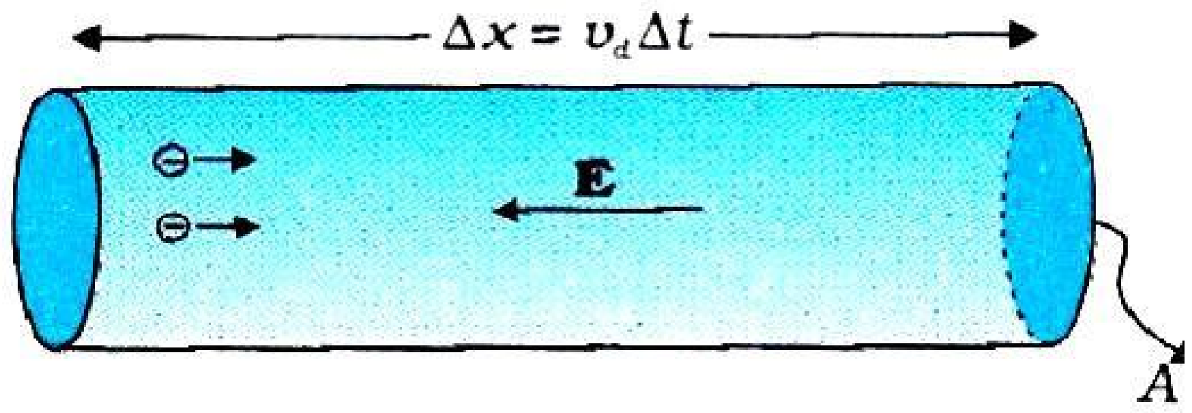
$$EL = \rho JL \qquad (\frac{I}{A} = J)$$

$$E = \rho J$$

$$J = \frac{E}{\rho} \qquad (\frac{1}{\rho} = \sigma)$$

$\vec{J} = \boldsymbol{\sigma}\vec{\boldsymbol{E}}$ → **This is the vector form of ohm's law.**

## 6. Obtain an Expression for conductivity ($\boldsymbol{\sigma = \frac{ne^2\tau}{m}}$) of a conductor.




The expression for current in the conductor is given by

$$I = nAev_d \qquad \text{but } v_d = \frac{e\tau}{m}E$$

$$I = nAe\frac{e\tau}{m}E \qquad \text{by defn., } \frac{I}{A} = J$$

$$\frac{I}{A} = \frac{ne^2\tau}{m}E$$

$$|J| = \frac{ne^2\tau}{m}|E| \qquad \text{As } J \text{ is parallel to } E$$

$$J = \frac{ne^2\tau}{m}E \qquad \text{but } J = \sigma E$$

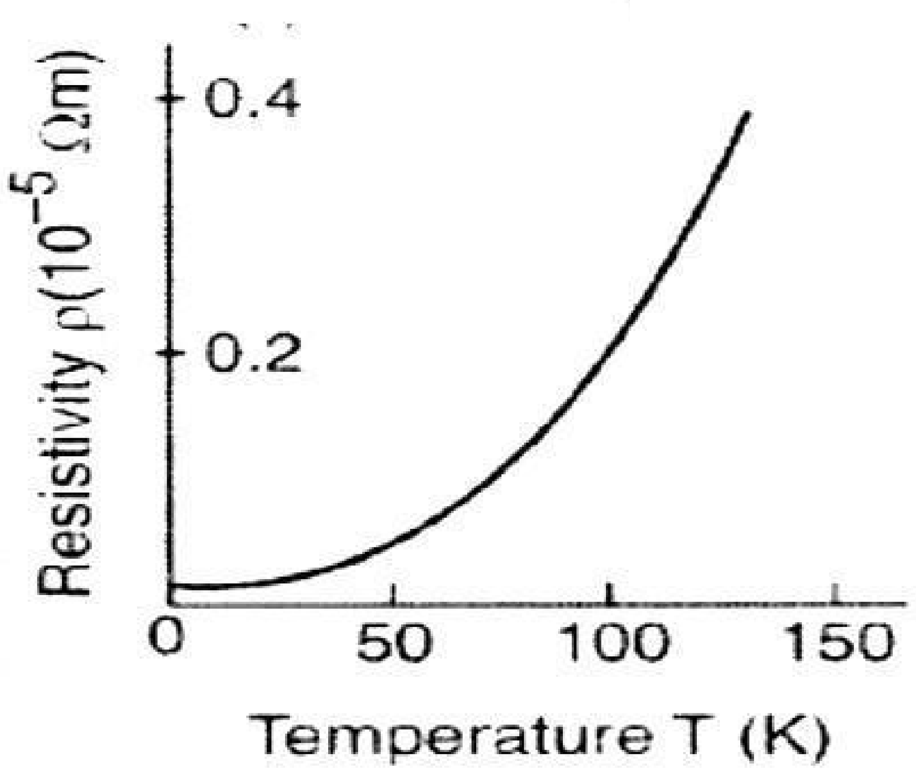
$$\sigma E = \frac{ne^2\tau}{m}E$$

$$\boldsymbol{\sigma} = \frac{\boldsymbol{ne^2\tau}}{\boldsymbol{m}}$$ → This is the **expression for conductivity**

**7. Draw the graph for temperature dependence of Resistivity of (a) metals and (b) semiconductors** (c) Nichrome

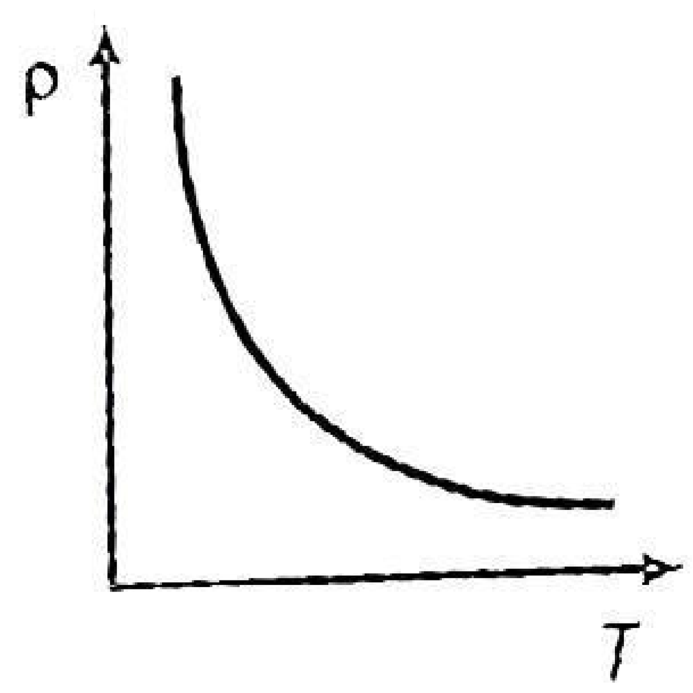
**1) In Metals:** Resistivity is directly proportional to temperature

**i.e.** $\rho\ \alpha\ T$

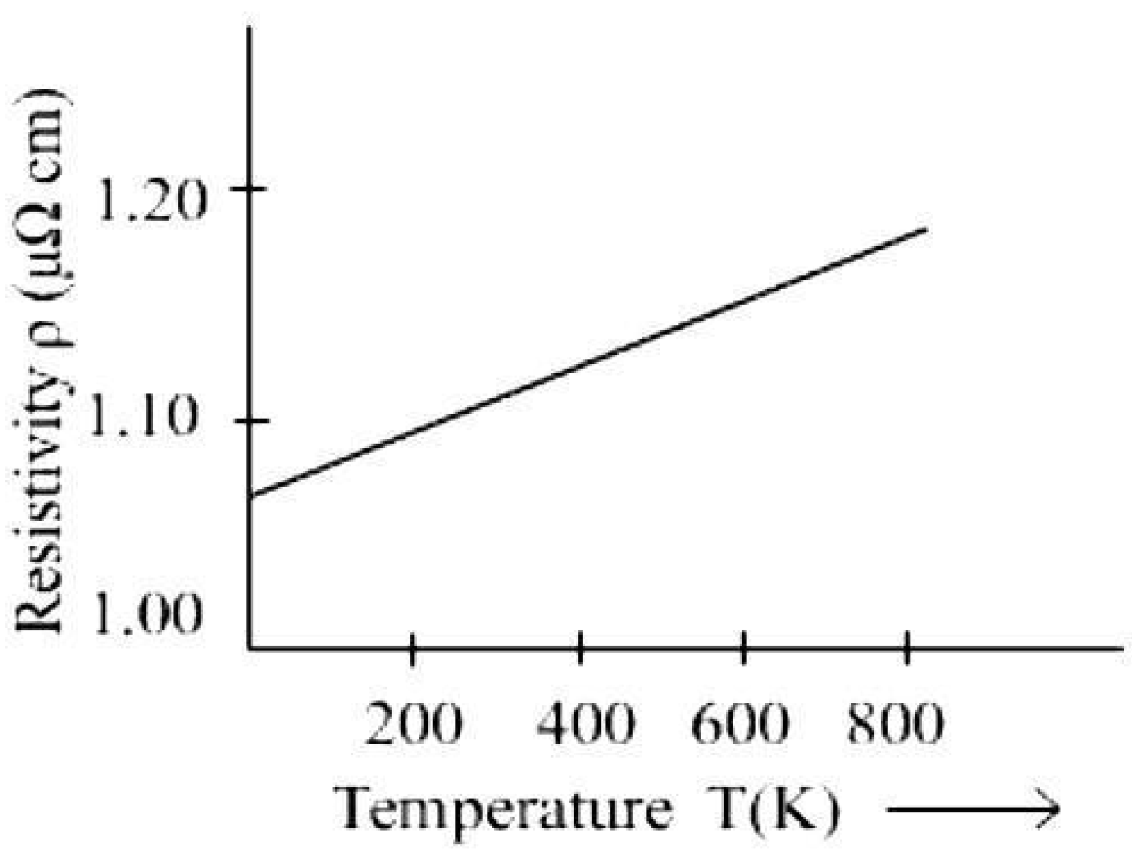



**2) In semiconductors :** Resistivity is inversely proportional to temperature

**i.e.** $\rho\ \alpha\ \frac{1}{T}$




**3) Nichrome :**



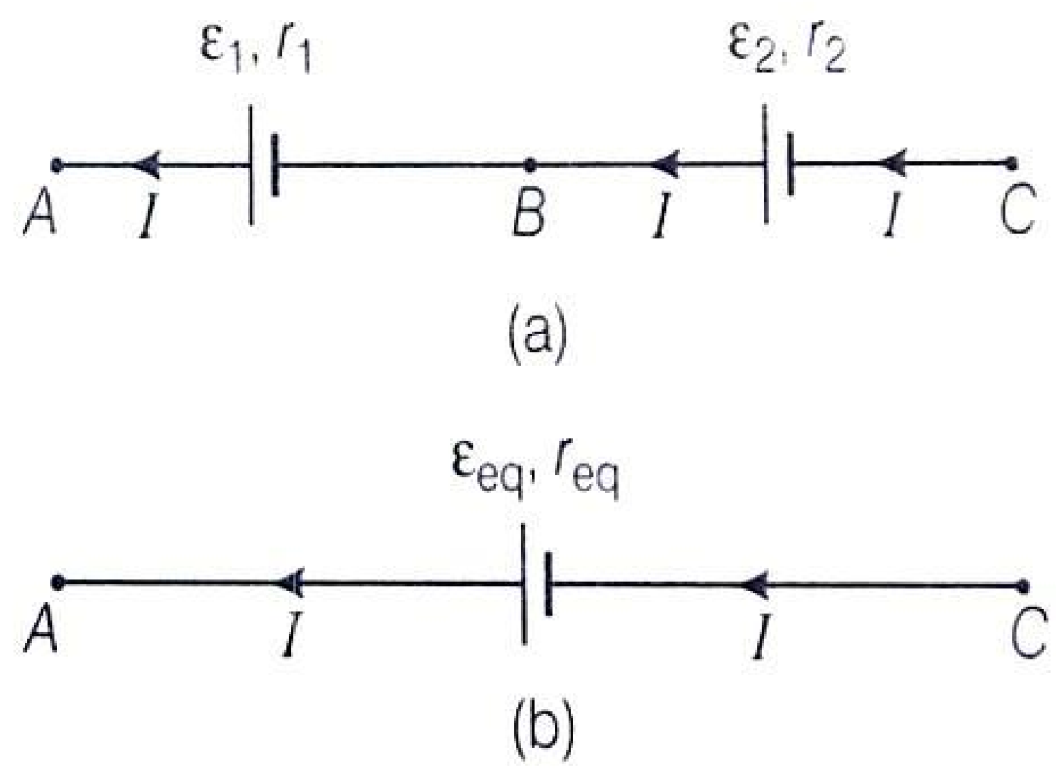
## 8. Obtain an expression for effective emf and internal resistance of Cells connected in series:

The terminal potential of cell $E_1$ is $V_1 = E_1 - I\gamma_1$

The terminal potential of cell $E_2$ is $V_2 = E_2 - I\gamma_2$

The terminal potential of the combination

$$V_{eff} = V_1 + V_2 = E_1 - I\gamma_1 + E_2 - I\gamma_2$$
$$= E_1 + E_2 - I(\gamma_1 + \gamma_2)$$




$$V_{eff} = E_1 + E_2 - I[\gamma_1 + \gamma_2] \quad \text{----- (1)}$$

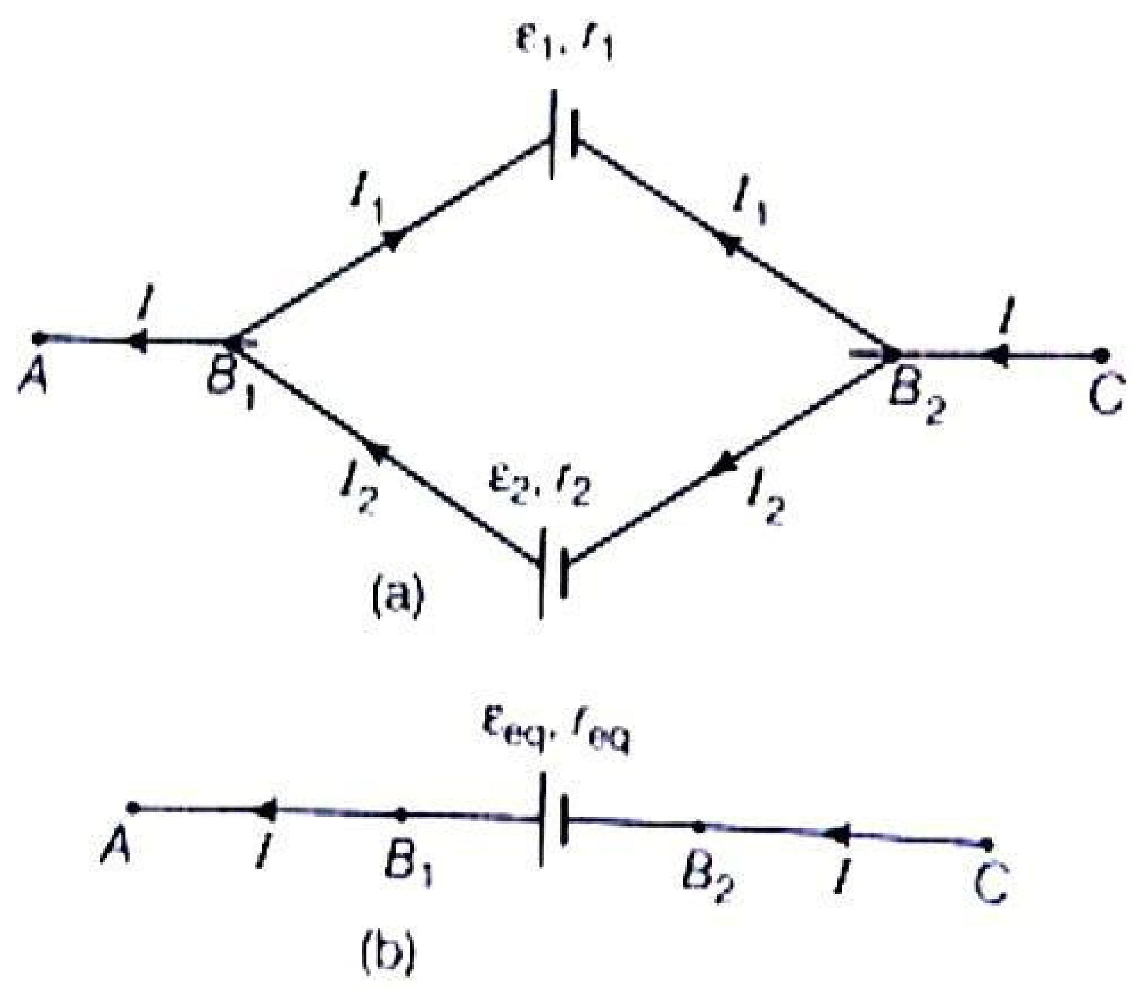
For the combination we have

$$V_{eff} = E_{eff} - I\gamma_{eff} \quad \text{------- (2)}$$

Comparing equations (1) and (2), we get.

$$E_{eff} = E_1 + E_2 \text{ and } \gamma_{eff} = \gamma_1 + \gamma_2$$

## 9. Obtain an expression for effective emf and internal resistance Cell in parallel.




Potential difference across cell $E_1$ is $V_1 = E_1 - I_1r_1$

Potential difference across cell $E_2$ is $V_2 = E_2 - I_2r_2$

$$I_1 = \frac{E_1 - V_1}{r_1} = \frac{E_1 - V}{r_1} \qquad (\because V_1 = V_2 = V)$$

|||$^{ly}$ $$I_2 = \frac{E_2 - V}{r_2}$$

Main current in the circuit is given by

$$I = I_1 + I_2$$

$$I = \frac{E_1}{r_1} - \frac{V}{r_1} + \frac{E_2}{r_2} - \frac{V}{r_2}$$

$$I = \frac{E_1}{r_1} + \frac{E_2}{r_2} - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

$$I = \frac{E_1r_2 + E_2r_1}{r_1r_2} - V\left(\frac{r_1 + r_2}{r_1r_2}\right)$$

$$V\left(\frac{r_1 + r_2}{r_1r_2}\right) = \frac{E_1r_2 + E_2r_1}{r_1r_2} - I$$

$$V = \frac{E_1r_2 + E_2r_1}{r_1 + r_2} - I\left[\frac{r_1r_2}{r_1 + r_2}\right] \quad \text{----- (1)}$$

For the combination we have

$$V = E_{eff} - I\,r_{eff}. \quad \text{------ (2)}$$

Comparing equations (1) and (2) we get

$$E_{eff} = \frac{E_1r_2 + E_2r_1}{r_1 + r_2} \text{ and } r_{eff} = \frac{r_1r_2}{r_1 + r_2}$$

## 10. State Kirchhoff's laws (or rules).

**Junction rule:** In any electrical network, the algebraic sum of the currents at a junction is zero. **i.e.** $\sum \mathbf{I} = \mathbf{0}$.

Significance of Kirchhoff's I law is **law of conservation of charge.**

**Loop rule**: In any closed loop, the algebraic sum of the e.m.f is equal to the algebraic sum of product of currents and resistances in that mesh.

$$\sum \mathbf{E} = \sum \mathbf{IR}.$$

Significance of Kirchhoff's II law is ' **law of conservation of energy'**.

**11. Applications of Potentiometer:**

1) It is used to verify the emf of the two different cells
2) It is used to find the internal resistance of the given cell.