CURRENT ELECTRICITY

PHYSICS - VOL 1 **UNIT - 2**

NAME :

STANDARD : 12 SECTION :

SCHOOL :

EXAM NO :

எண்ணென்ப ஏனை எழுத்தென்ப இவ்விரண்டும்
கண்ணென்ப வாழும் உயிர்க்கு

எண் என்று சொல்லப்படுவதும், எழுத்து என்று கூறப்படுவதும் ஆகிய இவை இரண்டும் இவ்வுலகில் வாழும் உயிர்களுக்கும் கண் என்பார்கள்

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PART - II 2 MARK QUESTIONS & ANSWERS

1. **Define current electricity.**
   - The branch of physics deals with moving charges is called current electricity.
2. **Define electric current.**
   - The electric current in a conductor is defined as the rate of flow of charges through a given cross - sectional area.

$$I = \frac{Q}{t} \qquad (or) \qquad i = \frac{dQ}{dt}$$

   - The S. I unit of current is ***ampere (A).***
   - It is a scalar quantity.
3. **Define one ampere (1 A)**
   - One ampere of current is equivalent to 1 coulomb of charge passing through a perpendicular cross section in 1 second. [$\mathbf{1\,A = 1\,C\,s^{-1}}$]
4. **What is called conventional current?**
   - By convention, this flow in the circuit should be from the positive terminal of the battery to the negative terminal. This is called the conventional current or simply current.
   - It is in the direction in which a positive test charge would move.
5. **What are called free electrons and positive ions?**
   - Any material is made up of neutral atoms with equal number of electrons and protons. If the outermost electrons leave the atoms, they become free electrons and are responsible for electric current.
   - The atoms after losing their outer most electrons will have more positive charges and hence are called positive ions. They will not move freely and hence the positive ions will not give rise to current.
6. **Define drift velocity.**
   - The average velocity acquired by the free electrons inside the conductor when it is subjected to an electric field is called drift velocity ($\vec{v}_d$). Its unit is $\boldsymbol{m\,s^{-1}}$
7. **Define mobility.**
   - The magnitude of drift velocity acquired by the free electrons per unit electric field is called mobility (μ). Its unit is $\boldsymbol{m^2\,V^{-1}s^{-1}}$
8. **Define current density.**
   - Current density (J) is defined as the current per unit area of cross section of the conductor.

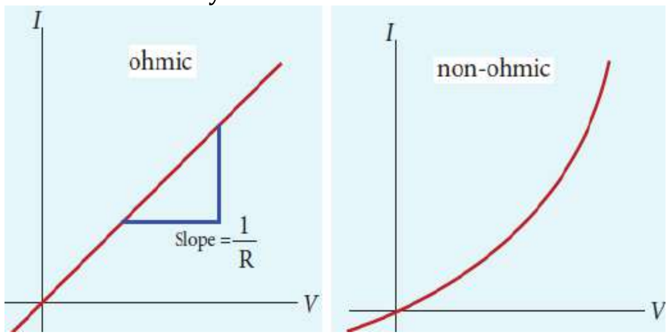
$$J = \frac{I}{A}$$

   - Its unit is $\boldsymbol{A\,m^{-2}}$
9. **Give the microscopic form of Ohm's law.**
   - The current density is given by,

$$\vec{J} = n\,e\,\vec{v}_d = n\,e\left[\frac{e\,\tau}{m}\,\vec{E}\right] = \frac{n\,e^2\,\tau}{m}\,\vec{E}$$

$$(or) \quad \vec{\boldsymbol{J}} = \boldsymbol{\sigma}\,\vec{\boldsymbol{E}}$$

   - Thus Currnt density is directly proportional to the applied electric field. This is known as microscopic form of Ohm's law.
10. **Current is a scalar quantity. Why?**
   - Current is defined as the scalar product of current density ($\vec{J}$) and area vector ($\vec{A}$) in which charges crosses. (i.e.) $\mathbf{I} = \vec{\boldsymbol{J}}\,.\,\vec{\boldsymbol{A}} = \boldsymbol{J\,A\cos\theta}$
   - The current can be positive or negative depending on the choice of unit vector normal to the surface area A.
11. **Give the macroscopic form of Ohm's law.**
   - Let 'V' be the potential difference, 'I' be the current and 'R' be the resistance, then the macroscopic form of Ohm's law is **V = I R**
12. **What are called ohmic and non ohmic materials?**
   - Materials for which the current against voltage graph is a straight line through the orgin are said to obey Ohm's law and they are called ohmic materials.
   - But materials for which the current against voltage graph is non - linear and they do not have a constant resistance are called non - ohmic. They do not obey Ohm's law.



13. **Define resistance of the conductor.**
   - The ratio of potential difference (V) across the given conductor to the current (I) passing through the conductor is called resistance (R).

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

   - Its unit is ***ohm (Ω)***
14. **What are the factors that the resistance depend on?**
   - The resistance of the conductor is,
     1) directly proportional to its length (l)
     2) inversely proportional to its area of cross section (A)

$$\boldsymbol{R = \frac{l}{\sigma A} = \frac{\rho\,l}{A}}$$

where, $\boldsymbol{\sigma}$ → conductivity of the conductor
$\boldsymbol{\rho}$ → resistivity of the conductor

15. **Define resistivity of the material.**
   - The electrical resistivity of a material is defined as the resistance offered to current flow by a conductor of unit length having unit area of cross section.

$$\boldsymbol{\rho = \frac{1}{\sigma} = \frac{R\,A}{l}}$$

   - Its unit is ***ohm - metre (Ω m)***
   - It depends only the type of material and not the dimension of the material.
16. **Define conductivity of the material.**
   - The reciprocal of resistivity is called conductivity and it is given by,

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

   - Its unit is ***mho- metre^{-1} (Ω^{-1} m^{-1})***
   - It depends only the type of material and not the dimension of the material.
17. **Reparing the electrical connection with the wet skin is always dangerous. Why?**
   - The humam body contains a large amount of water which has low resistance of around 200 Ω and the dry skin has high resistance of 500 k Ω.
   - But when the skin is wet, the resistance is reduced to 1000 Ω.
   - By Ohm's law $\left[R = \frac{V}{I}\right]$ if resistance decreses, current increases. Hence reparing electric connection with wet skin is dangerous.

18. Define temperature coefficient of resistivity.

- It is defined as the ratio of increase in resistivity per degree rise in temperature to its resistivity at T_o . Its unit is ***per*** °C

19. Define Superconductivity.

- The resistance of certain material become zero below certain temperature called critical or transition temperature (T_C)
- For mercury, T_C = 4.2 K
- The materials which exhibit this property are known as super conductors.
- The property of conducting current with zero resistance is called super conductivity.
- It is discovered by Kammerlingh Onnes.

20. Distinguish electric energy and electric power.

Electric energy	Electric power
1) Work has to be done to move the charge from one end to other end of the conductor and this workdone is called electric energy. $\boldsymbol{dW = dU = V\,dQ}$	1) The rate at which the electrical potential energy is delivered is called electric power. $\boldsymbol{P = \frac{dU}{dt} = V\,I}$
2) Its S.I unit is ***joule (J)***	2) Its S.I unit is ***watt (W)***
3) Its practical unit is kilowatt hour (kWh) $1\,kWh = 3.6\,X\,10^6\,J$	3) Its practical unit is horse power (H P) $1\,H\,P = 746\,W$

21. Prove that the expression for power in an electrical circuit is $\boldsymbol{P = V\,I}$

- Electric energy is given by, $dU = V\,dQ$
- By definition, the rate at which electric potential energy is delivered is called power. (i.e)

$$P = \frac{dU}{dt} = \frac{d\,(V\,dQ)}{dt} = V\,\frac{dQ}{dt}$$

- But $\frac{dQ}{dt} = \boldsymbol{I} \rightarrow$ electric current

$$\therefore \quad \boldsymbol{P = V\,I}$$

22. Write down the various equations for power.

- The electric power is given by,

$$\boldsymbol{P = V\,I}$$

- By Ohm's law, $V = I\,R$ and hence

$$\boldsymbol{P = I^2\,R}$$

- Also, $I = V/\,R$ and hence,

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

23. What is called electric cell (battery) ?

- An electric cell is a device which converts chemical energy in to electrical energy to produce electricity.
- It contains two electrods (anode and cathode) immersed in an electrolyte.

24. Define electromotive force.

- The amount of work a battery or cell does to move a certain amout of charge around the circuit is called as electromotive force (ξ). Its unit is ***volt (V)***
- The emf of a battery or a cell is the voltage provided by the battery when no current flows in the external circuit.

25. Define the internal resistance of the cell.

- A real battery is made of electrodes and electrolyte.
- There is resistance to the flow of charges within the battery and this resistance is called internal resistance (r)
- A freshly prepared cell has low internal resistance and it increased with ageing.

26. State Kirchoff's first law (current rule or junction rule)

- It states that the algebraic sum of currents at any junction in a circuit is zero ($\sum I\ = 0$).
- It is a statement of conservation of electric charge.

27. State Kirchoff's second law (voltage rule or loop rule)

- It states that in a closed circuit the algebraic sum of the products of the current and reistance of each part of the circuit is equal to the total emf included in the circuit ($\sum \boldsymbol{I\,R} = \sum \boldsymbol{\varepsilon}$).
- It is a statement of conservation of energy for an isolated system.

28. Give the sign convention followed by the Kirchoff's current rule.

- Current entering the junction is taken as positive and current leaving the junction is taken as negative.

29. Give the sign convention followed by the Kirchoff's votage rule.

- The product of current and resistance is taken as positive when the direction of the current is followed and is taken as negative when the direction of current is opposite to the loop
- The emf is considered positive when proceeding from the negative to the positive terminal of the cell and negative when proceeding from the positive to the negative terminal of the cell.

30. What is called Galvanometer?

- A galvanometer is an instrument used for detecting and measuring even very small electric currents.
- It is extensively useful to compare the potential difference between various parts of the circuit.

31. Define Seebeck effect.

- In a closed circuit consisting of two dissimilar metals, when the junctions are maintained at different temperature an emf is developed. This phenomenom is called Seebeck effect or thermoelectric effect.
- The current that flows due to the emf developed is called thermoelectric current.
- The two dissimilar metals connected to form two junctions is known as thermocouple.

32. What are the applications of Seebeck effect?

- Seebeck effect is used in thermoelectric generators (Seebeck generators) which are used in power plants to convert waste heat into electricity.
- This effect is utilized in automobiles as automotive thermoelectric generators for increasing fuel efficiency
- Seebeck effect is used in thermocouples and thermopiles to measure the temperature difference between the two objects.

33. Define Peltier effect.

- When an electric current is passed through a circuit of a thermocouple, heat is evolved at one junction and absorbed at the other junction. This is known as Peltier effect.
- Peltier effect is reversiable.

34. Define Thomson's effect.

- If two points in a conductor are at different temperatures, the density of electrons at these points will differ and as a result the potential difference is created between these points.
- Thomson effect is reversiable.

PART - III 3 MARK QUESTIONS AND ANSWERS

1. Obtain an expression for drift velocity. How it is related with the mobility?

Drift velocity ($\vec{v}_d$) :

- If there is no electric field, all the free electrons in a conductor are moves in random directions. As a result no net flow of electrons in any direction and hence there will not be any current.
- If the conductor is subjected toan electric field ($\vec{E}$) free electrons experinces a force given by,

$$\vec{F} = -e\,\vec{E} \qquad ------(1)$$

- So all the free electrons are accelerated in a direction opposite to the field. By Newton's second law

$$\vec{a} = \frac{\vec{F}}{m} = \frac{-e\,\vec{E}}{m} \qquad ------(2)$$

- But the positive ions scatter the electrons and change its direction of motion. So they move in zig-zag path.
- In addition to the zig-zag motion due to collisions, the electrons move slowly along the conductor in a direction opposite to that of $\vec{E}$
- *This average velocity acquired by the free electrons inside the conductors, when it is subjected to the electric field is called drift velocity ($\vec{v}_d$)*
- The average time between successive collision is called the mean free time or relaxation time (τ).
- Hence the drift velocity is given by,

$$\vec{v}_d = \vec{a}\,\tau = \frac{-e\,\vec{E}}{m}\,\tau = -\mu\,\vec{E}$$

where , $\frac{e\,\tau}{m} = \mu \rightarrow$ mobility of electrons

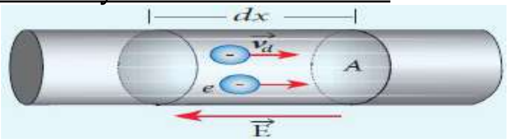
- *The magnitude of the drift velocity acquired by the free electron per unit electric field is called mobility.*

$$\mu = \frac{|\vec{v}_d|}{\vec{E}}$$

- It unit is $m^2V^{-1}s^{-1}$

2. Derive the relation between the drift velocity and the current.

Drift velocity and current - Relation :



- Area of cross section of the conductor $= A$
  Number of electrons per unit volume $= n$
  Applied electric field $= \vec{E}$
  Drift velocity of electrons $= v_d$
  Charge of an electrons $= e$
- Let 'dx' be the distance travelled by the electron in time 'dt', then

$$v_d = \frac{dx}{dt} \quad (or) \quad dx = v_d\,dt$$

- The number of electrons available in the volume of length 'dx' is $= A\ dx\ X\ n = A\ v_d\ dt\ X\ n$
- Then the total charge in this volume element is,

$$dQ = A\,v_d\,dt\ n\,e$$

- By definition, the current is given by

$$I = \frac{dQ}{dt} = \frac{A\,v_d\,dt\ n\,e}{dt}$$

$$\boldsymbol{I = n\,e\,A\,v_d}$$

3. Write a note on carbon resistors.

Carbon resistors :

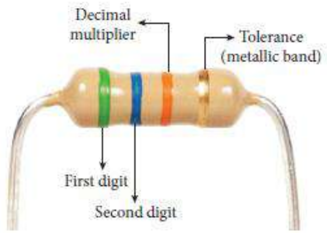
- Carbon resistors consists of a ceramic core on which a thin layer of crystalline carbon is deposited.
- They ar inexpensive, stable and compact in size.
- Colour rings drawn over it are used to indicate the value of the resistance according to the rules in the table.

Colour	Number	Multiplier
Black	0	1
Brown	1	10^1
Red	2	10^2
Orange	3	10^3
Yellow	4	10^4
Green	5	10^5
Blue	6	10^6
Violet	7	10^7
Grey	8	10^8
White	9	10^9

Coluur	Tolerance
Gold	5 %
Silver	10 %
No ring (colourless)	20 %

- There is three coloured bands on its left and one metallic coloured band on its right side.
- The first and second rings are the *significant figures* of the resistance and the third ring indicate the *decimal multiplier* after them. The fourth metallic ring shows the *tolerance* of the resistor.

Example :



- For the given carbon resistor,
  First ring (Green) = 5
  Second ring (Blue) = 6
  Third ring (Orange) = 10^3
  Fourth metallic ring (Gold) = 5%
- Value of the resistor = $\mathbf{56\ X\ 10^3\ \Omega = 56\ k\ \Omega}$
  Tolerance = **5 %**

4. Define temperature coefficient of resistivity. Obtain an expression for it.

Temperature coefficient of resistivity :

- Resistivity of the substance depends on the temperature. Let
- Resistivity at T_o°C $= \rho_o$
  Resistivity at T°C $= \rho_T$

$$\therefore \quad \rho_T = \rho_o\,[1 + \alpha\,(T - T_o)] \qquad ----(1)$$

Where, $\alpha \rightarrow$ Temperature coefficient of resistivity

- From equation (1)

$$\rho_T = \rho_o + \rho_o\,\alpha\,(T - T_o)$$

$$\rho_T - \rho_o = \rho_o\,\alpha\,(T - T_o)$$

$$\therefore \quad \boldsymbol{\alpha = \frac{\rho_T - \rho_o}{\rho_o\,(T - T_o)} = \frac{\Delta\rho}{\rho_o\,\Delta T}}$$

Where, $\boldsymbol{\Delta\rho = \rho_T - \rho_o} \rightarrow$ change in resistivity
$\boldsymbol{\Delta T = T - T_o} \rightarrow$ Change in temperature

- It is defined as the ratio of increase in resistivity per degree rise in temperature to its resistivity at T_o . Its unit is ***per*** °C

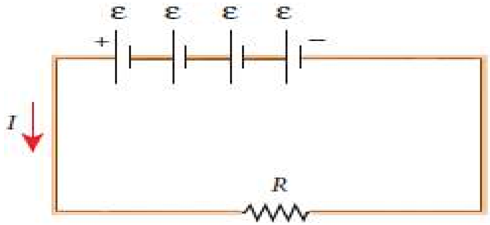
- For conductors α is positive (i.e) if the temperature of the conductor increases, its resistivity also increases.
- Thus resistance at T °C

$$R_T = R_o\,[1 + \alpha\,(T - T_o)]$$

- For semiconductor, α is negative. (i.e.) if temperature increases, resistance decreases.
- A semiconductor with a negative temperature coefficient of resistance is called a ***thermistor***.

5. Write a note on electric cells in series.

<u>Cells in series</u> :



- Let 'n' cells each of emf ε and internal resistance 'r' are connected in series with an external resistance 'R'.
- Total emf of the battery $= n\,\varepsilon$
  Total resistance of the circuit $= n\,r + R$
- By Ohm's law,

$$I = \frac{Total\ emf}{Total\ resistance} = \frac{n\,\varepsilon}{n\,r + R} \quad ---\ (1)$$

- If $r \ll R$, equation (1) becomes,

$$I = \frac{n\,\varepsilon}{R} \approx n\,I_1 \qquad \left[\because\ \frac{\varepsilon}{R} = I_1\right]$$

  (i.e.) if 'r' is negligible compared to 'R' the current supplied by the battery is 'n' times the that supplied by the single cell
- $r \ll R$, equation (1) becomes,

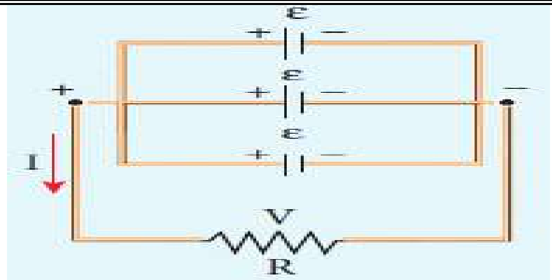
$$I = \frac{n\,\varepsilon}{n\,r} = \frac{\varepsilon}{r} \approx I_1$$

  (i.e.) if 'r' is very very greater than 'R', current due to the whole battery is same as due to single cell.

6. Write a note on electric cells in parallel.

<u>Cells in parallel</u> :

- Let 'n' cells each of emf ε and internal resistance 'r' are connected in parallel with an external resistance 'R'.
- Total emf of the battery $= n\,\varepsilon$
  Total resistance of the circuit $= \frac{r}{n} + R$



- By Ohm's law,

$$I = \frac{Total\ emf}{Total\ resistance} = \frac{\varepsilon}{\frac{r}{n} + R} = \frac{n\ \varepsilon}{n\,r + R} \quad --(1)$$

- If $r \ll R$, equation (1) becomes,

$$I = \frac{n\ \varepsilon}{R} \approx n\,I_1 \qquad \left[\because\ \frac{\varepsilon}{R} = I_1\right]$$

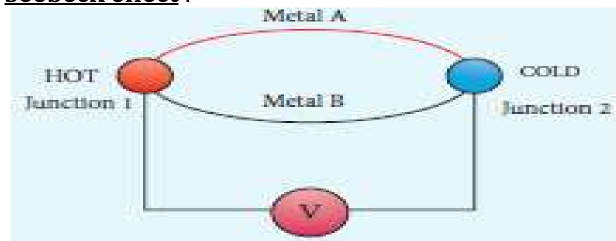
  (i.e.) if 'r' is negligible compared to 'R' the current supplied by the battery is 'n' times the that supplied by the single cell
- $r \ll R$, equation (1) becomes,

$$I = \frac{n\ \varepsilon}{n\,r} = \frac{\varepsilon}{r} \approx I_1$$

  (i.e.) if 'r' is very very greater than 'R', current due to the whole battery is same as due to single cell.

7. Explain Seebeck effect. Give its applications.

<u>Seebeck effect</u> :



- Seebeck discoved that in a closed circuit consisting of two dissimilar metals, when the juctions are maintained at different temperatures an *emf (potential difference) is developed*. This is called Seebeck effect.
- The current that flows due to the emf developed is called ***thermoelectric current***.
- The two dissimilar metals connected to form two junctions is known as ***thermocouple***.
- If hot and cold juntions are interchanged, the direction of current also reversed. Hence Seebeck effect is ***reversiable***.
- The magnitude of emf developed in thermocouple depends on,
  (i) Nature of the metals forming thermocouple
  (ii) Temperature difference between the junctions

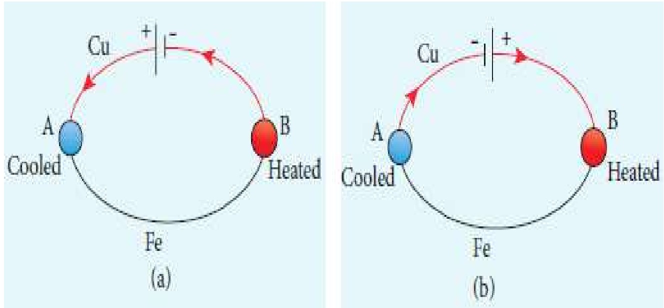
Applications :

- Seebeck effect is used in thermoelectric generators (Seebeck generators).
- This effect is utilized in automobiles as automotive thermoelectric generators.
- Seebeck effect is used in thermocouples and thermopiles.

8. Explain Peltier effect.

<u>Peltier effect</u> :

- When an electric current is passed through a circuit of a thermocouple, heat is evolved at one junction and absorbed at the other junction. This is known as Peltier effect.



- In Cu - Fe thermocouple, the junctions A and B are maintained at the same temperature.
- Let a current flow through the thermocouple.
- At junction 'A', where the current flows from Cu to Fe, heat is absorbed and it becomes cold.
- At juction 'B', where the current flows from Fe to Cu, heat is liberated and it becomes hot.
- When the direction current is reversed, junction 'A' becomes hot and junction 'B' becomes cold. Hence peltier effect is ***reversiable***.

9. Distinguish between Peltier effect and Joule's effect.

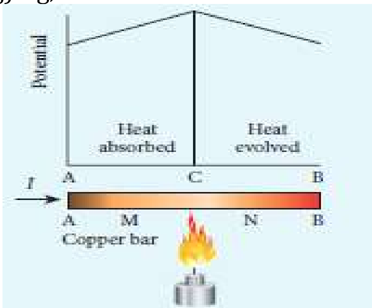
Peltier effect	Joule's effect
1) Both heat liberated and absorbed occur	1) Heat liberated only occur
2) Occurs at junctions	2) Occurs all along the conductor
3) Reversiable effect	3) Irreversiable effect

10. Explain Thomson effect.

Thomson effect :

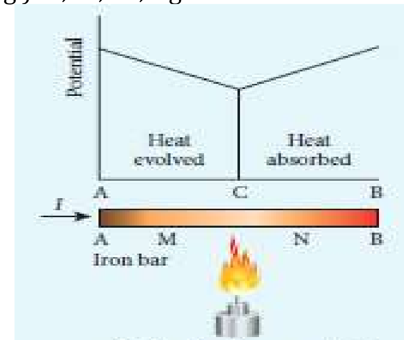
- Thomson showed that, if two points in a conductor are at different temperatures, the density of electrons at these points will differ and as a result the potential difference is created between these points. This is known as Thomson effect.
- Thomson effect is reversiable.
- If current passed through ***copper bar*** AB which is heated at its mid point C, the point C will be at higer potential. This indicates that the heat is absorbed along AC and evolved along CB. Thus heat is transferred in the direction of the current. It is called ***positive Thomson effect***.

(e.g) Ag, Zn. Cd



(a) Positive thomson effect

- When the copper bar is replaced by an ***iron bar***, heat is evolved along CA and absorbed along BC. Thus heat is transferred in the direction opposite to the current. It is called ***negative Thomson effect***.
- (e.g.) Pt, Ni, Co, Hg

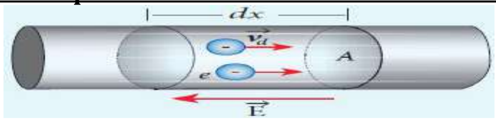


(b) Negative thomson effect

PART - IV 5 MARK QUESTIONS AND ANSWERS

1. Describe the microscopic model of current and obtain general form of Ohm's law.

Microscopic model of current and Ohm' law :



- Area of cross section of the conductor $= A$
  Number of electrons per unit volume $= n$
  Applied electric field along leftwads $= \vec{E}$
  Drift velocity of the electrons $= \boldsymbol{v_d}$
  Charge of the electron $= \boldsymbol{e}$
- If 'dx'be the distance travelled by the electron in time 'dt', then

$$v_d = \frac{dx}{dt} \quad (or) \quad dx = v_d\, dt$$

- The number of electrons available in the volume of length 'dx' is $= A\ dx\ X\ n = A\ v_d\ dt\ X\ n$
- Then the total charge in this volume element is,

$$dQ = A\, v_d\, dt\ \ n\, e$$

- By definition, the current is given by

$$I = \frac{dQ}{dt} = \frac{A\, v_d\, dt\ \ n\, e}{dt}$$

- $$\boldsymbol{I = n\, e\, A\, v_d}$$

Current density ($\vec{J}$) :

- Current density (J) is defined as the current per unit area of cross section of the conductor.

$$J = \frac{I}{A} = \frac{n\, e\, A\, v_d}{A}$$

$$\boldsymbol{J = n\ e\ v_d}$$

- Its unit is $\boldsymbol{A\, m^{-2}}$
- In vector notation,

$$\vec{J} = n\ e\ \vec{v_d}$$

$$\vec{J} = n\, e\left[-\frac{e\,\tau}{m}\,\vec{E}\right] = -\frac{n\, e^2\,\tau}{m}\,\vec{E}$$

- where, $\frac{n\, e^2\,\tau}{m} = \boldsymbol{\sigma} \rightarrow$ conductivity

$$\therefore \quad \vec{J} = -\,\sigma\,\vec{E}$$

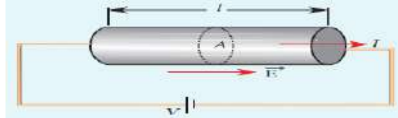
- But conventionally, we take the dirction of current density as the direction of electric field. So the above equation becomes,

$$\vec{J} = \ \sigma\,\vec{E}$$

- This is called microscopic form of Ohm's law.

2. Obtain the macroscopic form of Ohm's law from its microscopic form and discuss its limitation.

Macroscopic form of Ohm's law :



- Consider a segment of wire of length 'l' and area of cross section 'A'.
- When a potential difference 'V' is applied across the wire, a net electric field is created in the wire which constitutes the current.
- If we assume the electric field is uniform in the entire length, the potential difference is given by,

$$V = E\, l \qquad (or) \qquad E = \frac{V}{l}$$

- From the microscopic form of Ohm's law,

$$\boldsymbol{J = \sigma\, E = \sigma\,\frac{V}{l}}$$

- By definition, the current density is

$$\boldsymbol{J = \frac{I}{A}}$$

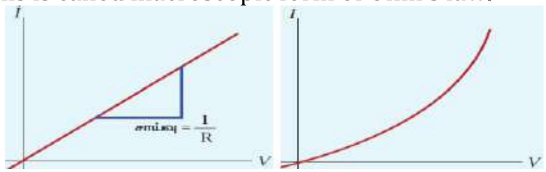
- Hence, $\quad \frac{I}{A} = \sigma\,\frac{V}{l}$

$$\therefore \quad V = I\left[\frac{l}{\sigma\, A}\right]$$

$$\boldsymbol{V = I\, R}$$

Where, $\frac{\boldsymbol{l}}{\boldsymbol{\sigma\, A}} = R \rightarrow$ Resistance of the conductor

- This is called macroscopic form of Ohm's law.

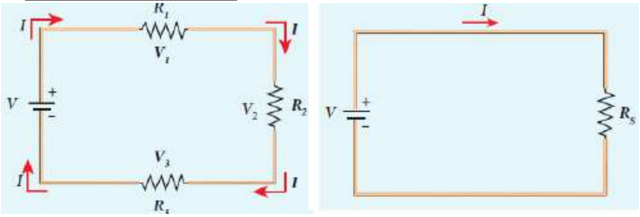


Limittations:

- From Ohm's law, the graph between current versus voltage is straight line with a slope equal to the inverse of resistance (R) of the conductor.
- Materials for which the current against voltage graph is a straight line through the origin are said to obey Ohm's law and their behavior is said to be ***Ohmic***.
- Materials that do not obey Ohm's law are said to be non - ohmic. These materials have more complex (non- linear) relationships between voltage and current.

3. Explain the equivalent resistance of a series and parallel resistor network.

Resistor in series :



- When two or more resistors are connected end to end, they are said to be in series.
- Let R_1, R_2, R_3 be the resistances of three resistors connected in series.
- Let 'V' be the potential difference applied across this combination.
- In Series connection,
  - (i) Current through each resistor will be same (I)
  - (ii) But potential difference across different resistor will be different.
- Let V_1, V_2, V_3 be the potential difference across R_1, R_2, R_3 respectively, then from Ohm's law

$$V_1 = I\,R_1$$
$$V_2 = I\,R_2$$
$$V_3 = I\,R_3$$

- Total potential difference,

$$V = V_1 + V_2 + V_3 = I\,R_1 + I\,R_2 + I\,R_3$$
$$\boldsymbol{V = I\,[R_1 + R_2 + R_3]} \qquad ---- \textbf{(1)}$$

- Let $\boldsymbol{R_S}$ be the equivalent resistance in series connection, then

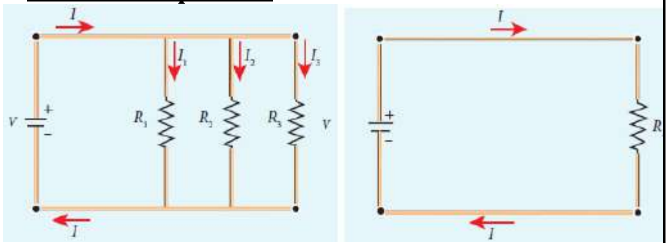
$$\boldsymbol{V = I\,R_S} \qquad ---- (2)$$

- From equation(1) and (2), we have,

$$I\,R_S = I\,[R_1 + R_2 + R_3]$$
$$\therefore \quad \boldsymbol{R_S = R_1 + R_2 + R_3}$$

- When resistances are connected in series, the equivalent resistance is the sum of the individual resistances.
- The equivalent resistance in series connection will be greater than each individual resistance.

Resistors in parallel :



- When two or more resistors are connected across the same potential difference, they are said to be in parallel.
- Let R_1, R_2, R_3 be the resistances of three resistors connected in parallel.
- Let 'V' be the potential difference applied across this combination.
- In parallel connection,
  - (i) Potential difference across each resistance will be the same (V)
  - (ii) But current flows through different resistors will be different.
- Let I_1, I_2, I_3 be the currents flow through R_1, R_2, R_3 respectively, then from Ohm's law

$$I_1 = \frac{V}{R_1} \quad ; \quad I_2 = \frac{V}{R_2} \quad ; \quad I_3 = \frac{V}{R_3}$$

- Hence the total current will be,

$$I = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$
$$\boldsymbol{I = V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]} \qquad ---- \textbf{(1)}$$

- Let $\boldsymbol{R_P}$ be the equivalent resistance in parallel connection, then,

$$\boldsymbol{I = \frac{V}{R_P}} \qquad ---- (2)$$

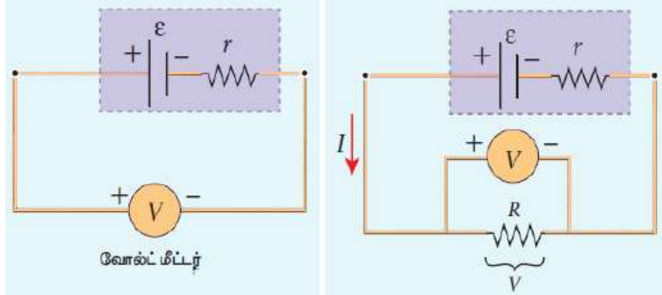
- From equation (1) and (2),

$$\frac{V}{R_P} = V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$
$$\therefore \quad \boldsymbol{\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

- When resistances are connected in parallel, the reciprocal of equivalent resistance is equal to the sum of the reciprocal of the values of resistance of the individual resistor.
- The equivalent resistance in parallel connection will be lesser than each individual resistance.

4. Explain the determination of the internal resistance of a cell using voltmeter.

Internal resistance of a cell :



- A real battery is made of electrodes and electrolyte.
- There is resistance to the flow of charges within the battery and this resistance is called internal resistance (r)
- The emf of the cell is measured by connecting high resistance voltmeter across it without connecting the external resistance R
- This circuit may be considered as open, the voltmeter reading gives the emf (ε) of the cell.
- Then external resistance is included in the circuit and current 'I' is established in the circuit.
- This circuit is then considered as close, the voltmeter reading gives the potential difference (V) across 'R'
- By Ohm's law, $V = I\,R$ (or) $I = \frac{V}{R}$
- Due to internal resistance of the cell, the voltmeter reads the value "V" which is less than the emf ξ
- It is because, certain amount of voltage (Ir) has dropped across the internal resistance 'r'. Hence

$$V = \varepsilon - I\,r \qquad ---- (2)$$
$$(or) \quad I\,r = \varepsilon - V$$
$$\therefore \quad \boldsymbol{r = \frac{\varepsilon - V}{I} = \left[\frac{\varepsilon - V}{V}\right] R}$$

- Since ξ, V and R are known, internal resistance 'r' and total current 'I' can be determined.
- The power delivered to the circuit is,

$$P = I\,\varepsilon = I\,(V + I\,r) = I\,(I\,R + I\,r)$$
$$\boldsymbol{P = I^2\,R + I^2\,r}$$

where, $I^2\,R \rightarrow$ power deliverd to R

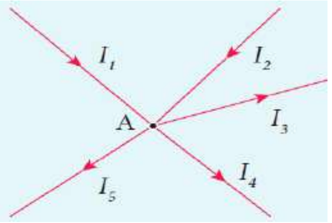
$I^2\,r \rightarrow$ power deliverd to r

5. Explain Kirchoff's law.

Kirchoff first law (current law) :

- It states that the algebraic sum of currents at any junction in a circuit is zero $(\sum I = 0)$.

Explanation :



- It is a statement of conservation of electric charge.
- Thus all charges that enter a given junction in a circuit must leave that junction.
- Current entering the junction is taken as positive and current leaving the junction is taken as negative.
- Applying this law at junction 'A'

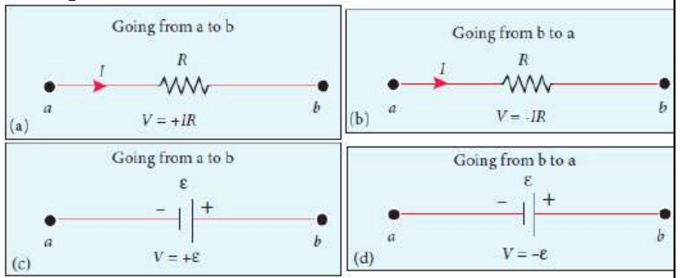
$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

$$(or) \qquad I_1 + I_2 = I_3 + I_4 + I_5$$

Kirchoff second law (voltage law) :

- It states that in a closed circuit the algebraic sum of the products of the current and reistance of each part of the circuit is equal to the total emf included in the circuit ($\sum \boldsymbol{I}\,\boldsymbol{R} = \sum \boldsymbol{\varepsilon}$)

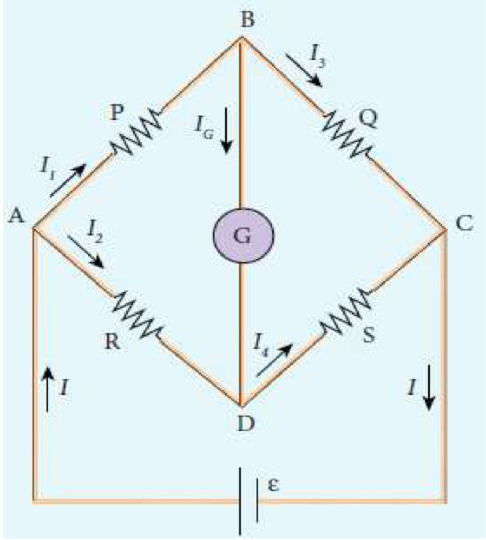
Explanation :



- It is a statement of ***conservation of energy*** for an isolated system.
- The product 'IR' is taken as positive when we proceed along the direction of current and taken as negative when we proceed opposite to the direction of current.
- Simillarly, the emf is considered as positive, when we proceed from negative to positive terminal of the cell and as negative, when we proceed from positive to negative terminal of the cell.

6. Obtain the condition for bridge balance in Wheatstone's bridge.

Wheatstone's bridge :



- An important application of Kirchoff's laws is the Wheatstone's bridge.
- It is used to compare resistances and also helps in determining the unknown resistance in the electrical network
- The bridge consists of four resistances P, Q, R, S connected as shown.
- A galvanometer 'G' is connected between B and D
- A battery 'ε' is connected between A and C
- Let I_1, I_2, I_3, I_4 currents through various branches and I_G be the current through the galvanometer.
- Applying Kirchoff's current law at B and D,

$$I_1 - I_G - I_3 = 0 \qquad ----(1)$$
$$I_2 + I_G - I_4 = 0 \qquad ----(2)$$

- Applying Kirchoff's voltage law ABDA and ABCDA,

$$I_1\,P + I_G\,G - I_2\,R = 0 \qquad ----(3)$$
$$I_1\,P + I_3\,Q - I_2\,R - I_4\,S = 0 \qquad ----(4)$$

- At balanced condition, the potential at B and D are same, and hence the galvanometer shows zero deflection. So $\boldsymbol{I_G} = \mathbf{0}$
- Put this in equation (1), (2) and (3)

$$I_1 - I_3 = 0 \quad (or) \quad I_1 = I_3 \qquad ----(5)$$
$$I_2 - I_4 = 0 \quad (or) \quad I_2 = I_4 \qquad ----(6)$$
$$I_1\,P - I_2\,R = 0 \quad (or) \quad I_1\,P = I_2\,R \qquad ----(7)$$

- Put equation (5) and (6) in (4)

$$I_1\,P + I_1\,Q - I_2\,R - I_2\,S = 0$$
$$I_1\,(P+Q) - I_2\,(R+S) = 0$$
$$\therefore \quad I_1\,(P+Q) = I_2\,(R+S) \qquad ----(8)$$

- Divide equation (8) by (7)

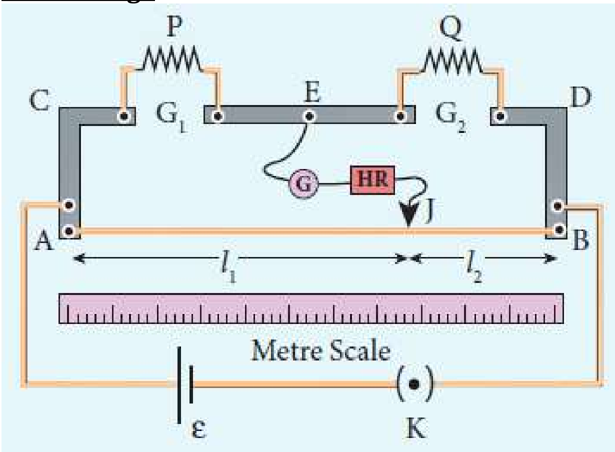
$$\frac{I_1\,(P+Q)}{I_1\,P} = \frac{I_2\,(R+S)}{I_2\,R}$$

$$\frac{P+Q}{P} = \frac{R+S}{R} \quad (or) \quad 1 + \frac{Q}{P} = 1 + \frac{S}{R}$$

$$\frac{Q}{P} = \frac{S}{R} \quad (or) \quad \frac{\boldsymbol{P}}{\boldsymbol{Q}} = \frac{\boldsymbol{R}}{\boldsymbol{S}} \qquad --\ \mathbf{(9)}$$

7. Explain the determination of unknown resistance using meterbridge.

Meterbridge:



- Metrebridge is another form of Wheatstone's bridge
- It consists of uniform ***manganin wire*** AB of 1m length.
- This wire is stretched along a metre scale between two copper strips C and D
- E is another copper strip mounted with two gaps G_1 and G_2
- An unknown resistance P is connected in G_1 and standard resistance connected in G_2
- A jockey J is connected from E through a galvanometer G and high resistance HR.
- A Lechlanche cell ε and key K is connected across the bridge wire.
- The position of jockey is adjusted so that the galvanometer shows zero deflection. Let the point be 'J'

- The lengths AJ and JB now replace the resistance R and S of the Wheatstone's bridge. Then

$$\frac{P}{Q} = \frac{R}{S} = \frac{R' AJ}{R' JB}$$

Where $R' \rightarrow$ resistance per unit length

$$\frac{\boldsymbol{P}}{\boldsymbol{Q}} = \frac{\boldsymbol{AJ}}{\boldsymbol{JB}} = \frac{\boldsymbol{l_1}}{\boldsymbol{l_2}} \qquad ----(\mathbf{1})$$

$$(\boldsymbol{or}) \qquad \boldsymbol{P} = \boldsymbol{Q}\ \frac{\boldsymbol{l_1}}{\boldsymbol{l_2}} \qquad ----(\mathbf{2})$$

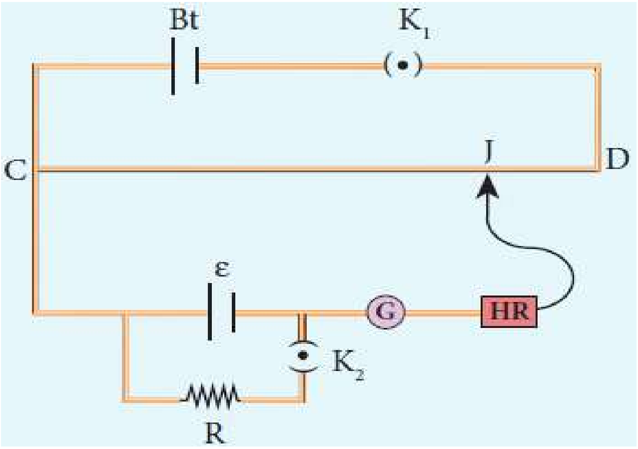
- Due to imperfect contace of wire at its ends, some resistance might be introduced at the contact. These are called end resistances.
- By interchange P and Q,tThis error can be eliminated, and the average value of P is found.
- Let l be the length and r be the radius of wire, its specific resistance (resistivity) is given be.

$$\boldsymbol{\rho} = \frac{\boldsymbol{P\,A}}{\boldsymbol{l}} = \frac{\boldsymbol{P\,\pi\,r^2}}{\boldsymbol{l}} \qquad ----(3)$$

8. Explain the method of measurement of internal resistance of a cell using potentio meter.

<u>Internal resistance by potentiometer</u> :

- Potentiometer wire CD is connected to battery (Bt) and a key (K_1) in series. This is the ***primary*** circuit.
- The cell ε whose internal resistance 'r' to be measured is connected to the ***secondary*** circuit.
- A resistance box R and a key K_2 is connected across the cell ε



- With key K_2 open, the balancing point J is found out and balancing length CJ = l_1 is measured.
- By the principle,

$$\varepsilon \propto l_1 \qquad ----(1)$$

- A suitable resistance is included in R and key K_2 is closed.
- The current flows through R and cell is,

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

- Hence potential difference across R

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

- For this potential difference, again the balancing point J is found out and the balancing length CJ = l_2 is measured.
- By the principle,

$$\frac{\varepsilon}{R + r}\,R \propto l_2 \qquad ----(2)$$

- Divide equation (1) by (2)

$$\frac{\varepsilon}{\left(\frac{\varepsilon}{R + r}\,R\right)} = \frac{l_1}{l_2}$$

$$\frac{R + r}{R} = \frac{l_1}{l_2}$$

$$1 + \frac{r}{R} = \frac{l_1}{l_2}$$

$$\frac{r}{R} = \frac{l_1}{l_2} - 1 = \frac{l_1 - l_2}{l_2}$$

$$\boldsymbol{r} = \boldsymbol{R}\ \left[\frac{\boldsymbol{l_1 - l_2}}{\boldsymbol{l_2}}\right] \qquad ---(\mathbf{3})$$

- By substituting R, l_1, l_2 in equation (3) the internal resistance of the cell can be measured.
- Here the internal reistance is not constant, and it increased with increase of external resistance R.