CHAPTER -3
CURRENT ELECTRICITY

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Ohm's law

- At constant temperature the current flowing through a conductor is directly proportional to potential difference between the ends of the conductor.
- Thus $V = IR$,
  V- potential difference, I – current,
  R- resistance

Resistance

- Ability of conductor to oppose electric current.

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

- SI unit – **ohm (Ω)**

Factors affecting resistance of a conductor

- Nature of material
- Proportional to length of the conductor
- Inversely proportional to area of cross section.
- Proportional to temperature

Relation connecting resistance and resistivity

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

Where ρ- resistivity, A – area, l- length

Resistivity (specific resistance)

- Resistivity of the material of a conductor is defined as the resistance of the conductor having unit length and unit area of cross section.

$$\rho = \frac{RA}{l}$$

- Unit – **ohm meter (Ωm)**
- Resistivity of conductor depends on **nature of material** and **Temperature**

Conductance (G)

- Reciprocal of resistance

$$G = \frac{1}{R}$$

- Unit- **Ω^{-1}, or mho or siemens (S)**

Conductivity (σ)

- Reciprocal of resistivity

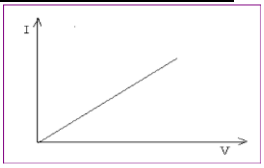
$$\sigma = \frac{1}{\rho}$$

- Unit- **$\Omega^{-1}m^{-1}$, or mho m^{-1}, or S m^{-1}**

Ohmic conductor

- A conductor which obeys ohm's law.
- Eg:- metals

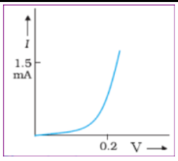
V-I graph of an ohmic conductor



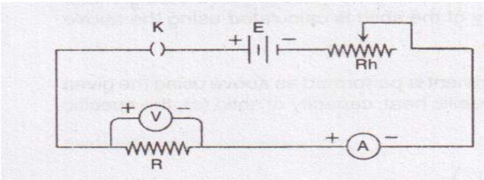
Non ohmic conductors

- Conductor which does not obey ohm's law.
- Eg :- diode, transistors, electrolytes etc.

V-I graph of a non- ohmic conductor (Diode)



Circuit diagram for the experimental study of ohm's law



Vector form of ohm's law

- We have $V = El$
- From ohm's law, $V = IR = \frac{I\rho l}{A}$
- Thus $El = \frac{I\rho l}{A}$
- That is $E = \frac{I\rho}{A} = \rho J$
- Therefore $\vec{E} = \rho \vec{J}$ or $\vec{J} = \sigma \vec{E}$

Resistors

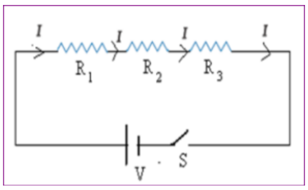
- The **resistor** is a passive electrical component to create resistance in the flow of electric current.

Symbol

Constant resisstance | **Variable resistance**

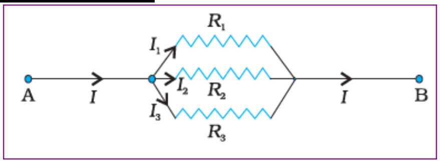
Combination of resistors

Resistors in Series



- In series connection same current pass through all resistors.
- The potential drop is different for each resistor.
- The applied potential is given by
$$V = V_1 + V_2 + V_3$$
- Where V_1, V_2 and V_3 are the potential drop across resistors R_1, R_2 and R_3 respectively.
- If all the resistors are replaced with a single effective resistance R_S , we get
$$V = IR_S$$
- Thus $IR_S = IR_1 + IR_2 + IR_3$
- Therefore the effective resistance is
$$R_S = R_1 + R_2 + R_3$$
- For n resistors
$$R_S = R_1 + R_2 + R_3 + ...R_n$$
- Thus effective resistance increases in series combination.

Resistors in parallel



- In parallel connection current is different through each resistors.
- The potential drop is same for all resistors.
- The total current
$$I = I_1 + I_2 + I_3$$
- If all resistors are replaced with an effective resistor of resistance R_P, we get
$$I = \frac{V}{R_P}$$
- Thus
$$\frac{V}{R_P} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$
- Therefore the effective resistance in parallel combination is
$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
- For n resistors in parallel
$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}$$
- For two resistors
$$R_P = \frac{R_1 R_2}{R_1 + R_2}$$
- Thus effective resistance decreases in parallel combination.

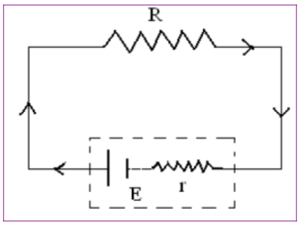
Internal resistance of a cell (r)

- Resistance offered by the electrolytes and electrodes of a cell.

Factors affecting internal resistance

- Nature of electrolytes
- Directly proportional to the distance between electrodes
- Directly proportional to the concentration of electrolytes.
- Inversely proportional to the area of the electrodes.
- Inversely proportional to the temperature of electrolyte.

Relation connecting emf and internal resistance



- Effective resistance = R+r
- Thus the current is $I = \frac{\varepsilon}{R+r}$
- Where ε –emf, R- external resistance, r- internal resistance.
- That is $I(R+r) = \varepsilon \Rightarrow IR + Ir = \varepsilon$
- From ohm's law, V=IR, therefore
$$r = \frac{\varepsilon - V}{I}$$
- The potential is given by
$$V = \varepsilon - Ir$$

Joule's law of heating

- The heat energy dissipated in a current flowing conductor is given by
$$H = I^2 Rt$$
- I- current, R –resistance, t –time

Electric power

- It is the energy dissipated per unit time.
- Power , $P = \frac{H}{t} = I^2 R$
- Also $P = VI = \frac{V^2}{R}$
- SI unit is **watt (W)**
- 1 kilo watt (1kW) = 1000W

- 1mega watt (MW) = 10^6W
- Another unit horse power (hp)
- 1 hp = 746 W

Electrical energy

- Electrical energy = electrical power X time
- SI unit – joule (J)
- Commercial unit – kilowatt hour (kWh)
- 1kWh = 3.6 x 10^6 J.

Efficiency

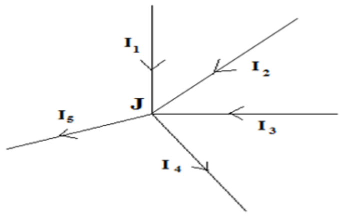
- The efficiency of an electrical device is

$$\eta = \frac{output\ power}{input\ power}$$

Kirchhoff's rule

First rule (junction rule or current rule)

- Algebraic sum of the current meeting at junction is zero.
- Thus , Current entering a junction = current leaving the junction



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

Sign convention

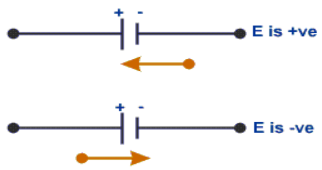
- Current entering the junction – positive
- Current leaving the junction - negative

Second rule (loop rule or voltage rule)

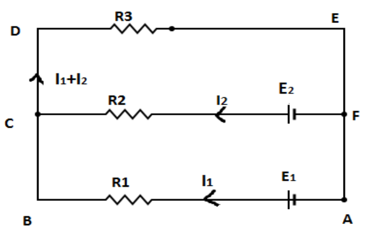
- Algebraic sum of the products of the current and resistance in a closed circuit is equal to the net emf in it.
- This rule is a statement of law of conservation of energy.

Sign convention

- Current in the direction of loop – positive
- Current opposite to loop - negative



Illustration



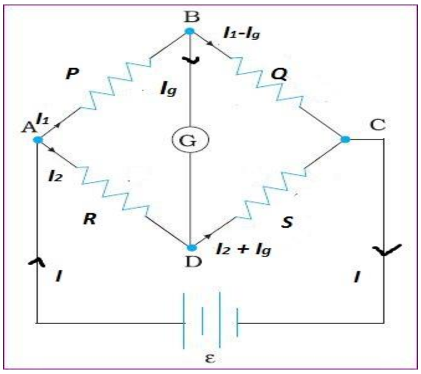
Loop ABCFA

$$I_1R_1 - I_2R_2 = E_1 - E_2$$

Loop CDEFC

$$I_2R_2 + (I_1 + I_2)R_3 = E_2$$

Wheatstone' s bridge



Wheatstone' s principle

- If galvanometer current is zero, $\frac{P}{Q} = \frac{R}{S}$

Derivation of balancing condition

- Applying voltage rule to the loop ABDA

$$I_1P + I_gG - I_2R = 0$$

- For the loop BCDB

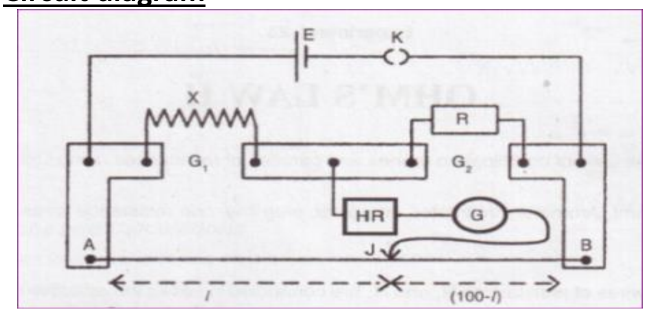
$$(I_1 - I_g)Q - (I_2 + I_g)S - I_gG = 0$$

- When the bridge is balanced I_g=0.
- Thus $I_1P - I_2R = 0$ and $I_1Q - I_2S = 0$
- Or , $I_1P = I_2R$ and $I_1Q = I_2S$
- Thus $\frac{P}{Q} = \frac{R}{S}$
- This is the balancing condition of a Wheatstone bridge.

Meter bridge (slide wire bridge)

- Works on Wheatstone's principle.
- Used to find resistance of a wire.

Circuit diagram



- Where k – key, X – unknown resistance, R- known resistance, HR- high resistance, G – Galvanometer, J – Jockey

Equation to find unknown resistance

- From wheatstone's principle

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

- Here P – unknown resistance , Q- known resistance, R- resistance of the wire of length *l* , S - resistance of wire of length (100-*l*).

- The length l for which galvanometer shows zero deflection – balancing length.

- Thus

$$\frac{X}{R}=\frac{lr}{(100-l)r}$$

- Where r – resistance per unit length of the meterbridge wire.
- Therefore the unknown resistance is given by

$$X=\frac{Rl}{(100-l)}$$

- The resistivity of the resistance wire can be calculated using the formula

$$\rho=\frac{\pi r^2 X}{l}$$

Where r – radius of the wire, l –length of the wire.

Potentiometer

- A device used to measure an unknown emf or potential difference accurately.

Principle

- When a steady current (I) flows through a wire of uniform area of cross section, the potential difference between any two points of the wire is directly proportional to the length of the wire between the two points.

- From ohm's law , $V=IR$

- That is . $V=\frac{I\rho l}{A}$

- Therefore , $V \alpha l$ or $V=kl$
- Thus $\frac{V}{l}=k$, where k – constant.

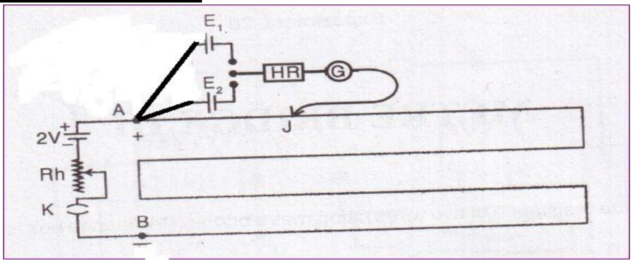
$\frac{V}{l}$ – potential gradient.

Uses of potentiometer

- To compare the emf of two cells
- To find the internal resistance of a cell

Comparison of emfs

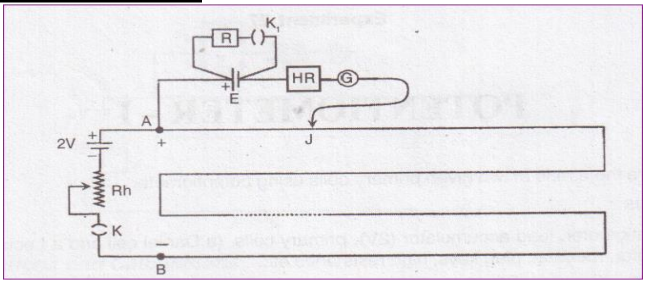
Circuit diagram



- We have, $E_1 \propto l_1$ and $E_2 \propto l_2$
- Thus $\frac{E_1}{E_2}=\frac{l_1}{l_2}$
- l_1- balancing length with cell E_1
- l_2- balancing length with cell E_2
- To get the balancing length E_1>E_2

To find internal resistance

Circuit diagram



- when the key K_1 is open

$$\varepsilon \propto l_1$$

- when the key K_1 is closed

$$V \propto l_2$$

- Thus $\frac{\varepsilon}{V}=\frac{l_1}{l_2}$

- But we have

$$V=IR$$

$$\varepsilon=I(R+r).$$

r – internal resistance

- Therefore $\frac{\varepsilon}{V}=\frac{I(R+r)}{IR}=\frac{(R+r)}{R}$
- Thus $\frac{(R+r)}{R}=\frac{l_1}{l_2}$
- The internal resistance is given by

$$r=\frac{R(l_1-l_2)}{l_2}$$

- Where l_1- balancing length, key K_1open, l_2- balancing length, key K_1 closed.

Why potentiometer is preferred over voltmeter for measuring emf of a cell?

- In potentiometer **null method** is used, so no energy loss in measurement.

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