7/7/23

CHAPTER - 3
CURRENT ELECTRICITY

The branch of Physics which deals with the study of electric charges in motion is called Current Electricity.

★ CHARGE CARRIERS

- SOLIDS
  - Insulators → No charge carrier
  - Conductors → Free e^-
  - Semiconductors → (a) Free e^- (b) Holes
- LIQUIDS → Ions
- GASES → (a) at room temp^r, no charge carrier (b) at high electric field, ions

★ DRIFT VELOCITY

The average velocity acquired by free e^- of a conductor under the influence of external ~~electric~~ field applied is called drift velocity.

10^{28} free e^- / volume
No field ⇒ 10^5 m/s
External field ⇒ 10^{-4} m/s

- **EXPRESSION OF DRIFT VELOCITY**

If $\vec{u}_1, \vec{u}_2, \ldots, \vec{u}_n$ ⇒ Initial thermal velocity of ~~fre~~ free e^-

$$\vec{u}_{avg} = \frac{\vec{u}_1 + \vec{u}_2 + \ldots + \vec{u}_n}{n} = 0$$

The force experienced by a free e^- due to external field

$$\vec{F} = -e\vec{E} \quad \text{—— (1)}$$

$\vec{F} = ma$ — ②

From ① and ②,

$m\vec{a} = -e\vec{E}$

$\Rightarrow \vec{a} = \frac{-e\vec{E}}{m}$ — ③

Thus,

$\vec{v_1} = \vec{u_1} + \vec{a}\tau_1$

$\vec{v_2} = \vec{u_2} + \vec{a}\tau_2$

$\vdots$

$+\ \vec{v_n} = \vec{u_n} + \vec{a}\tau_n$

$\vec{v_1} + \vec{v_2} + \dots + \vec{v_n} = (\vec{u_1} + \vec{u_2} + \dots + \vec{u_n}) + \vec{a}(\tau_1 + \tau_2 + \dots + \tau_n)$

Dividing by n on both sides

$$\frac{\vec{v_1} + \vec{v_2} + \dots + \vec{v_n}}{n} = \frac{(\vec{u_1} + \vec{u_2} + \dots + \vec{u_n})}{n} + \underbrace{\frac{\vec{a}(\tau_1 + \tau_2 + \dots + \tau_n)}{n}}_{\tau_{avg} \text{ (Average Relaxation time)}}$$

$\vec{v_d} = \vec{a}\,\tau_{avg}$ — ④

From ③ and ④,

$\vec{v_d} = \frac{-e\vec{E}\,\tau_{avg}}{m}$

In magnitude,

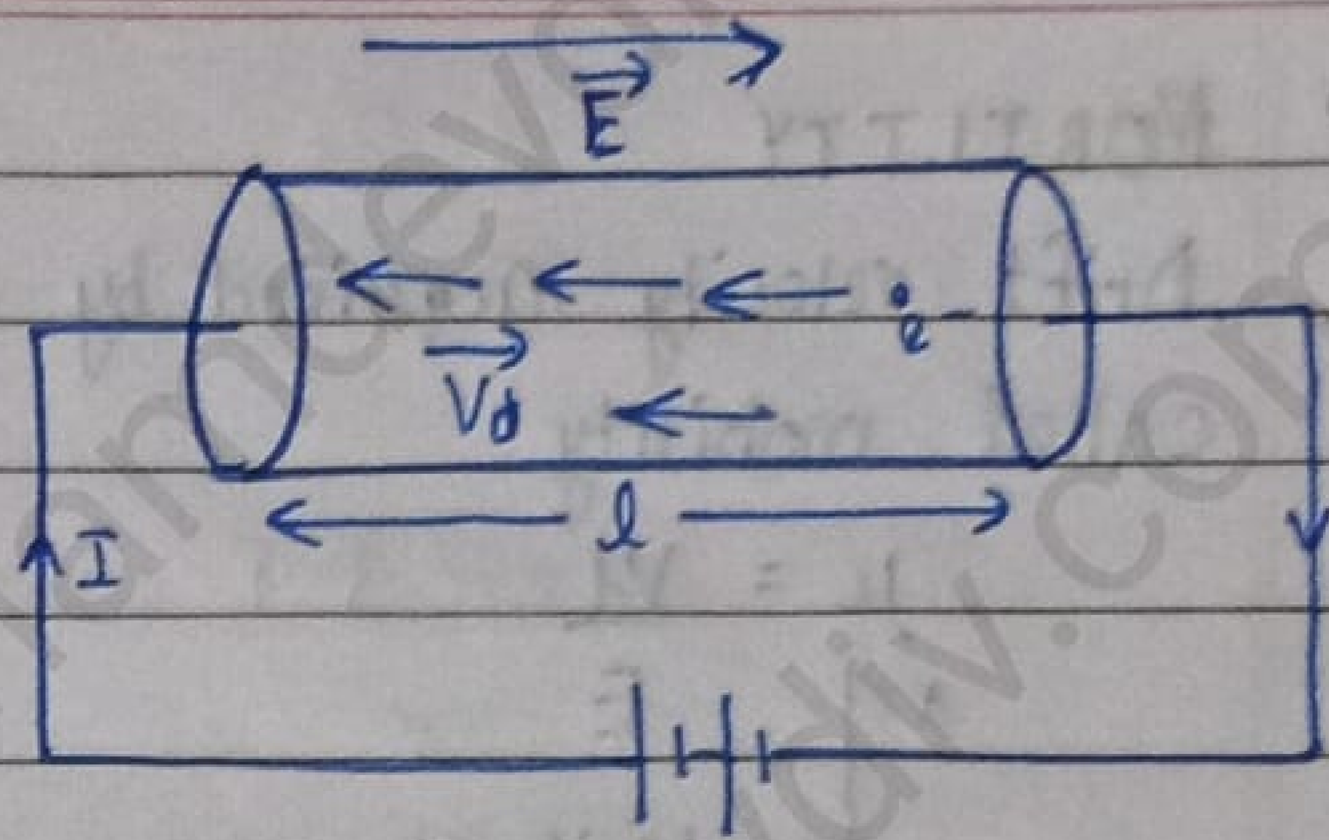
$v_d = \frac{eE\tau}{m}$

- RELATION BETWEEN I AND V_D

$I = \frac{Q}{t}$ — ①

Let $n \Rightarrow$ number density (no. of ~~fe~~ free e^- / unit volume)

$N \Rightarrow$ Total no. of free e^-



$N = nAl$ —— ②

$Q = Ne = nAle$ —— ③

If l = length of conductor,

$t = \frac{l}{V_d}$ —— ④

From ①, ③ and ④

$$I = \frac{nAle}{\frac{l}{V_d}}$$

$$I = neAV_d$$

NOTE → $I = neAV_d$
$\quad \hookrightarrow \frac{eE\tau}{m}$

$$\Rightarrow I = \frac{ne^2AE\tau}{m}$$

- CURRENT DENSITY

The current flowing per unit area of a conductor is called current density.

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

$I = \vec{J}.\vec{A} = JA\cos\theta$

- Unit $\Rightarrow A/m^2$
- Dimensional Formula $\Rightarrow [AL^{-2}]$
- Nature $\Rightarrow$ Vector

- MOBILITY

Drift velocity acquired by a free e^- per unit applied electric field is called mobility.

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

(a) Unit $\Rightarrow \frac{m/s}{N/C} = m\,A/N$

(b) Unit $\Rightarrow \frac{m/s}{V/m} \Rightarrow m^2/V\text{-}s$

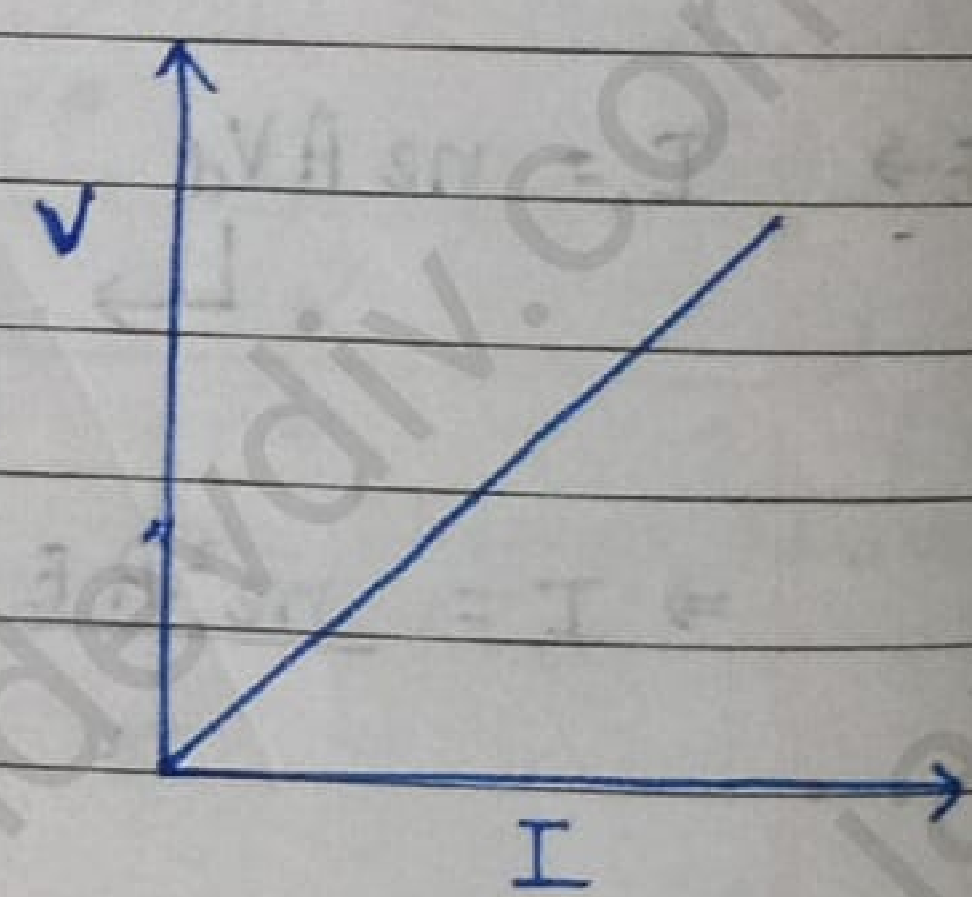
☆ OHM'S LAW

At constant temperature, the current flowing through a conductor is directly proportional to the potential difference across its ends.

$$I \propto V$$
$$V \propto I$$
$$V = IR$$

Here, $R = \frac{V}{I}$ = Resistance of conductor

→ Unit = ohm (Ω)



- PROOF

$$I = neAV_d \quad \text{— (1)}$$

$$V_d = \frac{eE\tau}{m} \quad \text{— (2)}$$

$$E = \frac{V}{l} \quad \text{— (3)}$$

We get,

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

$$I = \frac{ne^2 A V \tau}{ml}$$

$$\frac{V}{I} = \frac{ml}{ne^2 \tau A} \longrightarrow \text{constant}$$

$$R = \frac{ml}{ne^2 \tau A}$$

- **CONDUCTANCE**

The reciprocal of resistance is called conductance.

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

Unit ⇒ (a) ohm^{-1} (Ω^{-1})
(b) mho (℧)
(c) Siemens (S)

- **RESISTIVITY**

$$\rho = \frac{RA}{l} = \frac{m}{ne^2 \tau}$$

Unit ⇒ ohm-m (Ω-m)

- **CONDUCTIVITY**

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

Unit
(a) $(ohm\text{-}m)^{-1}$ $(\Omega\text{-}m)^{-1}$
(b) mho-m^{-1} (℧-m^{-1})
(c) Siemens-m^{-1} (S-m^{-1})

- **VECTOR FORM (μ-SCOPIC FORM) OF OHM'S LAW**

$$I = neA V_d \quad \text{--- (1)}$$

$$V_d = \frac{eE\tau}{m} \quad \text{--- (2)}$$

From ① and ②

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

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

$$J = \frac{ne^2 E \tau}{m} = \frac{E}{\frac{m}{ne^2 \tau}} \qquad \because \frac{m}{ne^2 \tau} = \rho$$

$$J = \frac{1}{\rho} E$$

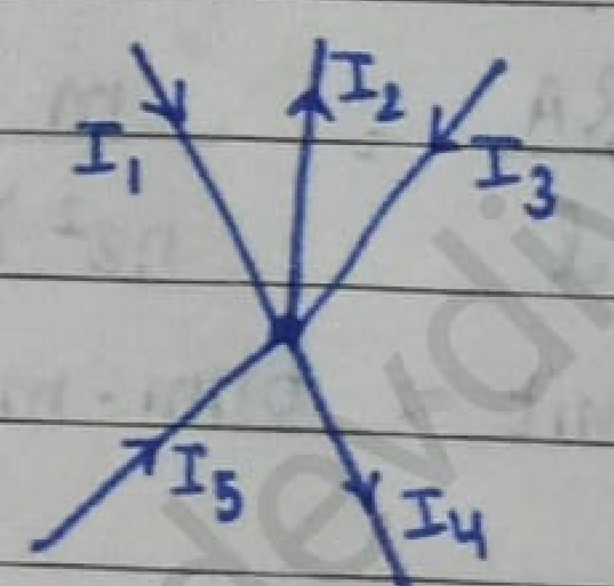
$$J = \sigma E$$

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

★ KIRCHHOFF'S ~~CONSTANT~~ CURRENT LAW (KCL) OR JUNCTION RULE

According to KCL, the algebraic sum of all currents entering or living at a junction is zero.

$$\Sigma I = 0$$



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

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

$$\Sigma I_{in} = \Sigma I_{out}$$

NOTE → KCL is based on the principle of conservation of charge

★ KIRCHHOFF'S VOLTAGE LAW (KVL) OR LOOP RULE

According to KVL, the algebraic sum of all potentials in a closed network is zero.

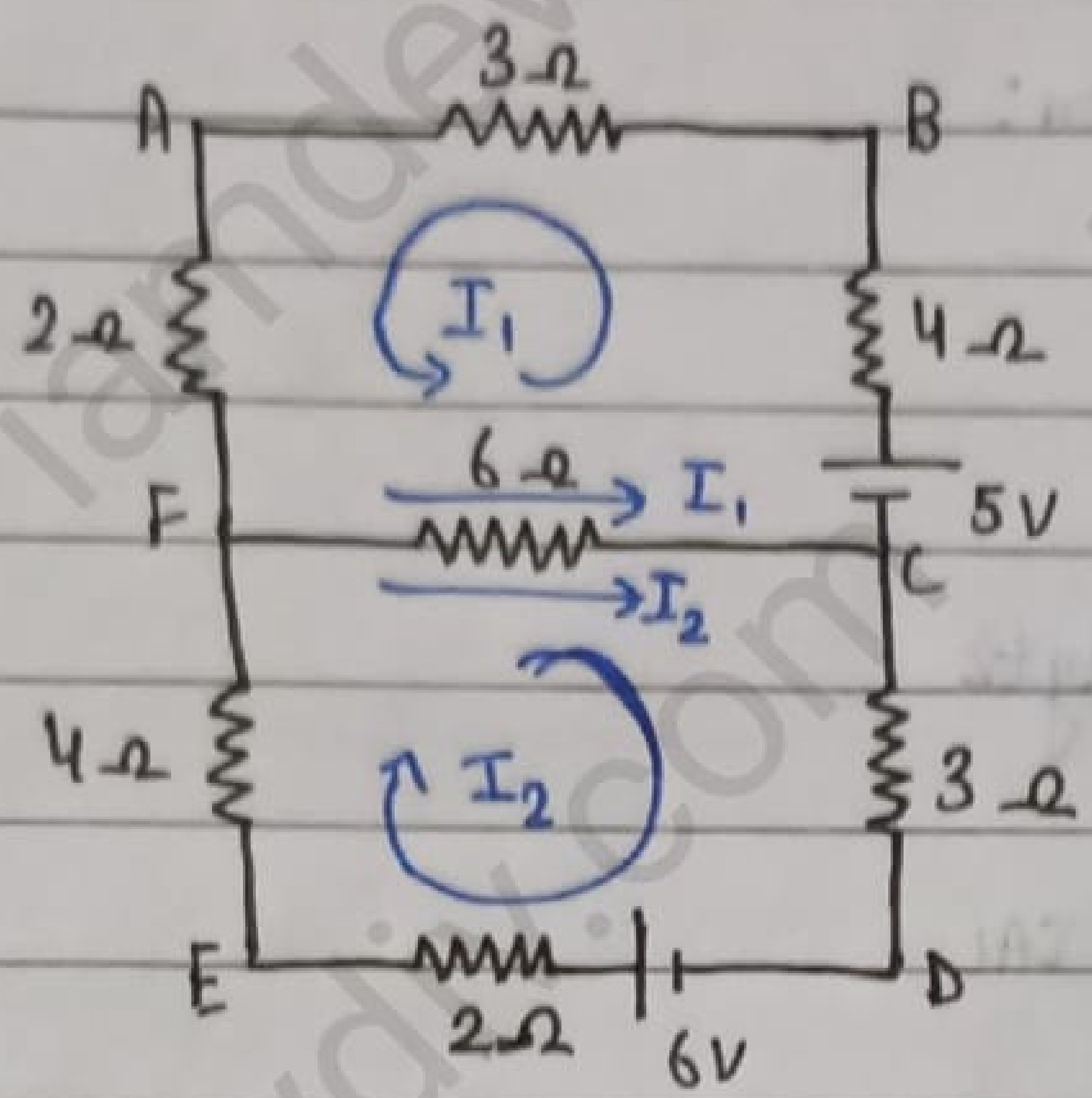
$$\Sigma V = 0$$

OR

$$\Sigma IR = 0$$

NOTE → KVL is based on principle of conservation of energy.

Q



Find $I_{6\Omega}$.

Sol. Applying KVL in loop-1 (AFCBA)

$$2I_1 + 6(I_1+I_2) - 5 + 4I_1 + 3I_1 = 0$$

$$15I_1 + 6I_2 = 5 \quad \text{——} \ (1)$$

Applying KVL in loop-2 (FCDEF)

$$6(I_1+I_2) + 3I_2 - 6 + 2I_2 + 4I_2 = 0$$

$$6I_1 + 15I_2 = 6 \quad \text{——} \ (2)$$

Solving (1) and (2),

$$I_1 = \frac{13}{63} A, \quad I_2 = \frac{20}{63} A$$

$$I_{6\Omega} = I_1 + I_2 = \frac{13}{63} + \frac{20}{63} = \frac{33}{63} = \frac{11}{21} A \quad \underline{\text{Ans}}$$

☆ EMF (ELECTROMOTIVE FORCE)

Cell ⇒ —|ε|— r

Used to maintain constant voltage.

Consists of - electrolyte (electrolysis)

Low for new cell (2-5 ohms)

Interal resistance depends upon:

i) Nature of electrodes
ii) Concentration of electrolyte
iii) Separation between electrode
iv) Level of electrodes in electrolyte

- EMF V/S TERMINAL POTENTIAL

(a) EMF of a cell is potential difference across the terminal of cell/battery when it is not connected with battery. (Unit- Volt)

(OR)

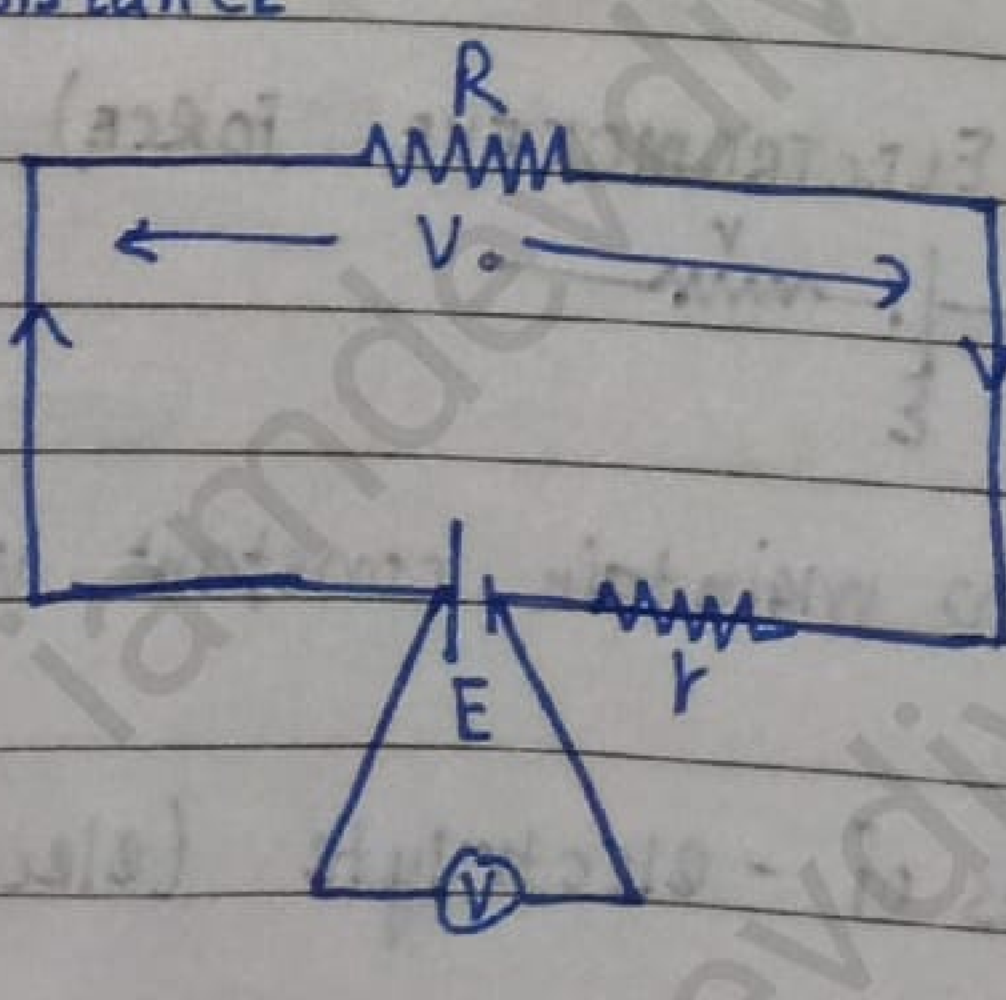
Amount of work done in moving unit charge from low potential to higher potential.

(b) Terminal potential is the potential difference when connected to cell.

NOTE → EMF > Terminal potential
When external force is applied ⇒ EMF < Terminal Potential

- RELATION BETWEEN EMF AND INTERNAL RESISTANCE OF A CELL

EMF = Potential drop across internal resistance (r)
+
Potential drop across load resistance



$E = Ir + IR$

$\because V = IR$

$\Rightarrow E = V + Ir$

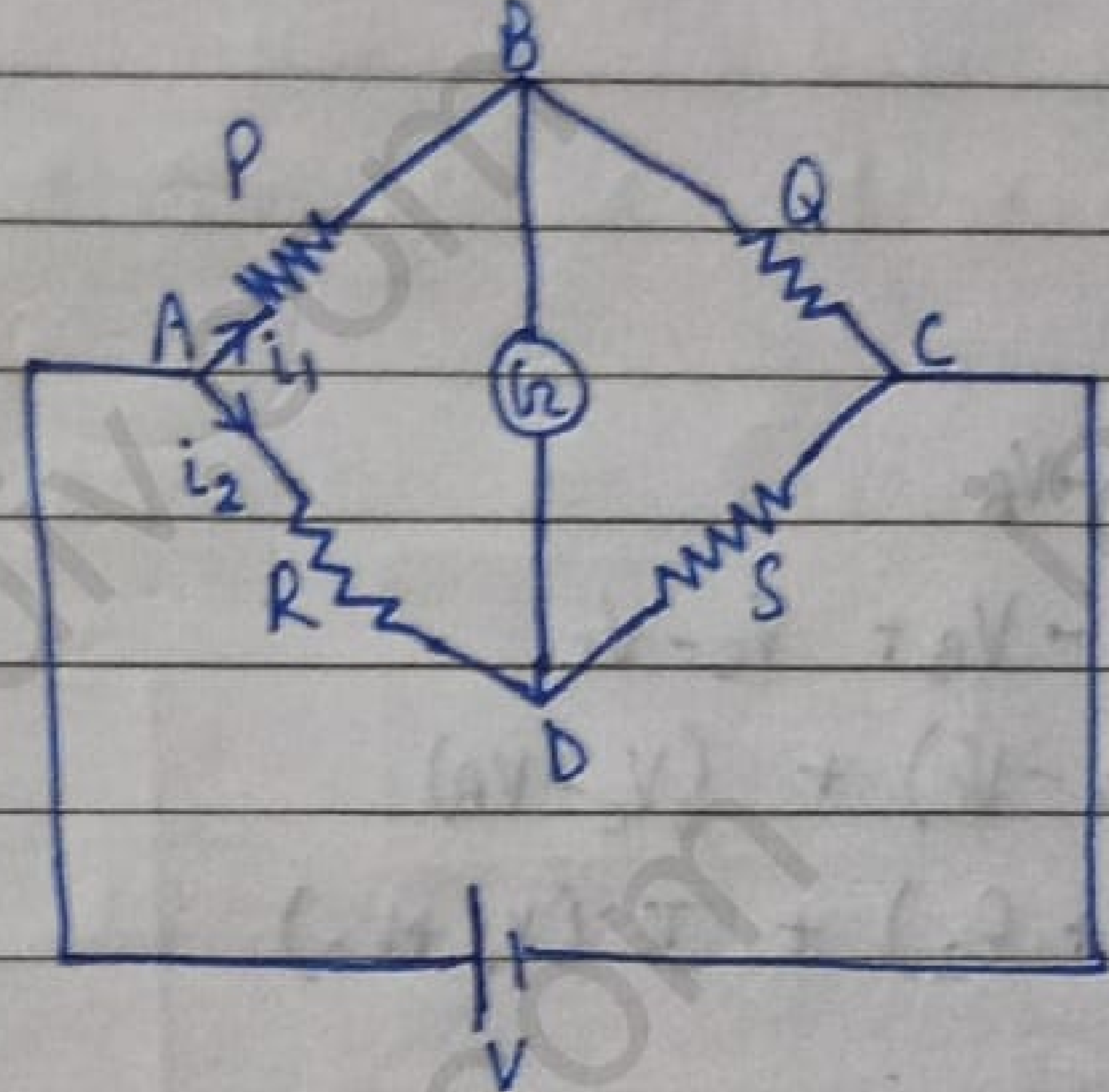
$\hookrightarrow E > V$

In case of charging,

$E = V - Ir$

$\hookrightarrow E < V$

✯ WHEAT STONE BRIDGE



In loop ABDA,

$\Sigma V = 0$

$\Rightarrow i_1 P - i_2 R = 0$

$\Rightarrow i_1 P = i_2 R$ — ①

In loop BCDB,

$\Sigma V = 0$

$\Rightarrow i_2 S - i_1 Q = 0$

$\Rightarrow i_1 Q = i_2 S$ — ②

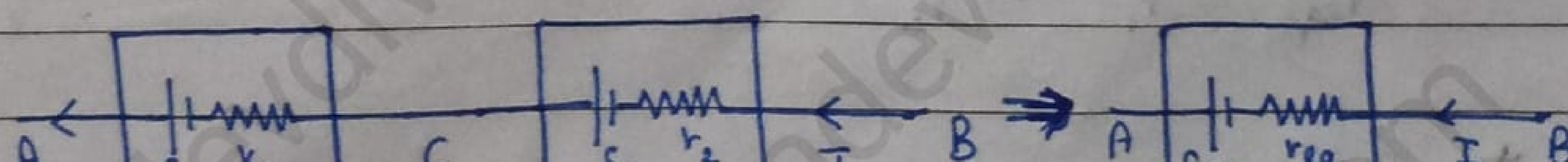
① ÷ ②,

$\frac{i_1 P}{i_1 Q} = \frac{i_2 R}{i_2 S}$

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

✯ GROUPING OF TWO UNIDENTICAL CELLS

- SERIES GROUPING



For cell 1,

$V_{AC} = V_A - V_C$

$= \varepsilon_1 - Ir_1$ —— ①

For cell 2,

$V_{CB} = V_C - V_B$

$= \varepsilon_2 - Ir_2$

For equivalent cell,

$V_{AB} = V_A - V_B$

$\varepsilon_{eq} - Ir_{eq} = V_A - V_B$

$= V_A - V_B + V_C - V_C$

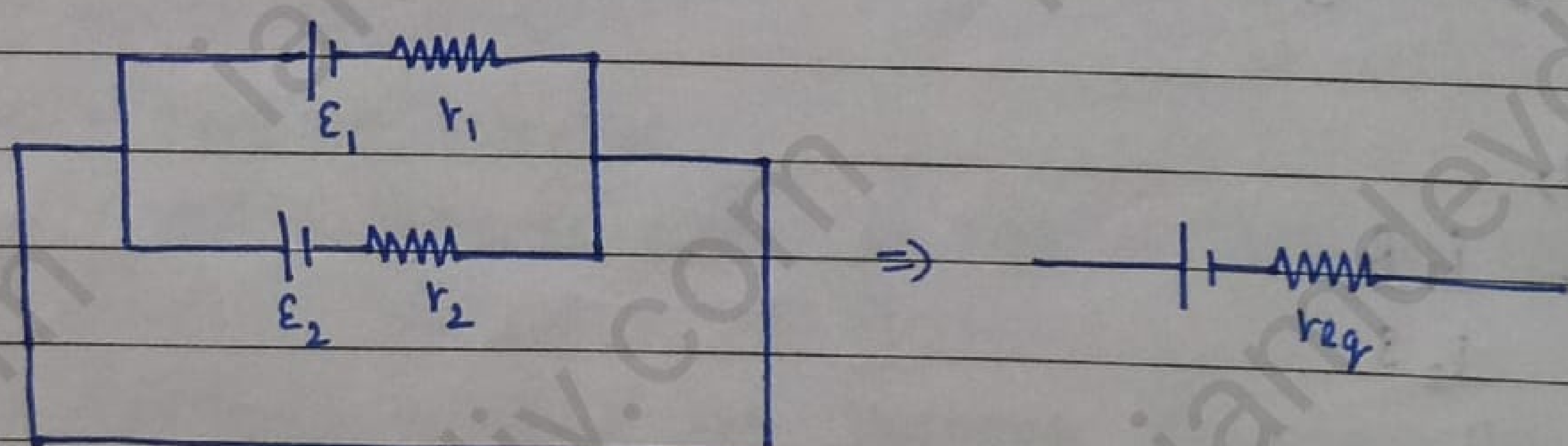
$= (V_A - V_C) + (V_C - V_B)$

$\varepsilon_{eq} - Ir_{eq} = (\varepsilon_1 + \varepsilon_2) + I(r_1 + r_2)$

$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$

$r_{eq} = r_1 + r_2$

- PARALLEL COMBINATION



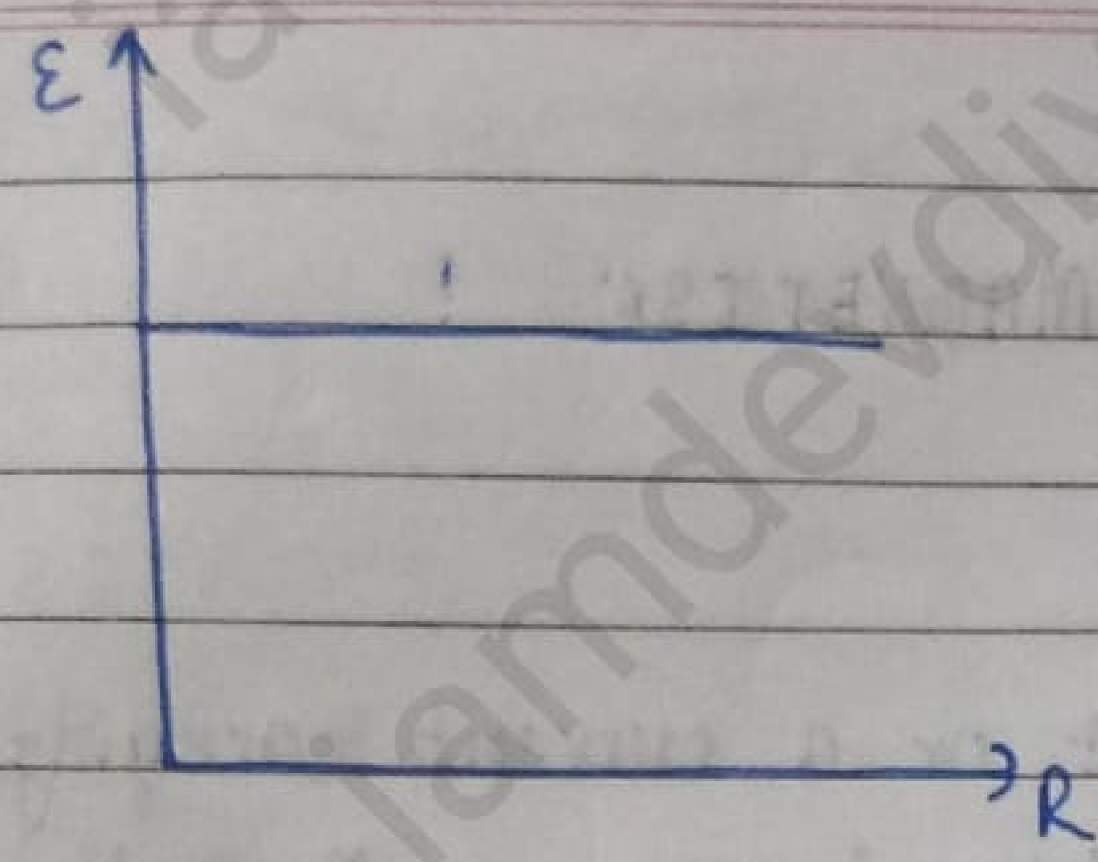
Net EMF $\Rightarrow$ E (parallel combination, V is same)

$r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$

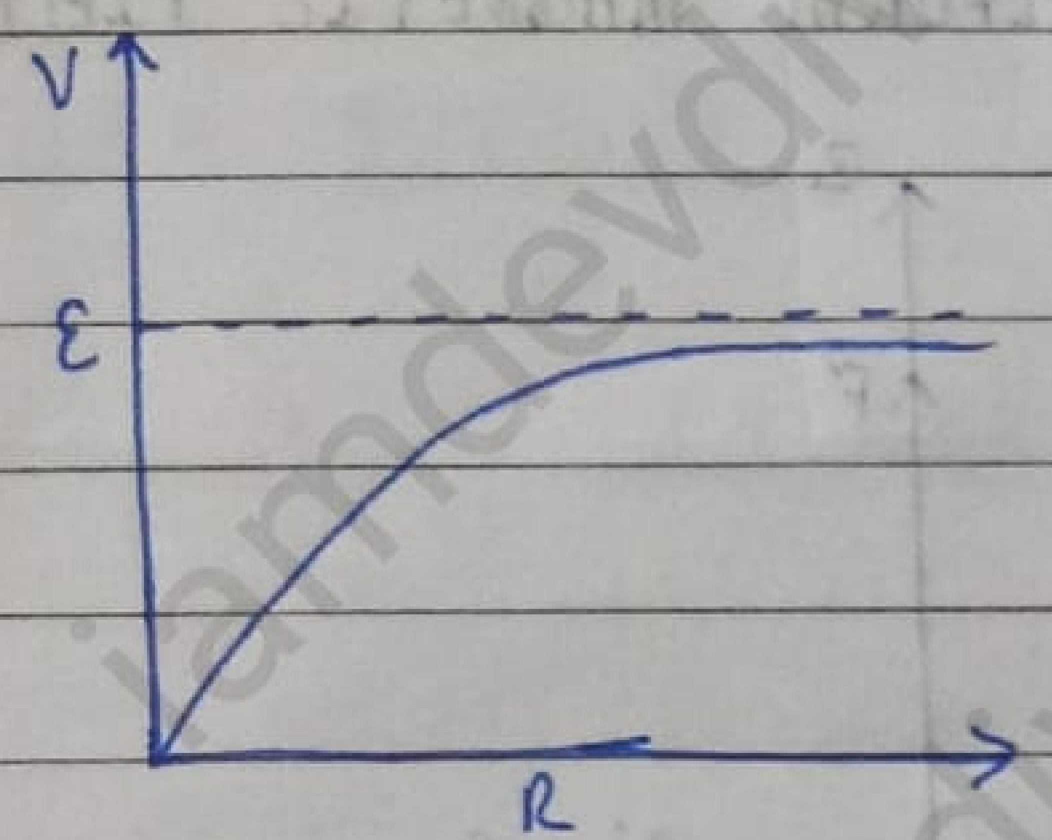
$\Rightarrow \frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}$

★ GRAPHS

- EMF v/s R



• V v/s R



• V v/s I