Current Electricity

Article-1 DRIFT VELOCITY OF FLOW ELECTR.

A) Conductor without battery

> Free e-s in the metals are responsible for current conduction.

> Free e-s are set in random motion due to thermal effect of surrounding.

> Order of free e⁻ density ~~10~~ in a metal is 10^{28} electrons / m^3 (independent of temp.)

This density is almost independant of Temp.

> Mean free path in an metal is of the order of 10 Å (distance b/w 2 collision) or 10×10^{-10} m $= 10^{-9}$ m

(λ depends upon nature of material)

> Thermal speed of electrons (V_T) :

$$\frac{3}{2} K_B T = \frac{1}{2} m_e V_T^2$$

$$\boxed{K_B = 1.38 \times 10^{-23} \text{ J/K}}$$

$T = 300$ K , $m_e = 9.1 \times 10^{-31}$ Kg

then $V_T \rightarrow 10^5$ m/s

> Relaxation time (τ): It is average time taken

b/w 2 successive collision.

(time) $\tau = \frac{\lambda}{v_T} = \frac{10^{-9} m}{10^5 m/s} = 10^{-14} sec$

> If battery is not connected then average velocity of free e⁻ group is 0.

$$\langle \vec{v} \rangle = \frac{\vec{V_1} + \vec{V_2} + \vec{V_3} \ldots\ldots + \vec{V_N}}{N}$$

$$= \frac{\sum_{i=1}^{N} \vec{v_i}}{N} = \vec{0}$$

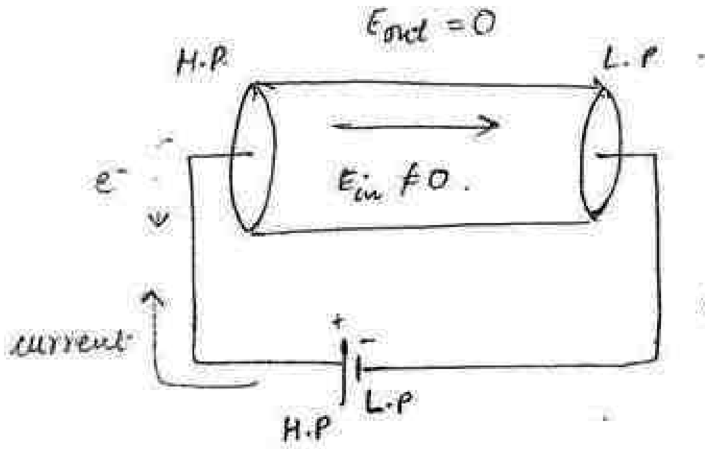
so that current in the wire is zero.

B) conductor across battery

> When battery is connected, a uniform electric field is set inside the conductor which is responsible for drift in e⁻ group

> A current carrying wire remains electrically neutral so ~~of~~ electric field outside the conductor is (It is opp. condition of electro-statics) zero

> Path of free e⁻s b/w 2 collisions is usually curved path when ~~f~~ battery is connected.



∵ flow of current is opposite to the flow of e^- (−ve charge)

Q) Derive expression of drift velocity of free e^-s in a metal

When battery is connected across a metallic wire, then a uniform electric field is created in the wire so all free e^-s experiences equal and constant acceleration

$$\vec{a} = \frac{q\vec{E}}{m} = \frac{-e\vec{E}}{m_e}$$

so, we can use equation of motion.

Consider an i^{th} e^- just after its last collision. It's initial velocity is $\vec{u_i}$ and after time interval t_i, velocity becomes $\vec{v_i}$, here $\vec{v_i} = \vec{u_i} + \vec{a}t$

* Drift velocity is the average velocity of group of free e^-s it means $\vec{V}_{drift} = \langle \vec{v_i} \rangle = \langle \vec{u_i} \rangle + \vec{a} \langle t_i$

$\langle \vec{u_i} \rangle = \vec{0}$ because it has random values

$\langle \vec{t_i} \rangle = \tau$ (Relaxation time)

so, $\vec{V}_{drift} = \vec{a}\tau = \left(\frac{-e\vec{E}}{m_e}\right)\tau$

$$\boxed{|\vec{V_d}| = \frac{e\tau}{m_e} E}$$ ($v = at$) its magnitude $\because$ I is scaler

conclusion :

The magnitude of drift velocity is independant of time (τ = constant = 10^{-14} sec) and order of drift velocity is $10^{-2}\ \frac{m}{s}$ or 10^{-3} m/s but electric field in the wire propagates with the speed of light. so, it takes very negligiable time in switching (ON and OFF)

$$* \boxed{V_d = \mu E} \quad \mu = \frac{e\tau}{m_e} = \text{mobility constant}$$

μ depends upon nature and temperature of material ~~and~~ of wire

Article : 2

$\boxed{I = n e A V_d}$ → no of e- per unit vol

> Rate of flow of charge is called electric current

$$\boxed{I = \frac{dq}{dt}}$$

$$I = \frac{\Delta q}{\Delta t} = \frac{q}{t} \quad \text{when } I = \text{constant}$$

* $$\boxed{q = \int_{t_1}^{t_2} I\,dt}$$

Q)) current in a wire is $I = (2t - 3t^2)$ A
How much charge will pass through a cross section b/w $t = 2s$ to $t = 3$ sec

$$\because \; I = \frac{dq}{dt}$$

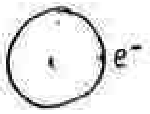
$$\therefore \; q = \int_{t_1}^{t_2} I\,dt = \int_{t_1}^{t_2} (2t - 3t^2)\,dt$$

$$= \left[\frac{2t^2}{2} - \frac{3t^3}{3}\right]_2^3 \Rightarrow \left[t^2 - t^3\right]_2^3$$

$$(3^2 - 3^3) - (2^2 - 2^3) \Rightarrow (9 - 27) - (4 - 8)$$

$$(-18) - (-4) \Rightarrow -18 + 4 = \boxed{-14\,C}$$

Q) An e^- is moving in a circular orbit of radius R. Its frequency of rotation is ν. Calculate magnitude of current associated with the e^-



$T \longrightarrow e$

$1 \longrightarrow \frac{e}{T} = I$

$\therefore \boxed{I = e\nu}$

$\boxed{T = \frac{2\pi R}{v}}$

$\therefore I = \frac{e}{T} = \frac{e}{\left(\frac{2\pi R}{v}\right)} = \boxed{\frac{ev}{2\pi R} = I}$

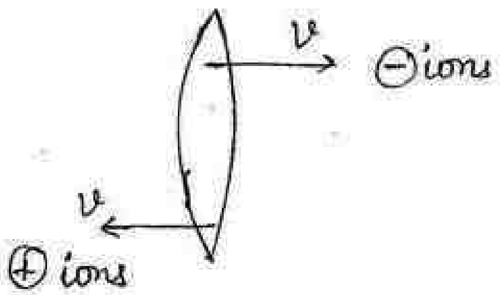
* In metals only free e^-s are responsible for current conduction.
* In electrolytes +ve and -ve ions are responsible for current conduction eg $NaCl \longrightarrow Na^+ + Cl^- (aq)$
* In gases +ve ions and e^-s are responsible for current conduction

  eg $H \longrightarrow H^+ + e^-$

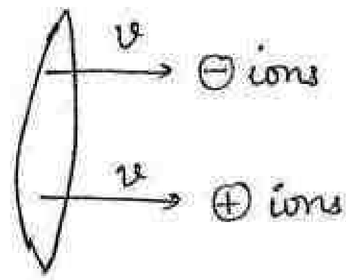
⇒ Electric current is scalar

In case of liquid / gases:

Case I



Case - II

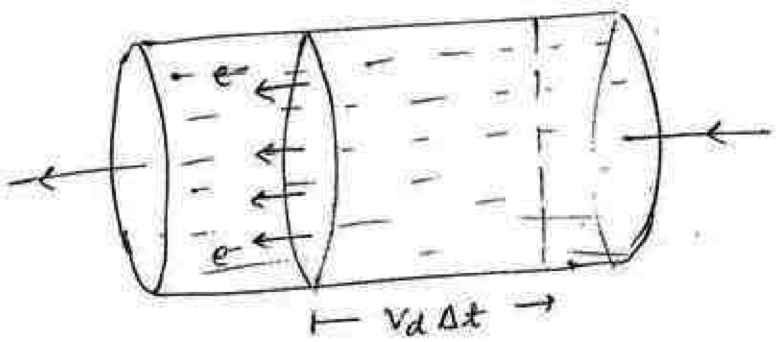


$I_{net} = I_1 + I_2 \ (\leftarrow)$

$I_{net} = I_1 - I_2 \ (\rightarrow)$

current moves in the dirⁿ of the +ve and in the oppo. dirⁿ of -ve

Q) In a conducting wire, area of cross section is A and free e- density is n. and drift velocity is V_d. Find expression of electric current in the wire.



group of e⁻s moves with constant velocity and it travels $V_d \Delta t$ distance in time interval Δt. so charge enclosed in the volᵐ, $A(V_d \Delta t)$ will pass through the cross sectional area and value of charge is

$\Delta q = A(V_d \Delta t) \times n \times e$

$$\therefore \boxed{\frac{\Delta q}{\Delta t} = I = neAv_d}$$

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

- It is current passing through per unit area of cross section.
- It's unit is A/m^2 and it is a vector quantity. • It's direction is in the direction of electric field.

$$I = neAV_d$$

$$\therefore J = \frac{I}{A} = \frac{neAV_d}{A} = \boxed{neV_d}$$

$$J = ne(\mu E)$$

$$J = ne\left[\frac{e\tau}{m_e}\right]E = \left(\frac{ne^2\tau}{m_e}\right)E$$

$$J = \sigma E$$

** $\therefore \boxed{\vec{J} = \sigma\vec{E}}$ here $\sigma = \frac{ne^2\tau}{m_e}$

conductivity.

$$\rho = \frac{1}{\sigma} = \frac{m_e}{ne^2\tau}$$

resistivity

specific resistance

conclusion :

> σ and ρ depends upon nature and temp. of material

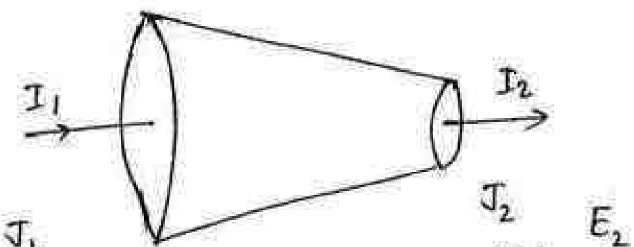
> * In case of metals, if temperature ↑es, then relaxation time ↓es (no of collision ↑es) so σ ↓es and ρ ↑es.

> * In insulators and semi- conductor, If temp ↑es then n ↑es (free e⁻ = excited e⁻), σ ↑es and ρ ↓es

> $I = \oint \vec{J} \cdot d\vec{A}$

It means current is flux of current density

Q)



i) I_1 __=__ I_2 (incoming ~~charge~~ current = outgoing charge)

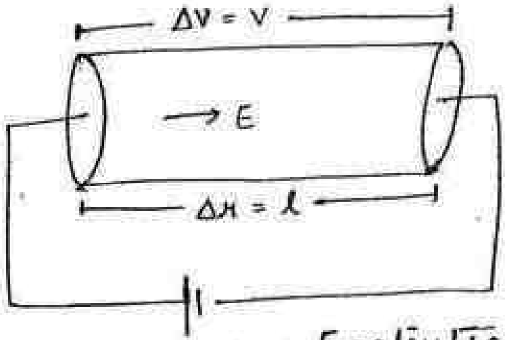
ii) J_1 __<__ J_2 $\left(J \propto \frac{1}{A} \right)$

iii) E_1 __<__ E_2 $\left(\cancel{V_d \propto \frac{1}{A}} \right)$ $[E \propto J]$

iv) Vd_1 __<__ Vd_2 $(E \propto V_d)$ $[V_d \propto E]$

Article 3 Ohm's law

* we talk of potential as a reference
∴ V as potential, makes no sense.
It's potential difference



$\Delta V = V$ [potential difference]

$J = \sigma E$

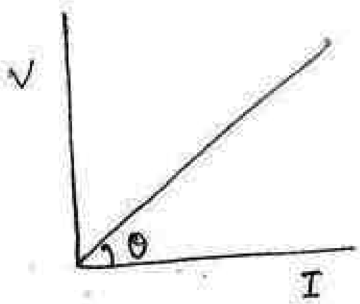
$$\frac{I}{A} = \frac{1}{\rho}\left(\frac{\Delta V}{\Delta x}\right)$$

$$\frac{I}{A} = \frac{1}{\rho} \times \frac{V}{l} \qquad \therefore \; V = \frac{\rho l}{A} I$$

$$\boxed{V = IR} \qquad \therefore \; R = \frac{\rho l}{A}$$

If R = constant

$V \propto I$ (Ohm's law)



$$\text{slope} = \tan\theta = \frac{V}{I} = R$$

Conclusion :

i) Ohm's law is not a fundamental law.

ii) Semiconductor device doesn't follow ohm's law

iii) Resistance depends upon ⇒ nature, Temp, length and area of cross section of wire but

ρ : independent of l and A

Q) Resistance of a wire is R. If it is stretched then its length becomes n times of initial. Find its final resistance

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

$$\therefore \quad R = \frac{\rho l'}{A'} = \frac{\rho\, nl}{A/n}$$

$$= n^2 \frac{\rho l}{A} = \boxed{n^2 R}$$

$$\left[\begin{array}{l} \because\ V_1 = V_2 \\ \therefore\ A \times l = nl \times A' \\ \therefore\ A' = \dfrac{A \times \cancel{l}}{n \cancel{l}} = \dfrac{A}{n} \end{array}\right.$$

Q) When a wire of resistance R is stretched its radius of cross section becomes $1/n$ times of initial. Find its final resistance

$$\because \quad V_1 = V_2$$

$$\therefore \quad A \times l = A' l'$$

$$l' = \frac{(\pi r^2)\, l}{\pi \left(\frac{r}{n}\right)^2}$$

$$\therefore \quad l' = n^2 l$$

$$\because \quad R = \frac{\rho l'}{A'} = \frac{\rho n^2 l}{\pi \left(\frac{r}{n}\right)^2}$$

$$= \frac{n^4 \rho l}{\pi r^2} = n^4 \frac{\rho l}{A}$$

$$= \boxed{n^4 R.}$$

Q) When a wire is stretched, its length increases by 50%. Find % change in its resistance.

$$l' = l \times \frac{50}{100} = \frac{l}{2} \Rightarrow l + \frac{l}{2} = \frac{3l}{2}$$

$\because V_1 = V_2$

$A \times l = A' \times l'$

$$\therefore A' = \frac{A \times l \times 2}{3l} = \frac{2A}{3}$$

$$\therefore R = \frac{\rho l'}{A'} = \rho \frac{3l}{2} \frac{3}{2A} = \frac{9}{4} \frac{\rho l}{A} = \frac{9}{4} R$$

$$\therefore \% \text{ change} = \frac{\Delta R}{R} \times 100$$

$$= \frac{\frac{9}{4}R - R}{R} \times 100$$

$$= \frac{5R}{4R} \times 100 = 25 \times 5 = \boxed{125\%}$$

* $\boxed{\text{Change} \Rightarrow \Delta R} \Rightarrow R_f - R_i$

* $\boxed{\text{Fractional change} \Rightarrow \frac{\Delta R}{R}} = \frac{R_f - R_i}{R_i}$

* $\boxed{\% \text{ change} \Rightarrow \frac{\Delta R}{R} \times 100} \Rightarrow \frac{R_f - R_i}{R_i} \times 100$

Q) There are 3 copper wire, Ratio of their length is 1:2:3 and Ratio of their mass is ~~3:2:1~~ 3:1:2 Find ratio of resistance

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

$$\therefore R = \frac{\rho l^2}{(Vol^m)} \quad \left[\because Vol^m = A \times l \quad \therefore A = \frac{Vol^m}{l}\right]$$

$$R = \frac{\rho l^2}{\left(\frac{m}{d}\right)} \Rightarrow \frac{\rho l^2 d}{m}, \quad d = \text{density}.$$

$$\therefore R \propto \frac{l^2}{m} \qquad \therefore R_1 : R_2 : R_3 = \frac{1^2}{3} : \frac{2^2}{1} : \frac{3^2}{2}$$

$$\frac{1}{3} : \frac{4}{1} : \frac{9}{2} \Rightarrow \boxed{2 : 24 : 27}$$

Q) There are three copper wire. Ratio of their area of cross section is 1:1:2 and ratio of their mass is 1:2:3

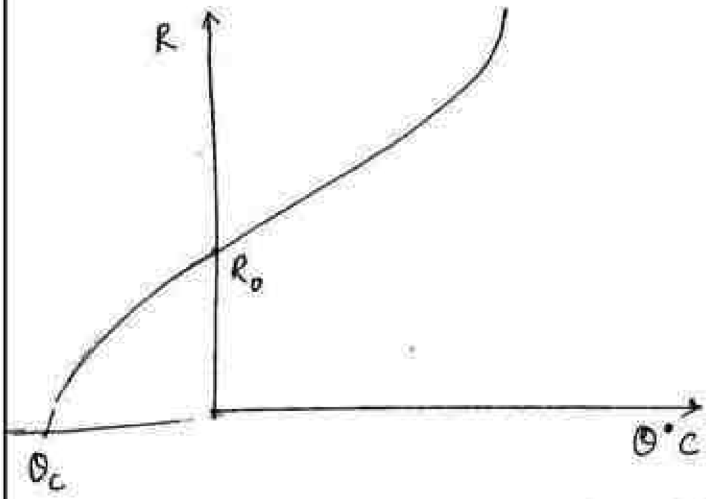
$$\because R = \frac{\rho l}{A} \Rightarrow \frac{\rho\,(vol^m)}{A \quad A} = \frac{\rho\, Vol^m}{A^2} \quad \left[\because l = \frac{Vol^m}{A}\right]$$

$$\therefore R = \frac{\rho\left(\frac{m}{d}\right)}{A^2} \quad \left[\because Vol^m = \frac{m}{d}\right]$$

$$\therefore R \propto \frac{m}{A^2} \Rightarrow \frac{1}{1^2} : \frac{2}{1^2} : \frac{3}{2^2} \Rightarrow 1 : 2 : \frac{3}{4}$$

$$\therefore R_1 : R_2 : R_3 \Rightarrow \boxed{4 : 8 : 3}$$

Variation in resistance with temperature



$$\boxed{R_{t_2} = R_{t_1}\left[1 + \alpha(t_2 - t_1)\right]}$$

$$R_{t_2} = R_{t_1} + R_{t_1}\,\alpha(t_2 - t_1)$$

$$\therefore \frac{R_{t_2} - R_{t_1}}{R_{t_1}(t_2 - t_1)} = \alpha$$

Conclusion:

i) graph is not a perfect straight line but in numerical. It can be taken as approx a straight line

ii) α is called, Temperature coefficient of resistance. It is defined as fractional change in resistance for unit change in temperature i.e. $\alpha = \frac{\Delta R}{R(s)}$
Its unit is per°c or per K ($\because$ change is same)

iii) θ_c is critical temp, at this temp, resistance becomes zero and conductor becomes super conductor

$\boxed{\theta = 4.2\ K}$

Q) Temp coefficient of a wire is 0.00125 per °. Its resistance at 300 K is 1 Ω. Find at which temp its resistance will be 2 Ω

$$\because \; R_{t_2} = R_{t_1}\left[1 + \alpha\,(t_2 - t_1)\right]$$

$$2 = 1\left[1 + \alpha\,(t_2 - t_1)\right]$$

$$1 = \alpha\,(t_2 - t_1)$$

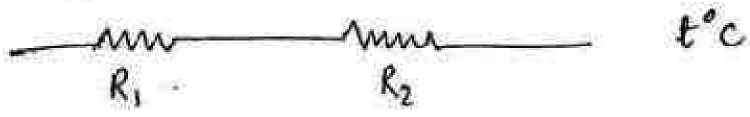
$$t_2 - t_1 = \frac{1}{\alpha} = 800$$

$$t_2 = 800 + t_1$$

$$= 800 + 300 = \boxed{1100}$$

Q) There are 2 wire of Temp coefficient (α) * and ($-\beta$). If effective resistance of their series combination is <u>independent</u> of temp. then find ratio of their resistances at 0°C

let the system be at t temp



$$R_{net} = R_1 + R_2$$

$$= R_{o_1}\left[1 + \alpha\,(t - 0)\right] + R_{o_2}\left[1 + (-\beta)(t - 0)\right]$$

$$= (R_{o_1} + R_{o_2}) + t\left[\alpha R_{o_1} - \beta R_{o_2}\right]$$

If R_{net} is independent of temp then

$$R_{o_1}\alpha - R_{o_2}\beta = 0$$

$$\therefore \frac{R_{o_1}}{R_{o_2}} = \frac{\beta}{\alpha}$$

Q) There are 2 wires with temp. coefficient α_1 and α_2 there resistance at $0°C$ are R_{o_1} and R_{o_2}. Find equivalent temp. coefficient of their series combination.

$$R_{eq} = R_1 + R_2 \quad (\because \text{~~series~~ series})$$

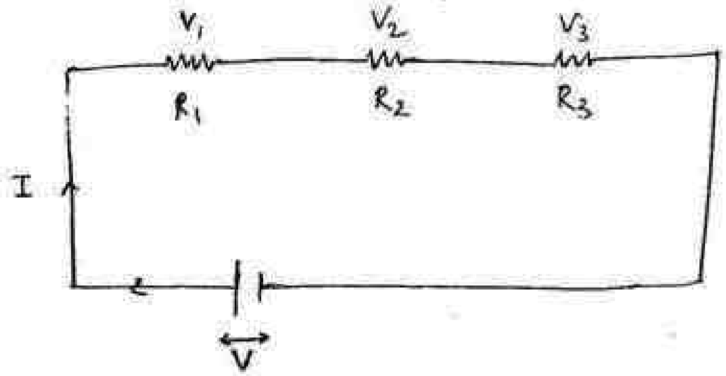
$$= R_{o_1}[1 + \alpha_1(t-0)] + R_{o_2}[1 + \alpha_2(t-0)]$$

$$= (R_{o_1} + R_{o_2}) + t(R_{o_1}\alpha_1 + R_{o_2}\alpha_2)$$

$$= (R_{o_1} + R_{o_2})\left[1 + \frac{(R_{o_1}\alpha_1 + R_{o_2}\alpha_2)}{R_{o_1} + R_{o_2}}t\right]$$

$$\therefore \boxed{\alpha_{eq} = \frac{R_{o_1}\alpha_1 + R_{o_2}\alpha_2}{R_{o_1} + R_{o_2}}}$$

Ⓐ Series combination of Resistance



$$\because \quad V = V_1 + V_2 + V_3$$

$$I R_{eq} = IR_1 + IR_2 + IR_3$$

$$R_{eq} = R_1 + R_2 + R_3$$

Imp. Points

i) If there is a single loop without any branch then all resistances are connected in series then current in the loop is

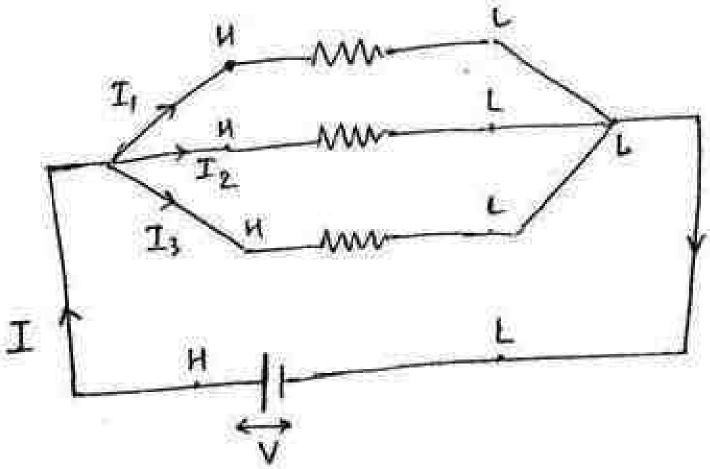
$$\boxed{I = \frac{V_{net}}{R_{net}} = \frac{V_{eq}}{R_{eq}}}$$

This is the current supplied by battery and current in each elements

ii) If all series resistance are equal and no. of resistance are N, then $\boxed{R_{eq} = NR}$

iii) In series combination, Req > resistance of greatest value

(B) Parallel combination of resistances.



$$I = I_1 + I_2 + I_3$$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Imp points:

i) Initial end of all resistances should be at common point as well as final ~~and~~ end of all resistance should be at common point.

ii) Potential across each element are equal

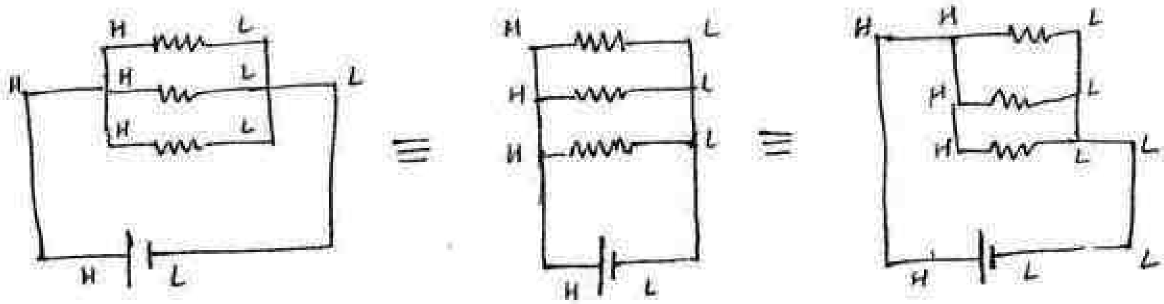
iii) If there are N resistance, each of value R, then $\boxed{R_{eq} = \frac{R}{N}}$

iv) If there are only 2 parallel wire 

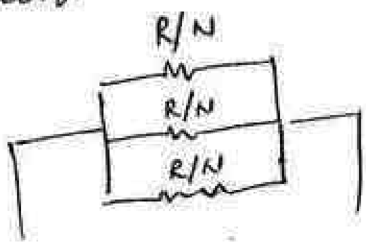
$\frac{1}{R} = \frac{1}{R} + \frac{1}{R}$ $\Rightarrow \therefore R_{eq} = R_1R_2$ is Product

v) In parallel combination,

$R_{eq} <$ smallest value



Q) Resistance of a wire is R. It is cut
* into N equal parts of length. Now these parts are connected in parallel with each other. Find equivalent resistance of combination.

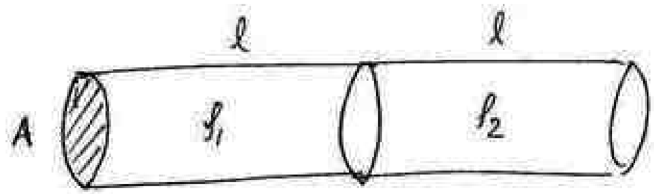


$R = \frac{\rho l}{A}$ $\quad R' = \frac{\rho (l)}{(n)(nA)} = \boxed{\frac{R}{n^2}}$

$$R_{eq} = \frac{R'}{N} = \frac{R/N}{N} = \frac{R}{N^2}$$

Q) There are 2 wires of equal length and equal area of cross section. There resistivity are ρ_1 and ρ_2 respectively. Find <u>equivalent resitivity</u> of their combination. if they are connected in i) series

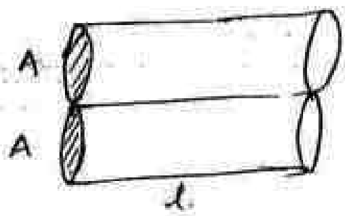
ii) Parallel

i) 

$$R_{eq} = R_1 + R_2$$

$$\frac{\rho_{eq}(2l)}{A} = \frac{\rho_1 l}{A} + \frac{\rho_2 l}{A}$$

$$\therefore \boxed{\rho_{eq} = \frac{\rho_1+\rho_2}{2}}$$ (A.M) Arithmetic mean

ii) 

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

$$\frac{\rho_{eq}\, l}{2A} = \frac{\left(\frac{\rho_1 l}{A}\right)\left(\frac{\rho_2 l}{A}\right)}{\frac{\rho_1 l}{A} + \frac{\rho_2 l}{A}}$$

$$\therefore \boxed{\rho_{eq} = \frac{2\rho_1\rho_2}{\rho_1+\rho_2}}$$ (H.M) Harmonic mean

Article : 4 Ⓐ Kirchoff's law (current) (KCL)

1) Kirchoff's first law (or current law or junction law)

At any junction of electric circuit, <u>algebric sum</u> of all current must be zero.
It is based on <u>charge conservations.</u>

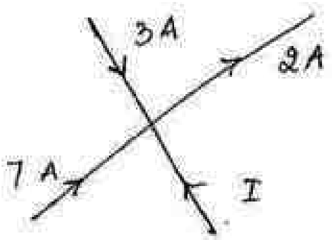
$$\boxed{\sum_{\text{junction}} I = 0}$$

OR

$$|I_{in}| = |I_{out}|$$

$$I_1 + I_2 = I_3 + I_4$$

Q)

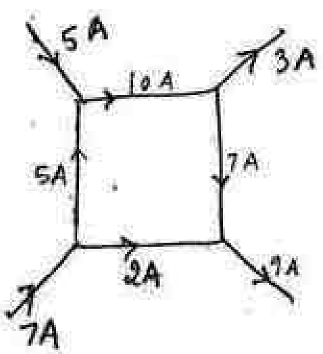


$7 + 3 + I = 2$

$\therefore \boxed{I = -8}$

here, –ve indicates that actual flow of current is opposite to given dirn.

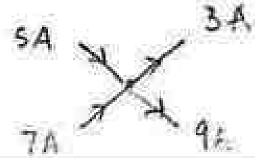
Q)



Incoming = Outcoming

$5 + 7 = 3 + I$

$\therefore I = 9A$

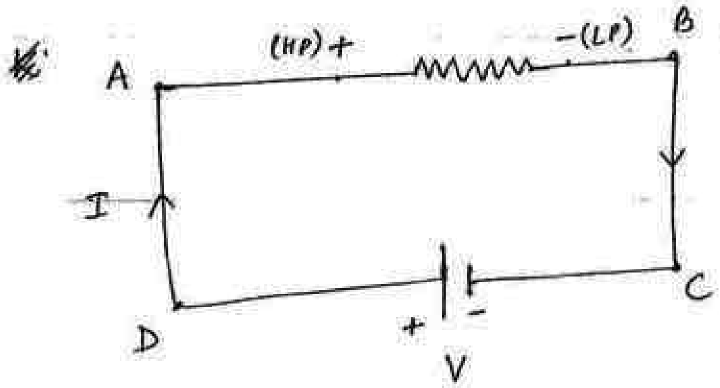


(B) Kirchoff's voltage law (KVL) /
Kirchoff's second law /
Kirchoff's loop law

* Algebric sum of all potential difference (including resistance and battery) in a loop must be zero.
* It is based on energy conservation.

$$\boxed{\sum_{loop} V = 0}$$

eg:



KVL in the loop ABCDA :

$$\cancel{V_A} - IR + V = \cancel{V_A}$$

$$= -IR + V = 0$$

so $\sum_{loop} V = 0$

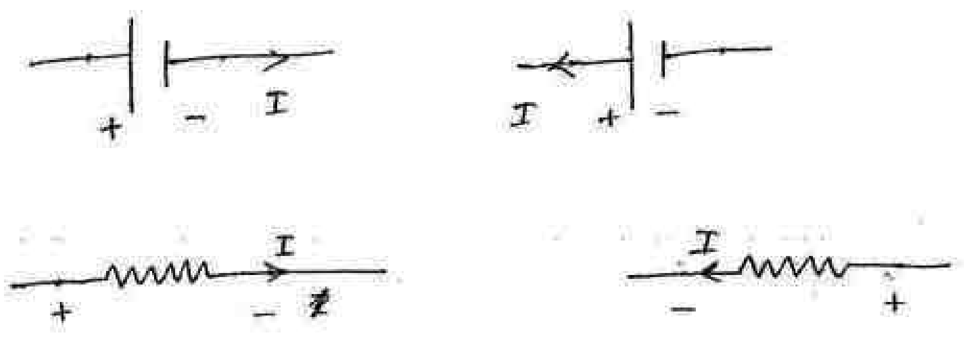
How to apply KVL :

i) select direction of current

ii) Put ⊕ve and ⊖ve sign across each elemen

iii) ⊕ve and ⊖ve sign on the resistence (resistor depends upon dirⁿ of current but ⊕ve and ⊖ve sign across battery is independant of dirⁿ of current.

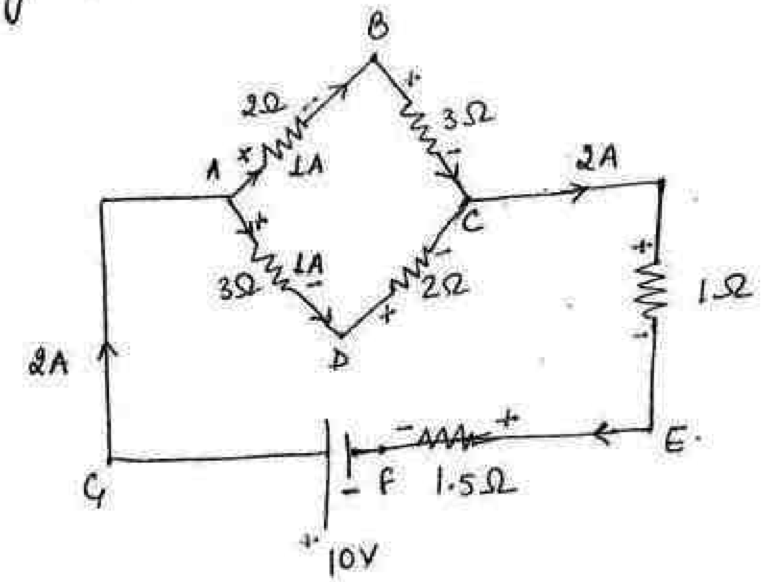
①



iii) select a loop or part of loop to apply KVL and selection of loop is <u>independent of dirⁿ of current</u>

iv) Apply KVL

Q)



$\because \quad V = IR$

$$\therefore I = \frac{V_{net}}{R_{net}} = \frac{10}{5} = 2A.$$

Find:

i) $V_A - V_C$

KVL in ABC

$V_A - 2\times1 - 3\times1 = V_C$

$\therefore \quad V_A - V_C = 3+2 = \boxed{5V}$

ii) $V_B - V_D$

KVL in BCD

$V_B - 3 + 2 = V_D$

$\therefore \; V_B - V_D = 3 - 2 = \boxed{1V}$

iii) $V_D - V_E$

KVL in DCE

$V_D - 2 - 2 = V_E$

$\therefore \; V_D - V_E = \boxed{4V}$

iv) $V_A - V_F$

KVL in ABCEF

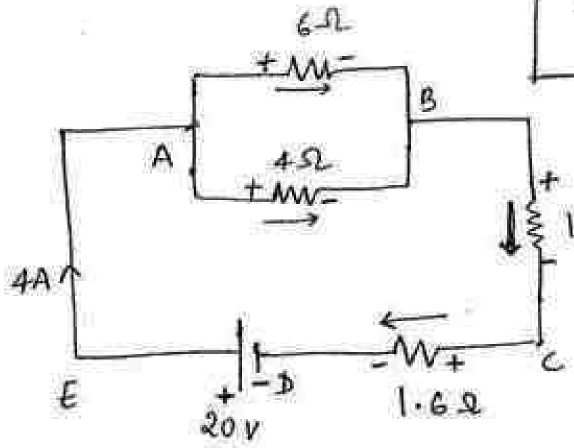
$V_A - 2 - 3 - 2 - 3 = V_F$

OR KVL in AGF

$V_A - 10 = V_F$

$\therefore V_A - V_F = \boxed{10V}$

a)



$I_1 : I_2 : I_3 = \frac{1}{R_1} : \frac{1}{R_2} : $

current is in the inverse ratio of resistance

$\therefore$ I across 6Ω $= \frac{4}{10} \times 4 = 1.6$

I across 4Ω $= \frac{6}{10} \times 4 = 2.4$

$\because \quad V = IR$

$\therefore \quad I = \frac{V_{net}}{R_{net}} = \frac{20}{5} = 4A$

i) $V_A - V_B$

~~V_A~~ KVL in AB

$V_A - IR = V_B$

$V_A - V_B = IR = 4 \times 2.4 = \boxed{9.6\ V}$

ii) $V_A - V_C$

KVL in ADC

$V_A - 20\ V + 1.6 \times 4 = V_C$

$\therefore \quad V_A - V_C = 20 - 6.4 = \boxed{13.6 V}$

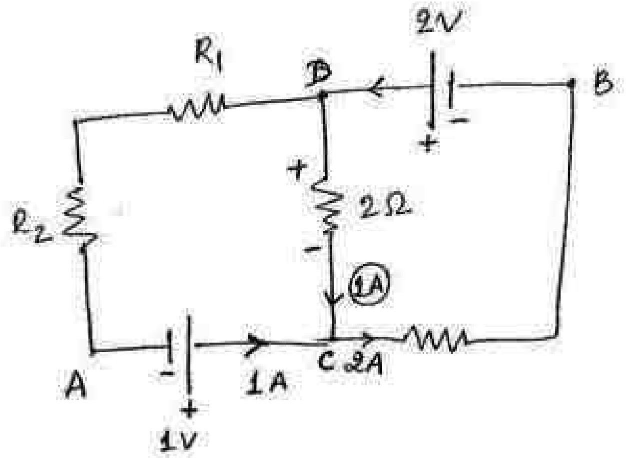
iii) $V_A - V_D$

KVL in AED

$V_A - 20V = V_D$

$\therefore \quad V_A - V_D = \boxed{20 V}$

Q)



If $V_A = 0$. Find V_B

KVL in ACDB

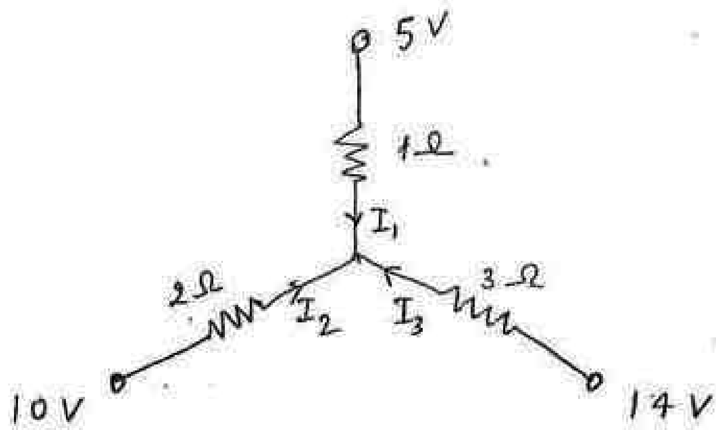
$$V_A + 1 + 2 - 2 = V_B$$

$$\therefore \quad V_A - V_B = -1$$

$$0 - V_B = -1$$

$$\therefore \quad V_B = 1$$

Q)



Find I_1, I_2 and I_3.

Find potential at junction

$$I_1 + I_2 + I_3 = 0 \quad \text{(KCL)}$$

$$\left(\frac{5-x}{1}\right) + \left(\frac{10-x}{2}\right) + \left(\frac{14-x}{3}\right) = 0$$

$$\therefore \quad \frac{6(5-x) + 3(10-x) + 2.(14-x)}{6} = 0$$

$$\therefore \; 30 - 6x + 30 - 3x + 28 - 2x = 0$$

$$\therefore \; 88 - 11x = 0$$

$$\therefore \; 11(8-x) = 0$$

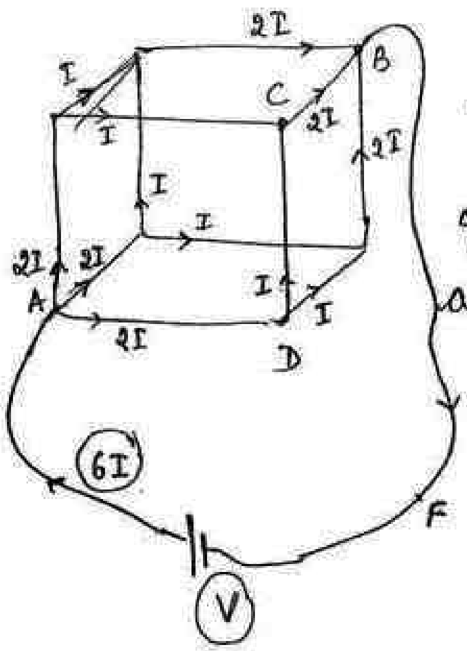
$$\therefore \; x = 8$$

$$I_1 = \frac{5-8}{1} = -3\,A$$

$$I_2 = \frac{10-8}{2} = 1\,A$$

$$I_3 = \frac{14-8}{2} = \frac{6}{2} = 3A$$

* Q)



There are 12 identical wire each of resistance R in a cubical network

distribute the charges at point A and then at point B. and then manipulate the charges within

i) $\therefore \quad R_{eq} = \dfrac{V}{6I} \quad \text{—} (1)$

KVL in loop ADCBFA

$$\cancel{V_A} - 2IR - IR - 2IR + V = \cancel{V_A}$$

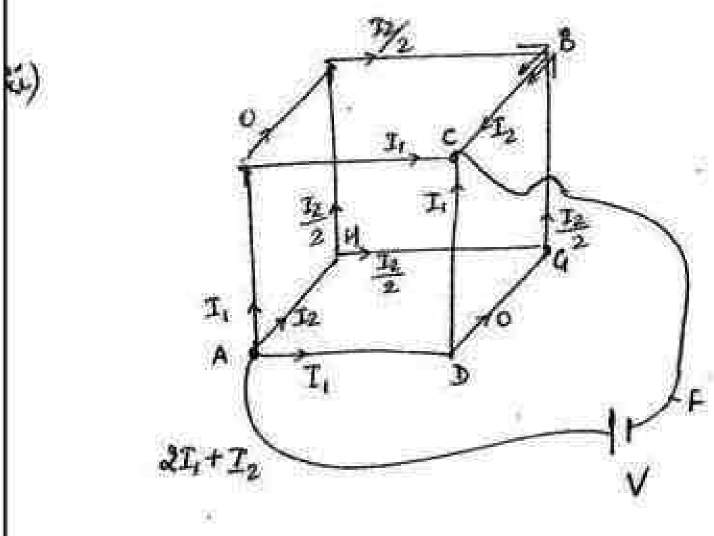
$$\therefore \quad V = 5IR$$

$$\therefore \quad \frac{V}{I} = 5R$$

Putting in eq (1)

$$R_{eq} = \frac{1}{6}\left(\frac{V}{I}\right) = \frac{1}{6}5R = \boxed{\frac{5}{6}R}$$

ii)



$$R_{eq} = \frac{V}{2I_1 + I_2} \quad \text{—} (1)$$

Loop ADGFA

$$\cancel{V_A} - I_1R - I_1R + V = \cancel{V_A}$$

$$\therefore \quad V = 2I_1R \qquad \therefore \quad \frac{V}{I_1} = 2R \quad \text{—} (11)$$

loop ADGHA

$$\cancel{V_A} - I_1 R + \left(\frac{I_2}{2}\right)R + I_2 R = \cancel{V_A}$$

$$\therefore \quad I_1 R = \frac{I_2 R}{2} + I_2 R = \frac{R(I_2 + 2I_2)}{2} = \frac{3I_2 R}{2}$$

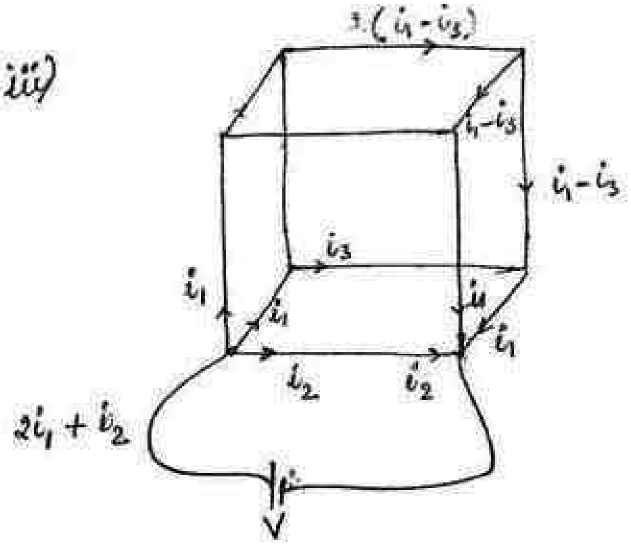
$$I_1 \cancel{R} = \frac{3}{2} I_2 \cancel{R}$$

$$\therefore \quad I_2 = \frac{2}{3} I_1 \qquad \text{put in eq } (1)$$

$$\therefore \; R_{eq} = \frac{V}{2I_1 + \left(\frac{2}{3} I_1\right)} = \frac{3}{8}\left(\frac{V}{I_1}\right) = \frac{3}{8} 2R$$

$$\therefore \quad \boxed{R_{eq} = \frac{3}{4} R}$$

iii)



Conclusion

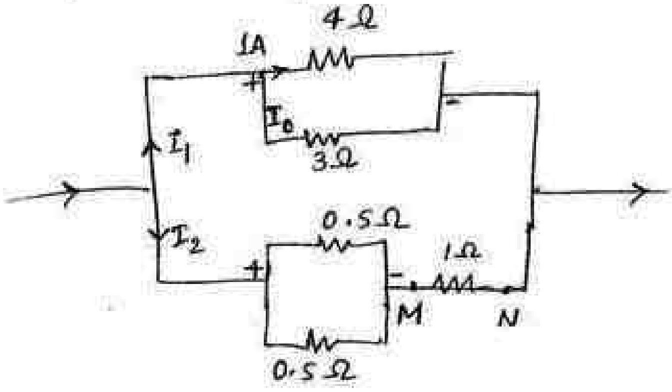
$$R > \frac{5}{6} R > \frac{3}{4} R > \frac{7}{12} R$$

$$R_{eq} = \frac{V}{2I_1 + I_2}$$

On solving, we get

$$\boxed{\frac{7}{12} R}$$

Q1) A part of network is given



Calculate $V_M - V_N$

$$1 \times 4 = I_0 (3) \quad \left[\because V_1 = V_2 \quad I_1 R_1 = I_2 R_2 \right]$$

$$\therefore \quad I_0 = \frac{4}{3}$$

$$I_1 = 1A + I_0$$

$$= 1 + \frac{4}{3} = \frac{7A}{3}$$

$\therefore I_1 \times R_1 = I_2 \times R_2$ ($\because$ they are in parallel)

$$\frac{7}{3} \times \frac{12}{7} = I_2 \times \frac{5}{4}$$

$$\therefore \quad I_2 = \frac{\cancel{7}}{\cancel{3}} \times \frac{\cancel{12}^{4}}{\cancel{7}} \times \frac{4}{5} = \frac{16}{5}$$

$$R_1 = \frac{4 \times 3}{4+3} = \frac{12}{7}\,\Omega$$

$$R_2 = \frac{0.5 \times 0.5}{0.5 + 0.5} + 1$$

$$= 0.25 + 1 = 1.25 = \frac{5}{4}\,\Omega$$

~~OR~~

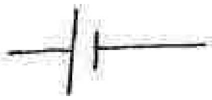
By KVL

$$V_M + \frac{16}{5} \times \frac{1}{4} - \frac{7}{3} \times \frac{12}{7} = V_N$$

$$\therefore V_M - V_N = \frac{12}{3} - \frac{4}{5} = \frac{60 - 12}{15} = \frac{48}{15} = \boxed{\frac{16}{5}}$$

$\boxed{\text{Article : 5}}$ Cell and Battery

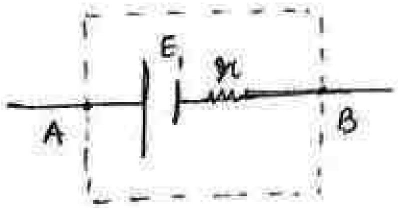
i) Ideal cell :



EMF : Electro motive force (in volt) ≠ force

Internal resistance $(r) = 0$

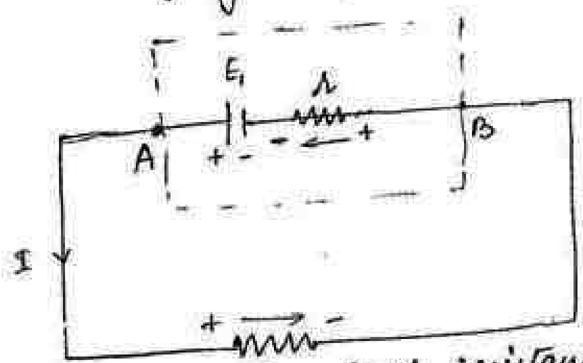
ii) Real cell :



$V_A - V_B$ = TPD (Terminal Potential diff)

always ⊕ve value

iii) Discharging of a cell :



current comes out from the +ve terminal of the battery (Discharging)

R_L = load resistance

KVL A to B (via battery)

$$V_A - E_1 + Ir = V_B$$

$$\therefore V_A - V_B = E_1 - Ir$$

$$\therefore \boxed{TPD = E_1 - Ir}$$

KVL A to B (via R_L)

$$V_A - IR_L = V_B$$

$$\left[V_A - V_B = IR_L \right]$$

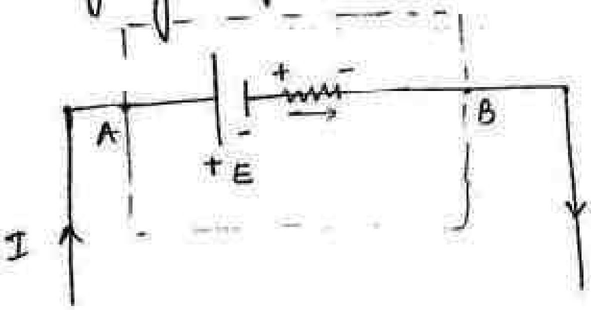
current feeds all the resistance whereas TPD feeds only the load resistance

***

$$\therefore \boxed{I = \frac{E_1}{r + R_L} = \frac{TPD}{R_L}}$$ NEET 2013

> If cell is not in used ($I = 0$), then its TPD is its EMF

(iv) charging of a cell



Current enters into the +ve terminal of the battery

KVL A to B

$$V_A - E - Ir = V_B.$$

$$\therefore V_A - V_B = Ir + E$$

$$\therefore \boxed{TPD = E + Ir}$$

Here, TPD > E_1

Points to remember

TPD may be greater than or less than EMF of the cell

charging $\Rightarrow$ greater

discharging $\Rightarrow$ lesser

Q) EMF of a cell is 10V. It is connected across a load of resistance 2Ω. If current supplied by battery is 4A, then find internal resistance of the cell

$$I = \frac{E}{r + R_L} \Rightarrow 4 = \frac{10}{r + 2}$$

$$r = 0.5\,\Omega$$

Q) If 1 A current is drawn from a cell, then its TPD is 20 V but if 2A current is drawn from the cell, then its TPD is 10V find its EMF and internal resistance

$$20 = E - Ir$$

$$20 = E - (1)r \quad \text{—— (I)}$$

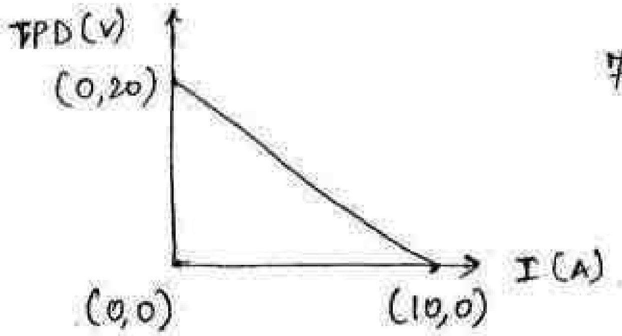
$$10 = E - (2)r \quad \text{—— (II)}$$

$$\therefore \; 10 = E - 2(E - 20) \Rightarrow E - 2E + 40$$

$$\therefore \boxed{E = 30}$$

$$r = E - 20 \Rightarrow 30 - 20 \Rightarrow \boxed{10}$$

2) A variable load is connected across the cell. and its graph for TPD verses I



Find its EMF and Internal resistance

$\because$ TPD = $E - Ir$

$20 = E - (0)r$

$\therefore \; E = 20V$

$\because$ TPD = $E - Ir$

$0 = 20 - (10)r$

$\therefore \; r = 2\,\Omega$

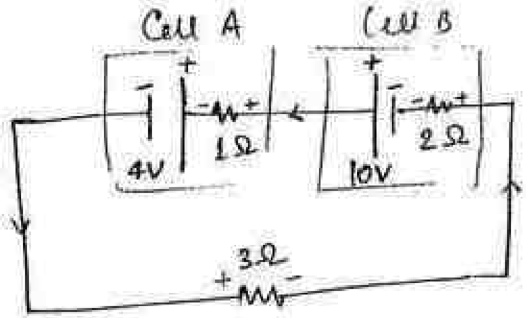
OR

TPD = $E - Ir$

$\downarrow$ TPD $\to y$, $\quad \downarrow I \to x$

$(\because y = c - mx)$

Q)



Find TPD of cell A and cell B

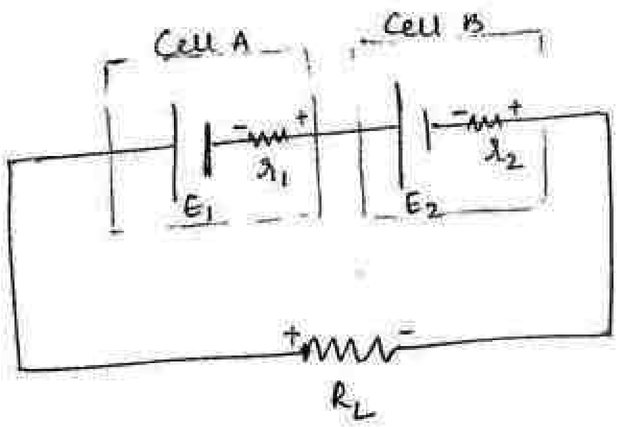
$$I = \frac{V_{net}}{R_{net}} = \frac{10-4}{1+2+3} = \frac{6}{6} = 1A$$

cell A (charging)

$$TPD_A = E \oplus Ir$$
$$= 4 + 1 \times 1 = 5V$$

cell B (discharging)

$$TPD_B = E - Ir$$
$$= 10 - 1 \times 2 = 8V$$



If $E_1 = E_2$ and TPD of cell A is zero then find value of R_L in terms of r_1 and r_2

$TPD = E_1 - Ir_1$

$\therefore E_1 = TPD + Ir_1$

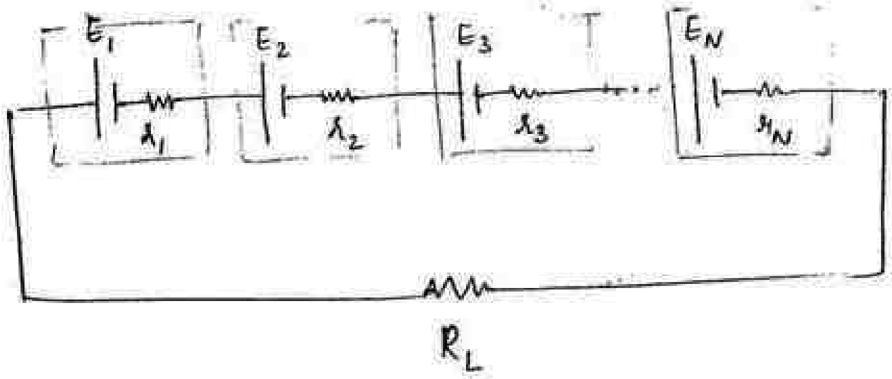
$= 0 + \left(\frac{E_1 + E_2}{\dots}\right) r_1$

$\therefore \cancel{E} = \frac{2\cancel{E} r_1}{r_1 + r_2 + R_L}$

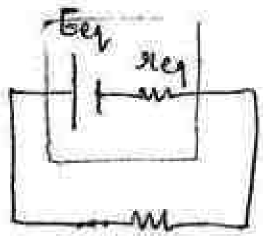
$\therefore r_1 + r_2 + R_L = 2r_1$

$\therefore \boxed{R_L = r_1 - r_2}$

Series combination of cells



$\equiv$



$$E_{eq} = E_1 + E_2 \ldots\ldots E_N$$

$$r_{eq} = r_1 + r_2 \ldots - r_N$$

cells having same polarity have ⊕ EMF and opposite polarity is taken as (-ve) EMF

Q) There are 12 identical cells, connected in series with same polarity. This combination is connected across a load. and current in the load is I. If polarity of N cells is reversed, then current in the load becomes $\frac{2}{3}$ of I. Find value of N

$$I = \frac{12E_1}{R_L + 12r} \quad \text{—(1)}$$

$$\frac{2}{3}I = \frac{(12-n)E_1 - nE_1}{R_L + 12r} = \frac{(12-2n)E_1}{R_L + 12r} \quad \text{—(2)}$$

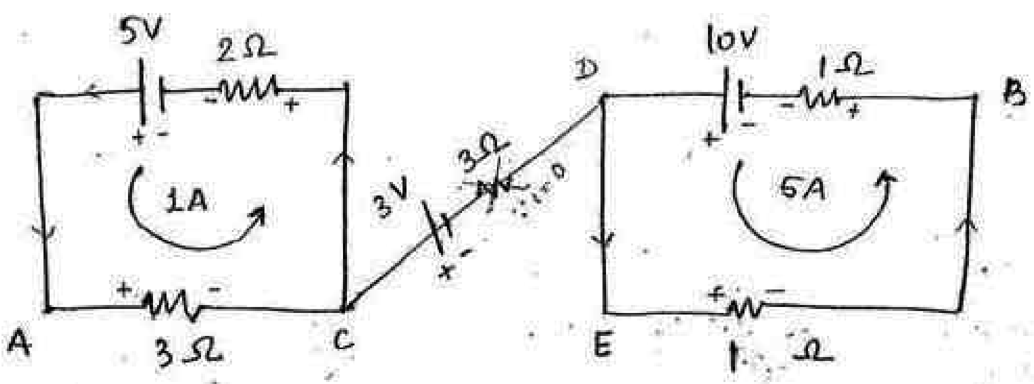
$$\frac{(2)}{(1)} = \frac{\dfrac{(12-2n)E_1}{\cancel{R_L+12r}}}{\dfrac{12E_1}{\cancel{R_L+12r}}} = \frac{\frac{2}{3}\cancel{I}}{\cancel{I}}$$

$$\Rightarrow \frac{12-2n}{12} = \frac{2}{3} \qquad \therefore 12-2n = 8$$

$$\therefore \boxed{n = 2}$$

Points to Remember:

If n cells are ~~removed~~ reversed then their will be diff. of 2n cells in net EMF

Q) 

find $V_A - V_B$

current in 1st loop $= \frac{V}{R} = \frac{5}{5} = 1A$

2nd loop $= \frac{V}{R} = \frac{10}{2} = 5A$

path ~~AB~~ ACDEB

$V_A - 3 - 3 - 5 = V_B$

$\therefore V_A - V_B = 5 + 3 + 1$

$= \boxed{11\,V}$

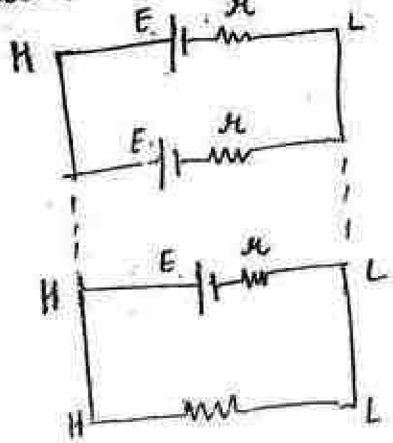
Points to remember:

> 2 loops are connected by a single wire then their will be no current in this wire.

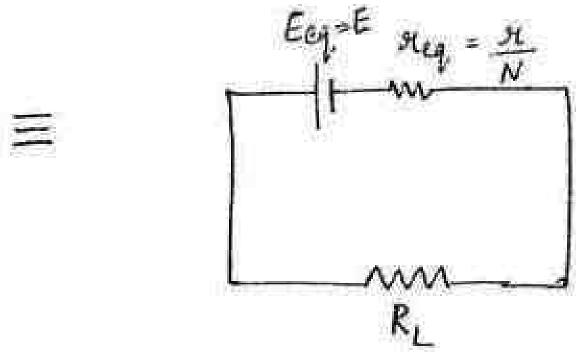
> ~~If~~ Its current from the cell is zero but it has potential difference b/w its terminal.

Parallel combination of cell:

1) N identical cell:



($\because$ In parallel combination, potential remains same)



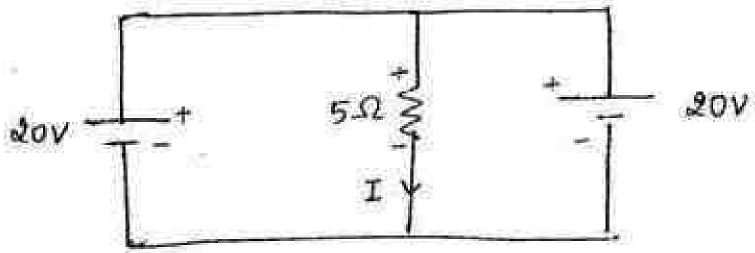
* Efficiency $(\eta) = \frac{\text{output}}{\text{input}}$

mAH ⇒ milli Ampere h

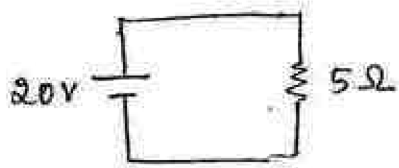
i) Parallel combination of cell increases ampere hour rating of the group of cell. and decreases effective internal resistance.

ii) Effective EMF will not increase.

Q)



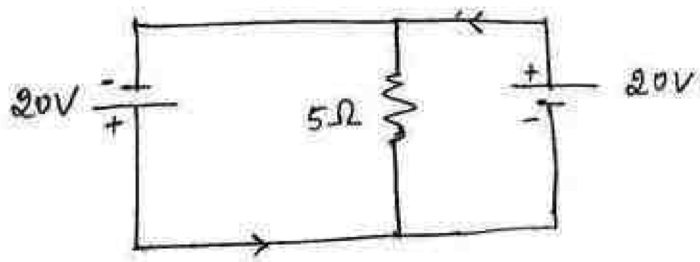
I = ?



$\therefore\ I = \frac{V_{net}}{R_{net}} = \frac{20}{5} = 4.$

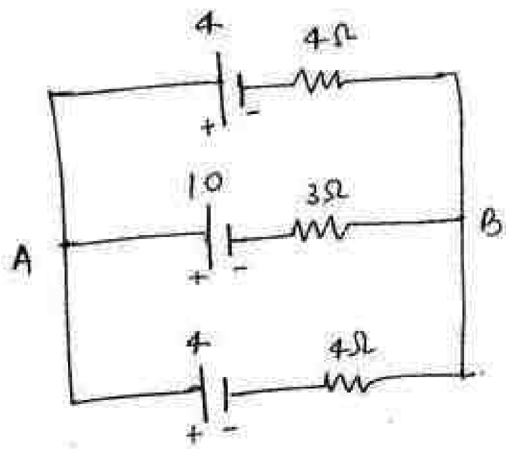
(∵ cells are in || arrangement)

Q)



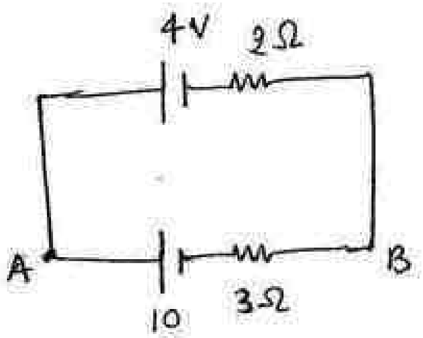
I = 0

Q)



Calculate I in line AB.

$\equiv$



$\because$ $R_{grouping} = \frac{R}{2}$

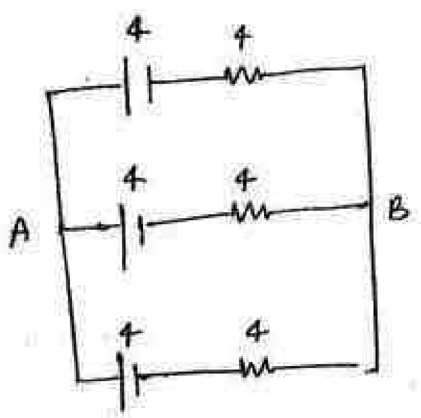
$= \frac{4}{2} = 2\Omega$

$V_{grouping} = V$ (Parallel)

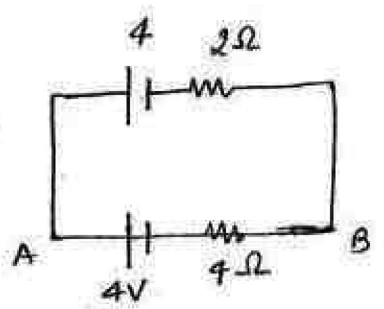
$\therefore I = \frac{V_{net}}{R_{net}} = \frac{10-4}{3+2} = \frac{6}{5} = 1.2$ A

* Do not include the line AB in grouping of cell.
(point of study)

Q)

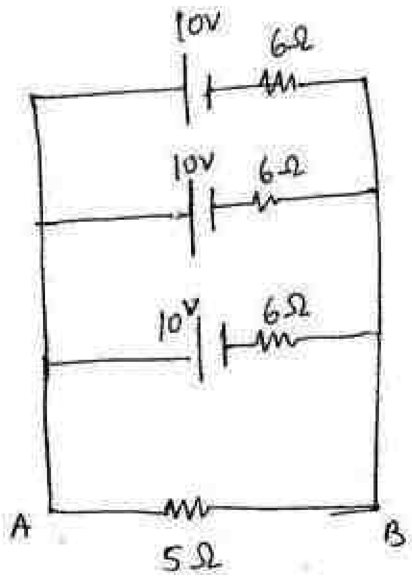


$\equiv$



$\therefore I = \frac{V_{net}}{R_{net}} = \frac{4-4}{6} = 0$

Q)



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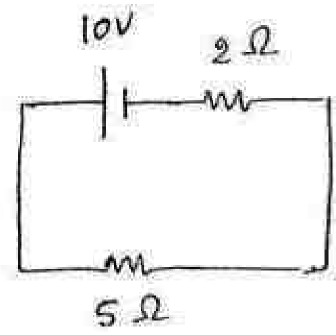
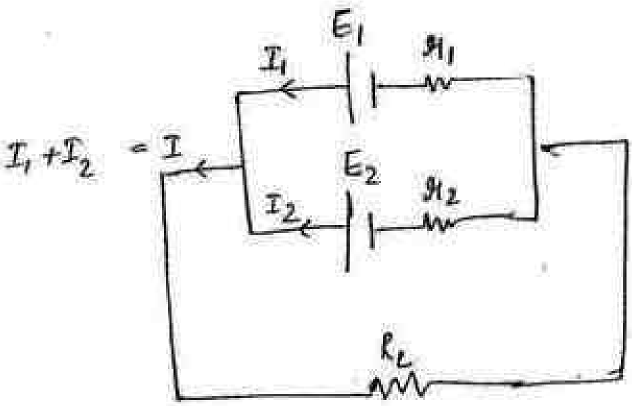


$$I = \frac{V_{net}}{R_{net}} = \frac{10}{2+5} = \frac{10}{7}$$

ii) Two cells of different (E, and r)



$\because I = I_1 + I_2$

$TPD = E_1 - I_1 r_1$ — (I)

$TPD = E_2 - I_2 r_2$ — (II)

[$\because$ its in parallel $\therefore$ TPD are equal]

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

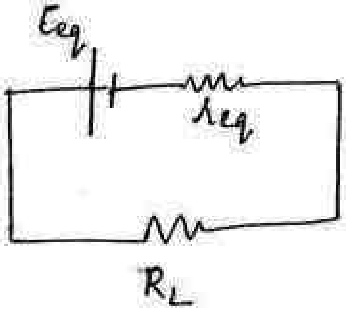
$$TPD\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - I$$

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

for N cells :

$$\boxed{E_{eq} = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2} + \frac{E_3}{r_3} \cdots\cdots \frac{E_N}{r_N}}{\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \cdots\cdots \frac{1}{r_N}\right)}}$$

* $V_{eq} = \frac{V\lambda(||)}{\lambda(||)}$

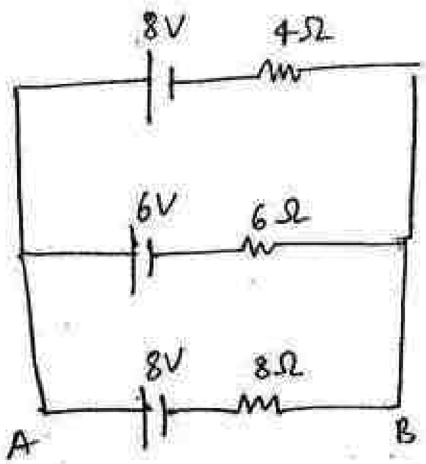


N = 2

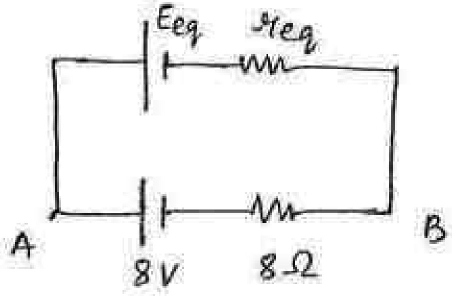
$$\boxed{E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}}$$

$$\therefore \; \boxed{r_{eq} = \frac{r_1 r_2}{r_1 + r_2}} \Rightarrow \frac{\text{product}}{\text{sum}}$$

Q)



after grouping,



here, $$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

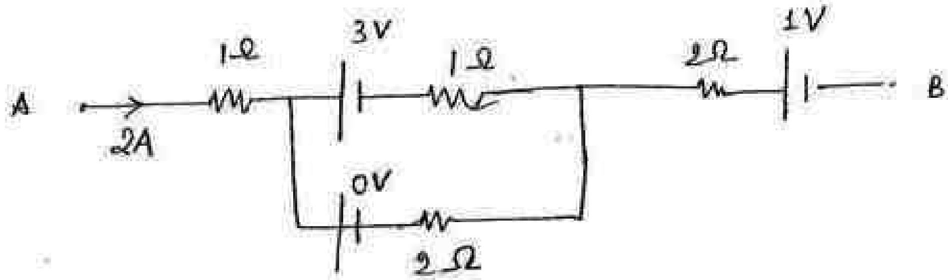
$$= \frac{8\times6 + 6\times4}{6+4} = \frac{72}{10} = 7.2\,V$$

$$r_{eq} = \frac{r_1 r_2}{r_1 + r_2} = \frac{6\times4}{6+4} = \frac{24}{10} = 2.4\,\Omega$$

$$\because \quad I = \frac{V_{net}}{R_{net}} = \frac{V_{eq}}{r_{eq}}$$

$$\Rightarrow \frac{8-7.2}{8+2.4} = \frac{0.8}{10.4} = \frac{1}{13}$$

Q)

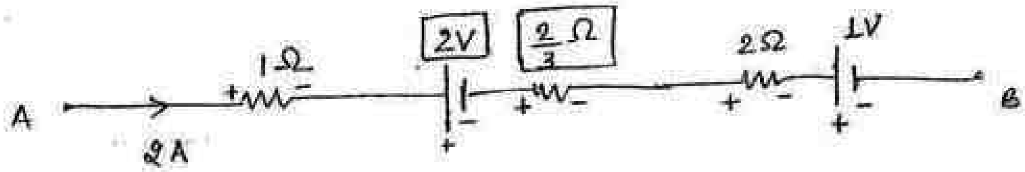


Find $V_A - V_B$

$$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

$$= \frac{3\times 2 + 1\times 0}{2+1} = \frac{\cancel{6}}{\cancel{3}} = 2V$$

$$r_{eq} = \frac{2\times 1}{2+1} = \frac{2}{3}\,\Omega$$



By KVL,

$$V_A - 2 - 2 - \frac{2}{3}\times 2 - 2\times 2 - 1 = V_B$$

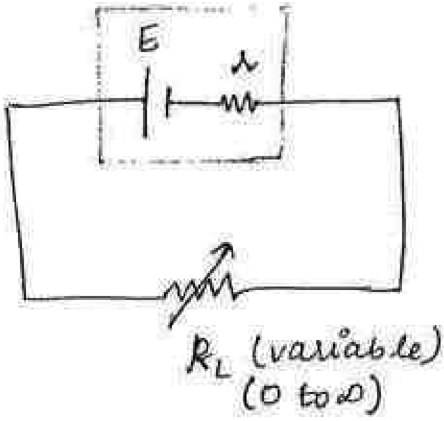
$$\therefore \quad V_A - V_B = 2 + 2 + \frac{4}{3} + 4 + 1$$

$$= \frac{6+6+4+12+3}{3}$$

$$= \boxed{\frac{31}{3}}$$

AIPMT 2012

Q)



Plot the graph b/w V across R_L and value of R_L

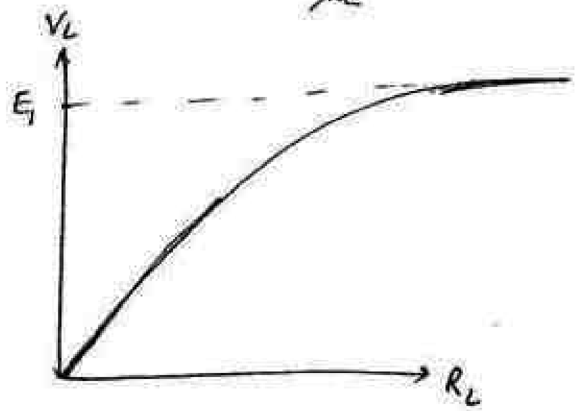
$V_L = I R_L$

$V_L = \left(\frac{E}{r + R_L}\right) R_L$

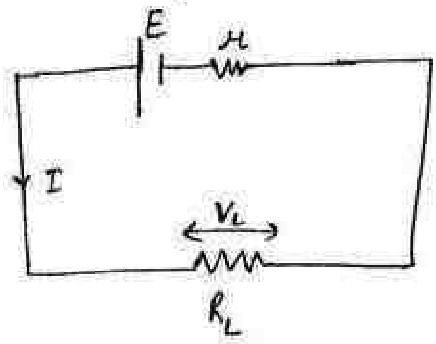
If $R_L << r$

$V_L = \left(\frac{E}{r}\right) R_L$ or $V_L \propto R_L$

If $R_L >> r$, $V_L = \frac{E}{\cancel{R_L}} \times \cancel{R_L}$ $\therefore V_L = E$



Electric power in the load R_L :



$w = q(\Delta V)$

$w = q(V_L)$

$\therefore P_L = \frac{dw}{dt} = \frac{d(qV_L)}{dt}$

Energy = $P \times t = VIt$

$= V_L \frac{dq}{dt} = V_L(I)$

$= V_L\left(\frac{V_L}{R_L}\right) = \frac{V_L^2}{R_L} = I^2 R_L$

$$\boxed{P_L = V_L I = \frac{V_L^2}{R} = I^2 R}$$

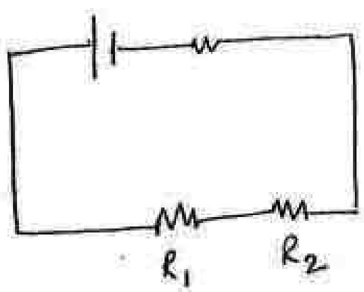
(Keep the corresponding values)

Power loss / Power gain / Power consumed / Power dissipated

Power in whole circuit :

$P_{total} = \frac{E^2}{r + R_L} = I^2(r + R_L) = E.I$

Q)

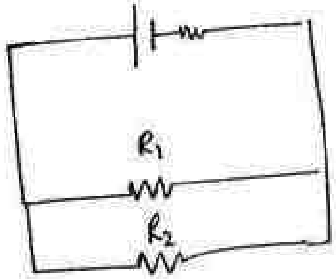


$I \Rightarrow$ same

$\therefore P = I^2 R$

$P \propto R$

$\therefore \frac{P_1}{P_2} = \frac{R_1}{R_2}$



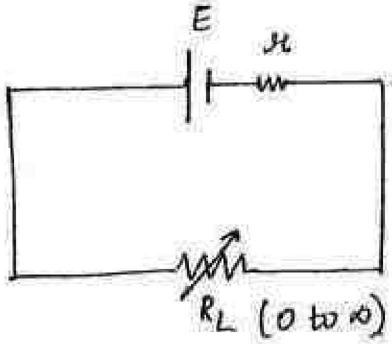
$V \Rightarrow$ same

$\therefore P = \dfrac{V^2}{R}$ $\quad \therefore P \propto \dfrac{1}{R}$

$\therefore \dfrac{P_1}{P_2} = \dfrac{R_2}{R_1}$

calculate ratio of power dissipated in both cases

Q)



what should be the value of R_L such that power in the load will be maximum

$P_L = I^2 R_L$ [we cannot use $\frac{V^2}{R}$ ∵ V is variable for every value, whereas I is constant

$= \left(\dfrac{E}{r + R_L}\right)^2 R_L = E^2 \left[\dfrac{R_L}{(r+R_L)^2}\right]$

constant

For $(P_L)_{max}$ $\quad \dfrac{dP_L}{dR_L} = 0$

$u = \cancel{E}\, R_L \qquad v = (r + R_L)^2$

$\dfrac{d(r+R_L)}{dR_L} \Rightarrow 0 + 1 = 1$

$\dfrac{dP_L}{dR_L} = E^2 \left[\dfrac{(r+R_L)^2 \times \overset{\frac{dR_L}{R_L}}{1} - R_L \times 2(r+R_L) \times 1}{(r+R_L)^4}\right] = 0$

$(r+R_L) - 2R_L = 0$

$r - R_L = 0$

$\boxed{R = r}$

Points to remember :

i) Power in the load will be maximum if internal resistance and external resistance are equal and value of this maximum power $\boxed{(P_L)_{max} = \left(\frac{E}{r+R_L}\right)^2 R_L}$

$$= \left(\frac{E}{2r}\right)^2 r = \boxed{\frac{E^2}{4r}} \text{ (load)}$$

r → internal resistance

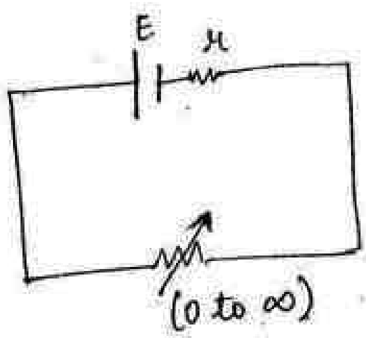
ii) Power in the circuit will be maximum if variable resistance becomes zero

$$P_L = \frac{E^2}{r+R_L}$$

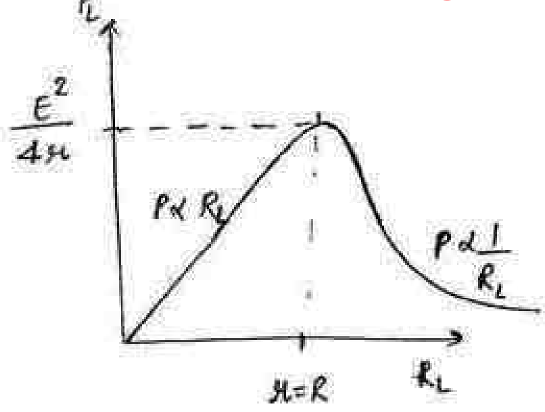
$\therefore$ If $R_L = 0$ then $P_T = max$

$$(P_T)_{max} = \boxed{\frac{E^2}{r}} \text{ (circuit)}$$

r → internal resistance

Q) 

Plot the graph b/w 'Power in load' v/s value of R_L



$$P_L = I^2 R_L$$

$$= \left(\frac{E}{r + R_L}\right)^2 R_L$$

i) $R_L <<< r$

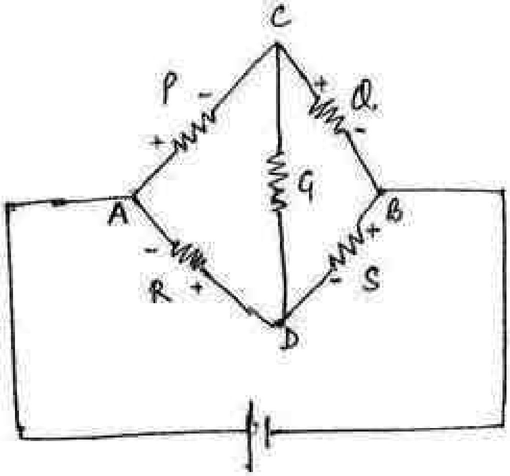
$$\therefore P_L = \left(\frac{E}{r}\right)^2 R_L \qquad \therefore \quad P_L \propto R_L \quad (\text{straight})$$

ii) $R_L >>> r$

$$P_L = \left(\frac{E}{R_L}\right)^2 R_L = \frac{E^2}{R_L} \qquad \therefore \quad P_L \propto \frac{1}{R_L}$$

(Hyperbola)

Article : 6 Wheat Stone Bridge (W.S.B)



Points to remember :

i) If one diagonal is connected by middle arm (G) and second diagonal is to be connected or connected by battery, then network is called wheat stone bridge (WSB)

ii) If bridge is balanced, then $V_C = V_D$ and ∴ current in middle arm will be zero so ammeter connected in middle arm will show zero deflection.

iii) If bridge is balanced, then $\boxed{\frac{P}{Q} = \frac{R}{S}}$ OR

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

iii) If posⁿ of battery and middle arm are interchanged in a balance WSB, Then after change, Bridge will be in balanced condⁿ

iv) If bridge is balanced the middle arm can

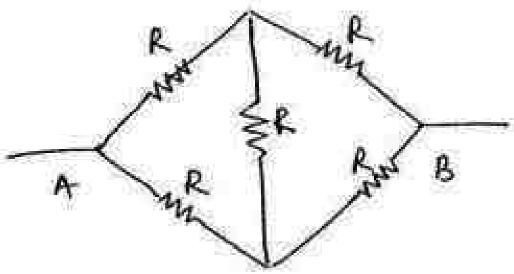
KVL in Δ ACDA

$I_1 P = I_2 R$ — (I) $|loss| = |gain|$

KVL in Δ CBDC

$I_1 Q = I_2 S$ — (II)

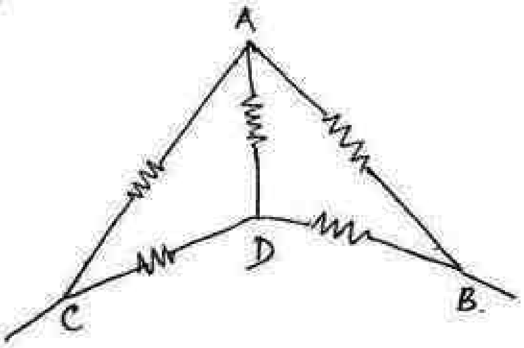
(I) / (II) $\therefore \frac{P}{Q} = \frac{R}{S}$

Q) 

$R_{AB} = \frac{2R}{2} = R$

In balance WSB, result is independent of resistance of middle arm

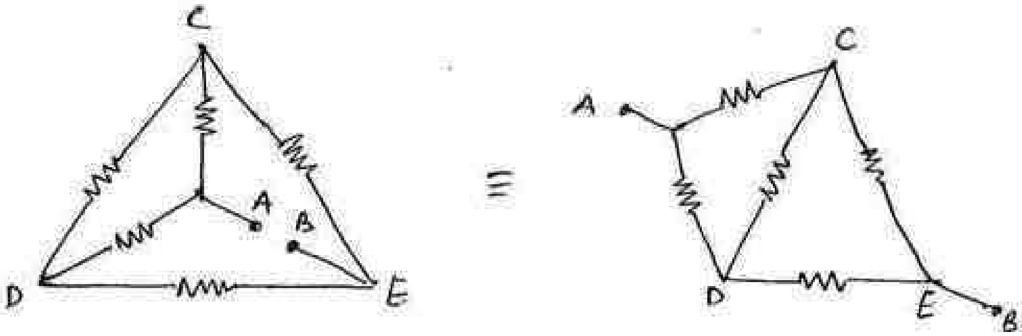
<u>Different form of WSB</u>:

(1) 

For CB, it is WSB

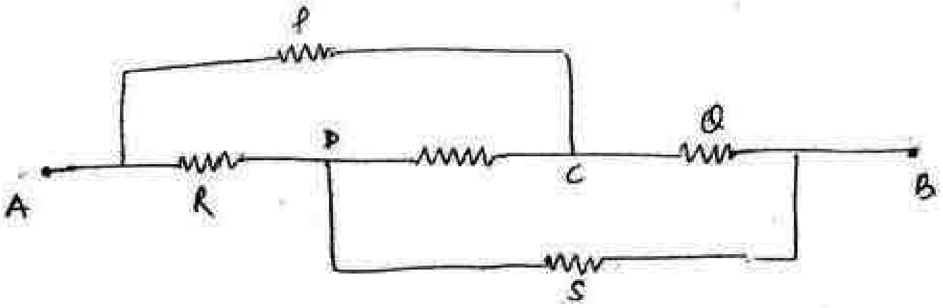
and middle ~~arm~~ arm → AD

(2)



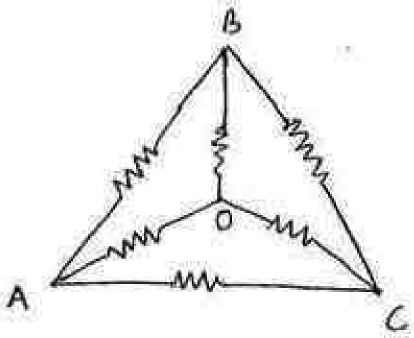
For AB, it is WSB and middle arm ⇒ CD

(3)



for AB, it is WSB and middle arm ⇒ CD

Q)

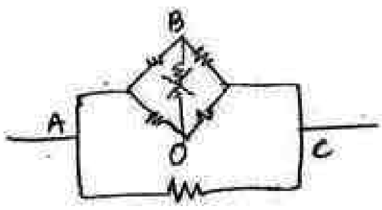


Each → R

find R_{AC}

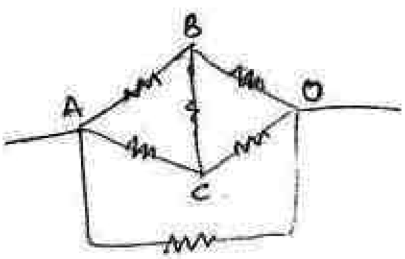
R_{AO}

R_{AC} ⇒

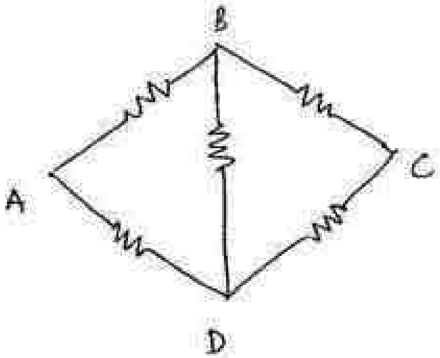


$\frac{R}{2}$

R_{AO} ⇒



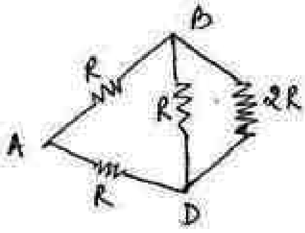
$\frac{R}{2}$



Each R

Find R_{AB}, R_{AC}, R_{AD}, R_{B}

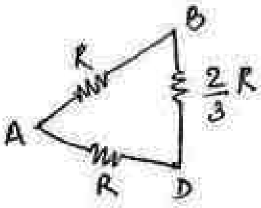
i) $R_{AB} \Rightarrow$



From B to D

$$(R_{net})_{BD} \Rightarrow \frac{R \times 2R}{R + 2R} = \frac{2}{3}R$$

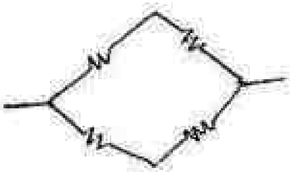
($\because$ its in parallel)



$$(R_{net})_{ABB} \Rightarrow \frac{2}{3}R + R = \frac{5}{3}R$$

$$\therefore (R_{net})_{AB} = \frac{\frac{5R}{3} \times R}{\frac{5R}{3} + R} = \frac{\frac{5R^2}{3}}{\frac{8R}{3}} = \frac{5}{8}R$$

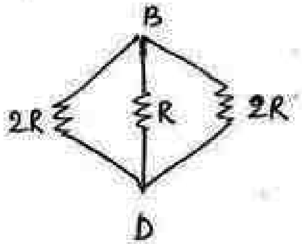
ii) $R_{AC} \Rightarrow$



$$\frac{2R}{2} = R$$

iii) $R_{AD} \Rightarrow \frac{5R}{8}$

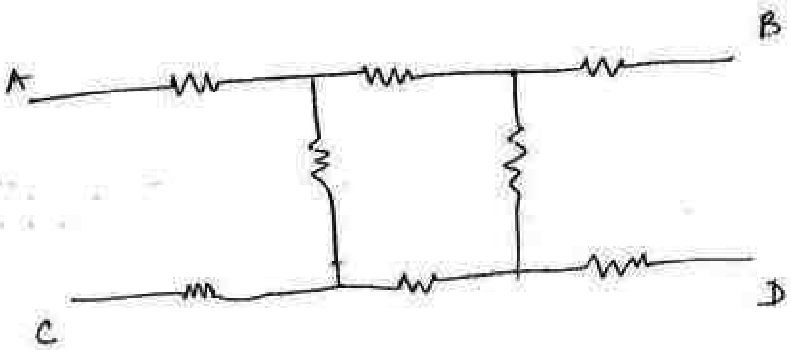
iv) $R_{BD} \Rightarrow$



$$\frac{1}{R_{net}} \Rightarrow \frac{1}{2R} + \frac{1}{R} + \frac{1}{2R}$$

$$\frac{1 + 1 + 2}{2R} = \frac{4}{2R} =$$

$$\therefore R_{net} \Rightarrow \frac{R}{2}$$

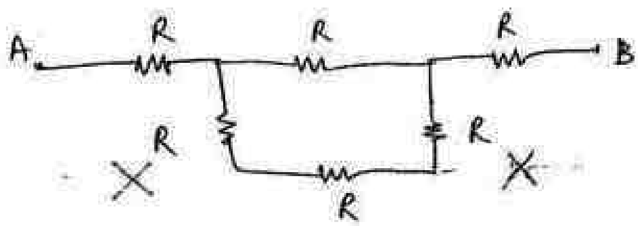
Q) 

Each → R

Find R_{AB}

R_{AC}

R_{AD}

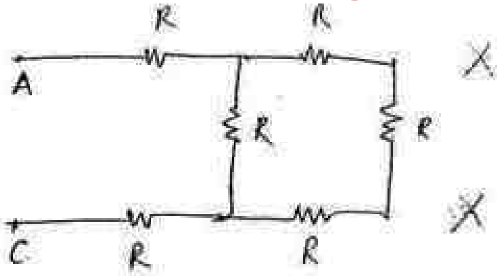
i) R_{AB} 

$\therefore$ R_{AB} = $\because$ 3R and R are in ||al

$$\therefore \quad \frac{3R \times R}{3R + R} = \frac{3}{4}R$$

For AB = $\frac{3}{4}R + R + R = \frac{11}{4}R$

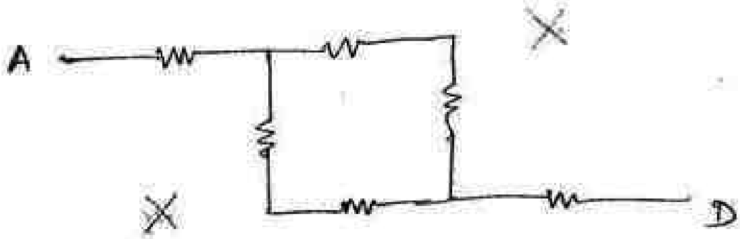
ii)



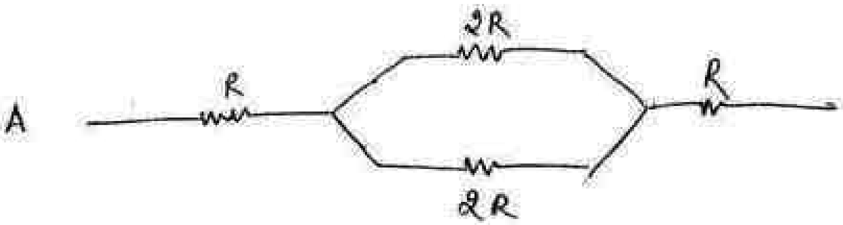
$$R_{AC} = \frac{3R \times R}{3R+R} \Rightarrow \frac{3}{4}R$$

$$\therefore \text{For } AC = \frac{3}{4}R + R + R = \frac{11}{4}R$$

iii)

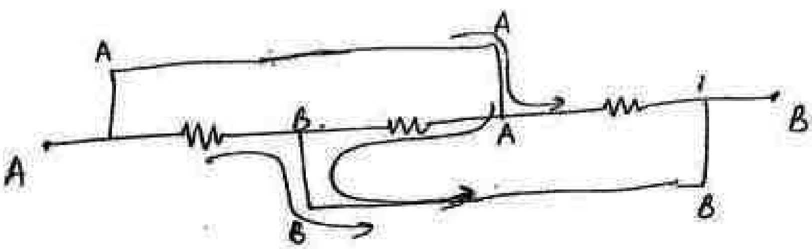


∴



$$\Rightarrow 3R.$$

Q)

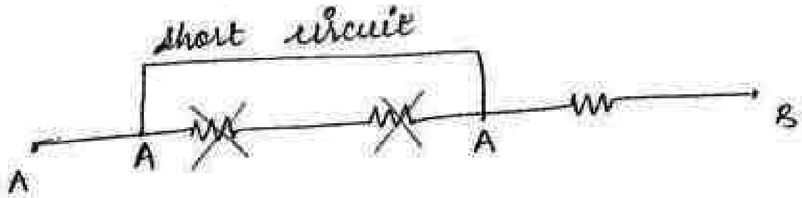


$$\frac{1}{R_{net}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R}$$

$$\frac{1}{R_{net}} = \frac{3}{R}$$

$$\therefore R_{net} = R$$

Q)

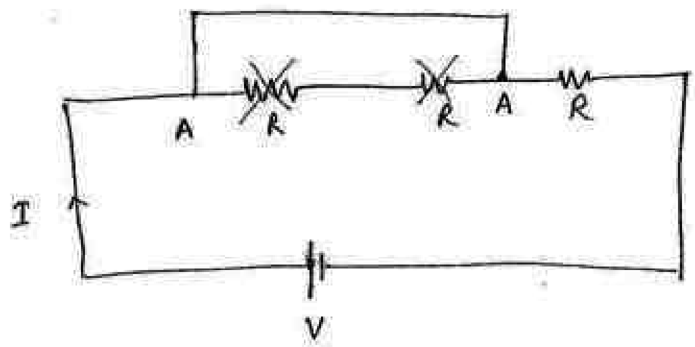


Find R_{AB}

$\therefore\ R_{AB} = R$

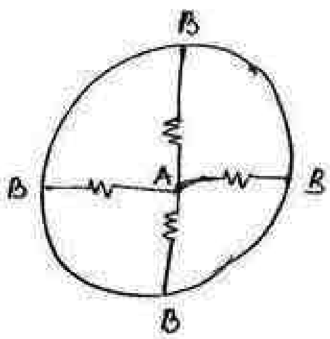
" Using equipotential method "

Q)

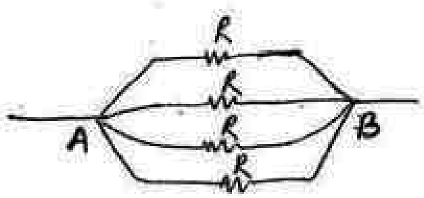


$\therefore \quad I = \dfrac{V}{R} \quad \left(\because R_{net} = R \right)$

Q)



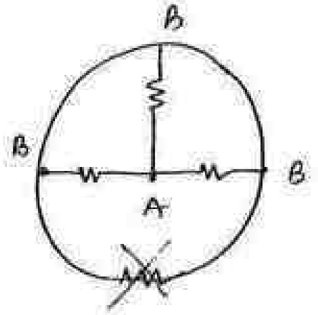
Each R



$$\frac{1}{R_{net}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R}$$

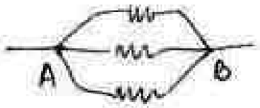
$$\frac{1}{R_{net}} = \frac{4}{R} \qquad \therefore\ R_{net} = \frac{R}{4}$$

Q)



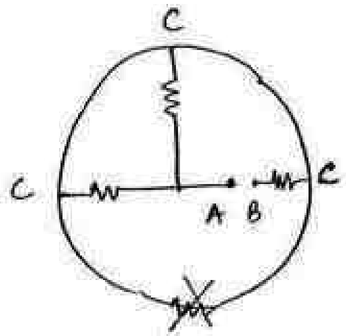
Each R

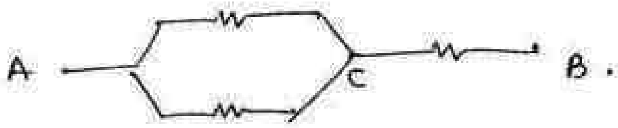
Find AB



$\because \; R_{AB} = \dfrac{R}{3}$

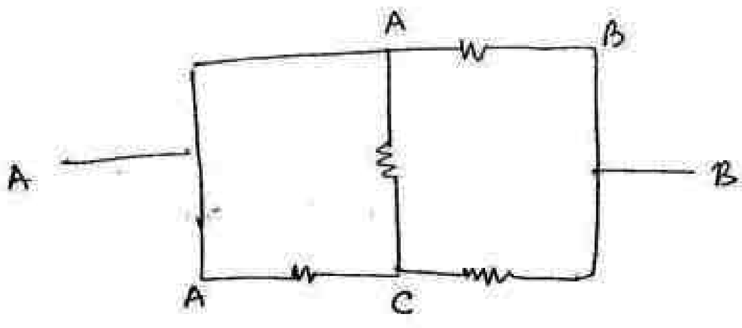
Q)

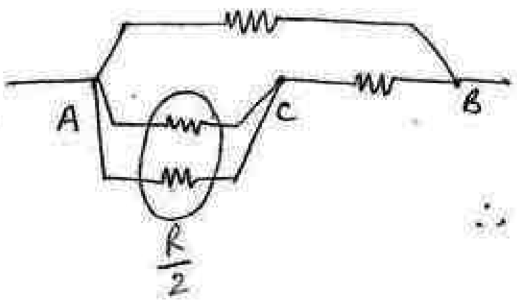




$\therefore \; R_{AB} = \dfrac{R}{2} + R = \dfrac{3}{2}R$

Q)

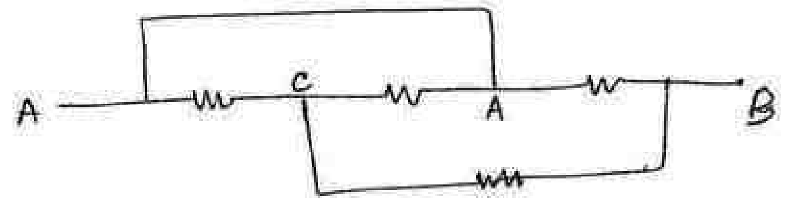


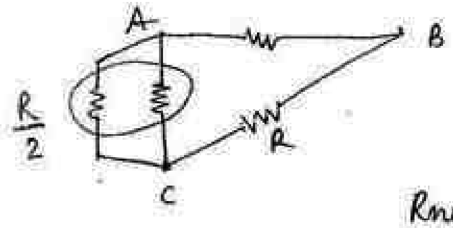


$\Rightarrow \dfrac{R}{2} + R \Rightarrow \dfrac{3R}{2}$

$\therefore R_{net} \Rightarrow \dfrac{\frac{3R}{2} \times R}{\frac{3R}{2} + R} \Rightarrow \dfrac{3R}{5}$

Q)



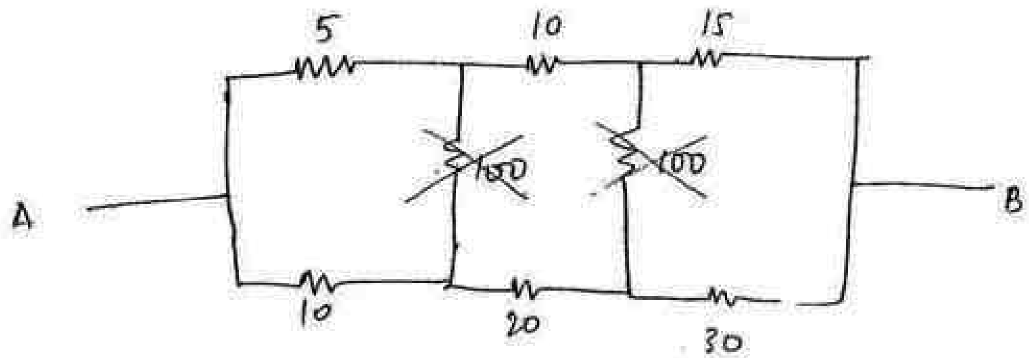


$\frac{R}{2} + R = \frac{3R}{2}$ ($\because$ series)

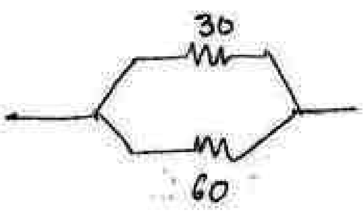
$$R_{net} = \frac{\frac{3R}{2} \times R}{\frac{3R}{2} + R} = \frac{3}{5} R$$

* Equipotential method can be used if few resistance or few branches are short circuiting

Q)



$\because$ It is extension of balanced WSB.

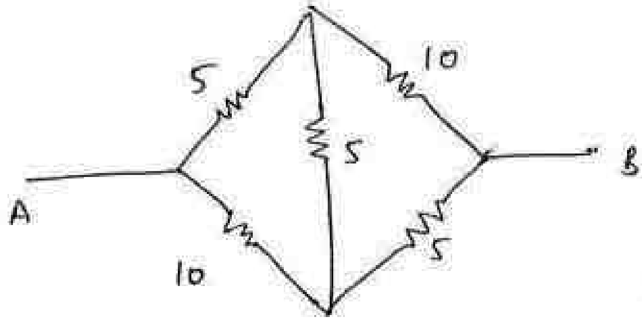


$$\frac{1}{R_{net}} = \frac{1}{30} + \frac{1}{60}$$

$$= \frac{6+3}{180} = \frac{9}{180} = \frac{1}{20}$$

$\therefore R_{net} = 20$

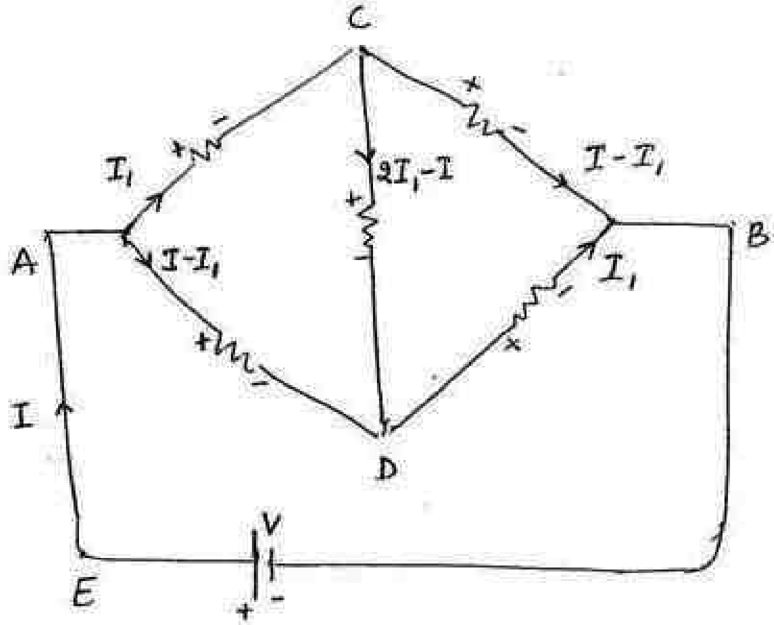
Q) *



Find R_{AB}

(Imbalanced W.S.B)

* $\boxed{|\text{gain}| = |\text{loss}|}$



By KVL, in ACBEA

$$V_A - 5(I_1) - (I - I_1)10 + V = V_A$$

$$\therefore \quad V = (I - I_1)10 + 5I_1$$

$$\therefore \quad V = 10I - 10I_1 + 5I_1 = 10I - 5I_1 \quad \text{— (1)}$$

By KVL in ACDA

$$V_A - 5(I_1) - (2I_1 - I)5 + (I - I_1)10 = V_A$$

$$\therefore \quad -5I_1 - 10I_1 + 5I + 10I - 10I_1 = 0$$

$$\therefore \quad 15I = 25I_1 \quad \Rightarrow \quad 3I = 5I_1 \quad \text{— (II)}$$

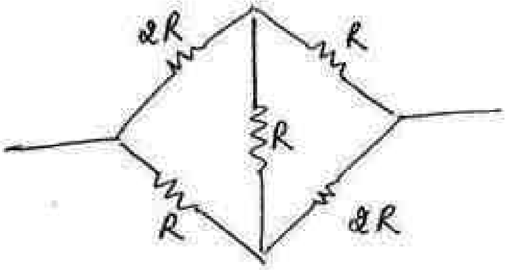
from (1) and (II)

$$10I - 3I = V \quad \therefore \quad V = 7I$$

$$\therefore \quad R_{eq} = \frac{V}{I} = \frac{7I}{I} = \boxed{7\Omega}$$

*Q)

Short trick



$\therefore \; R_{AB} = \dfrac{7R}{5}$

→ add all the resistance and then divide it by no by resistance

Symmetrical line method

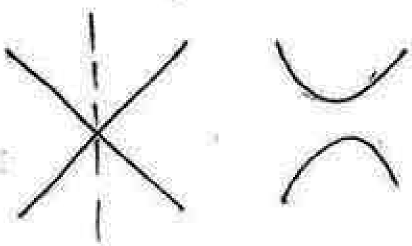
If there is a line which bisects the given network into two equal sections then all the points on this line have same potential so we can remove wires and junctions* lying on this symmetrical line.

Points to remember

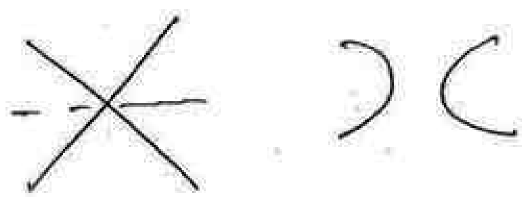
Symmetrical line is not allowed to pass through the terminals* given for study

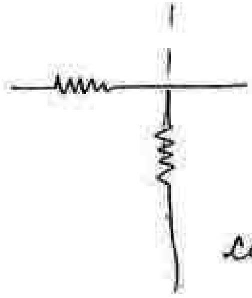
* Method of removing junction

i)



ii)

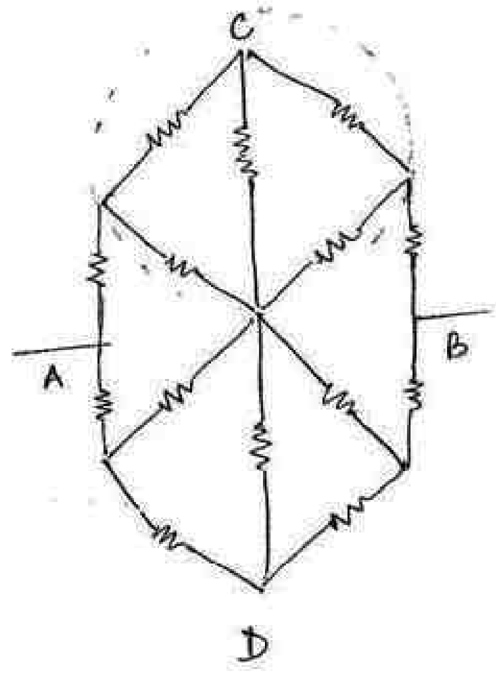


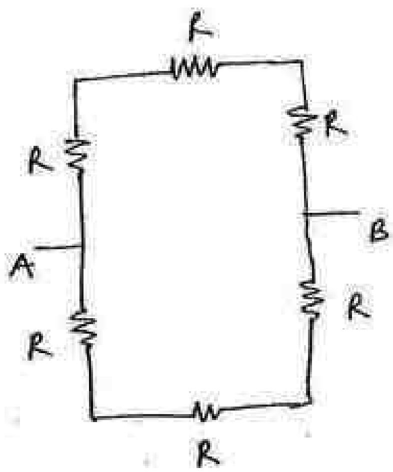


can't be removed ⇒ (across the line)

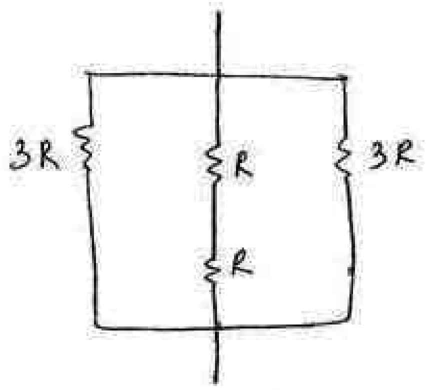
can be removed ⇒ (along the line)

Q)





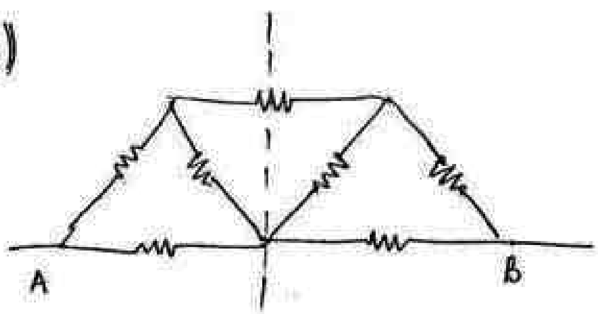
$\therefore (R_{eq})_{AB} = \frac{3}{2}R$

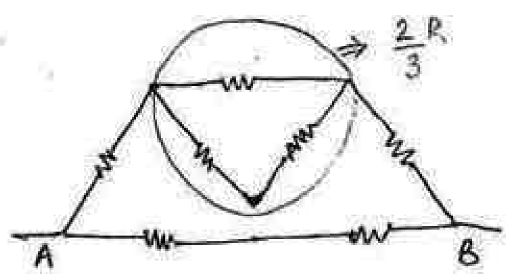


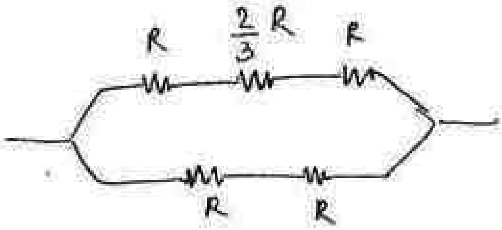
$$\therefore (R_{eq})_{CD} = \frac{\frac{3}{2}R \times 2R}{\frac{3}{2}R + 2R}$$

$$= \frac{6}{7}R$$

Q)

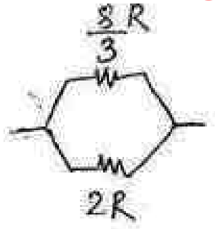






$\equiv$

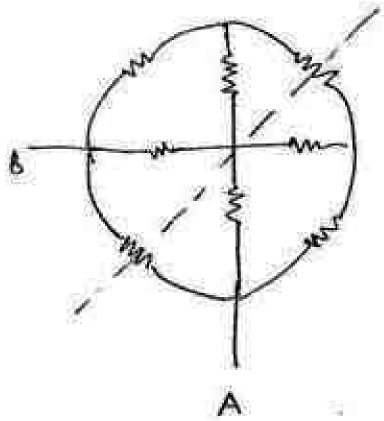
$\therefore$



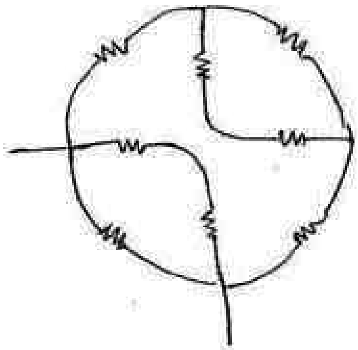
$$\therefore R_{eq} = \frac{\frac{8}{3}R \times 2R}{\frac{8}{3}R + 2R}$$

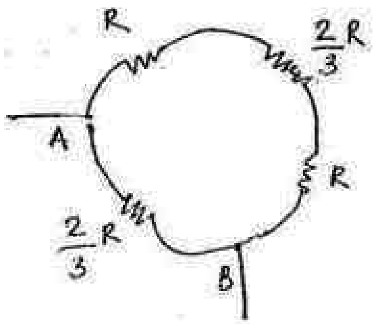
$$= \boxed{\frac{8}{7}R}$$

Q)

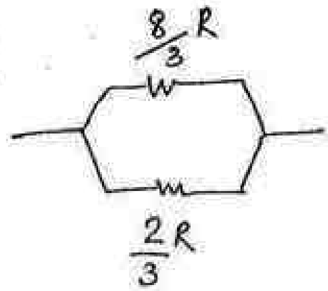


$\equiv$





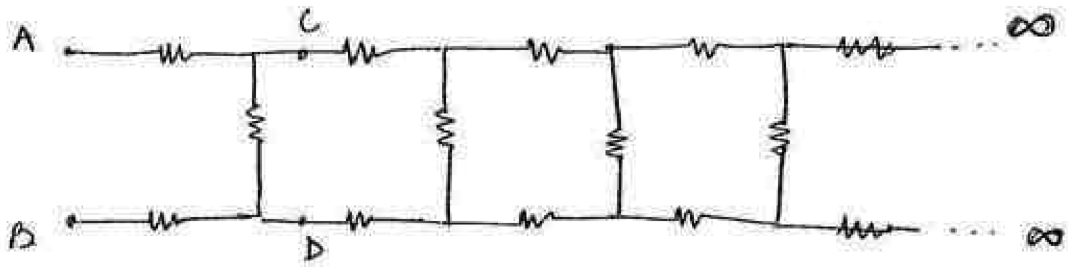
$\therefore$



$$\therefore R_{eq} = \frac{\frac{8}{3}R \times \frac{2}{3}R}{\frac{8}{3}R + \frac{2}{3}R}$$

$$= \frac{16R^2}{9} \times \frac{3}{10R} = \boxed{\frac{8}{15}R}$$

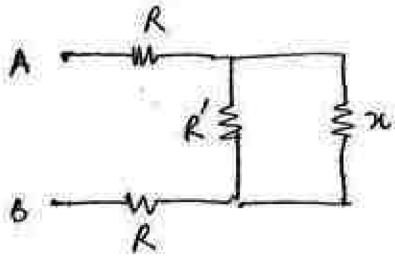
Ladder Network



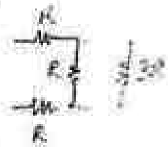
Each → R

find R_{AB}

let $R_{AB} = x$ $\therefore$ so $R_{CD} = x$ $(\because \infty - 1 = \infty)$



★ for competition



$\because R_{net} = 2R + \frac{R \times 3R}{R + 3R}$

$\approx \boxed{2.75\,R}$

$\therefore$ we can ignore other resistances which contributes almost negligible

$R_{AB} = R + R' + R = 2R + R'$

$\therefore x = 2R + \frac{Rx}{R+x} \Rightarrow x(R+x) = 2R(R+x) + Rx$

$\cancel{xR} + x^2 = 2R^2 + 2Rx + \cancel{Rx}$

$\therefore x^2 - 2Rx - 2R^2 = 0$
$\left[\begin{array}{l} a = 1 \\ b = -2R \\ c = -2R^2 \end{array}\right.$

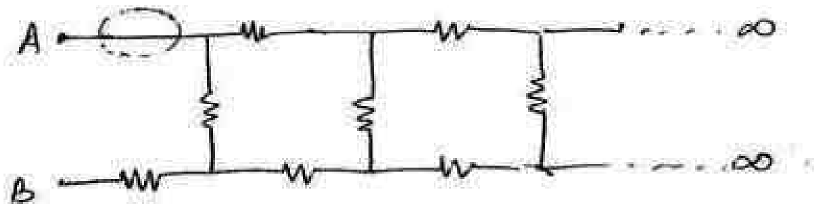
$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{2R \pm \sqrt{4R^2 - 4(1)(-2R^2)}}{2 \times 1} = R(1 \pm \sqrt{3})$$

$$= \frac{\cancel{2}R \pm \cancel{2}\sqrt{3}\,R}{}$$

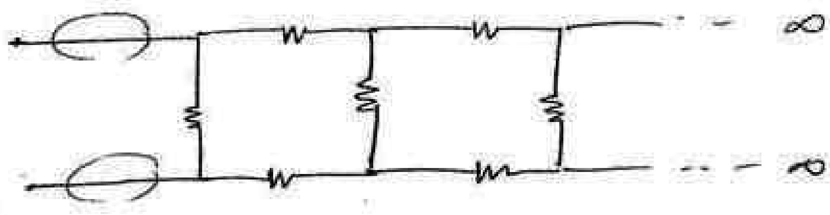
$\therefore \boxed{x = 2.732R}$

Q)



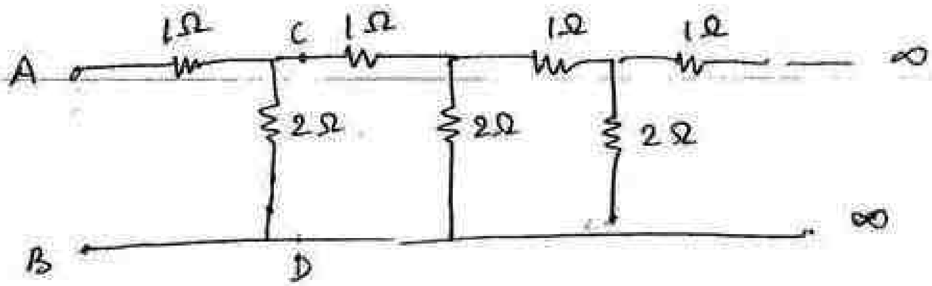
$\therefore R_{AB} = \sqrt{3}R = \boxed{1.732\ R}$

Q)



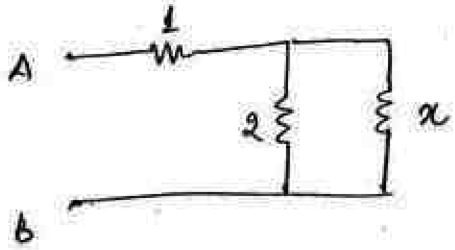
$\therefore R_{AB} = (\sqrt{3}-1)R = \boxed{0.732R}$

Q)



let $R_{AB} = x$

$\therefore$ so $R_{CD} = x$



$\therefore x = 1 + \frac{2x}{2+x}$

$x^2 + 2x = 2 + x + 2x$

$\therefore x^2 - x - 2 = 0$

$(x-2)(x+1) = 0$

$\therefore \boxed{x = 2}, x = -1$

Galvanometer / Voltmeter / Ammeter

-(G)-　　-(V)-　　-(A)-

Points to remember:

-(G)-, -(V)-, -(A)-

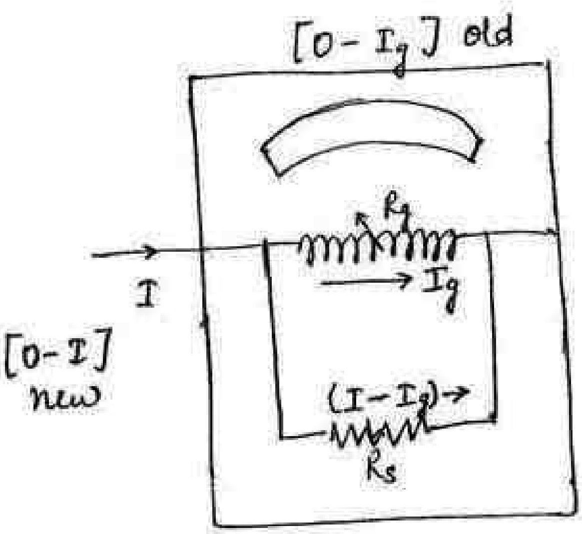
- Moving coil meters are based on magnetic effect of current

- Magnetic torque, $\boxed{\tau \propto I}$
  ∴ deflection ie $\boxed{\phi \propto I}$

  so that scale of these meters are uniform (equal distribution)

- Ammeter should have negligiable resistance and voltmeter should have very high resistance

- Resistance of ideal ammeter is zero and ideal voltmeter is infinite



Ammeter
(more delicate)

here, R_s = shunt resistance or small resistance

* $\underbrace{I_g}_{\text{previous range}} R_g = (\underbrace{I}_{\text{new range}} - I_g) R_s$

Q) Resistance of a galvanometer is G, we want to ↑ its current range n times of initial value. Find required value of shunt resistance

$$\because \quad R_g \underbrace{I_g}_{\text{previous range}} = (\underbrace{I}_{\text{new range}} - I_g) R_s$$

$$I_g \times G = (nI_g - I_g) R_s$$

$$\cancel{I_g} \times G = \cancel{I_g}(n-1) R_s$$

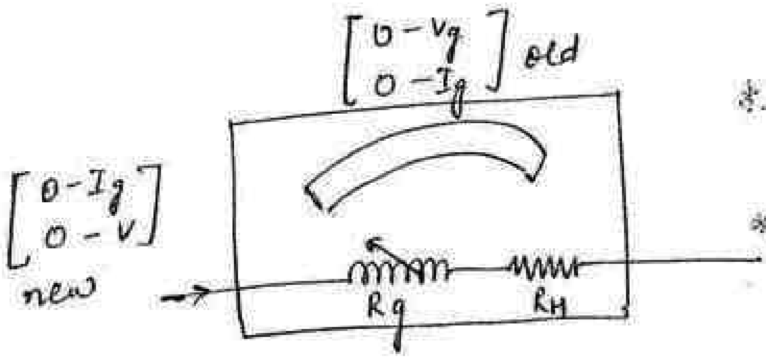
$$\therefore \quad R_s = \left(\frac{G}{n-1}\right)$$

A resistance of low value is connected in parallel with the coil of -(G)- so effective resistance of -(A)- can be decreased. This parallel resistance is called shunt resistance

- ~~the~~ with the ~~shunt~~ help of shunt resistance, desired current range can be achieved

I_g
- → max allowed current
- → current range
- → Full scale deflection current

Conversion of -(G)- into -(V)-



* $V_g = I_g R_g$ — (1)
* $V_{new} = I_g(R_g + R_H)$ — (2)

Note:

A resistance of high value is connected in series with the coil of -(G)- to ↑ effective resistance

» This additional resistance will change voltage range of meter

Q) Resistance of a galvanometer is (G)- we want to ↑ its voltage range upto n times of initial. Find required value of series resistance

$\because V_g = I_g R_g$ -(1) and $I_g R_g = I_g(R_g + R_H)$

$\therefore n I_g R_g = I_g(R_g + R_H)$

$\therefore R_g(n-1) = R_H$

$\therefore R_H = G(n-1)$

Q) Value of R_g is $30\,\Omega$ and its current range is $1\,mA$. We want to read max. $30\,V$ with this meter. Find required series resistance.

$$\because \quad V = I_g (R_g + R_H)$$

$$30 = 10^{-3} (30 + R_H)$$

$$\therefore \quad R_H = \frac{30 - (30 \times 10^{-3})}{10^{-3}} = 29970\,\Omega$$

Q) Voltage range of a meter is 10V. and its resistance is $10\,\Omega$. we want to read 100 V with ~~its~~ this meter. calculate value of addition series resistance

$$\because \quad V_g = I_g R_g$$

$$\therefore \quad I_g = \frac{V_g}{R_g} = \frac{10}{10} = 1\,A$$

$$\because \quad V = I_g (R_g + R_H)$$

$$\therefore \quad 100 = 1\,(10 + R_H)$$

$$\therefore \quad R_H = 100 - 10 = 90\,\Omega$$

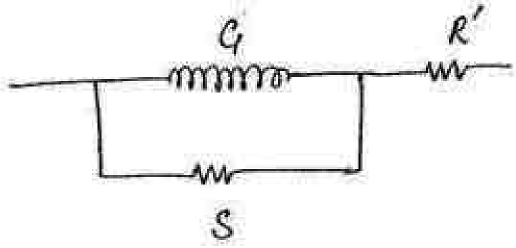
Q) $R_g = 100\,\Omega$ and its current range is $10^{-5}\,A$ we want to read $1A$ with this meter. Find approx value of shunt resistance

$$\because \quad I_g R_g = (I - I_g) R_s$$

$$\therefore \quad 10^{-5} \times 100 = (1 - 10^{-5}) R_s$$

$$\therefore \quad R = 10^{-5} \times 10^{+2} = 10^{-3}\,\Omega$$

*Q) Resistance of a galvanometer is G. It is shunted by a resistance S. ~~This meter~~ A series resistance is connected with this meter. what should be value of series resistance so main current in the meter remains same



same current

$\because I = \frac{V}{R} \rightarrow$ constant for a circuit

$\therefore R$ should be same

$$\therefore \frac{G \times S}{G+S} + R' = G$$

$$\therefore R' = G - \frac{GS}{G+S}$$

$$= \frac{G^2}{G+S}$$

*Q) $R_g = 10\,\Omega$, no of divisions in the scale of meter is 50. and 1A current is required for deflection of one division. we want to read 1kV with is meter. Find value of series resistance

$\because$ 1 division = 1A $\therefore$ 50 division = 50 A

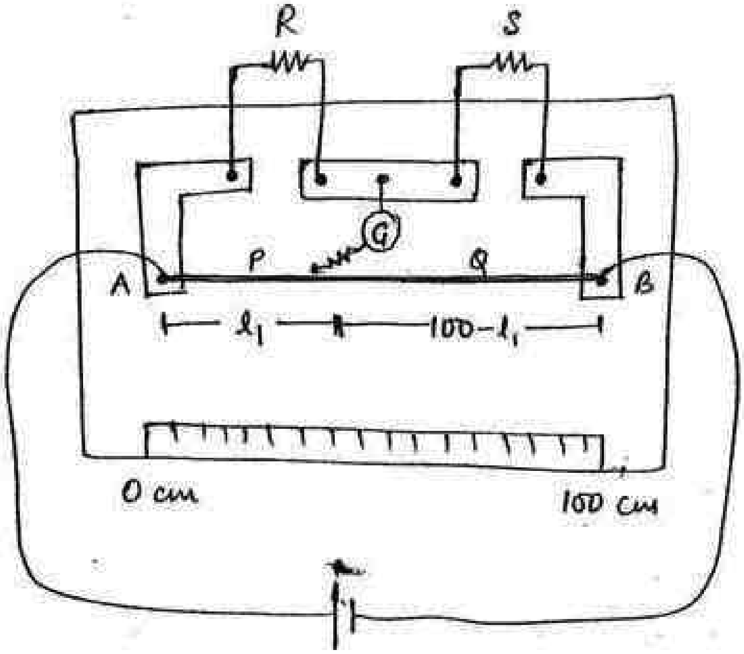
$\because V = I_g (R_g + R_H)$

$1000 = 50\ (10 + R_H)$

$\therefore R_H = \frac{1000 - 500}{\ } = 10\,\Omega$

Meter Bridge:

⇒ based on principle of balanced wheat stone bridge:



For null point:

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

$$\frac{l_1}{100-l_1} = \frac{R}{S}$$

Points to remember

⇒ length of AB ~~wa~~ wire is always 100 cm (1m)

⇒ Position of null point is independent ~~of~~ of area of cross section of AB wire.

Q) In the given diagram $R = 110\,\Omega$ and distance of null point from B is 45 cm find value of S

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

$$\frac{l_1}{100-l_1} = \frac{R}{S} \quad \Rightarrow \cancel{\frac{45}{100-45}} = \cancel{\frac{110}{S}}$$

$$\frac{55}{45} = \frac{110}{S} \qquad \therefore S = \frac{110 \times 45}{55} = 90\Omega$$

Q) In the given diagram $R:S \Rightarrow 1:4$ and distance of null point from A is l_1. If R and S are interchanged, then distance of null point from A is l_2, find $l_2 - l_1$

$$\because R:S = 1:4 = \frac{1}{5}\times 100 : \frac{4}{5}\times 100 \Rightarrow 20:80$$

$$\therefore 20:80 \Rightarrow l_1 : 100-l_1$$

now, $80:20 \Rightarrow l_2 : 100-l_2$

$$\therefore l_2 = 80, \quad l_1 = 20$$

$$\therefore l_2 - l_1 = 60$$

Q) In the given diagram, ~~dist~~ pos^n of null point is at midpoint of A and B. Now resistance R is shunted by 10Ω and null point shift by 20 cm. Find the value of shunted resista

$$R = S$$

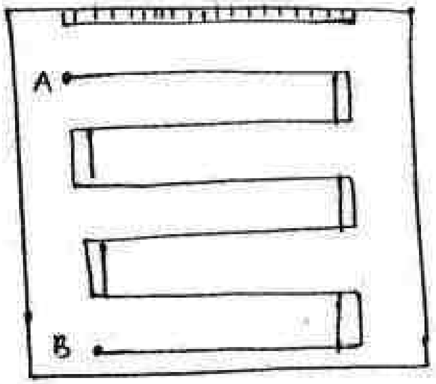
$$\frac{R'}{S} = \frac{30}{70}$$

$$\left(\frac{10R}{10+R}\right)\frac{1}{R} = \frac{3}{7} \quad \Rightarrow 70 = 30 + 3R$$

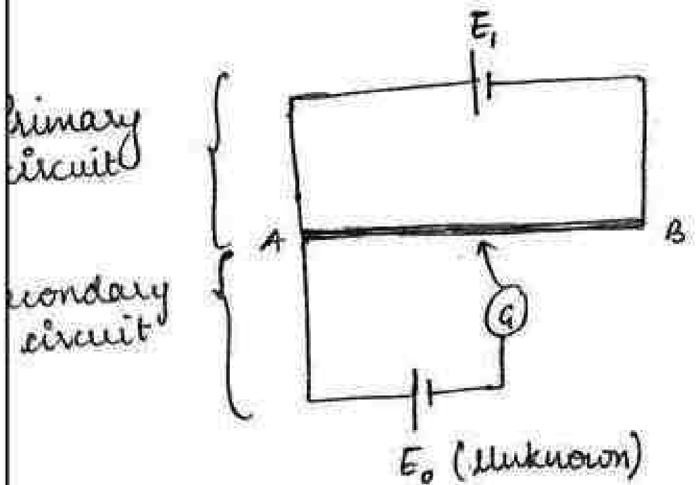
$$\therefore R = \frac{40}{3}\Omega$$

Article : 7 Potentiometer (P.M) ☆☆

used to measure emf



Points to remember:



- Its working is based on null deflection. it means it doesn't draw any current from secondary circuit so it can be used as an ideal voltmeter and ideal ammeter

- Potential gradient on the wire is potential per unit length,

$$\boxed{\phi = \frac{V_w}{L_w}} = \frac{\text{voltage of wire}}{\text{length of wire}}$$

» Sensitivity of potentiometer is inversely proportional to ϕ

$$\boxed{\text{Sensitivity} \propto \frac{1}{\phi} \propto \frac{L_w}{V_w}}$$

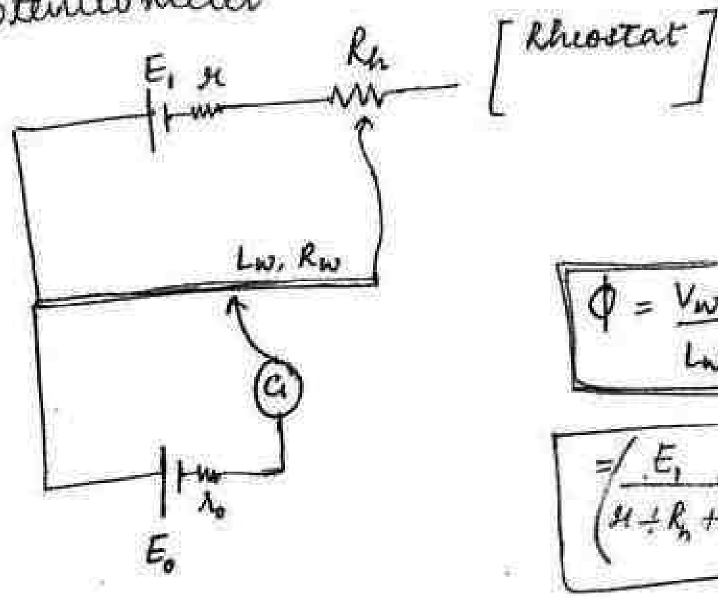
» By increasing length of wire, sensitivity can be increased without changing its range that's why its length is kept very long.

» If null deflection is not obtained on the wire, then there may be two possibilities.

(a) Potential of unknown cell is more than voltage of the wire.

(b) Same polarity of all cells is not connected at starting terminal of AB wire.

» Actual Potentiometer



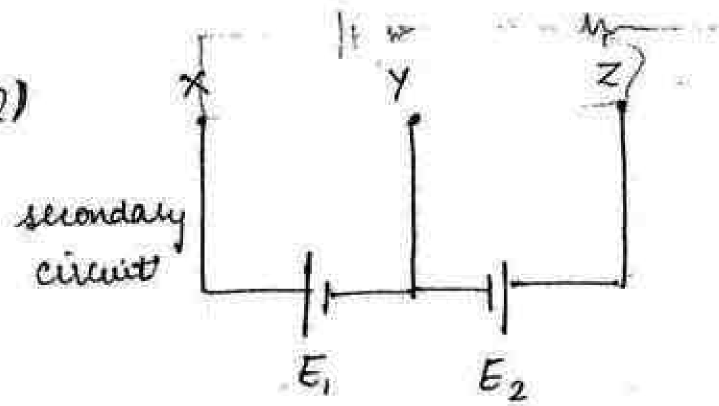
$$\boxed{\phi = \frac{V_w}{L_w}} = \boxed{\frac{I_w R_w}{L_w}}$$

$$\boxed{= \left(\frac{E_1}{r + R_h + R_w}\right)\frac{R_w}{L_w}}$$

Q1) In the given diagram. calculate ratio of ϕ_{min} and ϕ_{max}

$$\frac{\phi_{min}}{\phi_{max}} = \frac{r + R_w}{r + R_w + R_{max}}$$

Q)



when voltage b/w x and Y is balanced on a potentiometer than balancing length is 700 cm but if voltage b/w x and z is balaned on the same potentiometer, then balancing length is 500 cm. & Find E_1/E_2

$$E_1 = \phi l_1$$

$$E_1 = \phi\, 700 \quad \text{—— (i)}$$

$$(E_1 - E_2) = \phi\, 500 \quad \text{—— (ii)}$$

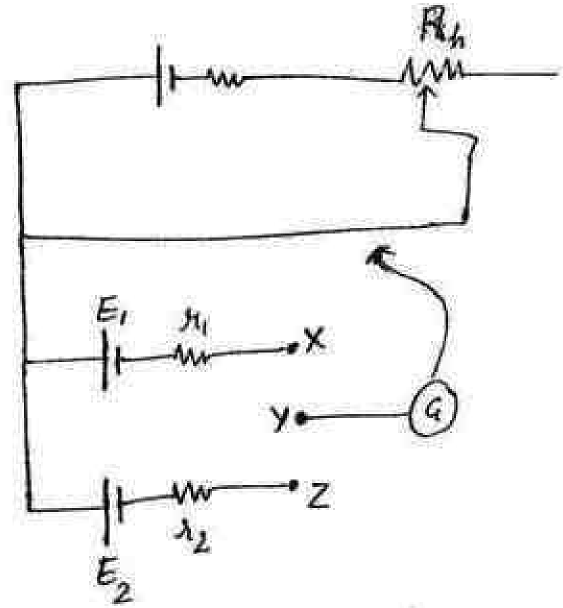
from (i) and (ii)

$$\frac{E_1}{E_1 - E_2} = \frac{7}{5}$$

$$\therefore \frac{E_1}{E_2} = \frac{7}{2}$$

* during experiment ϕ remains unchanged so we should not change setting of rheost

Q)



Comparison of EMF of 2 cells

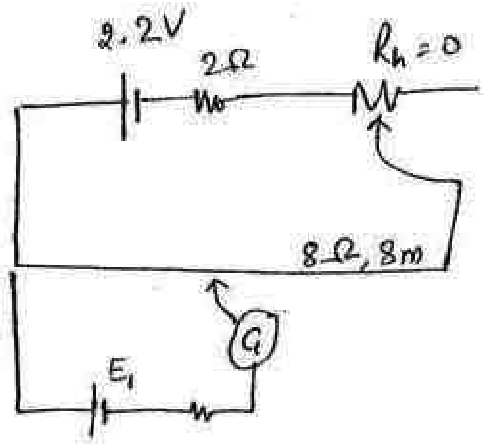
why X and Y are short circuited, then balan length is l_1, now X and Y are disconnected and Y and Z are short- circuited, then balance length is l_2. Find E_1/E_2

$E_1 = \phi l_1$

$E_2 = \phi l_2$

$\therefore \boxed{\dfrac{E_1}{E_2} = \dfrac{l_1}{l_2}}$ $\because$ Rheostat is not changed

(Q)



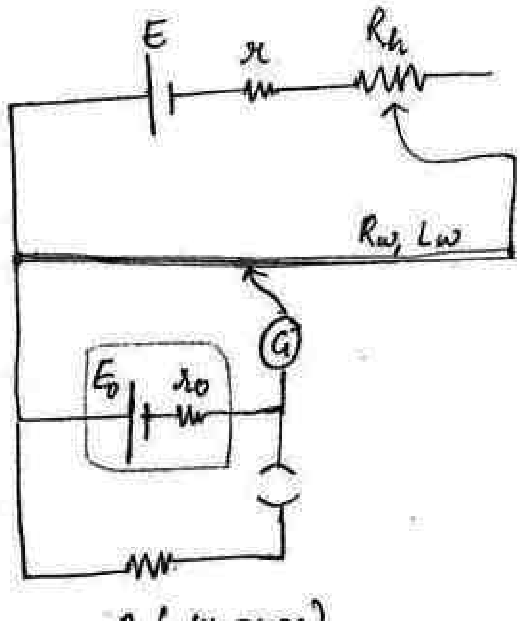
If balancing length of unknown cell is 5m. then find its emf

$$E_1 = \phi l$$

$$\therefore \phi = \frac{V_w}{L_w} = \frac{(I_w)R_w}{L_w} = \left(\frac{2.2}{2+0+8}\right) \times \frac{8}{8} = 0.22\ V/m$$

$$\therefore E_1 = 0.22 \times 5 = 1.1\ V$$

★★★★ To find internal resistance of a wire



In first part of experiment, key is kept open and emf, E_0 is balanced on length l_0 so

$$\boxed{E_0 = \phi l_0} \text{ --- } (1)$$

In second part of the experiment, key is kept closed so there will a current through the known resistance R.

Due to this current, potential of cell is its TPD and its balancing length is l_c ($l_c < l_0$)

and $\boxed{TPD = \phi l_c}$

$$IR = \phi l_c \quad (\because TPD = IR)$$

Put value of I

$$\left(\frac{E_0}{r_0 + R}\right) R = \phi l_c$$

$$\Rightarrow \left(\frac{\cancel{\phi} l_0}{l_0 + R}\right) R = \cancel{\phi} l_c$$

$$l_0 R = l_c r_0 + l_c R$$

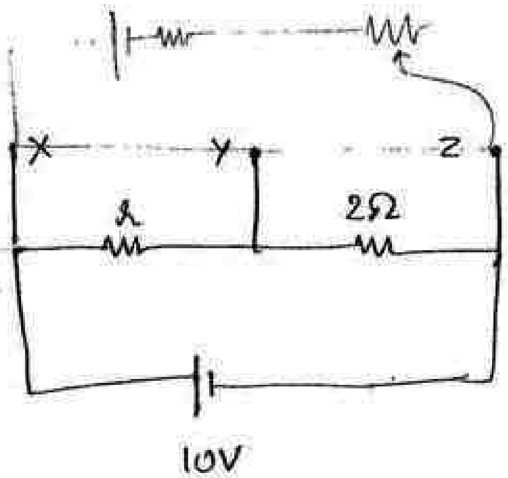
$$R(l_0 - l_c) = l_c r_0$$

$$\boxed{r_0 = \frac{R(l_0 - l_c)}{l_c}}$$

*

Q) A cell is balanced on a potentiometer with and without short circuited by 10Ω. Its balancing length are 100 cm and 110 cm respectively. Find its internal resistance.

$$\because r_0 = \left(\frac{l_0 - l_c}{l_c}\right) R = \frac{110-100}{100} \times 10 = 1\Omega$$

Q) 

only secondary circuit is given.

Voltage b/w X and Y can be balanced on 700 cm length of a potentiometer while voltage b/w X and Z can be balanced on 900 cm length of same potentiometer. Find value of r

short trick:

XY balances on 700

YZ balances on 200

∵ 200 cm is shunted by 2Ω to balance

∴ 700 cm will be shunted by 7Ω

$V_1 = Ir_1 = \phi(700)$ — (I) $[\because V = \phi l]$

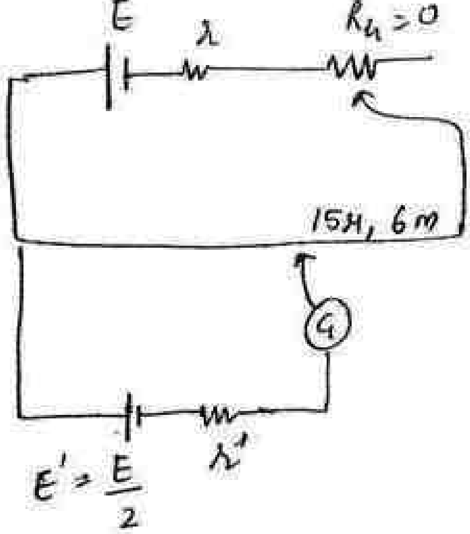
$V_1 + V_2 = Il_2 = \phi(900)$ — (II)

$$\frac{V_1}{V_1 + V_2} = \frac{700}{900}$$

$9V_1 - 7V_1 = 7V_2$

$\therefore V_1 = 7V_2 \quad 7\times 2 = 7V \quad [\because V_2 = 2]$

Q)



$$E' = \phi l$$

$$\frac{E}{2} = \left(\frac{E}{r + 15r + 0}\right) \frac{15r}{6} \times l$$

$$\therefore \quad 16r = 5rl$$

$$\therefore \quad l = \frac{16}{5}$$

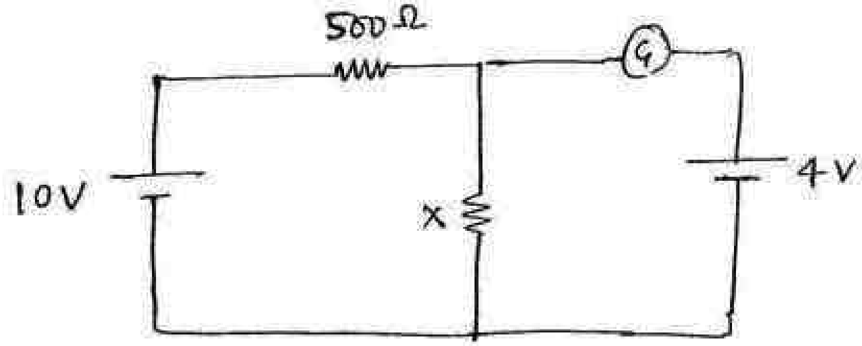
Standardisation of Potentiometer:

To find potential gradient of a potentiometer with the help of a standard cell of known emf is called standardisation

$$E = \phi l \qquad (E \text{ is known})$$

so, $\boxed{\phi = \frac{E}{l}}$ l has to be measured manually

Q)



If deflection in Ⓖ is 0 then find value of x

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

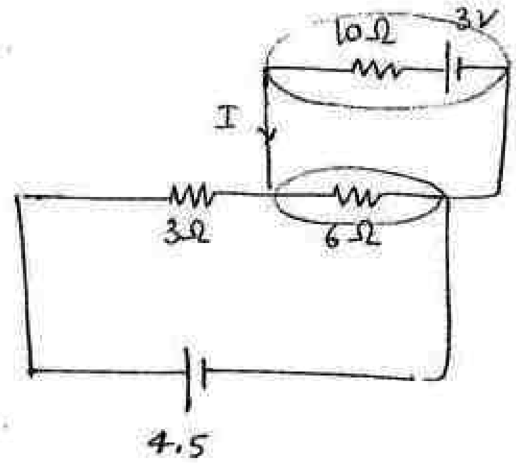
$$= \left(\frac{10}{500+x}\right)$$

$$V = IR \Rightarrow \left(\frac{10}{500+x}\right)x = 4$$

$$\therefore \quad 10x = 2000 + 4x$$

$$\therefore \quad x = \frac{1000}{3} = 333.33\ \Omega$$

Q)



calculate $I = ?$

$\because \; I = \frac{V}{R} = \frac{4.5}{6+3} = \frac{45}{90} = \frac{1}{2}$

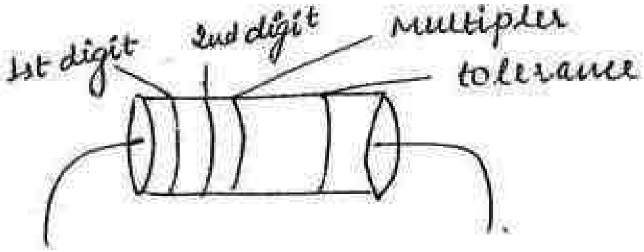
$\therefore \; V = IR = \frac{1}{2} \times 6 = 3V$

$\because$ both the wires have same potential

$\therefore$ no current will flow in 6Ω resistance

$\therefore \; \boxed{I = 0}$

Colour code :



B → 0 (Black)

B → 1 (Brown)

R → 2 (Red)

O → 3 (~~organ~~ orange)

Y → 4 (Yellow)

G → 5 (green)

B → 6 (Blue)

V → 7 (violet)

G → 8 (grey)

W → 9 (white)

Memory tips: :)

BB ROY great

britain very

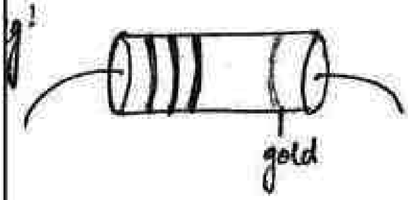
good wife

gold < III = 10^{-1}, IV = $\pm 5\%$

silver < III = 10^{-2}, IV = $\pm 10\%$

IV (no colour) ⇒ $\pm 20\%$

g!

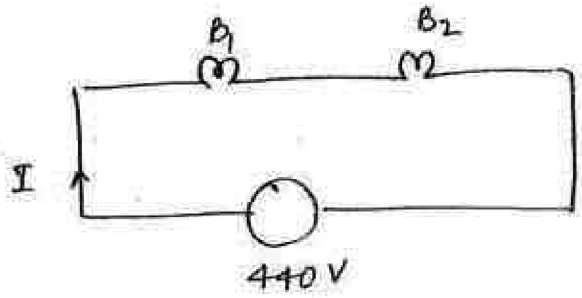


$(53 \times 10^{6} \pm 5\%)\,\Omega$

Q) 2 bulb B_1 (25 W − 220 V) and B_2 (100 W − 22… are connected in series ~~ta~~ across a supply of 440 V. calculate voltage on each bulb and which bulb is more likely to fuse

$$R_1 = \frac{V_1^2}{P_1} = \frac{(22\times 10)^2}{25} = (22)^2 \times 4$$

$$R_2 = \frac{V_2^2}{P_2} = \frac{(22\times 10)^2}{100} = (22)^2$$



$$I = \frac{V_{net}}{R_{net}} = \frac{440}{22^2(4+1)} = \frac{440}{5\times 22^2}$$

$$V_1 = I R_1 \Rightarrow \frac{440}{5\times 22^2} \times 22^2 \times 4 \Rightarrow 352\ V$$

$$V_2 = I R_2 = \frac{440}{5\times 22^2} \times 22^2 \Rightarrow 88 V$$

OR $\Rightarrow$ (440 − 352 = 88 V)

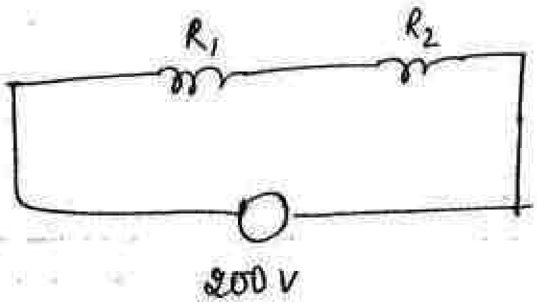
$\therefore$ B_1 is more likely to fuse

$\because$ it requires 220 V of voltage but it is being supplied with 352 V

Q) B_1 (60W − 200V) and B_2 (100W − 200V) and this combination is connected across a supply of 200V in series calculate total power generated

$$\because \; R_1 = \frac{V_1^2}{P_1} = \frac{200 \times 200}{60} = \frac{2000}{3}$$

$$R_2 = \frac{V_2^2}{P_2} = \frac{200 \times 200}{100} = 400$$



$$\therefore \; I_{net} = \frac{V_{net}}{R_{net}} = \frac{200}{R_1 + R_2}$$

$$= \frac{200}{\frac{2000}{3} + 400} = \frac{200 \times 3}{3200} = \frac{3}{16}$$

$$P = VI = 200 \times \frac{3}{16} = \frac{75}{2} = \boxed{37.5\,W}$$

$$\therefore \; V_1 = IR_1 = \frac{3}{16} \times \frac{2000}{3} = 125\ V$$

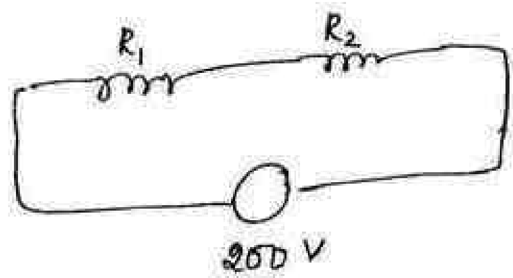
$$V_2 = IR_2 = \frac{3}{16} \times 400 = \cancel{82.5\,V}\ 75\ V$$

∴ None of the bulb will fuse

Q) B_1 (60W - 200 V) and B_2 (60W - 200 V) and this combination is connected across a supply of 200 V. calculates total power generated

$$R_1 = \frac{V_1^2}{P_1} = \frac{200 \times 200}{60} = \frac{2000}{3}$$

$$R_2 = \frac{V_2^2}{P_2} = \frac{200 \times 200}{60} = \frac{2000}{3}$$



$$\therefore \; I_{net} = \frac{V_{net}}{R_{net}} = \frac{200}{\frac{2000}{3} + \frac{2000}{3}}$$

$$= \frac{200 \times 3}{2 \times 2000} = \frac{3}{20}$$

$$\therefore \; P = VI = 200 \times \frac{3}{20} = \boxed{30W}$$

$$\therefore \; V_1 = IR_1 = \frac{3}{20} \times \frac{2000}{3} = 100\,V$$

$$V_2 = IR_2 = \frac{3}{20} \times \frac{2000}{3} = 100\,V \quad \text{OR}$$

$$\therefore \; V_2 = V - V_1 = 200 - 100 = 100\,V$$

Power :

$$\frac{1}{P_s} = \frac{1}{P_1} + \frac{1}{P_2} \quad \text{(series)}$$

$$P_p = P_1 + P_2 \quad \text{(Parallel)}$$