Physics Notes

BY

Er. Lalit Sharma
B.Tech (Electrical)
Ex. Lecturer Govt. Engg. College Bathinda
Physics Faculty Ranker's Point, Bathinda

Arun Garg
M.Sc. Physics
Gold Medalist
Physics Faculty Ranker's Point, Bathinda

Class:10+2
Unit: II
Topic: Current Electricity

SYLLABUS: UNIT-II

Electric current, flow of electric charges in a metallic conductor, drift velocity and mobility and their relation with electric current; Ohm's law, electrical resistance, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity, Carbon resistors, colour code for carbon resistors; series and parallel combinations of resistors; temperature dependence of resistance.
Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel. Kirchhoff's laws and simple applications. Wheatstone bridge, metre bridge.
Potentiometer-principle and applications to measure potential difference, and for comparing emf of two cells measurement of internal resistance of a cell.

Q1.a) What is Electric Current? Unit? Dimensions?

b) 4e^+ crosses a given cross-section to right and 2e^- charge crosses to left in one second. Find current.

c) q(t) = 2t^2 + 3t + 4

Find current at any instant of time *t*.

Find current at time *t* = 5 sec.

Ans.a) **<u>Current</u>**:-

Charge flowing per unit time.

I $= \frac{\Delta\theta}{\Delta t}$

Units → ampere (A)

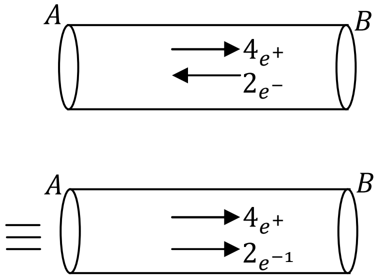
Dimension → $[M^0L^0T^0A']$

b) I = $|I_+| + |I_{-ve}|$

$= \frac{4_e+2_e}{1sec} = \frac{6_e}{1sec}$

= 6 x 1.6 x $\frac{10^{-19}C}{1sec}$

I = 9.6 x 10^{-19}A



c) q(t) = 2t^2 + 3t + 4

∵ I $= \frac{dq}{dt}$

⇒ = 2(2t) + 3(1)

$\boxed{I = 4t + 3}$

I at t = 5sec

= 4(5) + 3

= 23A

Q2. **Find relation between *drift velocity* and *electric field*.**

OR

Prove V_d = μ.E

$$\begin{pmatrix} V_d \rightarrow Drift\ Velocity \\ E \rightarrow Electric\ Field \end{pmatrix}$$

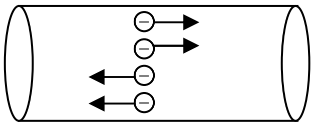
$E = 0$

↓

Mobility

Ans. **Case I**:- When no Electric Field is applied i.e. E = 0.

When no Electric Field is applied. Electrons move randomly. Number of e^- moving to right is equal to number of electron moving to left.



So, $\boxed{I_{net} = 0}$

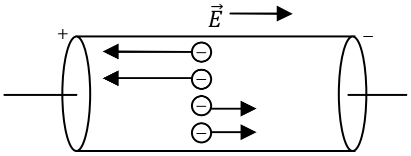
Also $\vec{u}_{avg} = \dfrac{\vec{u}_1 + \vec{u}_2 + \vec{u}_3 + ------ + \vec{u}_n}{n}$

$\boxed{\vec{u}_{avg} = 0}$

Example $\vec{u}_{avg} = \dfrac{10\hat{\imath} + 10\hat{\imath} + (-10\hat{\imath}) + (-10\hat{\imath})}{4}$

= 0

Case II:- When E ≠ 0



e^- moving to left → speed increases

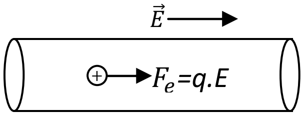
e^- moving to right → speed decreases

$$\vec{V}_{avg} = \frac{\vec{V}_1 + \vec{V}_2 + \vec{V}_3 + ------ + \vec{V}_n}{n}$$

$$= \frac{(\vec{u}_1 + \vec{a}t_1) + (\vec{u}_2 + \vec{a}t_2) + --- + (\vec{u}_n + \vec{a}t_n)}{n}$$

$$= \left(\frac{\vec{u}_1 + \vec{u}_2 + --- \vec{u}_n}{n}\right) + \vec{a}\left(\frac{t_1 + t_2 + --- t_n}{n}\right)$$

$$= \vec{u}_{avg} + \vec{a}.t_{avg}$$



$$= 0 + \left(\frac{q.\vec{E}}{m}\right).\ t_{avg}$$

$$= \left(\frac{-e.\vec{E}}{m}\right)\tau$$

$$\boxed{\begin{aligned} \vec{V}_{avg} &= \left(\frac{-e.\vec{\tau}}{m}\right).\ \vec{E} \\ &= -\mu.\ \vec{E}, \text{ where } \mu = \frac{e.\tau}{m} \text{ is mobility} \end{aligned}}$$

Q3. **a) Prove I = n.A.e. V_d**

b) Prove Ohm's Law i.e. V = I.R

OR

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

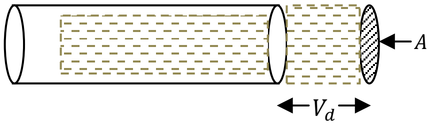
Ans.a)

$$I = \frac{charge\ flowing}{sec}$$

$$= (e)\left(\frac{no.of\ electrons}{sec}\right)$$

$$= (e)\ (n.A.V_d)$$

$$\boxed{I = n.A.e.V_d}$$



$Volume = A.V_d$

n → no. of e volumes

b)

$$I = n.A.e.V_d$$

$$= n.A.e\left(\frac{e.\tau}{m}.E\right)$$

$$\frac{I}{A} = \frac{n.e^2.\tau}{m}.E$$

Current Density,

$$J = \left(\frac{n.e^2.\tau}{m}\right).E$$

$$\boxed{J = \sigma.E}$$

Conductivity

J → Current Density

E → Electric Field

Q4. **a) Give approximate value of resistivity for conductors, semiconductors, insulators. Also discuss temperature co-efficient of resistivity values.**

b) What is "*Colour code for carbon resistors*"? Give Example.

Ans.

a)

Material	**Resistivity (Ω-m^{-1}) at Temperature 0^0C**	**Temperature Co-efficient α at temperature 0^0C**
Conductors	Conductors	Conductors
1. Silver	1. 1.6 x 10^{-8}	1. 0.0041
2. Copper	2. 1.7 x 10^{-8}	2. 0.0068
Semi conductors	Semi conductors	Semi conductors
1. Germanium	1. 0.46	1. -0.05
2. Silicon	2. 2300	2. -0.07
Insulator	Insulator	
1. Pure Water	1. 10^5	
2. Rubber	2. 10^{15}	

Conductors have low resistivity, semi conductors have medium resistivity and insulators have high resistivity.
Temperature co-efficient for metals are *+ve*.
Temperature co-efficient for semiconductors is *–ve*.

b) Coloured bands on carbon resistors are used as codes to find value of resistance.

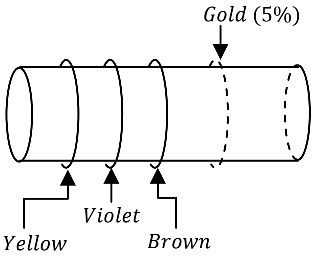
Step 1.	B	B	ROY	Great	Britain	Very	Good	Wife
Step 2.	Black	Brown	ROY	Green	Blue	V	Gray	W
Step 3.	B	B	ROY	G	B	V	G	W
	0	1	234	5	6	7	8	9
Example.	Y	V	B					
	↓	↓	↓					
	4	7	1					

$= 47\ x\ 10'$

$= 470\ \Omega\ \pm 5\%$

↓

error is indicated by last ring (tolerance)

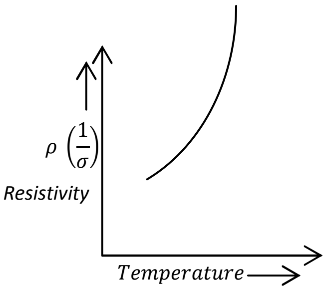


Q5. a) How resistivity of metals changes with change in temperature?

b) How resistivity of semiconductors changes with change in temperature?

c) How resistance of a wire changes with temperature.

Ans.a) **Metals**:-



As proved in Ohm's Law (in Q.No.3)

$$J = \left(\frac{n.e^2.\tau}{m}\right).E$$

$$\boxed{J = \underset{\substack{\downarrow \\ \text{Conductivity}}}{\sigma}.E}$$

Conductivity, $\sigma = \frac{n.e^2.\tau}{m}$

n → no. of electrons in metals remain same with temperature.
e → charge on electrons remain same.
m → mass of electrons remain same.

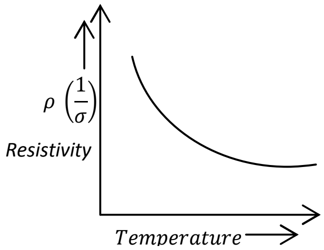
τ → relaxation time decreases with increase in temperature.

(Reason → As temperature increases, speed increase.
So, time between two collisions decreases.)

$$\sigma = \left(\frac{n.e^2}{m}\right).\underset{\text{Decreases with increase in temperature}}{\tau}$$

So, Conductivity decreases and resistivity increases.

b) **Semiconductors**:-



$$\sigma = \frac{n.e^2.\tau}{m}$$

e,m → remain same
n → increases with increase in temperature.

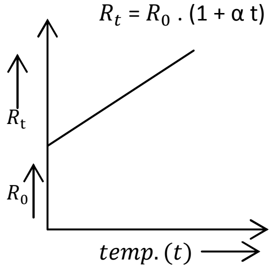
(Reason → same as given in metals.)

$$\text{So,} \quad \sigma = \overset{\substack{\text{increases} \\ \uparrow}}{n}.\frac{e^2}{m}.\underset{\substack{\downarrow \\ \text{decreases}}}{\tau}$$

Increase in *n* is more effective than decrease in τ.

So, Conductivity, σ → increases
Resistivity, ρ → decreases

By heating, semiconductors become good better conducting materials.

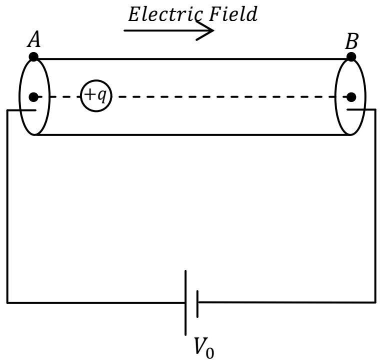


c) $$\underbrace{R_t}_{\text{Resistance at } t^0C} = \underbrace{R_0}_{\text{Resistance at } 0^0C} . (1 + \underbrace{\alpha}_{\text{Temperature coeff. Of Resistance}} \underbrace{t}_{\text{Temperatur}})$$

Q6. **a) Prove P = VI OR P = $\frac{V^2}{R}$.**

b) Why energy (electric) is transmitted at high voltage from one station to another?

Ans.a) **<u>Power loss in a conductor</u>**:-



Charge particle *+q* moves from *A* to *B*.

$V_A > V_B$

$\Delta V = V_A - V_B$

$$\boxed{V_0 = V_A - V_B}$$

As particle moves from A to B, change in Potential Energy,

$\Delta U = (\Delta V)\, q$

$= V_0 \,.\, I \,.\, \Delta t$

$$\boxed{\Delta U = V_0 \,.\, I \,.\, \Delta t}$$

Kinetic Energy of charged particle inside a conductor remains constant because drift speed remains constant at all point in a conductor.

So, change in energy,

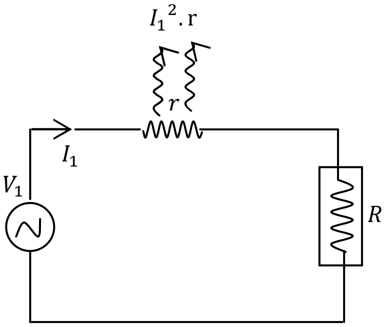
$|\Delta U| = |\Delta W|$ i.e. work done

So $\Delta W = V_0 \,.\, I \,.\, \Delta t$

$\frac{\Delta W}{\Delta t} = V_0 \,.\, I$

$\boxed{P = V_0 \,.\, I}$ *OR* $\boxed{P = (I.R)\, I = I^2.R}$

b) **<u>Low Voltage Transmission</u>**:-



Low Voltage → V_1

Current → I_1

$$\boxed{\text{Loss of energy} = I_1^2.r}$$

<u>High Voltage Transmission</u>:-

Transformer is used to increase voltage.

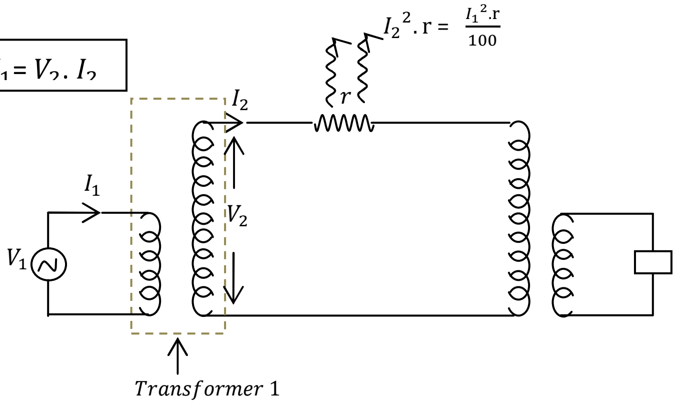
As per law of conservation of energy $\boxed{V_1 . I_1 = V_2 . I_2}$

$I_2 = \left(\frac{V_1}{V_2}\right) . I_1$ [say $V_2 = 10.V_1$]

$$\boxed{I_2 = \frac{1}{10} . I_1}$$

New loss of energy $= I_2^2.r$

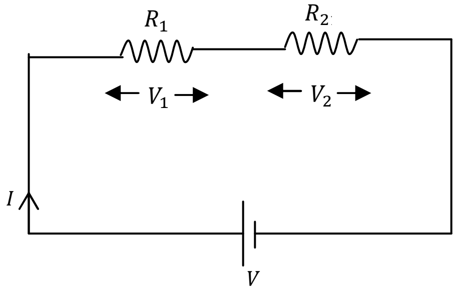
$= \left(\frac{I_1}{10}\right)^2 . r = \frac{I_1^2.r}{100} = \frac{Initial\ Loss}{100}$



Q7. **a) Prove for resistors in series $R_s = R_1 + R_2$.**

b) Prove for resistors in parallel $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$.

Ans.a) **Resistances in series**:-



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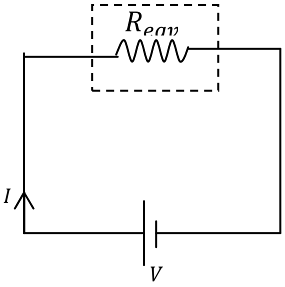


As per Kirchoff's Voltage Law

$$V = V_1 + V_2$$
$$= I.R_1 + I.R_2$$
$$\boxed{V = I.(R_1 + R_2)}$$

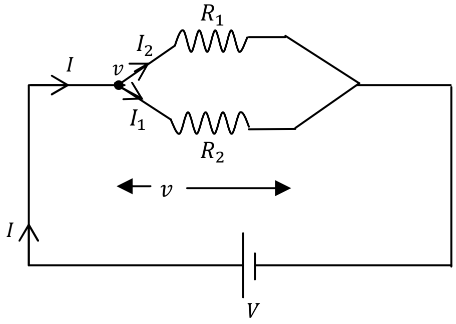
In the above diagram

$$V = I\,.\,R_{eav}$$
$$\boxed{V = I\,.\,R_{eqv}}$$

Comparing theses two equations

$$\frac{V}{I} = R_1 + R_2 = R_{eqv} \quad \therefore \quad \boxed{R_{eqv} = R_1 + R_2}$$

b) **Resistances in parallel**:-



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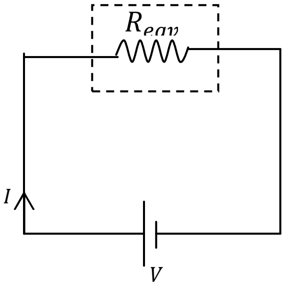


As per Kirchoff's Current Law of Junctions

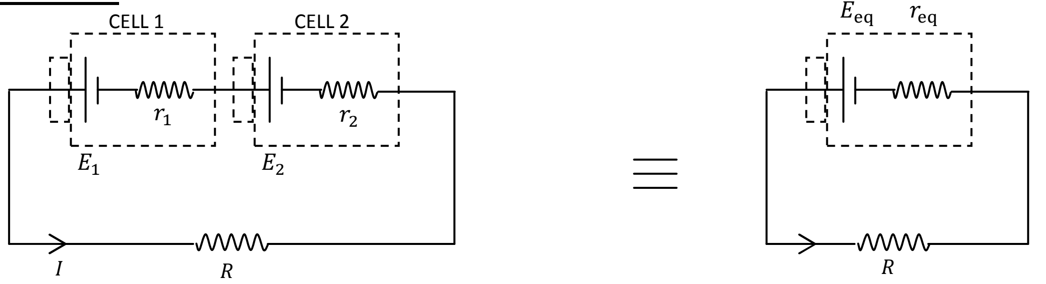
$$I = I_1 + I_2$$
$$I = \frac{V}{R_1} + \frac{V}{R_2}$$
$$\boxed{\frac{I}{V} = \frac{1}{R_1} + \frac{1}{R_2}}$$

$$I = \frac{V}{R_{eqv}}$$
$$\boxed{\frac{I}{V} = \frac{1}{R_{eqv}}}$$

Comparing the two $\boxed{\frac{1}{R_{eqv}} = \frac{1}{R_1} + \frac{1}{R_2}}$

Q9. a) Find E_{eq} and r_{eq} for two cells in series.
b) Find E_{eq} and r_{eq} for two cells in parallel.

Ans.a) **Cells in series**:-



Total e.m.*f.* = Total drop in voltage

$E_1 + E_2$ = I.R + I.r_1+ I.r_2

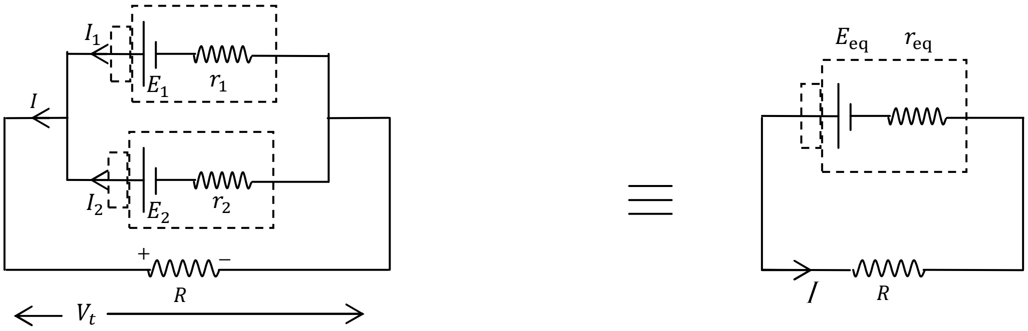
$(E_1 + E_2)$ = I.R + I. $(r_1 + r_2)$ ---------- ①

E_{eq} = I.R + I. r_{eq} ------- ②

Comparing equations ① and ②

$$\boxed{E_{eq} = E_1 + E_2 \text{ and } r_{eq} = r_1 + r_2}$$

b) **Cells in parallel**:-



I $= I_1 + I_2$

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

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

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

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

I $= \frac{E_{eq.}}{r_{eq} + R}$

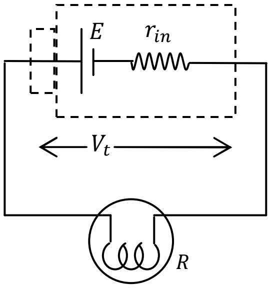
Comparing

$$E_{eq} = \frac{{E_1}/{r_1} + {E_2}/{r_2}}{{1}/{r_1} + {1}/{r_2}}$$

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

Q8. **a) Define e.m.*f.*, internal resistance and terminal voltage for a cell.**

b) Relationship between e.m.*f.*, E and terminal voltage V_t of a cell.



Ans.a) **E.M.*f.***:-

Total voltage developed inside a cell.

Internal resistance, r_{in}:-

Total opposition offered to current between terminals of a cell.

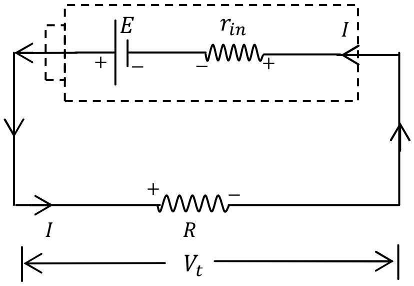
Terminal Voltage, V_t:-

Voltage across the terminals of a cell, is called terminal voltage.

b) **Relationship between E and V_t**:-

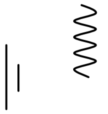
Discharging

In discharging of a cell, current comes out of *+ve* terminal of cell.



$E = I.R + I.r_{in}$

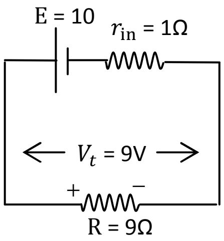
$= V_t + I.r_{in}$



$$\boxed{V_t = E - I.r_{in}}$$

Terminal voltage is less than e.m.*f*.

Example:-

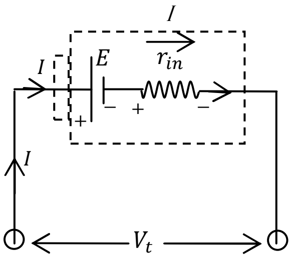


$E = V_t + I.r_{in}$

$10 = 9 + (1)(1)$

Charging

In charging of a cell, current enters into *+ve* terminal of cell.

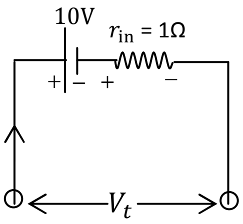


$V_t = E + I.r_{in}$

$$\boxed{V_t = E + I.r_{in}}$$

Terminal voltage is more than e.m.*f*.

Example:-



$V_t = E + I.r_{in}$

$11 = 10 + (1)(1)$

Q10. Explain:

a) Kirchoff's junction rule (Current Law).

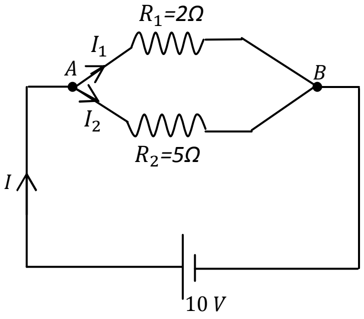
b) Kirchoff's loop rule (Voltage Law).

Ans.a) **<u>Kirchoff's Current Law</u>**:-

At any junction, the sum of currents entering the junction is equal to the sum of currents leaving the junction.

<u>Example</u>:-

Find current I using junction rule at *A*



$I_1 = \frac{10V}{2\Omega} = 5A$

$I_2 = \frac{10V}{5\Omega} = 2A$

At *A*

Current entering = Current leaving

$I = I_1 + I_2$

$= 5A + 2A$

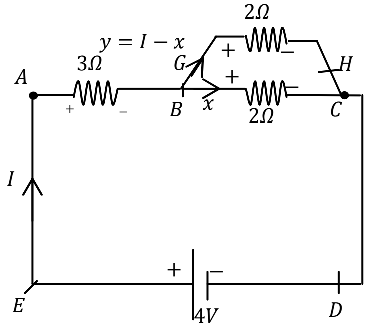
$\boxed{I = 7A}$

b) **<u>Kirchoff's Loop rule</u>**:-

The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero, (where voltage rise is taken as positive and voltage drop is taken as negative)

<u>Example</u>:-

Find current I in the circuit using Kirchoff's current and voltage law.



<u>Solutions</u>:-

<u>Step 1</u>:- Let the current flowing is *x* in *BC* as shown.

Use Kirchoff's junction rule at *B*

$I = x + y \Rightarrow y = I - x$

<u>Step 2</u>:- Kirchoff's loop rule ABCDEA

Voltage rise taken as +ve and voltage fall taken as -ve

$(-3\ I) + (-2x) + (+4) = 0$

$\boxed{4 = 2x + 3I}$ ------ (1)

<u>Step 3</u>:- Kirchoff's loop rule BGHCB

$-[2\ (I - x)] + 2(x) = 0$

$2\ (I - x) = 2x$

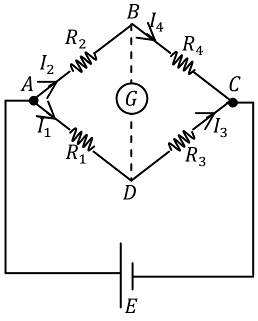
$x = {}^{I}/_{2}$

$\boxed{I = 1 \text{ amp} \quad x = \frac{1}{2} \text{ amp}, \; y = \frac{1}{2} \text{ amp}}$

Q11. **a) What is Wheatstone Bridge? Use?**
b) Derive condition for balanced Wheatstone Bridge? Give example to explain the use of Wheatstone Bridge?

Ans.**a)** Wheatstone Bridge is a device/apparatus having four resistances and galvanometer used to find unknown resistance

b) Under balance condition B and D are at same potential i.e. $I_g = 0$



$\boxed{I_2 = I_4 \text{ and } I_1 = I_3}$ ----------- ①

$V_{AB} = V_{AD}$

$\boxed{I_2 R_2 = I_1 R_1}$ ------ ②

$V_{BC} = V_{DC}$

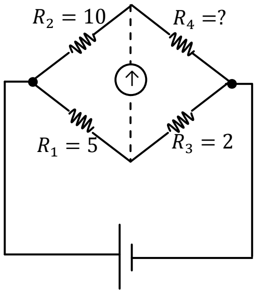
$\boxed{I_4 R_4 = I_3 R_3}$ ------ ③

Dividing eq. ② by ③

$$\frac{\cancel{I_2} . R_2}{\cancel{I_4} . R_4} = \frac{\cancel{I_1} . R_1}{\cancel{I_3} . R_3}$$

$$\frac{R_2}{R_4} = \frac{R_1}{R_3}$$

$$\boxed{R_4 = R_2 \frac{R_3}{R_1}}$$



<u>Example</u>:- Find R_4 for $I_g = 0$

$$\frac{R_2}{R_4} = \frac{R_1}{R_3}$$

$$\frac{10}{R_4} = \frac{5}{2}$$

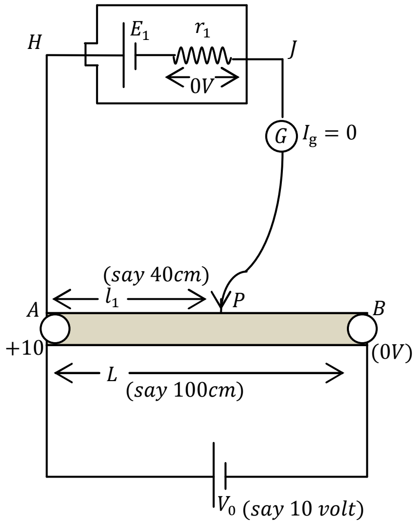
$$\boxed{R_4 = 4\Omega}$$

Q12. a) What is potentiometer? Use?
b) Use of Potentiometer to compare e.m.*f*'s of two cells.

Ans.a) Potentiometer is a device used to

1. Find e.m.*f*. of a cell.
2. Compare e.m.*f*. of two cells.
3. Find internal resistance of a cell.

It measures/compares e.m.*f*. by "Comparison Method" where signal drawn is zero i.e. "null defection method".

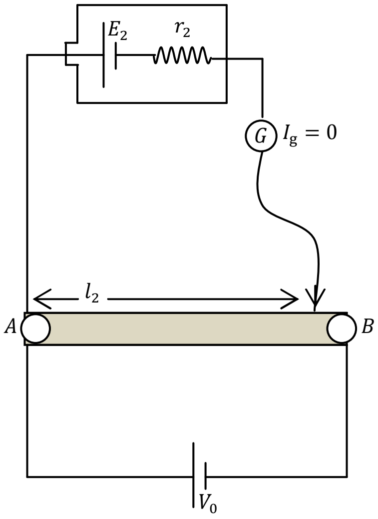


b) **Arrangement 1**:-

1. Voltage per unit length, K = $\frac{V_0}{L}$ (say $\frac{0.1Volt}{metre}$)
2. Voltage across *HJ* = E – (0) r = E
3. Voltage across *AP* = $\frac{V_0}{L}$. l (say 4V)
4. $(Volt)_{HJ}$ = $(Volt)_{AP}$

$$\boxed{E_1 = \left(\frac{V_0}{L}\right) l_1}$$ --------- ①

Arrangement 2:-



Similarly for 2nd figure

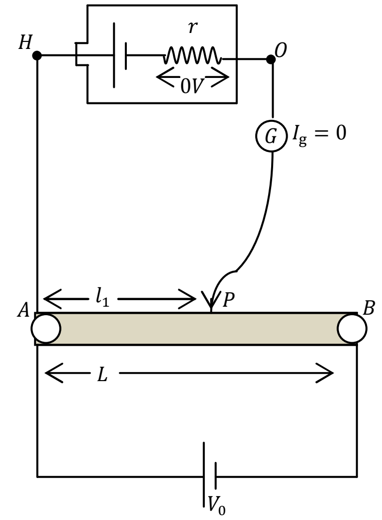
$$\boxed{E_2 = \left(\frac{V_0}{L}\right) l_2}$$ --------- ②

Dividing ① by ②

$$\boxed{\frac{E_1}{E_2} = \frac{l_1}{l_2}}$$

Q13. **a) Use Potentiometer to find internal resistance of a cell.**
b) Compare Potentiometer and Voltmeter.

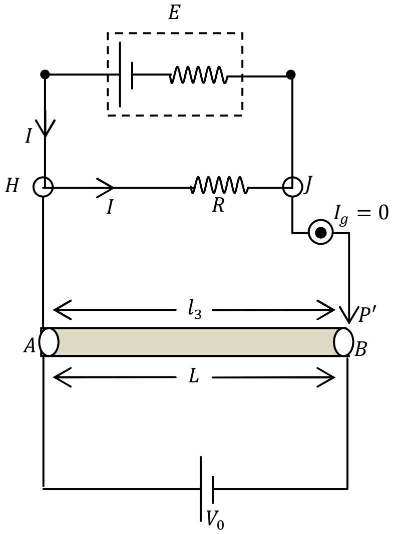
Ans.a) **<u>Arrangement 1</u>**:-



1. Voltage per unit length, *K* = $\frac{V_0}{L}$
2. Voltage across *HJ* = E – (0) r = E
3. Voltage across *AP* = $\frac{V_0}{L} \cdot l_1$
4. $(Volt)_{HJ} = (Volt)_{AP}$

$$\boxed{E_1 = \left(\frac{V_0}{L}\right) l_1} \quad \text{---------} \; ①$$

<u>Arrangement 2</u>:-



1. Voltage across *HJ* = R $\left(\frac{E}{R+r}\right)$
2. Voltage across *AP* = $\frac{V_0}{L} \cdot l_2$
3. $(Volt)_{HJ} = (Volt)_{AP}$

$$\boxed{E\left(\frac{R}{R+r}\right) = \left(\frac{V_0}{L}\right) l_2} \quad \text{---------} \; ②$$

Dividing ② by ①

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

$$\boxed{r = R\left(\frac{l_1}{l_2} - 1\right)}$$

b) **Comparison of voltmeter and potentiometer**

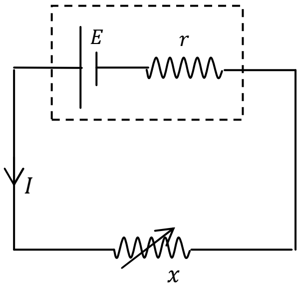
Voltmeter	Potentiometer

Q14. State, Explain and prove maximum power transfer theorem.

Ans. **Maximum power transfer theorem**:-

Power transferred to external resistance will be maximum, when external resistance is equal to internal resistance.

Proof:-



E → *e.m.f* of cell.

r → internal resistance of cell

x → external variable resistance

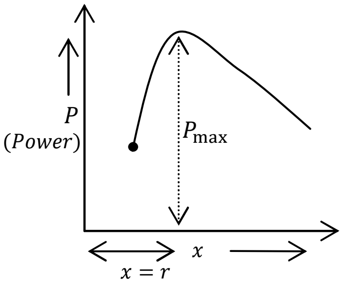
our objective is to find value of *x* for which power transferred to *x* is maximum.

Power across x, P

P $= I^2 . x$

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

P $= E^2 . (r+x)^{-2} . x^1$



Difference both sides

$\frac{dP}{dx} = \frac{d\left(E^2 .(r+x)^{-2} . x^1\right)}{dx}$

$= E^2 . \left[(r+x)^{-2} . \frac{dx}{dx} + x . \frac{d}{dx}(r+x)^{-2}\right]$

0 $= E^2 . [(r+x)^{-2} - 2 . x . (r+x)^{-3}]$ $\left[\frac{dP}{dx} = 0 \; at \; max. power\right]$

⇒ $\boxed{x = r}$

External resistance is equal to internal resistance for maximum power across *x*.