Chapter–3

Current Electricity

CBSE CLASS XII NOTES

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MES DOHA QATAR

 cell

 Battery

 switch

 key

 voltmeter

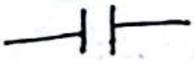
 Ammeter

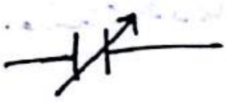
 Galvanometer

 Resistor

 variable resistor

 Bulb

 capacitor

 variable capacitor.

CURRENT ELECTRICITY

Electric current

Rate of flow of charge $I = \frac{q}{t}$

S.I unit - Ampere.

conventional current

opposite to the flow of electrons

Electromotive force [EMF]

Amount of work done by a source to move unit charge around a complete circuit.

current density (J)

$$j = \frac{\text{current}}{\text{unit area}}$$

$$j = \frac{I}{A}, \quad \text{S.I unit } A/m^2$$

→ vector quantity

→ Direction is along $\vec{E}$.

How electrons are drifted in an electric field?

In the absence of Electric field

Average velocity of $\bar{e} = 0$ (due to random motion)

In the presence of Electric field

$\bar{e}$ ns are accelerated

$F = ma = qE$ {q = e

$ma = -eE$

$$\boxed{\therefore a = -\frac{eE}{m}}$$

Thus they get scattered due to collision.

relaxation time (τ)

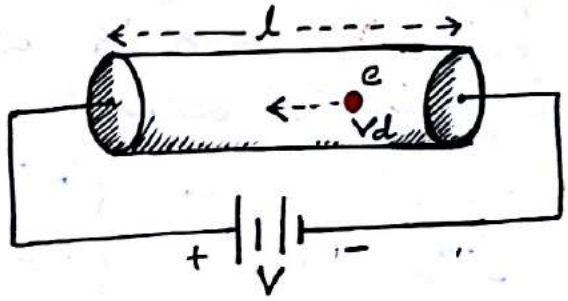
average time interval between successive collisions of $\bar{e}$.

Drift velocity

Average velocity with which free $\bar{e}$'s get drifted under the influence of an $\vec{E}$.

$$\boxed{\vec{V}_d = -\frac{e\vec{E}}{m}\tau}$$

$\vec{V}_d$ → drift velocity.



when an electric field $\vec{E}$ is applied, the $\bar{e}$s modify their speed in such a way that they drift slowly in the direction opposite to that of field.

$F = ma = qE$

$= -eE$

$$ma = -eE$$

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

$$V = u + at$$

$$V = 0 + at = at \quad --(1)$$

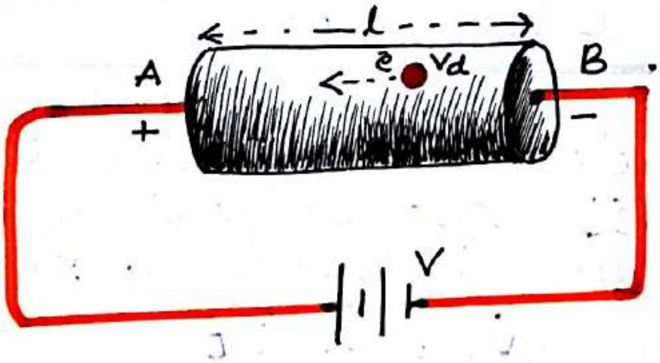
here $V = \vec{V_d}$ & $t = \tau$

$\therefore (1) \Rightarrow$

$$\boxed{\vec{V_d} = -\frac{e\vec{E}}{m}\tau} \qquad V_d = \frac{eE\tau}{m}$$

'$-$' ve sign indicates $\vec{V_d}$ is opposite to $\vec{E}$.

Relation between current and V_d

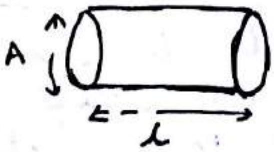


let 'q' charges pass through cross sectional area 'A' of the wire in 't' seconds.

$$t = \frac{l}{V_d} \qquad \because V = \frac{s}{t}, \quad t = \frac{s}{V}$$

$$n = \frac{\text{No of } \bar{e}\text{s}}{\text{unit volume}} \qquad \text{here } t = \frac{l}{V_d}$$

$$n = \frac{N}{Al}$$



Volume $= Al$

$$N = nAl$$

charge $q = N.e = nAle$

current $I = \dfrac{q}{t}$

$$I = \frac{Ne}{t} = \frac{nAle}{t} \quad ---(1)$$

since $t = \dfrac{l}{V_d}$

$$(1) \Rightarrow I = \frac{nAle}{\frac{l}{V_d}} = nAeV_d$$

$$I = nAeV_d \qquad I = nAeV_d$$

Relation b/w current density and relaxation time

$$I = nAeV_d$$

$$j = \frac{I}{A} = \frac{nAeV_d}{A} = neV_d$$

$$\therefore j = neV_d \qquad \because V_d = \frac{eE\tau}{m}$$

$$j = ne\frac{(eE)\tau}{m}$$

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

Mobility (μ), electron mobility or ionic mobility

$$\text{mobility} = \frac{\text{drift velocity}}{\text{unit electric field}}$$

$$\mu = \frac{|V_d|}{\vec{E}} = \frac{\frac{eE\tau}{m}}{E} = \frac{e\tau}{m}$$

S.I unit $= \left(\dfrac{ms^{-1}}{Vm^{-1}}\right) = m^2/Vs$

relation b/w μ & τ [mobility & Relaxation time]

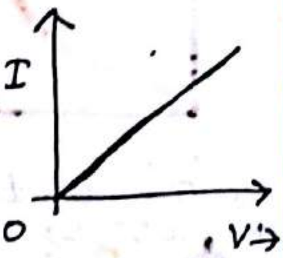
$$\mu = \frac{V_d}{E} = \frac{\frac{eE\tau}{m}}{E} = \frac{eE\tau}{mE}$$

$$\boxed{\mu = \frac{e}{m}\tau}$$

Ohm's Law.

At constant temperature current is directly proportional to the potential difference between ends of a conductor.

$$V \propto I$$
$$V = IR$$
$$\frac{V}{I} = R = \text{const}$$



* If temp changes ohm's law doesn't hold good because 'R' changes.

* unit of Resistance – Ω (ohm)

Factors affecting resistance.

(1) Nature of material
(2) length of conductor
(3) Area of cross section of conductor.

4. Temperature

i.e, $R \propto l$, ~~R∝l~~, $R \propto \frac{1}{A}$

$$\therefore R \propto \frac{l}{A}$$

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

Resistivity (ρ)

Resistivity of a conductor can be defined as the resistance of the conductor of unit length and unit area of cross section.

i.e, $\rho = \frac{RA}{l}$ $\because R = \frac{\rho l}{A}$

if $l = 1$, $A = 1$ $\quad \therefore \rho = \frac{RA}{l}$

$$\rho = R$$

SI unit = Ωm

Conductivity σ

Reciprocal of resistivity is conductivity

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

SI unit – $\Omega^{-1}m^{-1}$ or Sm^{-1}

[mho/metre]

Relationship between E and ρ, j and σ

$$V = IR = \frac{I\rho l}{A}$$

$V = I \frac{\rho l}{A}$ ∵ $V = Ed$, here $d = l$, ∴ $V = E \cdot l$

$El = \frac{I \rho l}{A}$

$E = \frac{I}{A} \cdot \rho$

$E = j\rho$ ∵ $j = \frac{I}{A}$

∴ $j = E/\rho$ ∵ $\frac{1}{\rho} = \sigma$

∴ $j = \sigma E$

Relation b/w ρ, n, τ

$I = nAeV_d$

$I = nAe\left(\frac{eE}{m}\right)\tau$

$I = nAe^2 \frac{E}{m}\tau$ ∵ $E = \frac{V}{d}$, $E = \frac{V}{l}$

$I = nAe^2 \frac{V}{lm}\tau$ -- (1)

∴ $\frac{V}{I} = \frac{V}{nAe^2 \frac{V}{lm} \tau}$

$\frac{V}{I} = \frac{ml}{nAe^2\tau}$ ∵ $\frac{V}{I} = R$

$R = \frac{m}{ne^2\tau}\left(\frac{l}{A}\right)$ .... (2)

but we know that

$R = \rho \frac{l}{A}$ .... (3)

∴ (2) & (3) ⇒ $\rho = \frac{m}{ne^2\tau}$

Resistivity of conductors (metals), Insulators and Semiconductors.

Metals - very low $10^{-8}\,\Omega m$ to $10^{-6}\,\Omega m$

Insulators - very high 10^{18} times of that of metals.

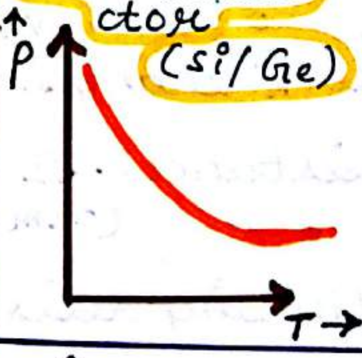
Semiconductors - between conductors and Insulators.

Graphical relationship b/w Resistivity (ρ) and Temperature T in kelvin

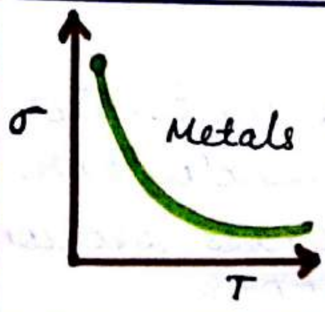
metals

Alloy [Nichrome]

Semi conductor (Si/Ge)



Super conductor (Hg)



⇐ conductivity σ versus Temperature T

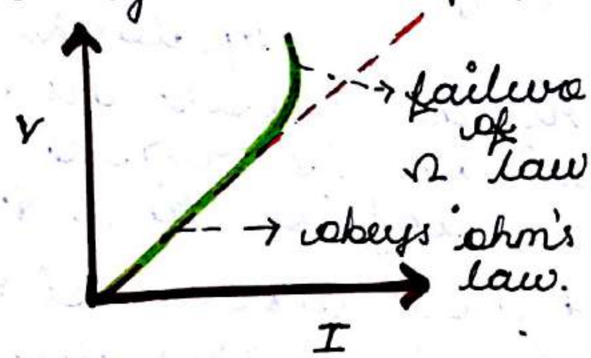
Ohmic and non ohmic conductors

Ohmic conductors: Obeys Ohm's law.
eg; Metals

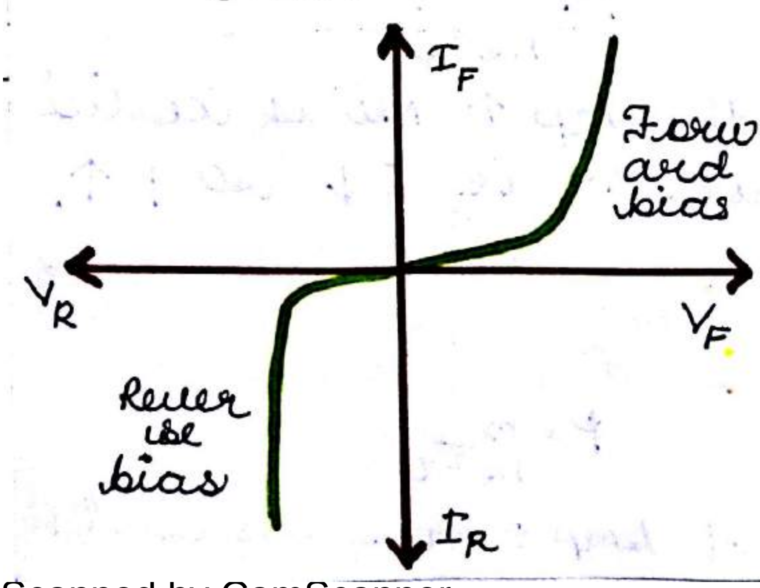
Non ohmic conductors: does not obey ohm's law
eg; Semiconductors.

Limitations of Ohm's law.

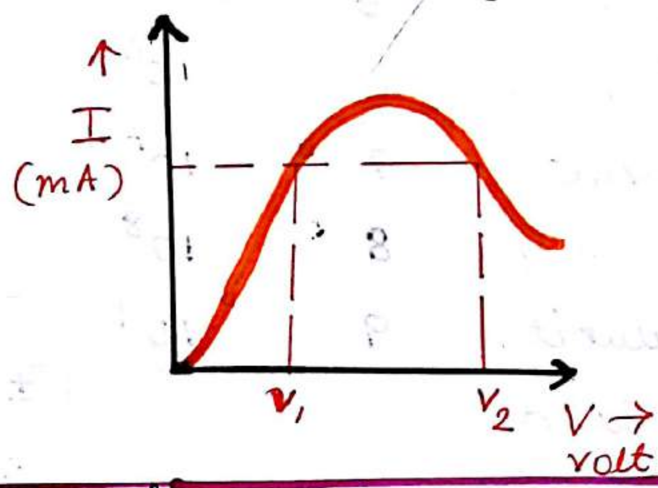
* VI graph is linear only for small amount of current. when temperature increases we won't get linear graph.



* semiconductors do not obey Ohm's law (Non-ohmic)



* more than one value of voltage for same current in GaAs



Types of resistors

(a) Wire bound resistor.
* Nichrome, Maganin (alloys) are used
* Resistances are typically in the range of a fraction of a Ω to few hundred Ω's.

(b) carbon resistor.
* They are compact, inexpensive
* high value of R
* smaller in size.
* colour codes are used.

colour codes of carbon Resistor.

colour code	Number	multiplier	Tolerance
Black	0	1	
Brown	1	10^1	
Red	2	10^2	

Orange	3	10^3	
yellow	4	10^4	
green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Grey	8	10^8	
white	9	10^9	
Gold			±5%
Silver			±10%
No colour			±20%

How to find R value using colour codes.

First 2 bands — significant figures

3rd band — multiplier.

4th band — Tolerance.

* A carbon resistor is marked in colour bands of red, black, orange and silver. what is the resistance and tolerance value of the resistor? [2002]

Red, Black, O, Silver

2 0 3 ±10%.

$R = 20 \times 10^3 \pm 10\%$

$R = \underline{20k\Omega \pm 10\%}$

* You are required to select a carbon resistor of resistance $47k\Omega \pm 10\%$ from a large collection. what should be the sequence of colour bands used to code it? [F-2011]

$47k\Omega \pm 10\%$.

$47 \times 10^3 \pm 10\%$.

yellow violet, orange silver

yellow, violet, Orange, silver

* How is relaxation time affected on rising temperature?

If temperature increases no of collision increases hence relaxation time ↓ (τ ↓)

* How does resistivity increases when Temperature ↑ in metals?

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

If temp ↑ No of collisions ↑ i.e, τ ↓ so ρ ↑.

* How does resistivity ρ ↓ when temperature ↑ in a semiconductor?

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

If temp ↑ no of free e s n ↑ ρ ↓

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Temperature co-efficient (α)

$$\boxed{\alpha = \frac{R_T - R_0}{R_0(T - T_0)}}$$

If $R_0 = 1$, $T - T_0 = 1$, $\alpha = R_T - R_0$

Temperature coefficient is the increase in resistance per unit original resistance at 0°c per unit rise in temperature.

Compare Temperature coefficient of (1) Metals (2) Alloys & (3) semiconductors.

(1) metals 'α' is positive

(2) alloys 'α' is positive but very small

(3) semiconductors 'α' is negative.

Expressions for ρ and R at a given temperature.

$$\rho_T = \rho_0 [1 + \alpha(T - T_0)]$$

$$\rho_2 = \rho_1 (1 + \alpha(T_2 - T_1))$$

$$R_T = R_0 [1 + \alpha(T - T_0)]$$

$$R_2 = R_1 [1 + \alpha(T_2 - T_1)]$$

ρ_T & ρ_0 → ρ at T°c and 0°c

R_T and R_0 — R at T°c and 0°c

R_1 and R_2 — R at T_1°c and T_2°c

Joule's law.

According to Joules law

$$\boxed{H \propto I^2}$$

$$\boxed{H = I^2 R t}$$

$$\boxed{H = VIt}$$

$$\boxed{H = \frac{V^2}{R} t}$$

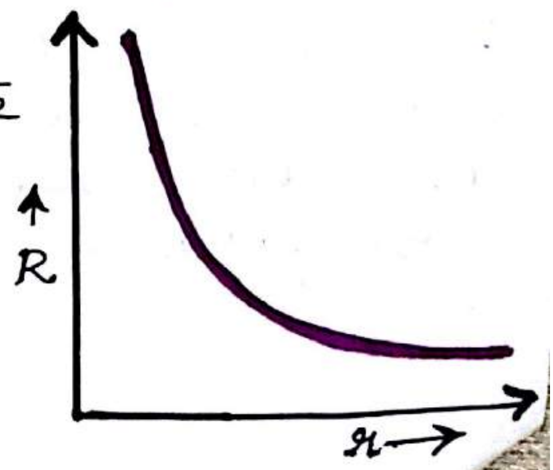
$\because R = \frac{V}{I}$

I → current, H → heat energy, t → time of flow of current.

Questions

Plot a graph showing the variation of resistance of a conducting wire as a function of its radius, keeping the length of the wire and its temperature as constant? [CBSE (F) 2013]

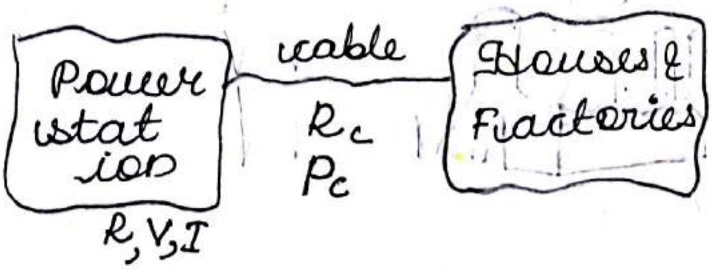
$$R = \rho \frac{l}{\pi r^2}$$



Power / power Transmission

Rate of energy dissipation in a resistor is called the power i.e; power

$$\boxed{P = \frac{W}{t} = \frac{Vit}{t} = VI}$$
$$\boxed{P = I^2R = \frac{V^2}{R}}$$



$P = VI$ $\quad \therefore I = \frac{P}{V}$

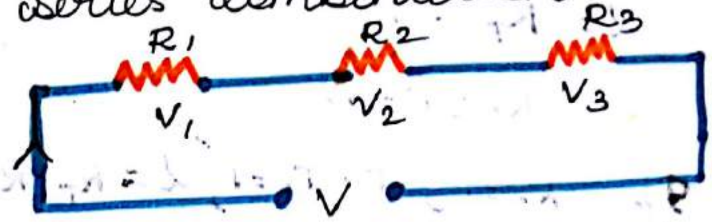
Power dissipation in cable

$$P_C = I^2 R_C$$
$$P_C = \left(\frac{P^2}{V^2}\right) R_C$$
$$P_C \propto \frac{1}{V^2}$$

* To reduce power loss increase voltage. If V is very high, it is dangerous, so in the other end step down transformers are used.

combination of Resistors

* Effective resistance in series combination



In series I constant
V - ADD's

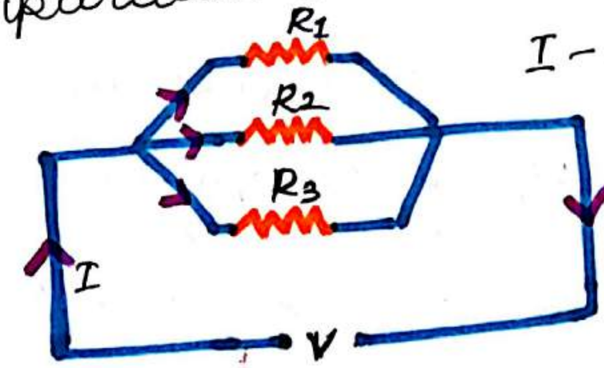
$V = V_1 + V_2 + V_3$ $\quad \circ\circ\circ$ $V = IR$, $V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$

$IR = IR_1 + IR_2 + IR_3$

$$\boxed{R_S = R_1 + R_2 + R_3}$$

* Effective resistance in parallel combination

I - ADD's



In parallel V - const

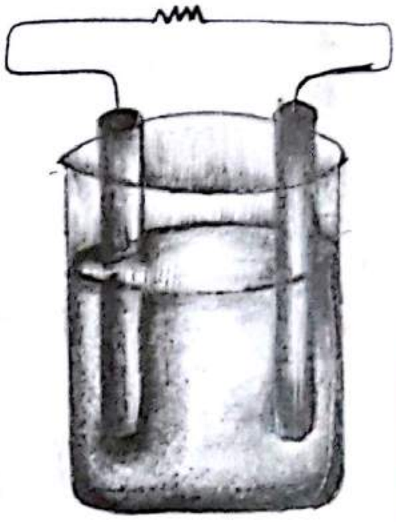
$I = I_1 + I_2 + I_3$ $\quad \circ\circ\circ$ $V = IR$, $I = \frac{V}{R}$, $I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$, $I_3 = \frac{V}{R_3}$

$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$

$$\boxed{\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Simil

CELL



An electric cell is a device which converts chemical energy into electrical energy.

Internal resistance of a cell (r)

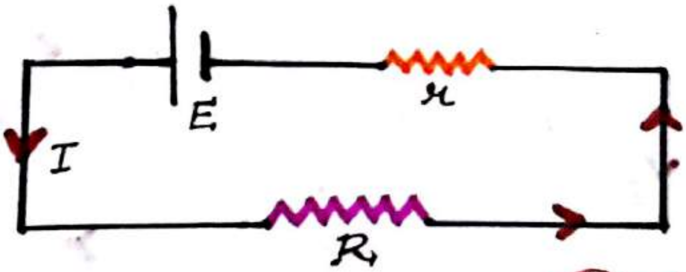
It is the resistance offered by the cell when current flows through it.

* Factors affecting Internal resistance

(1) Distance b/w the plates
(2) Nature of electrolyte
(3) Nature of electrodes
(4) Area of eletrodes.
(5) Temperature of the solution
(6) External Resistance.

Terminal Potential difference. (V)

Is the potential difference between the terminals of a cell in a closed circuit.



consider a cell of emf E and internal resistance r connected to an external Resistance 'R'.

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

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

$$I = \frac{\text{Total emf}}{\text{Total resistance}}$$

$$I = \frac{E}{R+r} \quad \ldots ⓐ$$

$$E = I(R+r) = IR + Ir \quad \ldots ①$$

Terminal p.d (V) = IR

$\therefore ① \Rightarrow \; E = V + Ir$

$$\therefore \boxed{V = E - Ir}$$

$$V = IR \quad \ldots (b)$$

ⓐ in ⓑ $\Rightarrow$ $\boxed{V = \left(\frac{E}{R+r}\right) R}$

$$\boxed{V = \frac{ER}{R+r}}$$

$\boxed{V = E - Ir}$ (when $I=0$, $r=0$.

$\boxed{V = E - 0 \times 0}$

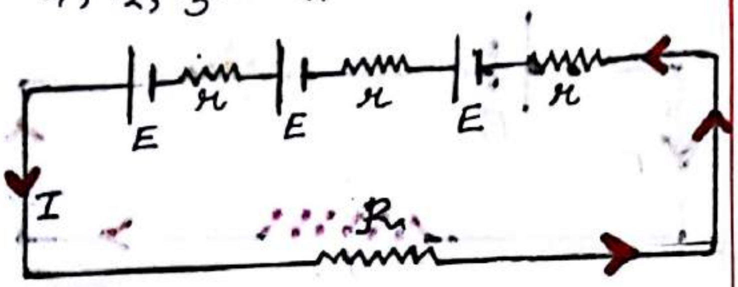
$\boxed{V = E}$ $\therefore$ Terminal p.d = emf

Combination of cells in series.

consider a number of cells of emf's $E_1, E_2, E_3 \ldots E_n$ of internal resistances $r_1, r_2, r_3 \ldots r_n$.

$I \rightarrow$ current

$v_1, v_2, v_3 \dots v_n$ terminal p.d s



$$I = \frac{\text{Total emf}}{\text{Total resistance}}$$

$$\boxed{I = \frac{nE}{nr+R}}$$

$$I(nr+R) = nE$$

$$nrI + IR = nE$$

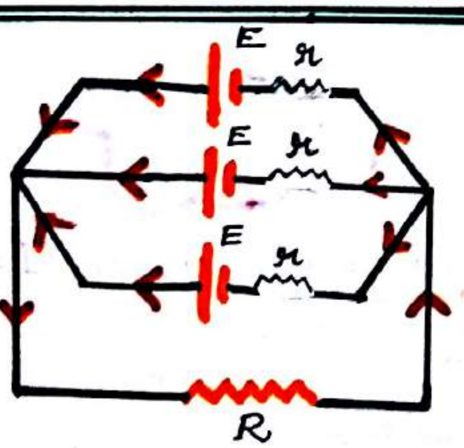
$$nrI = nE - IR.$$

$$r = \frac{nE - IR}{nI}$$

$$\boxed{\therefore r = \frac{E}{I} - \frac{R}{n}}$$

* $E_{eq} = E_1 + E_2 + E_3 + \dots E_n$
* $r_{eq} = r_1 + r_2 + r_3 + \dots r_n$

Cells in Parallel



$$I = \frac{\text{Total emf.}}{\text{Total resistance}}$$

$$I = \frac{E}{\frac{r}{n} + R}$$

$$I = \frac{E}{\frac{r+nR}{n}}$$

$$I = \frac{E}{\frac{r+nR}{n}} \quad \therefore \boxed{I = \frac{nE}{r+nR}}$$

$$I(r+nR) = nE$$

$$Ir + nRI = nE$$

$$Ir = nE - nRI$$

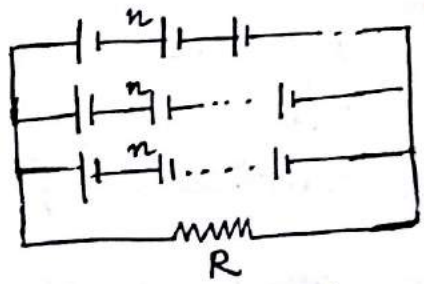
$$r = \frac{nE}{I} - \frac{nRI}{I}$$

$$\boxed{r = \frac{nE}{I} - nR}$$

* $\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots \frac{1}{r_n}$
* $E_{eq} = r_{eq}\left[\frac{E_1}{r_1} + \frac{E_2}{r_2} + \frac{E_3}{r_3} + \dots \frac{E_n}{r_n}\right]$

$E_1, E_2 \dots E_n$ etc are cells.

mixed grouping



$$i = \frac{nE}{\frac{nr}{m} + R} = \frac{nmE}{nr+mR}$$

$$i = \frac{nmE}{nr+mR}$$

n-cells no

m-rows

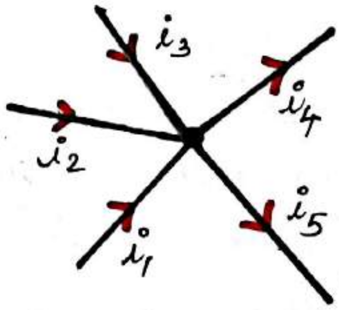
Simil

Kirchoff's law's

Kirchoff's first law. (Junction rule)

Algebraic sum of currents meeting at any junction is equal to zero.

$\Sigma i = 0$



i.e, from fig

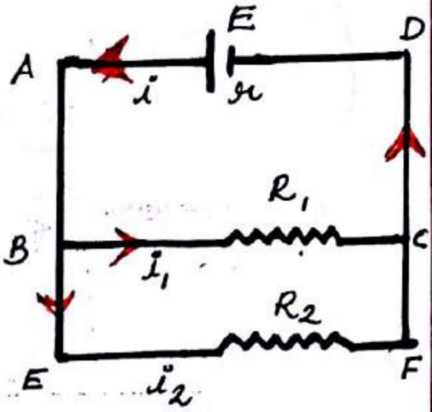
$i_1 + i_2 + i_3 - i_4 - i_5 = 0$

$\therefore i_1 + i_2 + i_3 = i_4 + i_5$

Krichoff's second law (Loop rule)

The Algebraic sum of product of current and resistance in a loop is equal to the algebraic sum of emf's in that loop.

i.e, $\Sigma iR = \Sigma E$



mesh ABCDA $\quad i_1 R_1 + i r = E$

mesh BEFCB $\quad i_2 R_2 - i_1 R_1 = 0$

mesh AEFDA, $\quad i_2 R_2 + i r = E$

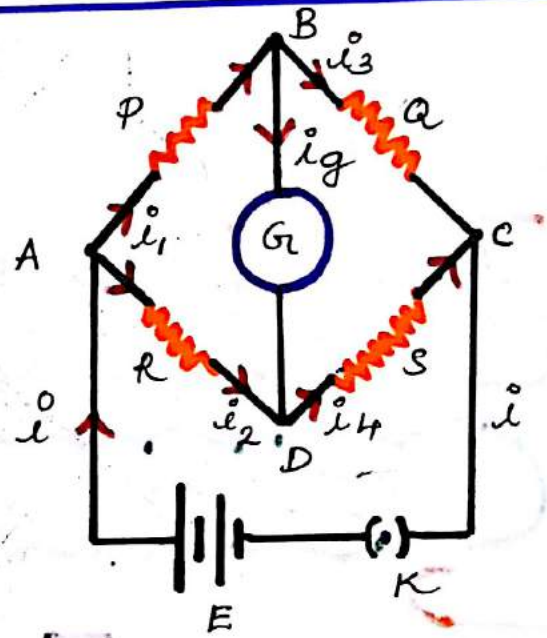
Wheatstone's Bridge

Wheatstone's principle

In the balanced condition, when $i_g = 0$.

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

Wheatstone's Network



At junction B (I^st rule)

$\therefore i_1 = i_g + i_3$

$i_g = 0$

$\therefore i_1 = i_3 \quad \ldots \quad (1)$

At junction D (I^st rule)

$i_2 + i_g = i_4 \quad (i_g = 0)$

$\therefore i_2 = i_4 \quad \ldots \quad (2)$

Applying Krichoff's II^nd law in ABDA & BCDB

(i) loop/Mesh ABDA

$i_1 P + i_g G - i_2 R = 0 \quad [i_g = 0]$

$\therefore i_1 P = i_2 R \quad \ldots \quad (3)$

loop BCDB

$$i_3 Q - i_4 S - i_g G = 0$$

$$i_3 Q = i_4 S \quad \ldots (4) \qquad i_g = 0.$$

(3) ÷ (4)

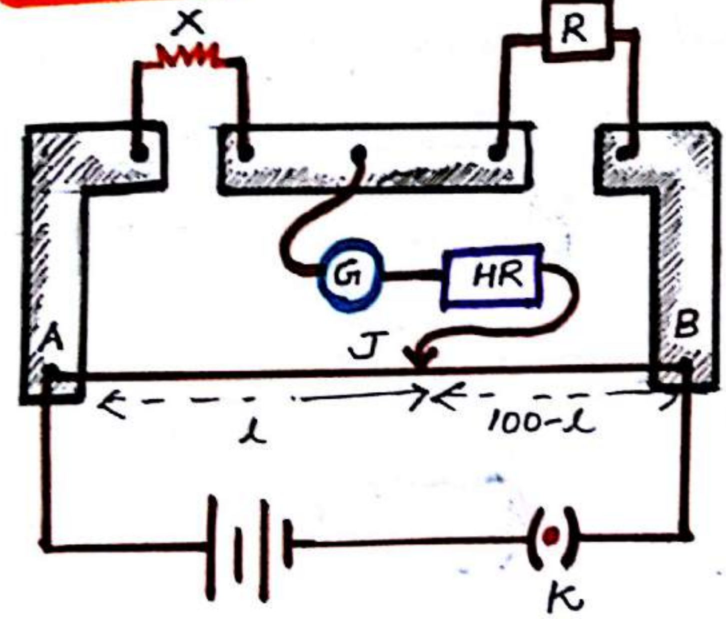
$$\frac{i_1 P}{i_3 Q} = \frac{i_2 R}{i_4 S} \quad \ldots (5)$$

substituting (1) & (2) in (5)

$$\boxed{\frac{P}{Q} = \frac{R}{S}} \quad \text{when } i_g = 0$$

METRE BRIDGE.

circuit



principle

wheatstone bridge principle is the principle of metre bridge. In a balanced condition when $i_g = 0$,

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

connections are made as shown in the figure. unknown resistance x is connected in one gap (left & right). known resistance R in other gap. Move the jockey until you get null deflection in galvanometer G. Measure Balancing length l ($=AJ$)

$\therefore BJ = 100 - l$.

According to wheatstones principle

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

$AJ = l$, $BJ = 100 - l$.

$$\therefore \frac{x}{R} = \frac{l}{100-l}$$

$$x = R\left(\frac{l}{100-l}\right)$$

Thus unknown resistance 'x' can be calculated by using metre bridge

* ρ → Resistance / unit length

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

* specific resistance ρ can be calculated by measuring 'r' and 'l'

Sunil...

POTENTIOMETER.

It is a device used to measure potential difference. It consists of a uniform resistance wire usually 10m long streched on a wooden board in zig zag manner.

comparing emf of primary cell's using potentiometer.

principle of potentiometer

$V \propto l$

when I, ρ and A - constants

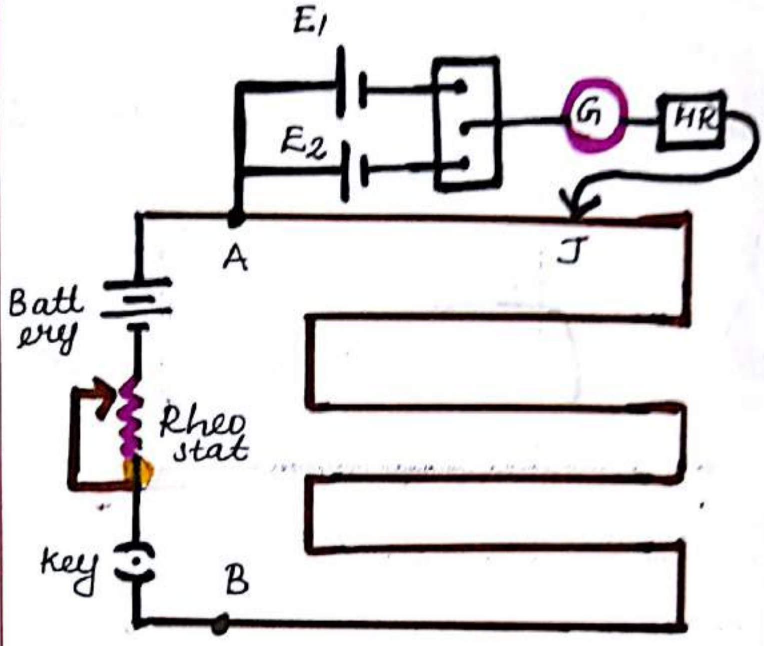
potential difference (V) across any length (l) of wire is directly proportional to the length when constant current (I) flows through a wire of uniform area of cross section (A) and resistivity (ρ).

circuit & procedure.

* make conections as shown below with 2 primary cells of emf's E_1 and E_2.
* According to principle of potentiometer

$$E \propto l$$
$$E = kl.$$

circuit



* Include the E_1 alone in the circuit and measure balancing length l_1

$$\boxed{E_1 = kl_1} \quad \dots \text{(1)}$$

* Include E_2 alone in the circuit and measure balancing length l_2

$$\boxed{E_2 = kl_2} \quad \dots \text{(2)}$$

(1) ÷ (2)

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

using this formula emf's of two cell's can be compared.

Internal Resistance of a cell - using potentiometer.

make the connections as shown be-law using a cell of emf E and external resistance R.

* with k_2 open measure balancing length.

$E \propto l_1$

$\therefore$ $\boxed{E = k l_1}$ ---- (1)

* close k_2, measure balancing length

$V \propto l_2$.

$\frac{ER}{R+r} \propto l_2$.

$\boxed{\frac{ER}{R+r} = k l_2}$ ---- (2)

(1)÷(2) $\Rightarrow$ $\frac{E}{\frac{ER}{R+r}} = \frac{l_1}{l_2}$.

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

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

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

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

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

by knowing the values of R, l_1, l_2, r can be calculated