PHYSICS INDUCTION

An institute of Science & Mathematics

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CLASS XII : NOTES : CHAPTER-3 : CURRENT ELECTRICITY : PHYSICS

CURRENT ELECTRICITY:- The branch of Physics, which deals with the study of charges in motion is called Current Electricity.

CHARGE CARRIERS IN DIFFERENT MATERIALS :-

(i) In solid conductors :- charged carriers are valence/outermost e^-.
(ii) In semiconductors :- charged carriers are negatively charged electrons & positively charged holes.

(iii) In Insulators :- No free charge/current carriers
(iv) In liquids: +vely & -vely charged ions (electrolytes).
(v) In gases :- Gases are insulators of electricity but they can be ionised by applying high p.d. at low pressures or by exposing them to X-rays.

ELECTRIC CURRENT :- Electric Current is defined as the rate of flow of electric charge through any cross-section of a conductor.

$\boxed{I = \frac{Q}{t}}$ S.I. Unit of Current, I = Ampere, A : $1A = 1\,C\,s^{-1}$

Electric Current is said to be 1A, when 1C of charge flows through a conductor in 1 second.

Current is a scalar Quantity.
∠b/w the wires carrying current doesn't effect the total current.

I → Conventional Current

(flow of positive charge)

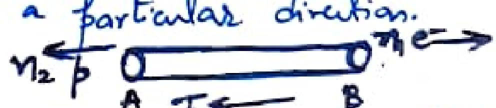
I → Electronic Current

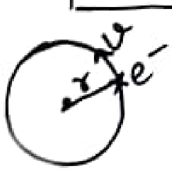
(flow of negative charge)

The Electric currents are not usually steady. If ΔQ = Net charge flowing across a cross-section of a conductor in a particular direction, during the time-interval, Δt. then,
$$\boxed{I(t) = \lim_{\Delta t \to 0} \underbrace{\left(\frac{\Delta Q}{\Delta t}\right)}_{\text{Average}} = \underbrace{\frac{dQ}{dt}}_{\text{Instantaneous}}}$$

$\frac{dQ}{dt}$: Current thro' a conductor at anytime in a particular direction.

$$\boxed{I = n_1 e + n_2 e = (n_1+n_2)e}$$



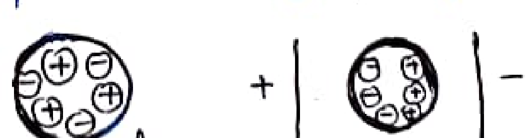


If an e^- is revolving in a circle of radius, r with a speed, v
Period of revolution of e^- : $T = \frac{2\pi r}{v}$

Frequency of revolution, $\nu = \frac{1}{T} = \frac{v}{2\pi r}$

Current at any point of the circular path : I = charge flowing × No. of rev. per second.

$$\boxed{I = e\nu = \frac{ev}{2\pi r}}$$



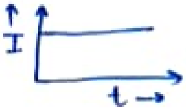
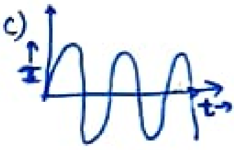
conductor

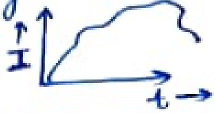
Transient Current :- (short duration)

a) Rearrangement of charges causes a current of short duration.

b) Lightning : flow of charge b/w 2 clouds or from cloud to Earth.

(to get a const. flow of q, P.d. needs to set maintained) ← STEADY CURRENT

Types :- → Steady Current (DC)  → Alternating Current (AC) 

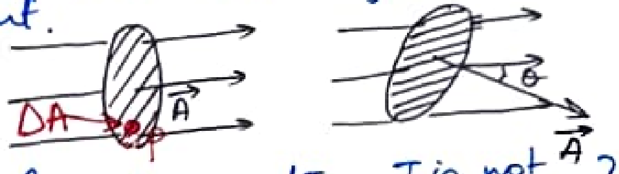
→ Varying Current : 

ELECTRIC CURRENT DENSITY : (j) :-

Current Density at a point in a conductor is defined as the amount of current flowing per unit area of the conductor around that point.

The magnitude of current density,

$$j = \frac{I}{A} = \frac{Q/t}{A}$$



for a small area element at P : $j = \lim_{\Delta A \to 0} \frac{\Delta I}{\Delta A} = \frac{dI}{dA}$ { I is not uniformly distributed }

If ΔA is not perpendicular to I :

$$j = \frac{\Delta I}{\Delta A \cos\theta} \Rightarrow \Delta I = j\,\Delta A \cos\theta = \vec{j} \cdot \vec{\Delta A}$$

for a finite Area, $I = \int \vec{j} \cdot \vec{\Delta A}$ | j is a vector quantity & its direct^n is same as that of current

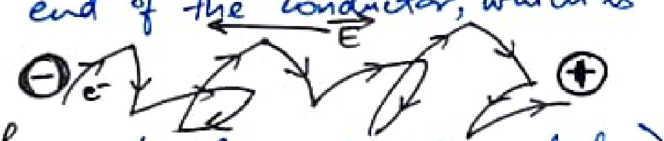
ELEMENTARY DESCRIPTION OF CURRENT FLOW THROUGH A CONDUCTOR — DRIFT SPEED:

A conductor contains a large no. of free e^- called conduction electrons. no. density of e^- is 'bout $10^{29} m^{-3}$. These electrons move randomly within the body of the conductor. The average thermal speed of the free e^- in random motion at room temperature is of the order of 10^5 m/s. The direct^n of motion are so randomly distributed that the average thermal velocity of the e^- is zero.

Avg. Thermal Velocity : $\frac{\vec{u}_1 + \vec{u}_2 + --- + \vec{u}_n}{n} = 0$

when some p.d. is applied across the two ends of a conductor, an Electric Field is set up. The free e^- in the conductor experience a force in a direct^n opposite to that of electric field. Accelerated free e^- suffer frequent collisions, lose their gained K.E., and acquire small velocities by virtue of acceleration due to Electric Field.

Each free e^- describes a curved path b/w two successive collisions. The average velocity of all free e^- is no longer zero. It has some little value towards the positive end of the conductor, which is called drift Velocity.



Drift speed is the average speed with which the electrons drift through the conductor.

(Drift speed < thermal speed)
10^{-4} m/s ≪ $10^5 - 10^6$ m/s

Force experienced by the electron in the conductor, $\vec{F} = -e\vec{E}$

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

velocity acqd by the e^- having thermal velocity, $\vec{u}_1$: $\vec{v}_1 = \vec{u}_1 + \vec{a}\tau_1$

τ_1 : time elapsed b/w successive collisions

As, Drift velocity, $\vec{v}_d = \frac{\vec{v}_1 + \vec{v}_2 + --- + \vec{v}_n}{n}$

$$= \frac{(\vec{u}_1+\vec{a}\tau_1) + (\vec{u}_2+\vec{a}\tau_2) + ----- + (\vec{u}_n+\vec{a}\tau_n)}{n}$$

$$= \left(\frac{\vec{u}_1+\vec{u}_2+--+\vec{u}_n}{n}\right) + \frac{\vec{a}(\tau_1+\tau_2+---+\tau_n)}{n}$$

$$= 0 + \vec{a}\tau = \underline{\vec{a}.\tau}$$

{ Avg Relaxation Time: $\frac{\tau_1+\tau_2+---+\tau_n}{n}$ } order of 10^{-14} s

As $\vec{v}_d = \vec{a}\tau$

$\Rightarrow \vec{v}_d = -\frac{e\vec{E}}{m}\tau$

- Average Drift speed: $v_d = -\frac{eE\tau}{m}$
- $\vec{v}_d$ is opp. to the direct^n of $\vec{E}$.
- Avg. Relaxation time = $\frac{\text{Mean Free Path of } e^-}{\text{Drift speed of } e^-}$

RELATION BETWEEN CURRENT AND DRIFT VELOCITY :-

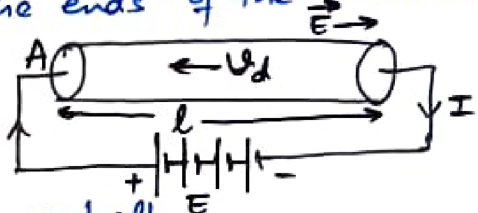
Consider a conductor of length, l & Uniform area of cross-section, A.

∴ Volume of the conductor, $V = Al$

& Total no. of free electrons $= n.V = nAl$ {where, n: Number Density}

∴ Total charge on all the free electrons, $q = Alne$

Let a constant p.d. be applied (V) across the ends of the conductor with the help of a battery.



The Electric field set up across the conductor is given by, $E = V/l$

Due to this field, the free e- present in the conductor will begin to move with a drift velocity, v_d towards the left end, A.

∴ Time taken by free e- to cross the conductor, $t = l/v_d$

Current, $I = \frac{q}{t} = \frac{Alne}{l/v_d} = Anev_d$

$$\therefore \boxed{I = Anev_d = \frac{Ane^2\tau E}{m}}$$ [where, $v_d = \frac{eE\tau}{m}$]

$$\& \; j = \frac{I}{A} \Rightarrow \boxed{j = nev_d = \frac{ne^2\tau E}{m}}$$

MOBILITY (μ) :- Mobility of charge carrier (μ), responsible for current is defined as the magnitude of drift velocity of charge per unit electric field applied.

$$\boxed{\mu = \frac{\text{Drift Velocity}}{\text{Electric Field}} = \frac{v_d}{E} = \frac{qE\tau/m}{E} = \frac{q\tau}{m}}$$ τ: Average Relaxation Time

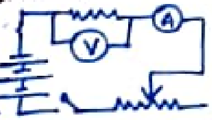
Mobility of e^-, $\mu_e = \frac{e\tau_e}{m_e}$; Mobility of holes, $\mu_h = \frac{e\tau_h}{m_h}$

τ_e & τ_h : Avg. relaxation time for e- & holes respectively.

S.I. Unit of μ :- $m^2 s^{-1} V^{-1}$ or $m\, s^{-1} N^{-1} C$

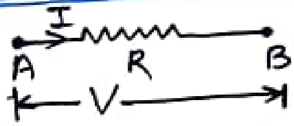
OHM'S LAW:- George Simon Ohm (1828) was the first to establish the relationship b/w p.d. (applied across the conductor) and I carrying conductor.

Ohm's Law states that the current, I flowing thro' a conductor is directly proportional to the potential difference, V applied across the ends of a conductor, provided physical conditions of the conductor such as temperature, Mechanical strain etc. are kept constant.



i.e., $I \propto V$ or $V \propto I \Rightarrow \boxed{V = IR}$ $\quad \frac{V}{I} = R = \text{constant}$

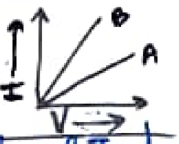
R: Resistance of the current. It is the obstruction posed by the conductor to the flow of electric current through it.



Deduction of Ohm's Law:- $v_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml}$ $\quad (\because E = V/l)$

As, $I = Ane v_d = Ane\left(\frac{eV\tau}{ml}\right) = \left(\frac{Ane^2\tau}{ml}\right).V$

$R_A > R_B$



$\Rightarrow \frac{V}{I} = \frac{ml}{Ane^2\tau} = R$, a constant for a given value of n, l, A & Temp.

S.I. Unit of Electrical Resistance, R: ohm, Ω , $1\Omega = 1V/A$

1Ω:- 1Ω is the electrical resistance of a conductor through which a current of 1A flows, when a p.d. of 1V is applied across the ends of a conductor.

Dimensions of R:- $\frac{V}{I} = \frac{W/q}{I} = \frac{[ML^2T^{-2}]/[AT]}{A} = [M^1L^2T^{-3}A^{-2}]$

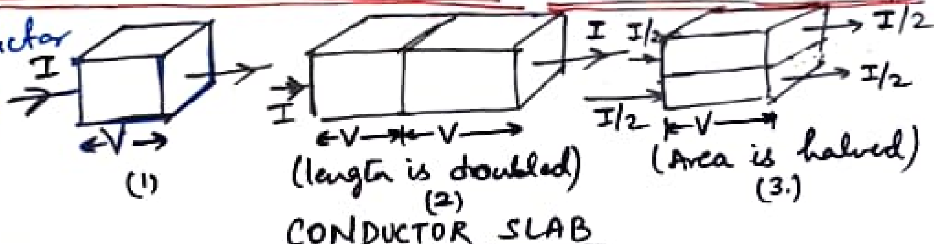
Cause of R:- It arises on account of frequent collisions of free e⁻ with the ions/atoms of the conductor.

Resistor:- Any material which offers the obstruction to the flow of current.

Symbol:- : Fixed Resistance OR : Variable Resistance

ELECTRICAL RESISTIVITY OR SPECIFIC RESISTANCE : Factors on which R depends

The Resistance of a conductor depends upon the following factors:



(i) **Length (l):-** $R \propto l$

(from fig (2): $R_c = \frac{V \times 2}{I} = 2\frac{V}{I} = 2R$)

(ii) **Area of cross-section (A):-** $R \propto 1/A$ $\quad$ (from fig (3): $R_c = \frac{V}{I/2} = 2R$; halving A, doubles the Resist., R)

$\therefore R \propto \frac{l}{A} \Rightarrow \boxed{R = \rho\frac{l}{A}}$ $\quad \rho$: Sp. R // Resistivity

(iii) R depends upon the nature of material & temperature of the conductor

for $l = 1m$, $A = 1m^2$, $R = \rho$

- Sp. R or Resistivity of the material of a conductor is defined as the Resistance of a unit length with unit area of cross-section of the material of the conductor.

Unit of Resistivity :- Ω-m   **Dimensions of Resistivity** :- $[ML^3T^{-3}A^{-2}]$

factors affecting electrical Resistivity :-

As, $R = \frac{V}{I} = \frac{ml}{Ane^2\tau} \Rightarrow R = \left(\frac{m}{ne^2\tau}\right)\frac{l}{A} = \frac{\rho l}{A}$ where, $\rho = \frac{m}{ne^2\tau}$

$\rho \propto \frac{1}{n} \Rightarrow \rho$ depends upon nature of material of the conductor.

$\rho \propto \frac{1}{\tau}$ & $\tau \propto \frac{1}{T} \Rightarrow \rho$ depends upon the temperature of the conductor.

CONDUCTANCE AND CONDUCTIVITY :-

Conductance, G of a conductor :- It's the measure of ease, with which the charges flow through a conductor. $\boxed{G = \frac{1}{R}}$ Unit : Ω^{-1}/mho/siemen, S

Electrical Conductivity, σ of a conductor :- $\boxed{\sigma = \frac{1}{\rho}}$ Unit : $\Omega^{-1}m^{-1}$/mho m^{-1}/ Sm^{-1}

$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$ $\sigma \propto \tau$, $\sigma \propto n$

MICROSCOPIC FORM OF OHM'S LAW : RELATION B/W j, σ & E :-

$I = Ane v_d = Ane\left(\frac{eE\tau}{m}\right) = \frac{Ane^2\tau E}{m}$

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

$\Rightarrow \boxed{j = \sigma E}$ ← Microscopic form of Ohm's Law

$\vec{j} = \sigma\vec{E}$

Rel^n b/w ρ & μ:

$I = Ane v_d$, $v_d = \mu E$

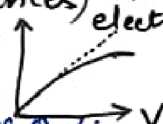
$j = \frac{I}{A} = \sigma E = \frac{E}{\rho}$

$\Rightarrow \frac{E}{\rho} = nev_d = ne\mu E$

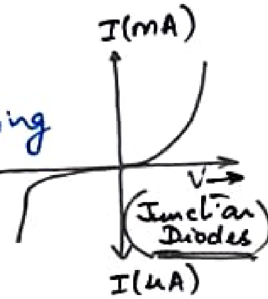
$\Rightarrow \boxed{\rho = \frac{1}{ne\mu}}$

LIMITATIONS OF OHM'S LAW: NON-OHMIC DEVICES :- which don't obey ohm's law. ($\frac{V}{I} \rightarrow$ valid)

$\frac{V}{I} = R$ → constant (ohmic devices)
→ Not Constant (Non-ohmic Devices) → Examples : Vacuum Tubes, Semiconductor diodes, Liquid electrolyte, Transistor etc.

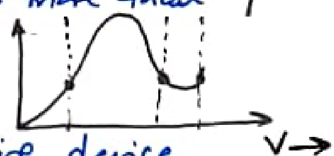


- The relation b/w V-I is non-linear.
- The relation b/w V & I depends on the signs of V :- If I is the current for a certain value of V, then reversing the direct^n of V, doesn't produce the current of same magnitude.



- The relation b/w V & I is not unique : There is more than one value of V for same current.

GaAs (LEDs) →



THERMISTORS :-

A Thermistor is a heat sensitive device, whose resistivity changes very rapidly with change in temperature. They are usually prepared from oxides of various metals such as Ni, Fe, Cu, Co etc. Their size is small & can have a resistance in the range of 0.1 Ω to $10^7\Omega$, depending upon its composition. It can be used over a wide range of temp.

EFFECT OF TEMPERATURE ON RESISTANCE :-

R (metallic cond) $= \frac{m}{ne^2\tau} \times \frac{l}{A} \Rightarrow R \propto \frac{1}{\tau}$ | As T↑ ⇒ ν of collision↑ ⇒ τ↓ ⇒ R↑ with rise in Temp.

R at t°C, $R_t = R_0(1 + \alpha t + \beta t^2)$ || α & β: Const. $R_0 \rightarrow$ at 0°C , $R_t \rightarrow$ at t°C

$\Rightarrow R_t = R_0(1+\alpha t)$ [if the temp., $t^\circ C$ is not sufficiently large]

$$\Rightarrow \boxed{\alpha = \frac{R_t - R_0}{R_0 \times t} = \frac{\text{Increase in Resistance}}{\text{Original Resistance} \times \text{Rise of temp}}}$$

α = temp. coeff. of Resistance
Unit: K^{-1} or $^\circ C^{-1}$

for Metals: α – +ve $\therefore$ R ↑ with ↑ in T

For Insulators & semiconductors: α: –ve
R ↓ with ↑ in T

$R_1 \rightarrow$ at $t_1^\circ C$, $R_2 \rightarrow$ at $t_2^\circ C$, $R_0 \rightarrow$ at $0^\circ C$

$R_1 = R_0(1+\alpha t_1)$, $R_2 = R_0(1+\alpha t_2)$

$$\Rightarrow \frac{R_1}{R_2} = \frac{1+\alpha t_1}{1+\alpha t_2} \Rightarrow R_1(1+\alpha t_2) = R_2(1+\alpha t_1) \Rightarrow \boxed{\alpha = \frac{R_2 - R_1}{R_1 t_2 - R_2 t_1}}$$

VARIATION OF ELECTRICAL RESISTIVITY WITH TEMPERATURE:-

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

In most Metals:- n doesn't change appreciably with T.

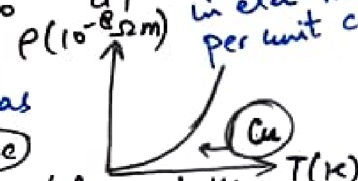
But v of collision inc, resulting in dec. in $\tau \Rightarrow \rho$ ↑ with ↑ in T

$\rho \propto \frac{1}{n\tau}$

(α=+ve metals) $\rho = \rho_0[1+\alpha(T-T_0)] \Rightarrow \alpha = \frac{\rho - \rho_0}{\rho_0(T-T_0)} = \frac{d\rho}{\rho_0} \times \frac{1}{dT}$ = fractional change in elec. Resistivity per unit change in dT.

+ve (for metals)

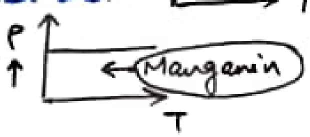
$\alpha \approx 4 \times 10^{-3}\,^\circ C^{-1}$

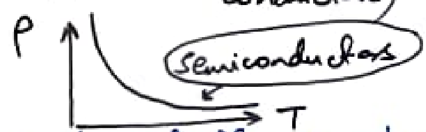


(for metallic conductors)

• for alloys: high ρ. The ρ of Nichrome (Ni + Fe + Cr) has weak temperature dependence

• The ρ of Manganin is almost ind. of temperature. This is why wire bound std resistors are made of manganin.





For semiconductors:- With ↑ in Temp., n increases exponentially & τ decreases But the inc in n compensates more than dec in τ. $\therefore$ ρ decreases with ↑ in T. Exp.

K_B: Boltzmann constant $\boxed{n(T) = n_0 e^{-E_g/K_BT}}$ E_g: Energy gap b/w cond. Band & Valence Band.

As, $\rho \propto \frac{1}{n} \Rightarrow \frac{1}{\rho(T)} = \frac{1}{\rho_0} e^{-E_g/KT} \Rightarrow \boxed{\rho(T) = \rho_0 e^{E_g/KT}}$

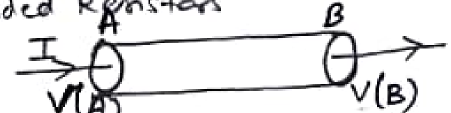
for Insulators:- α: –ve ρ ↑ exponentially with ↓ in T, b'comes infinitely large at absolute zero (0K)

for electrolytes:- α: –ve ρ ↑ with ↓ in T, ions move with less speed, v_d dec, τ ↑

R → series, R – parallel, carbon-coded Resistors

ELECTRICAL ENERGY AND POWER:-

V(A) > V(B)



P.d. across AB = V = V(A) – V(B) > 0

If ΔQ (charge) flows in time interval, Δt : $\Delta Q = I\Delta t$

P.E. at A, $U_A = QV(A)$; P.E. at B, $U_B = QV(B)$

Thus, change in P.E., $\Delta U_{pot} = U_B - U_A = \Delta Q[V(B) - V(A)] = -\Delta Q \cdot V = -IV\Delta t < 0$

Change in K.E. = – change in P.E (Law of conservation of charge)

i.e., $\Delta K = IV\Delta t > 0$

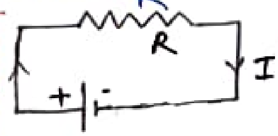
Thus, in case, charges were moving freely thro' the conductor under the action of electric field, their K.E. would increase as they move. On the average, charge carriers do not move with acceleration but with a steady drift velocity. During collisions, energy gained by the charges vibrate the atoms more vigorously. i.e., the conductor heats up.

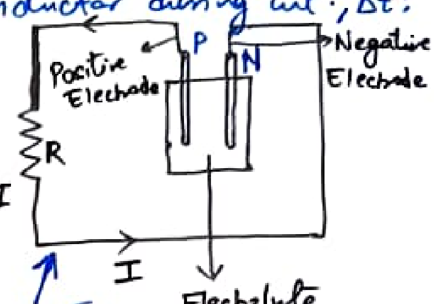
Amount of energy dissipated as heat in the conductor during int., Δt:

$\Delta W = IV\Delta t$

power dissipated, $P = \frac{\Delta W}{\Delta t} = VI = I^2R = \frac{V^2}{R}$

CELLS, EMF, INTERNAL RESISTANCE:-





It's the chemical energy of the cell, which supplies Power

P.d. b/w the +ve electrode and electrolyte $= V_+ \; (>0)$

P.d. b/w the −ve electrode and electrolyte $= -(V_-)$; $V_- (>0)$

$\therefore$ P.d. b/w (P & N) the electrodes $= V_+ - (-V_-)$

Electromotive force (EMF) $= V_+ + V_-$

$\therefore \quad \mathcal{E} = V_+ + V_- > 0$

Consider a resistor, R connected across a cell. A current, I flows across R. The electrolyte thro' which the current flows, has a finite resistance, r, called internal resistance.

when R is infinite: $I = V/R = 0$ & $V = \mathcal{E}$

when R is finite: $I \neq 0$, $V = \mathcal{E} - Ir$

$\therefore IR = \mathcal{E} - Ir \quad (\because V = IR)$

$\Rightarrow \boxed{I = \frac{\mathcal{E}}{R+r}}$

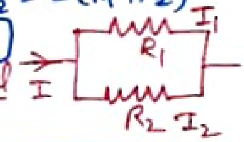
Resist in series

$V = V_1 + V_2$

$IR_s = IR_1 + IR_2 = I(R_1+R_2)$

$\Rightarrow \boxed{R_s = R_1 + R_2}$

Resist in parallel

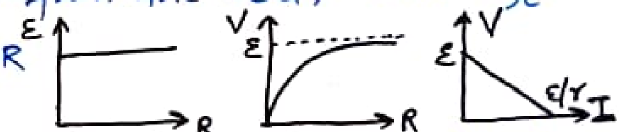


$I = I_1 + I_2$

$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} \Rightarrow \boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}}$

for R = 0: Max current can be drawn from the cell, $I_{max} = \frac{\mathcal{E}}{r}$

As $V = \mathcal{E} - Ir \Rightarrow r = \frac{\mathcal{E}-V}{I} = \left(\frac{\mathcal{E}-V}{V}\right) \times R$



* $\mathcal{E}$ is independent of R.

* $V = \mathcal{E} - Ir = \mathcal{E} - \frac{V}{R}r \Rightarrow \mathcal{E} = V\left(1 + \frac{r}{R}\right) \Rightarrow V = \frac{\mathcal{E}}{(1 + r/R)}$, As R↑, V also↑

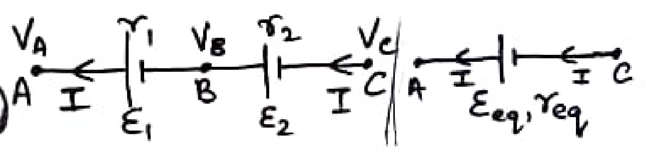
$R = \infty$, $V = \mathcal{E}$

* $V = \mathcal{E} - Ir = -Ir + \mathcal{E}$. As I↑, V↓

$(y = mx + c)$ $m = -r$

CELLS IN SERIES AND PARALLEL:-

Cells in series



ε_1 & ε_2: emfs of the two cells.

r_1 & r_2: Internal resistances.

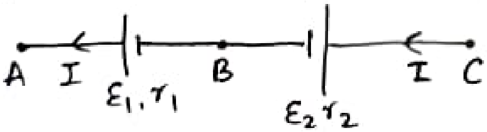
$V_{AB} = V_A - V_B = \varepsilon_1 - Ir_1$, $V_{BC} = V_B - V_C = \varepsilon_2 - Ir_2$, $V_{AC} = V_A - V_C = \varepsilon_{eq} - Ir_{eq}$ —(1)

Also, $V_{AC} = V_A - V_C = (V_A - V_B) + (V_B - V_C) = (\varepsilon_1 - Ir_1) + (\varepsilon_2 - Ir_2)$

$= (\varepsilon_1 + \varepsilon_2) - I(r_1 + r_2)$ —(2)

$\Rightarrow \varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$ & $r_{eq} = r_1 + r_2$ (from (1) & (2))

for n cells: $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \text{------} + \varepsilon_n$ & $r_{eq} = r_1 + r_2 + \text{-----} + r_n$



$V_{AB} = V_A - V_B = \varepsilon_1 - Ir_1$

$V_{BC} = V_B - V_C = -\varepsilon_2 - Ir_2$

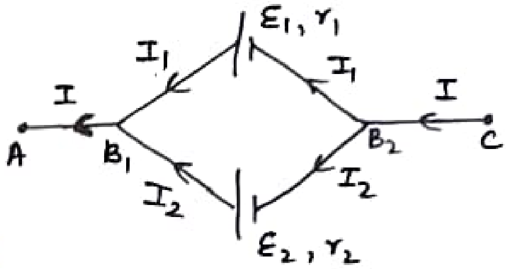
$V_{AC} = V_{AB} + V_{BC} = (\varepsilon_1 - Ir_1) + (-\varepsilon_2 - Ir_2)$

$= (\varepsilon_1 - \varepsilon_2) - I(r_1 + r_2)$

$\Rightarrow \varepsilon_{eq} = \varepsilon_1 - \varepsilon_2$ & $r_{eq} = r_1 + r_2$

Cells in parallel

$I = I_1 + I_2$

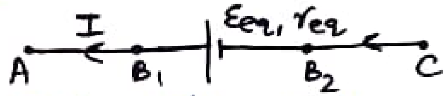


for the first cell: $V = V_{B_1} - V_{B_2} = \varepsilon_1 - I_1 r_1$

$$\Rightarrow I_1 = \frac{\varepsilon_1 - V}{r_1}$$

for the second cell: $V = V_{B_1} - V_{B_2} = \varepsilon_2 - I_2 r_2$

$$\Rightarrow I_2 = \frac{\varepsilon_2 - V}{r_2}$$



As $I = I_1 + I_2 = \left(\frac{\varepsilon_1 - V}{r_1}\right) + \left(\frac{\varepsilon_2 - V}{r_2}\right) = \left(\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$

$$\Rightarrow I = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 r_2} - V\left(\frac{r_1 + r_2}{r_1 r_2}\right)$$

$$\therefore V = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} - \frac{I r_1 r_2}{r_1 + r_2}$$

Also $V = \varepsilon_{eq} - I r_{eq}$. $\therefore \varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$ $\quad r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$

$$\Rightarrow \varepsilon_{eq} = \frac{(\varepsilon_1/r_1) + (\varepsilon_2/r_2)}{(1/r_1) + (1/r_2)} = \frac{(\varepsilon_1/r_1) + (\varepsilon_2/r_2)}{1/r_{eq}}$$

GROUPING OF A NUMBER OF IDENTICAL CELLS

→ Series Grouping
→ Parallel Grouping
→ Mixed Grouping

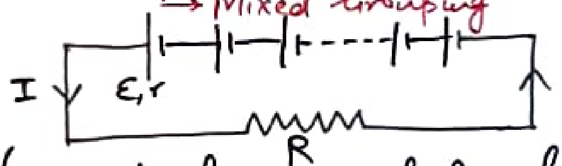
1.) Series Grouping of Cells:

$\varepsilon_{eq} = n\varepsilon$

$r_{eq} = nr$

Total Resistance $= nr + R$

$$I = \frac{n\varepsilon}{nr + R}$$



(n identical cells each of emf, ε & internal resistance, r)

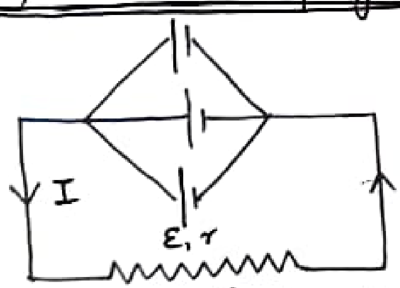
If $R << nr \Rightarrow I = \frac{n\varepsilon}{nr} = \frac{\varepsilon}{r}$

If $R >> nr \Rightarrow I = \frac{n\varepsilon}{R}$

I is max, if $R >> nr$

2.) Parallel Grouping of cells:-

Total Resistance $= R + \frac{r}{m}$



$\varepsilon_{eq} = \varepsilon$

$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \dots + \frac{1}{r_n}$; $I = \frac{\varepsilon}{R + \frac{r}{m}} = \frac{m\varepsilon}{mR + r}$

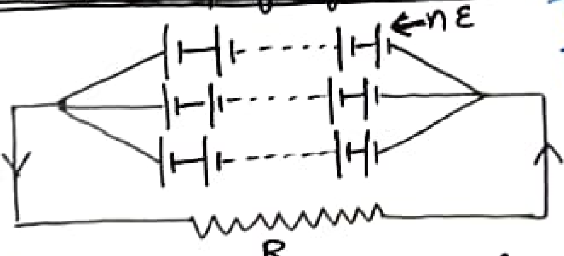
If $R << r$, $I = \frac{m\varepsilon}{r}$

(m - identical cells, +ve terminals are connected together)

If $R >> r$, $I = \frac{\varepsilon}{R}$

I is max if $R << r$

3.) Mixed Grouping of cells:-



(n cells in series & m cells in parallel)

Total internal Resistance (series) $= nr$

Total emf $= n\varepsilon$

$\frac{1}{r_p} = \frac{1}{nr} + \frac{1}{nr} + \dots$ m times $= \frac{m}{nr}$

$\Rightarrow r_p = \frac{nr}{m}$

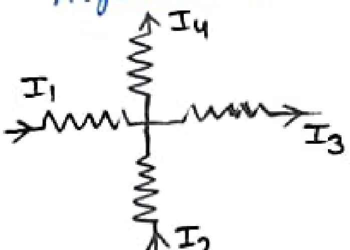
$\therefore$ Total Resistance $= R + \frac{nr}{m}$

$I = \frac{n\varepsilon}{R + nr/m} = \frac{mn\varepsilon}{mR + nr}$

I is max if $mR + nr$ is minimum.
$mR + nr$ is min. if $mR = nr \Rightarrow R = \frac{nr}{m}$

KIRCHHOFF'S RULES :- Junction/Node : where two or more conductors are connected.
Loop/Mesh : closed path in an electric circuit.

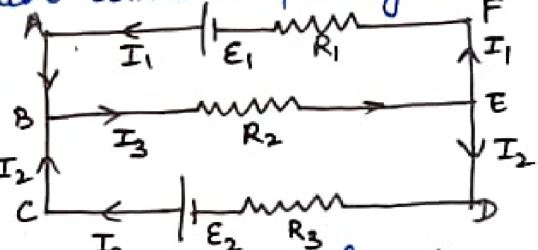
(i) Junction Rule :- At any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.
OR
Algebraic sum of currents meeting at a junction in a closed circuit is zero.



$I_1 + I_2 + (-I_3) + (-I_4) = 0$, supports the law of conservation of charge.

(ii) Loop Rule :- The Algebraic sum of changes in pot around any closed loop involving resistors & cells in the loop is zero. OR.
In any closed path of an electrical circuit (or closed loop), the algebraic sum of the emfs is equal to the algebraic sum of the products of the resistances & the respective currents flowing thro' them.

$$\Sigma \mathcal{E} = \Sigma IR$$

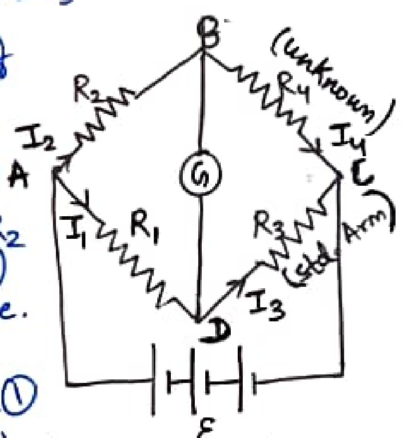


- If –ve terminal is encountered first, e.m.f. is taken as +ve & vice versa.
- If the direct^n of I thro' a resistance is the same along which the loop is being traversed, then the product of resistance & current is taken as +ve & vice-versa. It supports the law of conservation of energy.

for a cld path ABEFA, $\mathcal{E}_1 = I_1R_1 + I_3R_2$

for a closed path ABCDEFA, $\mathcal{E}_1 - \mathcal{E}_2 = I_1R_1 - I_2R_3$

WHEATSTONE BRIDGE :- It's an arrangement of four resistances which can be used to measure one of them in terms of the rest. 4 joints : A, B, C, D.



Wheatstone Bridge is said to be balanced when the current in R_4 is same as the current in R_2 & current in R_3 is same as that in R_1. (OR $V_B = V_D$)
We assume that cell has no internal resistance.
when the bridge is balanced, $I_g = 0$.
$\therefore I_1 = I_3$ and $I_2 = I_4$

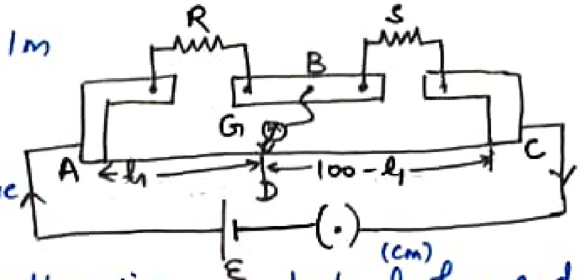
In the cld loop ADBA: $I_2R_2 + 0 - I_1R_1 = 0$ ($\because I_g = 0$) ① AC- Battery Arm
In the cld loop CBDC: $I_1R_3 - I_gR_4 + 0 = 0$ ($I_g = 0$) ($\because I_3 = I_1$ & $I_4 = I_2$) ② BD- Galvanometer Arm

① ÷ ② gives

$$\boxed{\frac{R_2}{R_1} = \frac{R_4}{R_3}}$$ ← Balance condition for the galvanometer to give zero or null deflection.

METER BRIDGE :- It's the special case of wheatstone Bridge & simplest form of wheatstone Bridge. It's useful for comparing Resistances more accurately.

It consists of a wire of length, 1m & of uniform cross-section area, A.
S: std. known Resistance
R: Unknown Resistance, whose value we want to determine.



Jockey is connected to some pt., D on the wire, a dist, l from end A.
Resist. of AD = $R_{cm} \cdot l$ (R_{cm} → Resistance of the wire per unit cm)
" " DC = $R_{cm}(100-l)$

Jockey is moved along the wire, null point is obtained, where Galvano-meter shows no deflection.

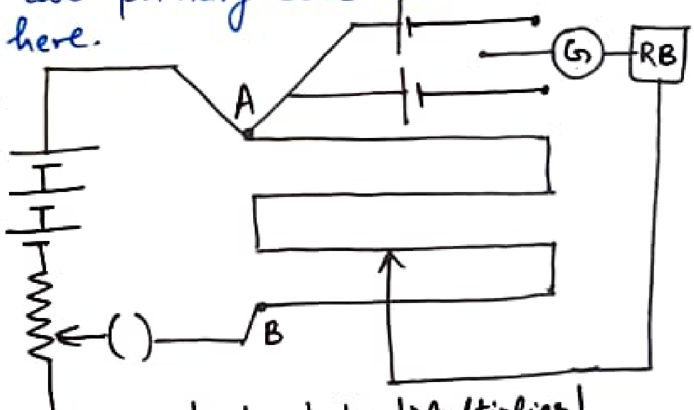
The balance condⁿ gives, $\frac{R}{S} = \frac{R_{cm} \cdot l_1}{R_{cm}(100-l_1)} = \frac{l_1}{(100-l_1)}$

$$\Rightarrow \boxed{R = \frac{S\, l_1}{(100-l_1)}}$$

POTENTIOMETER:- It's a device used to compare potentials. Since, the method involves a condⁿ of no current flow, the device can be used to compare e.m.fs of two cells (sources). Potentiometer is an arrangement of a long wire of uniform cross-section & composition.

Principle:- When there is a constant current in a wire of uniform cross-section & composition, the fall of potential along any length of the wire is directly proportional to the length. $V \propto l$.

Application:- Comparison of emfs of two primary cells can be done with the help of the circuit shown here.



If l_1 and l_2 are the balancing lengths obtained for the cells of emf E_1 & E_2 respectively for the same potential gradient along the potentiometer wire, then,

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

COLOUR CODE FOR CARBON RESISTORS:-

B B R O Y Great Britain Very Good Wife:

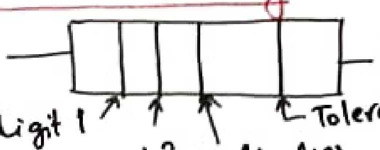
Colour	No.	Multiplier
B	0	10^0
B	1	10^1
R	2	10^2
O	3	10^3
Y	4	10^4
G	5	10^5
B	6	10^6
V	7	10^7
G	8	10^8
W	9	10^9

Gold → 10^{-1}
Silver → 10^{-2}

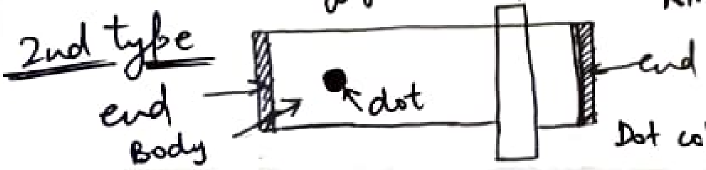
	Tolerance
Gold	5%
Silver	10%
No colour	20%

2 types of colour coding:

Ist type:



2nd type



Ring colour - Tolerance
Body colour - Ist Digit
End colour - 2nd Digit
Dot colour → no. of zeroes