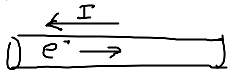
CURRENT.

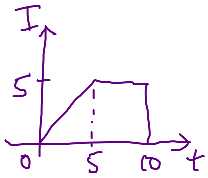
$I = \frac{Q}{t}$ Unit c/s → 1A.

direction of flow of electron is opposite to the Conventional current



$Q = ne$ → n = No of electrons.
e = charge. → 1.6×10^{-19} C.

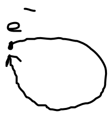
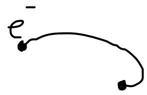
Q



Area = l×b.
= I·t = q.
Area = charge.

Q If $q(t) = 4t^2 + 3t + 9$. Find Current at t = 0 Sec t = 5 Sec.

Sol $i = \frac{dq}{dt} = 8t + 3$ → t = 0 I = 3 A
→ t = 5 I = 43 A

emf.	P.D
1. Electro motive force.	1. Potential difference.
2  work done in taking a Unit +ve charge in full round.	2.  It exists between two points.
3. It exists even when the circuit is open	3 Exist only when closed
4. It is a Cause	4. It is effect.
5. They can be added	5. It exist across Components

Ohm law – $V \propto I$.

$V = IR$ ⟶ $R = \frac{V}{I}$ → opposes flow of current both in AC and DC.

R = 0

Short ckt.

R = ∞.

open ckt.

linear device.

Based material $R = \frac{\rho l}{A}$. ρ = Resistivity $\longrightarrow$ Varies from conductor to conductor

$\rho = \frac{RA}{l}$ Unit $\rightarrow \frac{\Omega m^2}{m} = \Omega \cdot m$.

$R = \frac{\rho l}{A}$: $l = 1m$. $A = 1m^2$. $R = \rho$.

- Resistivity is defined as the resistance of a conductor of that material, having unit length and unit cross sectional area.

- Current density $J = \frac{I}{A}$ — A/m^2.

$J = \frac{q}{tA}$

Vector $\vec{J} = \frac{I}{\vec{A}} \rightarrow \boxed{I = \vec{J} \cdot \vec{A}}$

Integration $I = \vec{J} \cdot \vec{A}$

$\boxed{I = \vec{J} \int d\vec{A}}$

Conductance (G). $G = \frac{1}{R}$. Unit – Ω^{-1} or $\mho$.

Conductivity (σ) $\sigma = \frac{1}{\rho}$. Unit – $\Omega^{-1} m^{-1}$ or $\mho/m$.

$V = E \cdot l$.

$V = IR$

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

$E\cancel{l} = \frac{I \rho \cancel{l}}{A}$

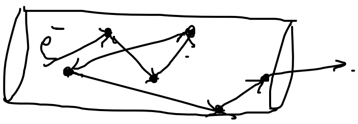
$E = \rho\left(\frac{I}{A}\right)$

$\boxed{E = \rho J}$

$E = \frac{1}{\sigma} J$.

$\boxed{J = \sigma E}$

Relaxation Time :– (τ)



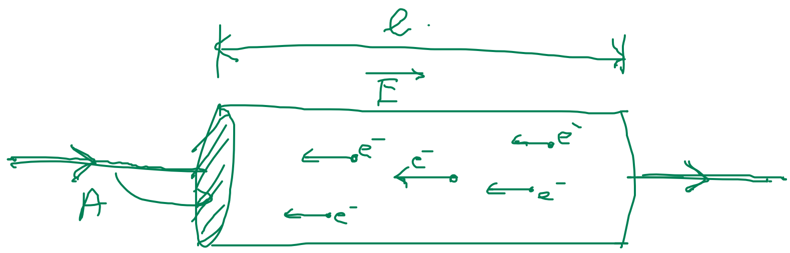
The avg time that elapses between two successive collision of an electron.

$V_d = a\tau$ $\longrightarrow$ V_d = drift velocity – avg velocity the electrons gain in a conductor due to which it moves in the opposite direction of current.

$F = ma = qE$.

$a = \frac{qE}{m}$.

$\boxed{V_d = \frac{qE}{m}\tau}$



$\boxed{V = E \cdot l}$

n – electron density

No. of electrons in length l $= n \times$ Volume
$= n \times Al$

Total Charge $= q = e(nAl)$

we know

$V = \frac{d}{t} \longrightarrow t = \frac{d}{V} = \frac{l}{V_d} \longrightarrow$ edge to edge.

$I = \frac{q}{t} = \frac{enAl}{l/V_d} \rightarrow \boxed{I = enAV_d}$

$\frac{I}{A} = \boxed{J = enV_d}$ or $\vec{J} = en\vec{V_d}$

Using ohm law – $V = IR \Rightarrow R = \frac{V}{I}$

$V_d = \frac{eE\tau}{m}$ $\qquad V = El$

$V_d = \frac{eV\tau}{lm}$

$I = neAV_d = neA\left(\frac{eV\tau}{lm}\right)$

$\frac{I}{V} = \frac{ne^2A\tau}{lm} \Rightarrow \frac{V}{I} = \boxed{R = \frac{lm}{ne^2\tau A}}$

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

$R = \rho\left(\frac{l}{A}\right)$ Compare.

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

$V_d = \frac{qE\tau}{m} = \frac{eE\tau}{m}$

$J = enV_d$ $\qquad J = \sigma E$

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

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

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

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

$\boxed{J = \sigma E}$

Mobility :— drift velocity that exists when unit electric feild is applied.
It is ratio of drift velocity and electric feild.

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

Unit $\frac{m s^{-1}}{N C^{-1}} = m C / N s$

$$V_d = \frac{q E \tau}{m} \Rightarrow \frac{V_d}{E} = \frac{q \tau}{m}$$

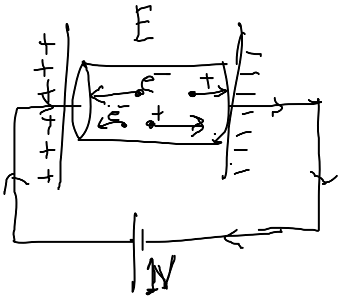
$$\boxed{\mu = \frac{V_d}{E} = \frac{q\tau}{m}}$$

electron: $\mu_e = \frac{e \tau_e}{m_e}$

hole: $\mu_h = \frac{e \cdot \tau_h}{m_h}$

- Reason for Mobility —
  Speed of electron and hole are not same.

$$I = \frac{q}{t} \to \frac{e}{t} \to V_d \text{ is high}$$
$$\to \frac{h}{t} \to V_d \text{ is low}$$



Total $I = I_e + I_h$

$$I = neA\mu_e E + peA\mu_p \cdot E$$
$$\boxed{I = eAE(n\mu_e + p\mu_p)}$$

n = electron density
p = hole density

$I = neAV_d \Rightarrow I = neA\mu E$

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

$V_d = \mu E$

$R = \frac{\rho l}{A}$; $\frac{V}{I} = \frac{\rho l}{A}$

$$I = \frac{VA}{\rho l} = \frac{E \cdot \cancel{l} A}{\rho \cancel{l}} = \frac{EA}{\rho}$$

$$\frac{\cancel{E}\cancel{A}}{\rho} = e\cancel{A}\cancel{E}(n\mu_e + p\mu_p)$$

$$\boxed{\sigma = e(n\mu_e + p\mu_p)}$$

→ Conductivity.

Temperature dependence of Resistivity (ρ) $\left[R = \frac{\rho l}{A}\right]$

Metal

$\rho = \rho_0[1 + \alpha \Delta T]$

We know $\rho \uparrow$ conductivity $\sigma \downarrow$

$\tau \uparrow R \downarrow \rho \downarrow \sigma \uparrow$

$\rho = \rho_0 + \alpha \rho_0 \Delta T$

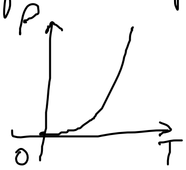
$\rho - \rho_0 = \alpha \rho_0 \Delta T$

$\alpha = \frac{\rho - \rho_0}{\rho_0 \Delta T} \rightarrow$ Co-efficient of resistivity. (depends on material)

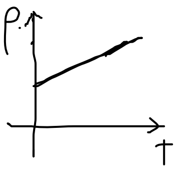
Unit - $°C^{-1}$

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

ρ_0 is the resistivity at a lower reference temp T_0.



for Cu



for Nichrome

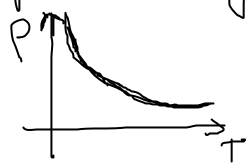
$R \propto \rho$

$\boxed{R = R_0(1 + \alpha \Delta T)}$

Semiconductor/Insulator

$\rho = \rho_0 e^{E_g/K_B T}$

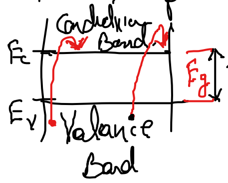
- τ does not change with temp.
- Exponential change



- E_g - Energy gap.

  K_B - Boltzmann Constant

  T - Temp in Kelvin.

- 

  $E_g \leq 1eV$ - Semiconductor.

  $E_g > 1eV$ - Insulator

- α is -ve $\rightarrow$ which shows their resistivity $\downarrow$ with temp.

Electrolytes

- $T \uparrow$ Viscous force $\downarrow$

ions move freely.

Resistance $\downarrow$

Resistivity $\rho \downarrow$

conductivity $\sigma \uparrow$.

Internal Resistance of a Cell :-

Electrolytes of Cell offer resistance which is called internal resistance of Cell.

factors on which it depends -

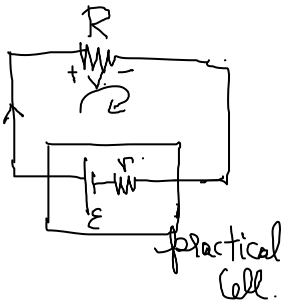
1. Nature of Electrolyte.
2. Concentration of Electrolyte. (directly proportional).
3. Distance between two electrodes (directly proportional)
4. Common area of the electrodes (Inversely ").
5. Temperture. (Increases with decrease in temp).

Analysis of Cell :-

EMF - Electromotive force ($\mathcal{E}$)

$\mathcal{E} = \frac{\text{Work done}}{\text{charge}}$.

$$\boxed{\mathcal{E} = \frac{W}{q}}$$



$\mathcal{E} = IR + Ir$.

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

Voltage of load resistance R.

$V = IR$. $\rightarrow I = V/R$.

$V = \frac{\mathcal{E}R}{R+r} = IR$

$$\boxed{\begin{aligned} \mathcal{E} &= V + Ir. \\ V &= \mathcal{E} - Ir. \end{aligned}}$$

$Ir = \mathcal{E} - V$.

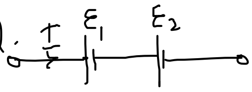
$r = \frac{\mathcal{E}-V}{I} = \frac{(\mathcal{E}-V)R}{V} = \left(\frac{\mathcal{E}}{V} - 1\right)R$.

Connectivity of Cell.

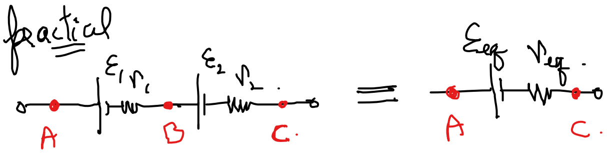
Series. — Parallel.

Cells in series :-

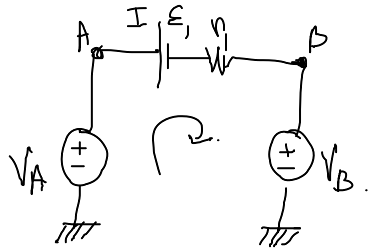
Ideal:



Practical



KVL



$-V_A + \varepsilon_1 + r_1 I + V_B = 0$

$\varepsilon_1 + r_1 I = V_A - V_B$

$V_{AB} = V_A - V_B$

$V_{AB} = V_A - V_B = \varepsilon_1 - r_1 I$

Similarly

$V_{BC} = V_B - V_C = \varepsilon_2 - r_2 I$

$V_{AC} = V_A - V_C = \varepsilon_{eq} - r_{eq} I$

$V_{AC} = (V_A - V_B) + (V_B - V_C)$

$V_{AC} = \varepsilon_1 - r_1 I + \varepsilon_2 - r_2 I$

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

$$\boxed{\begin{aligned} \varepsilon_{eq} &= \varepsilon_1 + \varepsilon_2 \\ r_{eq} &= r_1 + r_2 \end{aligned}}$$

NOTE

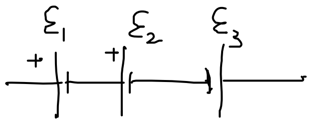
For n number of Cells in Series :-

$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \cdots \varepsilon_n$

$r_{eq} = r_1 + r_2 + r_2 + \cdots r_n$

With same polarities.

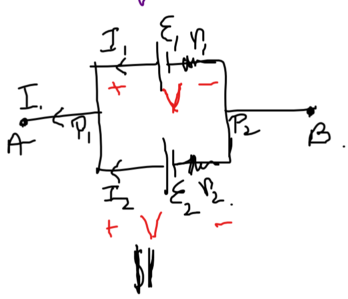
KVL



$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 - \varepsilon_3$

$r_{eq} = r_1 + r_2 + r_3$

Cells in parallel :-



$\Rightarrow$

$V = \varepsilon_{eq} - I r_{eq}$

$I r_{eq} = \varepsilon_{eq} - V$

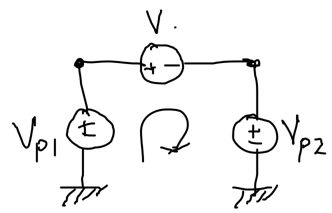
$I = \dfrac{\varepsilon_{eq}}{r_{eq}} - V\left(\dfrac{1}{r_{eq}}\right)$ —— (A)

$I = I_1 + I_2$ —— (1)

$V = \varepsilon - Ir$

$V = \varepsilon_1 - I_1 r_1 \rightarrow I_1 = \dfrac{\varepsilon_1 - V}{r_1}$ —— (2)

$V = \varepsilon_2 - I_2 r_2 \rightarrow I_2 = \dfrac{\varepsilon_2 - V}{r_2}$ —— (3)



$-V_{P1} + V + V_{P2} = 0$

$V = V_{P1} - V_{P2}$

Putting (2) & (3) $\rightarrow$ (1)

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

$I = \left(\dfrac{\varepsilon_1}{r_1} + \dfrac{\varepsilon_2}{r_2}\right) - V\left(\dfrac{1}{r_1} + \dfrac{1}{r_2}\right)$ —— (B)

Comparing (A) & (B)

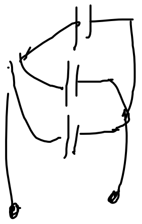
$$\boxed{\begin{aligned} \frac{\varepsilon_{eq}}{r_{eq}} &= \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} \\ \frac{1}{r_{eq}} &= \frac{1}{r_1} + \frac{1}{r_2} \end{aligned}}$$

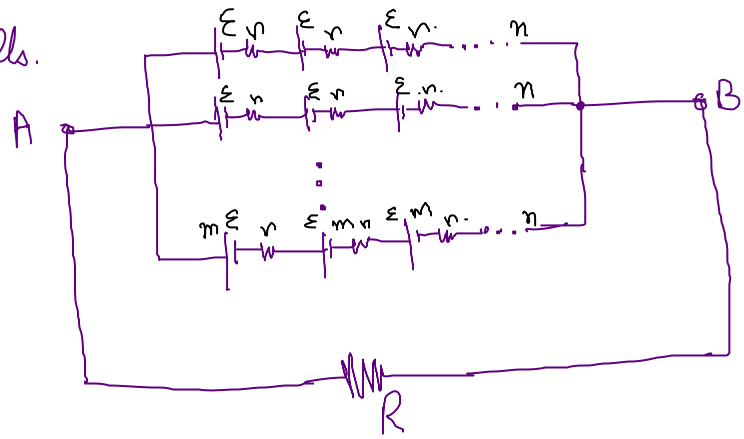
For m number of cells in parallel :-

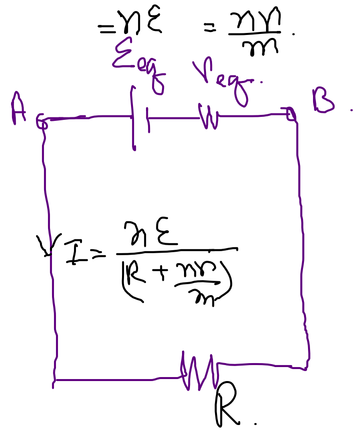
$$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + \cdots \frac{\varepsilon_m}{r_m}$$

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

Mixing of Cells (Grouping)







n — No of rows in series.
m — No of rows in parallel.
} Total No of Cells $= m \times n$.

Voltage of R does not depend on no of Rows (m), It depends on No of n cells connected in each row. $\therefore$ Total emf $= n\varepsilon$. and its resistance $_{eq} = nr$.

Resistance of m rows connected in parallel.

$$\frac{1}{r_p} = \frac{1}{nr} + \frac{1}{nr} + \frac{1}{nr} + \cdots m \text{ terms} = \frac{m}{nr}.$$

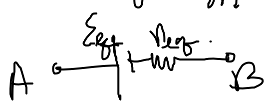
$$r_p = \frac{nr}{m}$$

$$\varepsilon_{eq} = n\varepsilon$$

$$r_{eq} = \frac{nr}{m}$$

$\therefore$ Total resistance $\Rightarrow R + r_p \Rightarrow R + \frac{nr}{m}$.

$$I = \frac{V}{R} = \frac{n\varepsilon}{R + \frac{nr}{m}} = \boxed{\frac{mn\varepsilon}{Rm + nr} = I}$$



For Max Current :-

When we connect a load, a source should deliver max power, This is only possible when we find the max current, the circuit is capable off.

$$P = I^2 R$$

$$P_{max} = I_{max}^2 R$$

we need this.

For grouped cells. $I = \dfrac{mnE}{mR + nr}$ → To get Max I, the denominator should be minimum.

$mR + nr = (\sqrt{mR})^2 + (\sqrt{nr})^2$

$= \left[(\sqrt{mR})^2 + (\sqrt{nr})^2 - 2\sqrt{mR}\sqrt{nr}\right] + 2\sqrt{mR}\sqrt{nr}$

$= (\sqrt{mR} - \sqrt{nr})^2 + 2\sqrt{mR}\sqrt{nr}$ ⟶ we need to make this minimum. and it is only possible when $(\sqrt{mR} - \sqrt{nr})^2 = 0$

$\boxed{mR = nr}$ → For max current

$\boxed{R = \dfrac{nr}{m}}$ This R needs to be connected to get I_{max}.

Heating effect :- When Current flows, heat is generated, which is considered as loss in elements. This is heating effect.

(→ heat)

Reason of heat - movement of electrons inside the elements.

- Collision of electrons.
- K.E is converted to heat energy.
- Highly dependent on time.
- Heat is a form of energy — Work done.
- Rate of doing work is Power.

$$P = \frac{W}{t}$$

$$W = H = Pt.$$

$$P = I^2R = \frac{V^2}{R} = VI$$

Joule's law of heating.

$$\rightarrow \boxed{H = I^2Rt = \frac{V^2t}{R} = VIt.}$$

→ Joule (J)
→ Calories (Cal)

$$4.18\ J = 1\ Cal.$$

$$1\ Cal = \frac{1}{4.18}\ J.$$

Power

Work done → Rate of Converting electrical energy to any other form of energy.

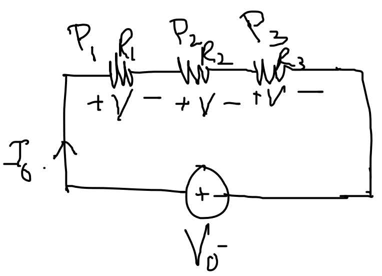
$$\boxed{P = VI = \frac{V^2}{R} = I^2R} \rightarrow \text{Watts (W)}.$$

$1\ KW = 1000\ W$

$1\ hp = 746\ W.$

Power Consumption

① Series



$$P_1 = \frac{V^2}{R_1} \quad P_2 = \frac{V^2}{R_2} \quad P_3 = \frac{V^2}{R_3}$$

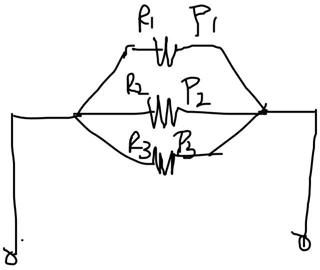
$$R_{eq} = R_1 + R_2 + R_3.$$

$$\frac{V^2}{P_{eq}} = \frac{V^2}{P_1} + \frac{V^2}{P_2} + \frac{V^2}{P_3}$$

$$\frac{1}{P_{eq}} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3}$$

Reciprocal of effective Power is equal to the sum of the reciprocals of the individual powers.

② Parallel.



$R_1 = \frac{V^2}{P_1}$ $R_2 = \frac{V^2}{P_2}$; $R_3 = \frac{V^2}{P_3}$.

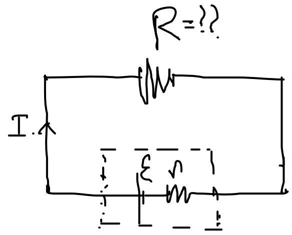
$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$. $\times V^2$.

$\frac{V^2}{R_{eq}} = \frac{V^2}{R_1} + \frac{V^2}{R_2} + \frac{V^2}{R_3}$.

$$\boxed{P = P_1 + P_2 + P_3}$$

The effective Power is equal to the sum of powers of Individual

Max Power transfered



$R_{eq} = R + r$.

$I = \frac{\varepsilon}{R+r}$.

$P = I^2 R$

$P = \left(\frac{\varepsilon}{R+r}\right)^2 R. \Rightarrow P = \varepsilon^2 \frac{R}{(R+r)^2}$

differentiating w.r.t 'R'.

$\left.\frac{dP}{dR}\right|_{max} = \varepsilon^2 \left[\frac{1(R+r)^2 - R.2(R+r).1}{(R+r)^4}\right] = 0$.

$(R+r)\left[R + r - 2R\right] = 0$

$(R+r)\left[r - R\right] = 0$

$R + r = 0$ | $r - R = 0$

$R = -r$. | $\boxed{R = r}$

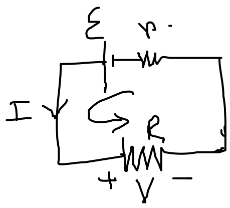
not possible.

For Max Power transfer the Condition is $\boxed{R = r}$.

$P_{max} = \varepsilon^2 \frac{R}{(R+R)^2} = \frac{\varepsilon^2 R}{4R^2}$

$$\boxed{P_{max} = \frac{\varepsilon^2}{4R}}$$

Efficiency $\eta = \frac{O/P}{I/P}$.



$\eta = \frac{P_o}{P_{in}} = \frac{VI}{\varepsilon I} = \frac{V}{\varepsilon} = \frac{IR}{IR + Ir} = \frac{R}{R+r}$.

$-\varepsilon + V + Ir = 0$

$\varepsilon = V + Ir$ $V = IR$.

$$\boxed{\eta = \frac{R}{R+r}}$$

At max Power . $R = r$.

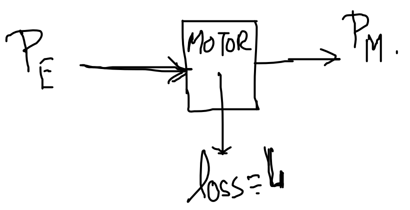
$\eta_{max} = \frac{R}{R+R} = \frac{1}{2}$ $\therefore$ In %

$\eta = \frac{1}{2} \times 100$

$$\boxed{\eta = 50\%}$$

Electrical device :- Motor:
- I/P = Electrical Energy.
- O/P = Mech. Energy.

$$\eta = \frac{\text{Mech Energy}}{\text{Elect. Energy}} = \frac{O/P}{I/P}$$



$$\eta = \frac{P_M}{P_M + L} \times 100\%$$

$$\eta = \frac{P_E - L}{P_E} \times 100\%$$

Examples Based on Electric Current :-

Q. 10^{20} electrons, each having a charge of 1.6×10^{-19} C. pass from point A to B in 0.1 s. What is the current in Ampere?

Sol
No. of electron $= 10^{20}$
$q = 1.6\times10^{-19}$ C.
$t = 0.1$ s.

$$I = \frac{q}{t} = \frac{ne}{t} = \frac{10^{20}\times1.6\times10^{-19}}{0.1} = 16\times10^{1} = 160\text{ A}.$$

Q How many electrons pass through a lamp in 1 minute, If the current is 300 mA?

Sol
$n = ??$
$t = 60$ s.
$I = 300\times10^{-3}$ A

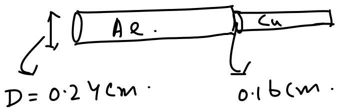
$$I = \frac{q}{t} \Rightarrow 300\times10^{-3}\times60 = q = \cancel{18000}\times\frac{1}{1000} = 18\text{ C}.$$

$$q = ne = 18 = n\times1.6\times10^{-19}.$$

$$n = \frac{180}{16}\times10^{19} = 11.25\times10^{19}\text{ electrons}.$$

Q An Aluminium wire of diameter 0.24 cm is connected in series with Cu wire of diameter 0.16 cm. The wire carries a current of 10 A. Determine the current density in Al wire. Find the Ratio of current densities.

Sol



For Al

$$J_{Al} = \frac{I}{A} = \frac{I}{\pi r^2}$$

$$= \frac{10}{\pi\left(\frac{.24}{2}\times10^{-2}\right)^2}$$

$$= \frac{10\times4\times10000}{\pi\times0.24\times0.24} = \frac{400000\times10^{4}}{24\times24\times\pi}$$

$$= 2.21\times10^{6}\text{ A/m}^2 \quad \text{Ans}$$

For Cu

$$J_{Cu} = \frac{I}{A} = \frac{I}{\pi r^2}$$

$$= \frac{10}{\pi(.08\times10^{-2})^2}$$

$$J_{Cu} = \frac{10\times10^{4}}{(.08)^2\pi} = 4.97\times10^{6}\text{ A/m}^2$$

Ratio

$$\frac{J_{Al}}{J_{Cu}} = \frac{2.21\times10^{6}}{4.97\times10^{6}} = 0.44 \quad \text{Ans}$$

Q A negligible small current is passed through a wire of length 15 m and Uniform Cross section $6\times10^{-7}\text{ m}^2$ and $R = 5\,\Omega$, Find Resistivity of material at that temp.

Sol

$$R = \frac{\rho l}{A} \Rightarrow \rho = \frac{RA}{l} = \frac{\cancel{5}\times\cancel{6}^{2}\times10^{-7}}{\cancel{15}} = 2\times10^{-7}\ \Omega\text{ m}$$

Q A Silver wire has resistance of $2.1\,\Omega$ at $27.5\,^\circ$c and resistance of $2.7\,\Omega$ at $100\,^\circ$c. Determine the temp Co-efficient of resistivity of Silver. (α)

Sol

$$\rho = \rho_0[1+\alpha\Delta T]$$

$$R = R_0[1+\alpha\Delta T] \Rightarrow \alpha = \frac{R_2 - R_1}{R_1\Delta T} = \frac{2.7-2.1}{2.1(100-27.5)} = 0.0039\ ^\circ\text{C}^{-1}.$$

$$\frac{2.1}{2.7} = \frac{\cancel{R_0}(1+\alpha\times27.5)}{\cancel{R_0}(1+\alpha\times100)}$$

$\alpha = ??$

Q Estimate the avg drift speed of conduction electrons in a Cu wire of cross sectional area $1\times10^{-7}\,m^2$ carrying a current of 1.5A. Assume density of conduction electron to be $9\times10^{28}\,m^{-3}$.

Sol $V_d = ??$

$A = 1\times10^{-7}\,m^2$

$I = 1.5\,A$

$n = 9\times10^{28}$

$$I = neV_dA$$

$$V_d = \frac{I}{neA} = \frac{1.5}{9\times10^{28}\times1.6\times10^{-19}\times1\times10^{-7}}$$

$$\doteq 1.042\times10^{-3}\,m/s.$$ Ans

Q Find the current flow through Cu wire of length 0.2m, $A = 1\,mm^2$, when connected to a battery of 4V. given that electron mobility is $4.5\times10^{-6}\,m^2/sV$. electron density $= 8.5\times10^{28}\,m^{-3}$.

Sol $E = \frac{V}{l} = \frac{4}{0.2} = 20\,V/m.$

$I = nAeV_d.$

$I = nAe\mu E.$

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

$V_d = \mu E.$

$$I = 8.5\times10^{28}\times1\times10^{-6}\times1.6\times10^{-1}\times4.5\times10^{-6}\times20$$

$$I = 1.22A$$ Ans

Q Find the time of Relaxation between Collision and free path of electron in Cu at room temp. $\rho_{Cu} = 1.7\times10^{-8}\,\Omega m$, density of electron in Cu $= 8.5\times10^{28}\,m^{-3}$, mass of electron $= 9.1\times10^{-31}\,kg$. $V_d = 1.6\times10^{-4}\,m/s$.

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

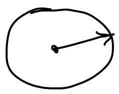
$$\therefore \tau = \frac{m}{e^2 n\rho}$$

$$= \frac{9.1\times10^{-31}}{(1.6\times10^{-19})^2\times8.5\times10^{28}\times1.7\times10^{8}} = 2.5\times10^{-14}\,s$$ Ans

mean Path $x = v\cdot t = V_d\times\tau = 1.6\times10^{-4}\times2.5\times10^{-14} = 4\times10^{-18}\,m.$ Ans

Q In a hydrogen atom, an electron moves in an orbit of radius 5×10^{-11} m with a speed 2.2×10^{6} m/s. Find the equivalent current.

Sol $I = \frac{q}{t}$.



$\omega = 2\pi f$.

$\omega = \frac{2\pi}{t}$.

$t = \frac{2\pi}{\omega}$.

$v = \frac{d}{t}$.

$V = \frac{2\pi r}{t}$.

$t = \frac{2\pi r}{V} = \frac{2\pi \times 5\times10^{-11}}{2.2\times10^{6}} = 14.279\times10^{-17}$ s.

$I = \frac{1.6\times10^{-19}}{14.279\times10^{-17}} = 0.11205\times10^{-2}$.

$= 1.12$ mA.

The amount of charge passing through a wire $q(t) = at^2 + bt + c$.

① Write the dimensional formula for a, b, and c.

② If the value of a b and c in S I Units are 5, 3, and 1 resp. Find the value of current at 5 s.

Sol $q = at^2 + bt + c$.

For a

$I = \frac{q}{t}$.

$q = It$.

$[A.T]$

$q = at^2$.

$a = \frac{q}{t^2}$.

$= \frac{[AT]}{[T^2]}$

$a = [AT^{-1}]$ Ans

For b $q = bt$

$b = \frac{q}{t}$.

$= \frac{[AT]}{[T]}$

$b = [A]$ Ans

For C $q = c$.

$c = q$

$c = [AT]$ Ans.

② $q = at^2 + bt + c$.

$\frac{dq}{dt} = 2at + b = i$

At $t = 5$ sec

$i = 2a(5) + b$.

$= 2(5)(5) + 3 = 50 + 3 = 53$ A Ans

Q A solution of Sodium chloride discharges 6.1×10^{16} Na^+ Ions and 4.6×10^{16} Cl^{-1} in 2 s. Find the current passing through the solution.

Sol $I = \frac{q}{t}$.

$t = 2s$

$q_{Na^+} = 1.6\times10^{-19} \times 6.1\times10^{16}$ C.

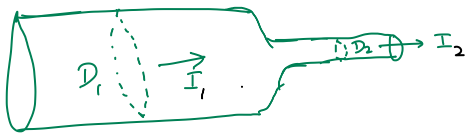
$q_{Cl^-} = 1.6\times10^{-19} \times 4.6\times10^{16}$ C.

Total charge $q_{Na^+} + q_{Cl^-} = 1.6\times10^{-19}(6.1\times10^{16} + 4.6\times10^{16})$

$= 1.6(10.7)\times10^{-3}$.

$I = \frac{1.6\times10.7}{2}$ mA $= 8.56$ mA. Ans

Q Current flows through a constricted conductor as shown. The diameter $D_1 = 2\,mm$ and current density to the left of the constriction is $j = 1.27 \times 10^6 \frac{A}{m^2}$.
① What current flows.
② If the current density is doubled as it comes out of right side, what is the diameter D_2?



Sol ① $J = \frac{I}{A}$ ∴ $I = J \cdot A$ ⟶ $I_1 = J_1 \times A_1$

$= J_1 \times \left[\pi\left(\frac{D_1}{2}\right)^2\right] = 1.27 \times \cancel{10^6} \times \pi \, (1 \times \cancel{10^{-3}})^2$

$= 1.27\pi = 3.9898\,A$

② $I = J \cdot A \rightarrow I_2 = J_2 A_2$.

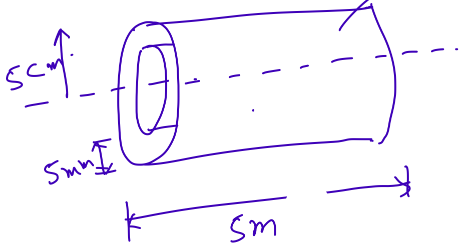
$J_2 = 2 \times 1.27 \times 10^6$
$= 2.54 \times 10^6\ A/m^2$.

For steady flow $I_1 = I_2$.
$J_1 A_1 = J_2 A_2$
$\cancel{1.27 \times 10^6} \times \cancel{\pi}(1 \times 10^{-3})^2 = 2 \times \cancel{1.27 \times 10^6}\ \cancel{\pi} R^2$.
$R^2 = (1 \times 10^{-3})^2 \times \frac{1}{2}$.
$R = \frac{1}{\sqrt{2}} \times 10^{-3} = 0.707 \times 10^{-3}$.

∴ $D_2 = 2R = 2 \times 0.707 \times 10^{-3}$.
$= 1.414 \times 10^{-3} = 1.414\ mm$ Ans

Q The external diameter of a 5m long hollow tube is 10 cm and thickness of wall is 5 mm. If the specific resistance of Cu be $1.7 \times 10^{-3}\ \Omega m$ then determine the resistance.

Sol



$\rho = 1.7 \times 10^{-3}$

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

$R = \frac{1.7 \times 10^{-3} \times 5}{\pi[25 - 20.25]}$

$= 5.7 \times 10^{-5}\ \Omega$ Ans

$A = \pi R^2 - \pi r^2$.
$= \pi[5^2 - (5 - 0.5)^2]$
$= \pi[5^2 - 4.5^2]$

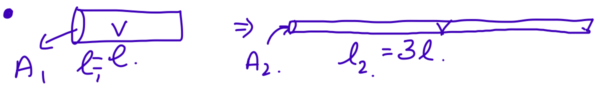
Q A wire of 10Ω resistance is stretched to thrice its original length. What will be its ① new resistivity ② New Resistance. (90Ω)

Q. A wire has a resistance of 16Ω. It is melted and drawn into wire of half its length. Calculate the resistance of new wire. What is the % change in its resistance. 75%

Q. The resistance of a wire is RΩ. What will be its new resistance if it is stretched to n times its original length? (n^2R)

Sol ① • No change in Resistivity.

•



$V = Al$

$A_1 l_1 = A_2 l_2$.

$A_1 \cdot \cancel{l} = A_2 \cdot 3\cancel{l}$.

$A_1 = 3A_2$.

$$R = \frac{\rho l}{A} \Rightarrow \frac{R_1}{R_2} = \frac{\rho l_1 / A_1}{\rho l_2 / A_2} = \frac{l_1}{l_2} \times \frac{A_2}{A_1}$$

$$= \frac{\cancel{l}}{3\cancel{l}} \times \frac{\cancel{A_2}}{3\cancel{A_2}} \Rightarrow \frac{R_1}{R_2} = \frac{1}{3}. \quad \therefore R_2 = 9R_1 = 90\,\Omega.$$

$R_1 = 10\,\Omega$ given.

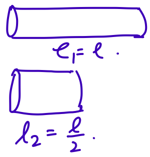
Sol ②

$V = Al$.

$A_1 l_1 = A_2 l_2$.

$A_1 \cdot l = A_2 \cdot \frac{l}{2}$

$A_2 = 2A_1$



$$\frac{R_1}{R_2} = \frac{\frac{\rho l_1}{A_1}}{\frac{\rho l_2}{A_2}} = \frac{l_1}{A_1} \times \frac{A_2}{l_2} = \frac{2\cancel{l}}{\cancel{l}} \cdot \frac{2\cancel{A_1}}{\cancel{A_1}} = 4.$$

$$R_2 = \frac{R_1}{4} = \frac{16}{4} = 4\,\Omega.$$

$$\therefore \% \text{ change} = \frac{16-4}{16} = \frac{\cancel{12}^{3}}{\cancel{16}_{4}} \times \cancel{100}^{25} = 75\%. \quad R_1 = \rho l.$$

Sol ③ $V = V$

$A_1 l_1 = A_2 l_2$.

$$\frac{A_1}{A_2} = \frac{l_2}{l_1} = \frac{n l_1}{l_1} = n.$$

$$\frac{R_1}{R_2} = \frac{l_1}{l_2} \times \frac{A_2}{A_1} = \left(\frac{A_2}{A_1}\right)\left(\frac{l_1}{l_2}\right)$$

$$= \frac{1}{n} \cdot \frac{1}{n}.$$

$$\frac{R_1}{R_2} = \frac{1}{n^2} \quad R_2 = n^2 R_1. \quad \text{Ans.}$$

Q A wire of 1m long and ·13mm in diameter has a resistance of 4·2 Ω. Calculate the resistance of another wire of the same material whose length is 1.5 m and diameter 0.155 m.

Sol $R = \frac{\rho l}{A} = \frac{\rho l}{\pi R^2} = \frac{4\rho l}{\pi D^2}$. $\Rightarrow \frac{R_1}{R_2} = \frac{\rho l_1}{D_1^2} \times \frac{D_2^2}{\rho l_2} \Rightarrow \boxed{\frac{R_1}{R_2} = \frac{l_1}{l_2} \times \frac{D_2^2}{D_1^2}}$

$$\frac{R_1}{R_2} = \frac{1}{1.5} \frac{0.155^2}{0.13^2} = 0.9477 \quad \therefore R_2 = \frac{R_1}{0.9477} = \frac{4.2}{0.9477} = 4.4316\,\Omega. \quad \text{Ans}$$

Q On applying the same potential difference the end of the wires of Iron and Copper of the same length, the same current flows in them. Compare their radii.

$\rho_{Fe} = 1 \times 10^{-7}$ and $\rho_{cu} = 1.6 \times 10^{-8}\,\Omega m$.

Can their Current densities be made equal by taking appropriate radii??

Sol: Same Potential, same length, same current — given.

$V = IR$.

$\frac{V}{I} = R \rightarrow \frac{V_1}{I_1} = R$, $\frac{V_2}{I_2} = R$

$R_1 = R_2$.

$\frac{\rho_{Fe}\,l}{A_{Fe}} = \frac{\rho_{Cu}\,l}{A_{Cu}} \Rightarrow \frac{\rho_{Fe}}{A_{Fe}} = \frac{\rho_{Cu}}{A_{Cu}}$

$\frac{A_{Fe}}{A_{Cu}} = \frac{\rho_{Fe}}{\rho_{Cu}} = \frac{1\times10^{-7}}{1.6\times10^{-8}} = \frac{100}{16}$

$= \frac{100}{16}$

$\frac{\pi R_{Fe}^2}{\pi R_{Cu}^2} = \frac{100}{16} \quad \therefore \frac{R_{Fe}}{R_{Cu}} = \frac{10}{4}$.

$5:2$ Ans.

• No, Nature of material is the factor on current density depends.

Q A Copper wire has a resistance of $10\,\Omega$ and an area of cross section $1\,mm^2$. A potential difference of 10 V exists across the wire. Calculate the drift speed of electrons if the number of electrons per cubic meter in Copper is 8×10^{28} electron.

Sol
$R = 10\,\Omega$
$A = 1\times10^{-6}\,m^2$
$V = 10\,V$
$n = 8\times10^{28}$ electrons.

$V = IR$
$10 = I\times10$
$I = 1\,A$

$I = qAV_d$
$I = neAV_d$
$V_d = \dfrac{I}{neA}$

$$V_d = \frac{1}{8\times10^{28}\times1.6\times10^{-19}\times1\times10^{-6}}$$
$$= \frac{1}{8\times1.6}\times\frac{1}{10^{28-25}} = 0.078\times10^{-3}\,m/s.$$
Ans

Q a) Estimate the avg drift speed of conductor electrons in a copper wire of cross-sectional area $1\times10^{-7}\,m^2$, carrying a current of 1.5 A. Assume that each copper atom contribute roughly one conduction electron. $\rho_{Cu} = 9\times10^3\,Kg/m^3$. Atomic No of Cu = 63.5 U. Avogadro's No = $6\times10^{23}\,mole^{-1}$.

b) Compare the drift speed obtained above with (1) Thermal speeds of Cu atom at ordinary temperature. (2) Speed of electron carrying the current. (3) Speed of propagation of electric field along the conductor which causes the drift motion.

Sol
$$n = \text{No of electrons} = \frac{\text{Avogadro's No}}{\text{Atomic No}}\times\text{density}$$
$$= \frac{6\times10^{23}}{63.5}\times9\times10^3 = 8.5\times10^{28}\ \text{Atoms}.$$

$I = qAV_d$
$I = neAV_d$
$$V_d = \frac{I}{neA} = \frac{1.5}{8.5\times10^{23}\times1.6\times10^{-19}\times1\times10^{-7}}$$
$$= 1.1\times10^{-3}\,m/s$$

(2) Thermal speed at $T = 27^\circ C$ or $300^\circ K$.
$$V_{rms} = \sqrt{\frac{3K_BT}{M}} = \sqrt{\frac{3\times1.38\times10^{-23}\times300}{(63.5\times10^{-3}/6\times10^{23})}}$$
$$M = \frac{(63.5\times10^{-3}\,kg)}{6\times10^{23}} =$$
$$= 342.57\,m/s.$$

$$\therefore \frac{V_d}{V_{rms}} = \frac{1.1\times10^{-3}}{342.57} = 3.21\times10^{-6}.$$
Ans

Speed of electron carrying the current ⟶ ??

(3) $= \dfrac{\text{Speed of electron}}{\text{Speed of emw}} = \dfrac{1.1 \times 10^{-3}}{3 \times 10^{8}} = \dfrac{1.1}{3} \times 10^{-11} = 0.36 \times 10^{-11}$ Ans

Q A potential difference of 100V is applied to the ends of a copper wire 1m long. Calculate the avg drift velocity of the electron. Compare it with the thermal velocity at 27°C. Given conductivity of copper $\sigma = 5.81 \times 10^{7} / \Omega m$ and density of conduction electron $n = 8.5 \times 10^{28}\, m^{-3}$.

Sol

$V = E\ell$

$V = 100V$

$\ell = 1m$

$E = \dfrac{V}{\ell} = \dfrac{100}{1}$

$E = 100\, V/m$

$I = qAV_d$

$\dfrac{I}{A} = J = qV_d$

$V_d = \dfrac{J}{q} = \dfrac{581 \times 10^{7}}{ne}$

$J = \sigma E$

$= 5.81 \times 10^{7} \times 100$

$J = 581 \times 10^{7}\, A/m^2$

$n = 8.5 \times 10^{28}$

$V_d = \dfrac{581 \times 10^{7}}{1.6 \times 10^{-19} \times 8.5 \times 10^{28}}$

$= 42.72 \times 10^{7+19-28}$

$= 42.72 \times 10^{-2}\, m/s = 0.427\, m/s$

Thermal Velocity

$V_{rms} = \sqrt{\dfrac{3K_BT}{M}}$

$= \sqrt{\dfrac{3 \times 1.38 \times 10^{-23} \times (273+27)}{9.1 \times 10^{-31}}} = 1.17 \times 10^{5}\, m/s$

Comparing $\dfrac{V_d}{V_{rms}} = \dfrac{0.43}{1.17 \times 10^{5}} = 0.367 \times 10^{-5}$ Ans

Q. A potential difference of 6V is applied across a conductor of length 0.12 m. Calculate the drift velocity of electron, if the electron mobility is $5.6\times10^{-6}\ m^2/Vs$

Sol. $V_d = \mu E$
$= \mu \frac{V}{l} = \frac{5.6\times10^{-6}\times 6}{0.12} = 2.8\times10^{-4}\ m/s^2$

Q. A semiconductor has the electron concentration of $0.45\times10^{12}\ m^{-3}$ and hole constration $5\times10^{20}\ m^{-3}$. Find its Conductivity. $\mu_e = 0.135\ m^2/Vs$. $\mu_h = 0.048\ m^2/Vs$.

Sol. $n = 0.45\times10^{12}/m^3$.
$p = 5\times10^{20}/m^3$.

$\sigma = ne\mu_e + pe\mu_h$.
$= 1.6\times10^{-19}\left[0.45\times10^{12}\times0.135 + 5\times10^{20}\times0.048\right]$
$= 3.84\ S/m$.

Q. The resistance of a Pt wire of a Pt resistance thermometer at a ice point is 5Ω and steam point $5.23\ \Omega$. When the thermometer is inserted in a hot bath, the resistance of the platinum wire is 5.795Ω. Calculate the temperature of bath.

R' at temp $t = ??$ $= 5.795\Omega$.

Sol. $R = R_0[1+\alpha\Delta T]$
$R_t = R_0[1+\alpha(t-0)]$
$R_{100} = R_0[1+\alpha(100-0)]$.

$\frac{R_t - R_0}{R_{100}-R_0} = \frac{R_0\alpha t}{\cancel{R_0}\cancel{\alpha}100}$ $\Rightarrow$ $\frac{R_t - R_0}{R_{100}-R_0} = \frac{t}{100}$.

$\Rightarrow \frac{5.795-5}{5.23-5} = \frac{t}{100}$

$t = 345.65^\circ c$.

Q. A nichrome heating element connected to a 220V supply draws an initial Current of 2.2A which settles down after a few seconds to a steady value of 2A. Find the steady temperature of heating element. The room temp is $30^\circ c$ and avg temp Co-effient of resistance of $Ni = 1.7\times10^{-4}/^\circ c$.

Sol. Case I $I = 2.2A$
$R_1 = \frac{V}{I} = \frac{\cancel{2200}\ 100}{\cancel{22}}$
$= 100\Omega$

Case II $I = 2A$
$R_2 = \frac{V}{I} = \frac{220}{2}$
$= 110\Omega$

$R_2 = R_1[1+\alpha(t_2-t_1)]$

$\alpha = \dfrac{R_2 - R_1}{R_1(t_2-t_1)}$

$t_2 - t_1 = \dfrac{R_2 - R_1}{R_1 \alpha}$

$= \dfrac{110 - 100}{100 \times 1.7 \times 10^{-4}}$

$= \dfrac{100}{100 \times 1.7} \times 10{,}000 = \dfrac{10000}{17} = 588.235$

$t_2 = 588.235 + 30 = 618.235°c$ Ans

Q The resistance of a Tungsten filament at 150°c is 133 Ω. What will be its resistance at 500°c? $\alpha = 0.0045/c°$.

Sol $R_1 = R_0(1 + \alpha \times 150)$

$R_2 = R_0(1 + \alpha \times 500)$

$\dfrac{R_1}{R_2} = \dfrac{1 + 0.0045 \times 150}{1 + 0.0045 \times 500} = \dfrac{133}{R_2}$ $\therefore R_2 = \dfrac{133 \times 3.25}{1.675}$

$= 258.06\,\Omega$ Ans

Q The resistance of a Conductor at 20°c is 3.15 Ω and at 100°c is 3.75 Ω. Determine the temp Co-efficient of the Conductor. What will be the resistance of the Conductor at 0°c.

Sol $\dfrac{R_1 = \cancel{R_0}(1+\alpha t_1)}{R_2 = \cancel{R_0}(1+\alpha t_2)}$

$\dfrac{R_1}{R_2} = \dfrac{1+\alpha t_1}{1+\alpha t_2}$

$R_1 + R_1\alpha t_2 = R_2 + R_2 \alpha t_1$

$R_1 \alpha t_2 - R_2 \alpha t_1 = R_2 - R_1$

$\alpha[R_1 t_2 - R_2 t_1] = R_2 - R_1 \longrightarrow \alpha = \dfrac{R_2 - R_1}{R_1 t_2 - R_2 t_1}$

$\alpha = \dfrac{3.75 - 3.15}{3.15 \times 100 - 3.75 \times 20}$

$\alpha = 0.0025/°c$

$R_1 = R_0(1 + \alpha t)$

$R_0 = \dfrac{R_1}{1+\alpha t} = \dfrac{3.15}{1 + 0.0025 \times 20} = 3\,\Omega$ Ans