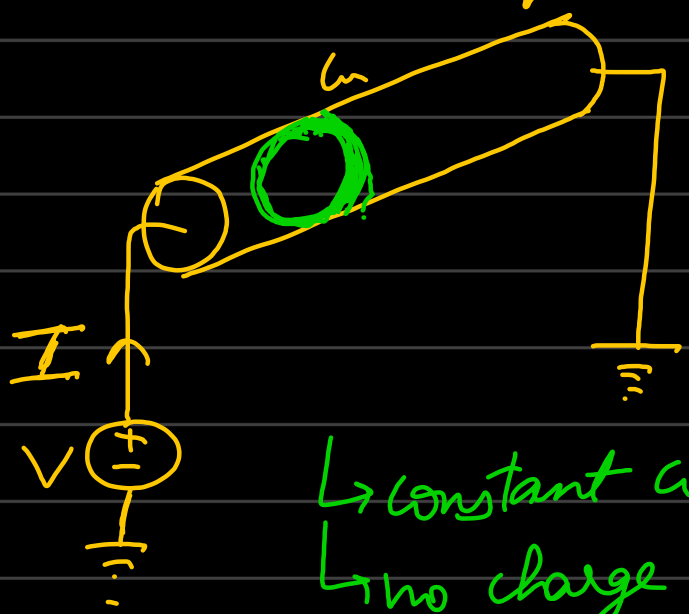
MLL 253

Electrical, Magnetic, Optical Properties of Materials.

Electrical Properties:



↳ constant current in bar
↳ no charge accumulation.

$I = \frac{\Delta q}{\Delta t}$ $J = \frac{\Delta q}{A \Delta t}$ current density

→ Uniform Electric field around conductor

$$E = \frac{V}{L}$$

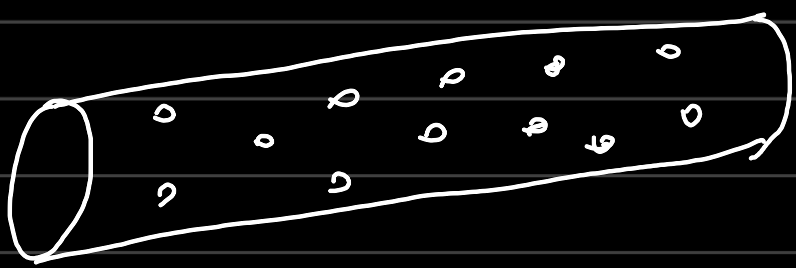
→ linear gradient of potential V exists across conductor.

→ $V = RI$ {Ohm's Law}

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

→ ρ depends on temperature (T), AC frequency of excitation (ω)

→ fluid like flow of electrons



→ $U \Rightarrow$ Thermal Energy (T)

Kinetic Energy (KE) $= \frac{3}{2} k_B T$ {3 dof}

{ $\frac{1}{2} kT$ per dof }

$$\frac{1}{2} m_e v_d^2 = \frac{3}{2} k_B T$$

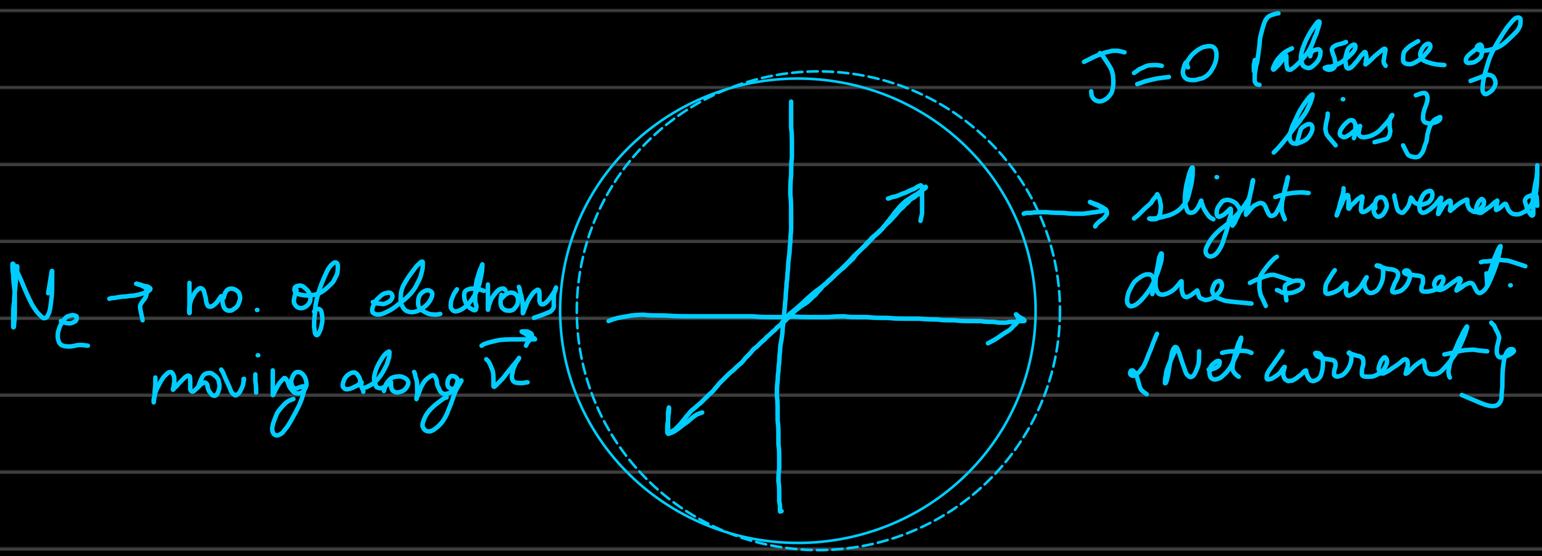
$$v_d = \sqrt{\frac{3 k_B T}{m_e}} \text{ m/s}$$

→ Considering $T = 300K$ $m_e = 9.31 \times 10^{-31}$ kg

$k = 1.38 \times 10^{-34}$

$$v_d \approx 10^5 \text{ cm/s}$$

→ net current $J=0$ in absence of bias.

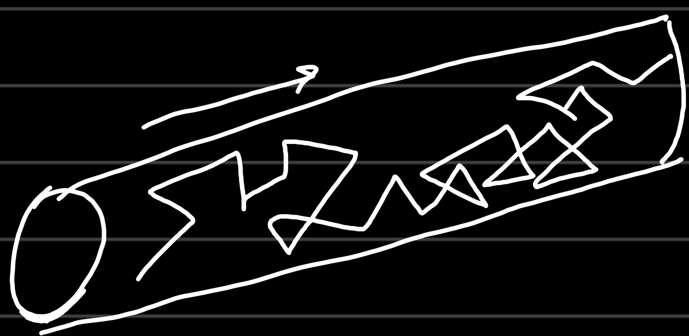


V_d → velocity of electrons along x.

$$V_d = \frac{\Delta x}{\Delta t} \Rightarrow \Delta x = V_d \Delta t$$

$$J = \frac{\Delta q}{A \Delta t} = \frac{e N_e V_d \Delta t \cdot A}{A \Delta t} = N_e e V_d$$

$$\boxed{J = N_e \cdot e \cdot V_d}$$



→ not rectilinear propagation of electron

→ scatters at positive ion cores

$$\frac{dv}{dt} = \frac{eE}{m} - \underbrace{\frac{V_d}{\tau}}$$

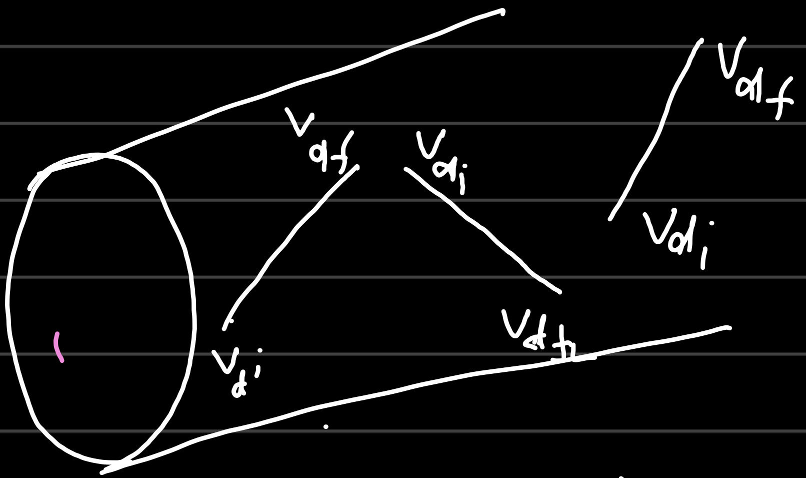
$\tau \rightarrow$ relaxation time.

↳ additional component to account for scattering.

↳ acceleration and deceleration work simultaneously to steady state net flow of electrons.

↳ electron accelerates from V_{d_i} to V_{d_f} until it gets scattered.

↳ duration of this motion ⇒ relaxation time (τ)



τ : probability to scatter ↓ turns out to be the mean time to scatter.

Effective velocity = $\langle V_{d_f} \rangle$

Effective lifetime = $\langle \tau \rangle$

$$\langle V_{d_f} \rangle = \frac{eE}{m} \langle \tau \rangle$$

$$J = e \cdot N_e \cdot \frac{eE}{m} \langle \tau \rangle = \sigma E$$

$$\boxed{\sigma = \frac{N_e e^2 \langle \tau \rangle}{m}}$$

$a = \frac{eE}{m}$; $\langle \tau \rangle$ effective time

$$\langle V_d \rangle = \frac{eE}{m} \langle \tau \rangle$$

$$J = N_e \cdot e \langle V_d \rangle = \frac{N_e \cdot e^2 \langle \tau \rangle}{m} E$$

$$J = \sigma E \quad \text{[Ohm's Law]}$$

Conductivity $\leftarrow$ $\sigma = \underbrace{(N_e e)}_{\text{no. of electrons}} \underbrace{\left(\frac{e \langle \tau \rangle}{m} \right)}_{\text{electron mobility}}$

mobility : how free it is to move.

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

↳ Classical Transport of Metals.

In a Nutshell:

$$J = \frac{\Delta q}{A\Delta t} = N_e e \langle v_d \rangle$$

$\langle v_d \rangle \to$ drift velocity

$$\langle v_d \rangle = \frac{eE\langle \tau \rangle}{m}$$

$\langle \tau \rangle \to$ relaxation time.

$\to$ probability to scatter.

$$\langle v_d \rangle = \mu E$$

$\mu \to$ mobility of electron

$N_e e$, $N_e \to$ no. of electrons.

$$\mu = \frac{e\langle \tau \rangle}{m}$$

$$J = \frac{N_e e^2 \langle \tau \rangle}{m} E = \sigma E$$

$\sigma \to$ conductivity

$$\sigma = \frac{N_e e^2 \langle \tau \rangle}{m}$$

$$= (N_e e)\underbrace{\left(\frac{e\langle \tau \rangle}{m}\right)}_{\text{mobility}(\mu)}$$