→ The conductivity varies in presence of M.F.
This effect is known as Magnetoresistance.

→ The ratio of thermal conductivity (K) to electrical conductivity (σ) is directly proportional to absolute temp. (Kelvin)

$$\boxed{\frac{K}{\sigma} \propto T}$$

This is known as Wiedmann-Franz law.

Theoretical explaination of electrical Properties :→

Free-electron Theory

classical free electron theory (Drude-Lorentz Theory)

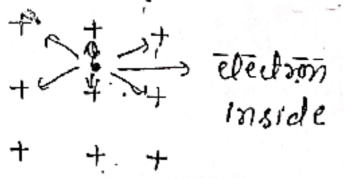
Quantum free electron Theory (Sommerfield Theory)

Classical free electron Theory (Drude-Lorentz Theory) :→

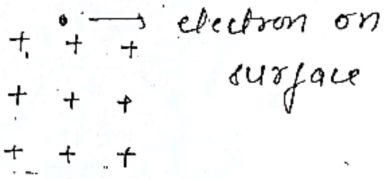
According to this theory:
Metals achieve structural stability by letting (छोड़ना) their e⁻s roam freely throughout the crystal lattice.

The valance electrons are equivalent of the molecules of an ordinary gas. The law's of classical kinetic theory of gases and hence Maxwell-Boltzmann statistics can be applied to a free e^- gas. Thus $\bar{e}$ can be assigned a mean free path d, a mean collision time τ & average speed $\bar{c}$.

→ ~~$\bar{e}$ can~~ move freely inside the solid but cannot leave the surface because average force of +ve ion on $\bar{e}$ is sufficient so that it can't leave surface.



(Net force zero)



(Net force is inside)

$\left[\vec{F} = 0 \right.$

$\left[\vec{F} \neq 0 \rightarrow \right.$ Accelerating motion.

→ In absence of external potential difference, net current is zero. { Because of zig-zag motion (thermal motion of electron)

<u>Calculation:</u>→

For unit volume of metal

Pressure ↙ $P = \frac{1}{3} \rho \bar{c}^2 = \frac{1}{3} m n \bar{c}^2$

$$P = \frac{1}{3} m \frac{N}{V} \bar{c}^2$$

for 1-mole

$$P_m = \frac{1}{3} m \cdot \frac{N_A}{V_m} \bar{c}^2$$

$$P_m V_m = \frac{1}{3} m N_A \bar{c}^2 = RT$$

$$\frac{1}{2} m\bar{c}^2 = \frac{3}{2} \frac{R}{N_A} T$$

$$\boxed{K.E. = \frac{3}{2} K_B T}$$ K_B = Boltzmann constant

where, $K_B = \frac{R}{N_A}$ $R \longrightarrow$ universal-gas-constant

& $$\boxed{\bar{c} = \sqrt{\frac{3K_BT}{m}}}$$

$$\boxed{\frac{1}{\bar{c}} = \sqrt{\frac{m}{3K_BT}}}$$

In presence of external electric field (E)

The eqn: of motion of $\bar{e}$

$$m\frac{dv}{dt} = -eE - \underbrace{\alpha m v}_{\text{Damping force or Retarded force due to collision}} \quad \text{---} (1)$$

$\alpha \rightarrow$ unknown Quantity

In case of drift motion

$$V = V_d = \text{constant}$$

$$\frac{dv}{dt} = 0$$

From eqn ①

$$0 = -eE - \alpha m V_d$$

$$\boxed{V_d = \frac{-eE}{\alpha m}}$$

$$\boxed{\mu = \frac{V_d}{E} = \frac{-e}{\alpha m}}$$

mobility

Now, when applied field is off, the eqn of motion of electron,

$$m\frac{dv}{dt} = -\alpha m V \quad \text{—— ②}$$

with initial cond $t=0, V=V_d$

$$\int \frac{dv}{V} = -\int \alpha\, dt$$

$$\ln V = -\alpha t + A$$

$$t=0,\ V=V_d$$

$$\boxed{A = \ln V_d}$$

$$\ln V = -\alpha t + \ln V_d$$

$$\ln \frac{V}{V_d} = -\alpha t$$

$$\boxed{V = V_d e^{-\alpha t}}$$ → Decreases exponentially on switching off the field

Average collision time/Retardation time/mean collision time:-($t = \tau$)

$V = \frac{V_d}{e} \rightarrow$ exponantial (2.718)

on putting $\alpha\tau = 1$

$\boxed{\alpha = \frac{1}{\tau}}$

$\boxed{V = V_d e^{-t/\tau}}$

$\boxed{V_d = \frac{-eE\tau}{m}}$

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

Current density :-> $J = -neV_d$

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

$\boxed{J \propto E}$

$\boxed{J = \sigma E}$

$\sigma \rightarrow$ electrical conductivity

$\rho \rightarrow$ electrical Resistivity

lectrical nductivity $\boxed{\sigma = \frac{ne^2\tau}{m} = ne\mu}$

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

* Features of classical free Theory (Lorentz-Drude Theory) :->

(1) Free electron in a solid constitutes a free electron gas. These electron

can compared to gas molecules of an ideal gas.

② These free electrons obey M-B statistics.

③ It successfully explains ohm's law.

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

④ These free electron can move freely so metals have high electric and thermal conductivities.

⑤ Ratio of thermal conductivity to electrical conductivity is constant at a particular temp. (Wiedmann-Franz's law). It explains this law successfully.

$$\frac{K}{\sigma} = \frac{\pi^2}{3}\left(\frac{K_B}{e}\right)^2 = 2.45 \times 10^{-8} \text{ watt-}\Omega/\text{degree kelvin}$$

* **Failure of classical free electron Theory :->**

① This theory cannot explains the temperature dependence of electrical resistivity.

② It fails to explain electronic heat capacity and paramagnetic susceptibility of free electron.

According to this theory:

$$\boxed{(C_v)_e \propto T} \quad 4 \quad \boxed{(\chi_{Par.})_e \propto \frac{1}{T}}$$

↳ experimentally

But experimentally,

→ $(C_e)_v$ is independent of T & $(\chi_{para})_e$ is also independent of T
↳ classically

for some metal,

R_H (Hall coefficient) = +ve
↓
measure the sign of charge carrier.

This theory couldn't explain it.

It fails to explain why some metals are good conductor of electricity and some are bad conductor of electricity. i.e.
It can't differentiate conductor, semiconductor and insulator.

Sommerfield Free electron Theory (Quantum free electron Theory):→

All assumption in Quantum free e^--theory are same as in classical free-e^- theory except he applied the F-D statistics (Quantum) for electron rather M-B statistics.

→ In FD statistics, the distribution of electron is different from that of M-B distribution.

→ In F-D statistics Pauli-exclusion principle is followed by particle.

The partition function will be changed and properties of solid changes.

→ In Quantum statistics the property of a particle is describe by wavefunction ψ.

* Construction of wave equation and wave function for electron inside the solid :→

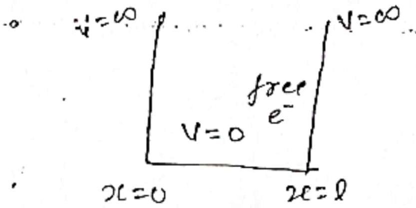
Schrodinger wave eqn.

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}(E-V)\psi = 0$$

For 1 Dim. solid,

$$V = \begin{cases} 0 & , 0 < x < l \\ \infty & , \text{otherwise} \end{cases}$$

l = length of 1D solid



$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}E\psi = 0$$

$$k^2 = \frac{2mE}{\hbar^2}$$