UNIT II

Free electron theory of Metals:

Introduction: This theory of metals was proposed by P. Drude in 1900. Later it was extended by H.A. Lorentz in 1909.

This theory is known as classical free electron model. & is based on the principle that a metal consists of large number of free electrons which can move freely throughout the body of the metal.

Free electron: is a electron not connected to an atom in a structure.

Classical Free electron theory:-

All the metal atoms consist of valence electrons. These valence electrons are responsible for electrical conduction in the bulk state of the metal.

For an ex: consider the case of copper atom consists of 29 electrons. Out of which 28 fill the first 3 shells & form the core part. The remaining single electron of the atom will be present in the fourth shell that is the valence electron of cu atom. The total negative charge due to all the core electrons balanced by the valence electrons (balances +ve charge), so the Nucleus is neutral.

When a large number of copper atoms join to form a metal, the boundaries of the adjoint atoms slightly overlap on each other. Due to such an overlapping the core electrons remains unaffected & valence electrons find continuity from atom to atom & can move freely throughout the body of the metal.

This disconnection of every valence electron from parent atom caused by its free movement results in virtual loss of a negative charge, for that atom, therefore the electrical neutrality of the atom is lost & becoms as ion.

Thus each atom contributes equal number of valence electrons, there will be very large number of electrons which are free in a metal, such electrons are called as free electrons, & they result for many properties of the metal such as electrical conductivity, Thermal conductivity etc.

Assumptions of Free electron model:

1. A metal contains a large number of free electrons which are free to move about in entire volume of the metal like the molecules of a gas in a container
2. The free electrons move in random directions & collide with either +ve ions fixed in the lattice or other free electrons. All the electrons are elastic & there is no loss of energy.
3. The velocity & the energy distribution of the free electron obey the classical Maxwell Boltzmann statistics
4. The free electrons are moving in a completely uniform potential due to the ions fixed in the lattice
5. In the Absence of the $\vec{E}$ the random motion of free electron is equally probable in all direction so the current density vector is zero.
6. When the external $\vec{E}$ is applied across the metal, the electrons drift slowly with some average velocity drift velocity in the opposite direction of $\vec{E}$. This drift velocity is responsible for the flow of Electric current in a metal.

Drift velocity:- In the absence of electric field though the free electrons are in motion, it doesnot give rise to the current due to the randomness in ē motion. $V_{avg} = 0$.

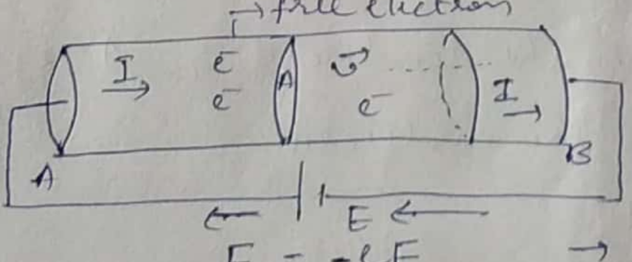
When an electric field is applied there will be net displacement in the randomly moving free electrons position with the time in the direction opposite to the direction of the field. Thus the transportation of the charge results in the generation of current.

"The Net displacement in the electron's positions per unit time caused by the application of an electric field is called Drift velocity.

Conductivity: σ:- It is physical property of the material that gives the measure of conducting ability & it is Inverse of Resistivity

Expression for Electrical Conductivity σ:

consider the motion of an electron in a conductor subjected to the influence of Electric field. If 'e' is the charge on the electron & $\vec{E}$ is the strength of the applied field then the force $\vec{F}$ on the electron is .



$$F = -eE \quad \rightarrow ①$$

If 'm' is the mass of the electron then as per Newton's second law of motion, force on the electron can be written as

$$F = m\frac{dv}{dt} \rightarrow (2)$$

From eqn ① & ②

$$-eE = m\frac{dv}{dt} \Rightarrow dv = -\frac{eE}{m}dt$$

Integrating on both sides

$$\int dv = \int_0^t \frac{eE}{m}\,dt$$

$$\therefore \quad v = -\frac{eE}{m}t \longrightarrow (3)$$

where 't' is the time of traverse.

Let the time of traverse t be taken as the collision time 'τ' & by definition collision time applies to the average velocity (value). Hence the velocity in eq (3) becomes the average velocity $\vec{v}$.

$$\therefore \quad \bar{v}_d = -\frac{eE}{m}\tau \rightarrow (4)$$

From the definition of conductivity σ, we have

$$\sigma = \frac{J}{E} \rightarrow (5)$$

where $\vec{J}$ is the current density.

But w.k.t $J = \frac{I}{A}$.

where 'I' is the current in the conductor & 'A' is the area of cross section of the conductor.

$$\therefore \sigma = \frac{I}{AE} \rightarrow (6)$$

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If '-e' the charge on the electron, 'n' is the no of electrons/unit volume, then the quantity of charge crossing a given point in the conductor/unit area/unit time is, the current I is

$$dq/dt = -enA.\left(\frac{dl}{dt}\right)$$

$$I = n(-e)\bar{v}_d A \rightarrow (7)$$

$-e \rightarrow$ electron charge

$\frac{dl}{dt} \rightarrow v_d$.

substituting (7) in (6)

$$\sigma = \frac{-n.e\bar{v}_d}{E} \rightarrow (8)$$

substituting (4) in (8)

$$\sigma = \frac{n(-e)}{E}\left(\frac{-eE}{m}\right)\tau$$

$$\boxed{\sigma = \frac{ne^2\tau}{m}} \rightarrow (9)$$

This is the Expression for Electrical conductivity in a conductor.