8.1. Introduction

Many properties of metals can be explained by using the free electron theory. However there are many properties which can not be explained by this theory at all. For example, free electron theory does not tell us why some chemical elements crystallize to form good conductors of electricity whereas the others are insulators or semiconductors.

In the free electron theory, it was assumed that the electron is free to move inside a box of constant or zero potential. Therefore, no force acts on the electron in moving throughout the body of the metal. However, this is not actually true. When an electron passes near an ion, a force acts on it. There is a regular arrangement of ions in the metallic crystal. Therefore in moving from one place to another, the electron passes over the changing potential of one ion to the other. We may say that electron is under the impact of a periodic potential instead of being in a constant potential as assumed in free electron theory. The most appropriate potential for the physical system would be the muffin tin potential. It takes into account the fact that the electrons which actually take part in the bonding are the valence electrons and they are acted upon by the potential of the nucleus that decays inversely with the distance of the electron from the centre of the nucleus *i.e.* $V \propto \frac{1}{r}$. The variation of potential experience by an electron in perfectly periodic crystal lattice with lattice parameter a may be shown in Figure 8.1. The potential on the surface in shown on the left.

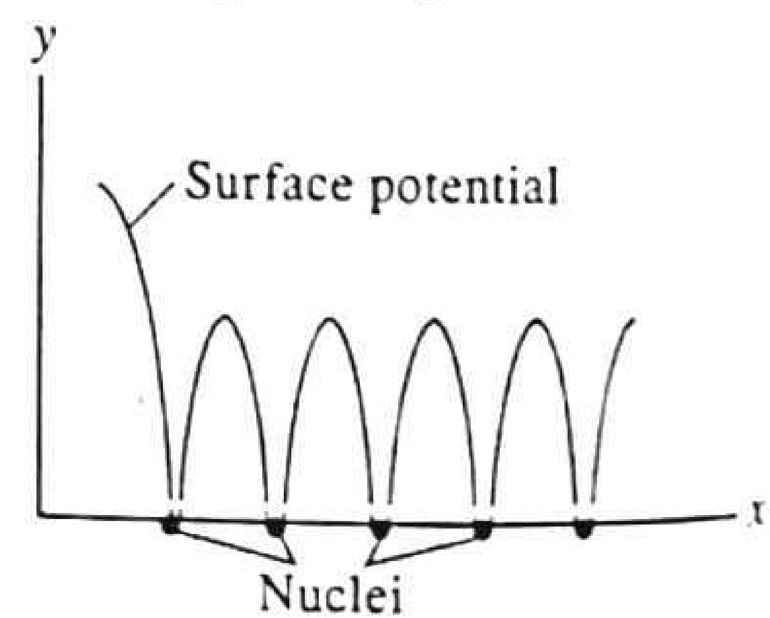


Figure 8.1.

(Salient features) (Assumptions)

Q:- Give Postulates of Classical free electron theory (DRUDE - LORENTZ THEORY of Metals) and obtain expression for $\boxed{\text{electrical}}$ conductivity and drift Velocity.

Ans:- The $\boxed{\text{main assumptions}}$ of classical free $e^{\ominus}$ theory are:

(1.) A metal is imagined as the structure of 3-D array of ions in b/w which there are free moving valence electrons confined to the body of the material.

(2.) The free $e^{\ominus}$s (electron gas), available in a metal move freely here and there, but are restricted to jump out of the metal due to external forces

(3.) ~~These~~ Such freely moving $e^{\ominus}$s are the cause of Conduction in the metal when it is subjected to a potential difference and also called the Conduction electrons.

(4.) The free electrons are treated as equivalent to gas molecules & they are assumed to obey the laws of kinetic theory of gases,

$$\frac{3}{2}kT = \frac{1}{2}mV_{th}^2$$

thermal velocity

Scanned by CamScanner

(5.) The electric ~~potential~~ current due to an applied field is a consequence of the drift velocity in a direction opposite to the direction of the field.

(6) Electric potential due to the ionic cores is taken to be essentially constant throughout the body of the metal.

→ The effect of repulsion b/w the $e^{\ominus}$s is considered insignificant.

(7) The free $e^{\ominus}$s are non-interacting & obey Pauli's exclusion Principle.

1. **Give the assumptions of the classical free electron theory.**

OR

Bring out the salient features of Drude-Lorentz theory.

(Jan-2009, Feb-2003, Feb-2005, Jan-2004)

Ans. The main assumptions of classical free electron theory are:

1. A metal is imagined as the structure of 3-dimensional array of ions in between which, there are free moving valence electrons confined to the body of the material. Such freely moving electrons cause electrical conduction under an applied field and hence referred to as conduction electrons

Scanned by CamScanner

2. The free electrons are treated as equivalent to gas molecules and they are assumed to obey the laws of kinetic theory of gases. In the absence of the field, the energy associated with each electron at a temperature T is given by 3/2 kT, where k is a Boltzmann constant.

   It is related to the kinetic energy,

   $3/2\ kT = \frac{1}{2} mv_{th}^2$

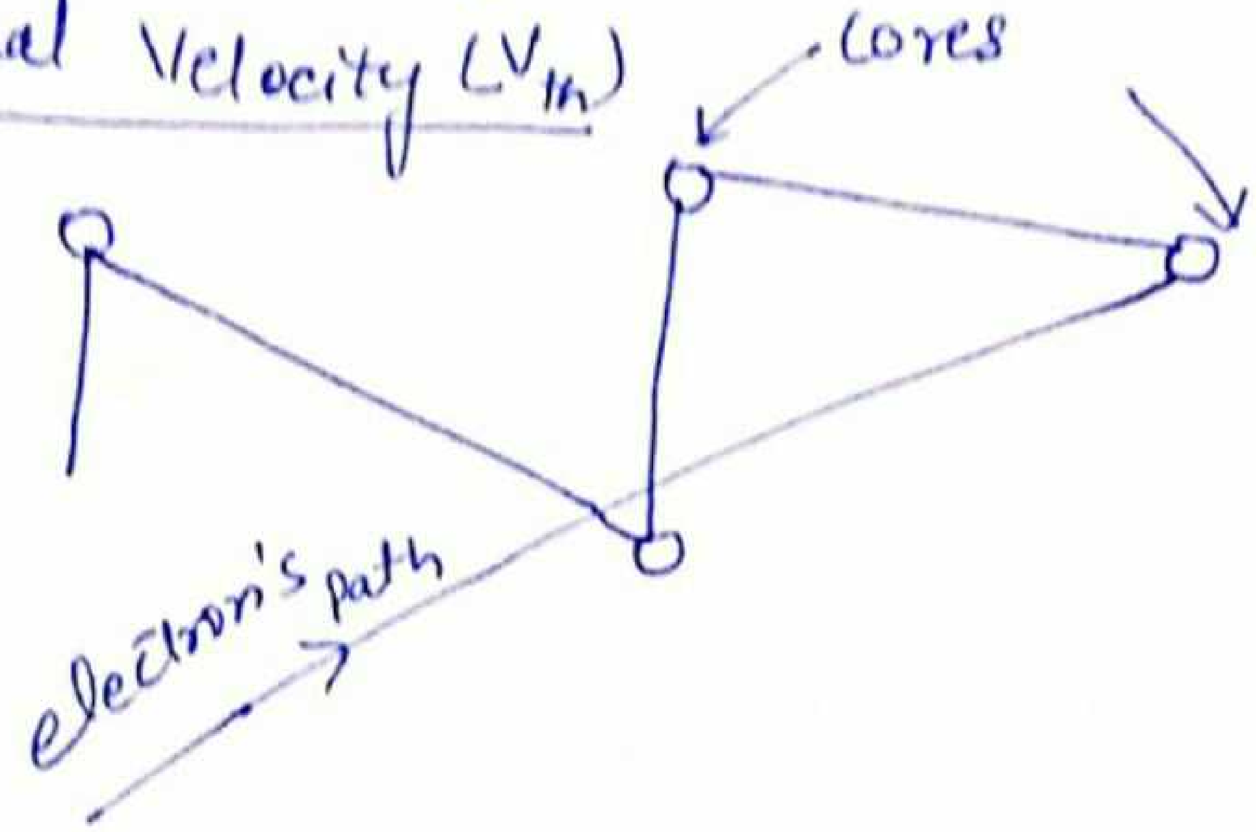
   Where v_{th} is the thermal velocity same as root mean square velocity.
3. The electric potential due to the ionic cores is taken to be essentially constant throughout the body of the metal and the effect of repulsion between the electrons is considered insignificant.
4. The electric current in a metal due to an applied field is a consequence of the drift velocity in a direction opposite to the direction of the field.
5. The free electrons are non-interacting and obey pauli's exclusion principle.
6. The motion of free electrons obeys the classical Maxwell-Boltzmann velocity distribution law and laws of kinetic theory of gases.

exam

Drift Velocity :- The average velocity ~~occupied~~ (aquired) by the free electrons in a particular direction during the presence of an electric field.

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

Thermal Velocity (V_{th})



The velocity of electrons in random motion due to thermal agitation called thermal velocity.

Mean Free path (λ) :- The average distance travelled by the conduction electrons b/w any two successive collisions with lattice ions.

exam
Relaxation time (τ_r) :- The relaxation time is defined as the time taken by a free electron to reach its equilibrium position from its disturbed position, during the presence of an applied field.

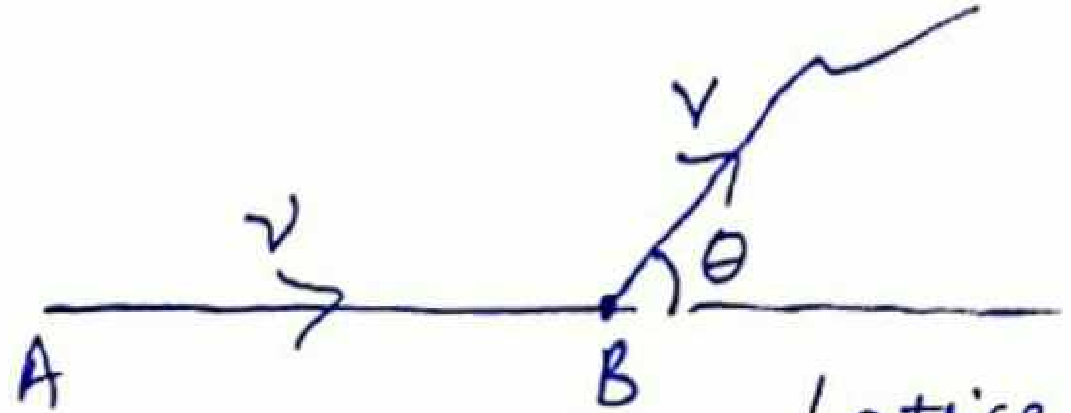
$$\tau = \frac{l}{\langle v \rangle}$$ where l is the distance travelled by the electron.

OR

From the instant of sudden disappearance of an electric field, across a metal, the average velocity of the conduction electrons decays exponentially to zero, and the time required in this process for the average velocity to reduce to $(1/e)$ times its value is known as Relaxation time.

$$\tau_r = \frac{\tau}{1 - \langle \cos\theta \rangle}$$, τ is mean collision time

For isotropic scattering or symmetrical scattering $\langle \cos\theta \rangle = 0$ then $\tau_r = \tau$



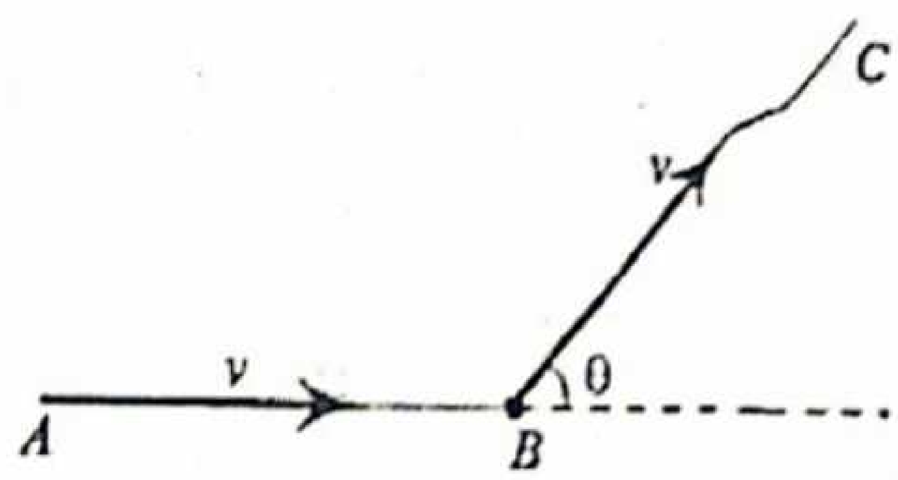
Latice scattering

Relaxation time (τ_r):

From the instant of sudden disappearance of an electric field across a metal, the average velocity of the conduction electrons decays exponentially to zero, and the time required in this process for the average velocity to reduce to (1/e) times its value is known as Relaxation time. The relaxation time τ_r and mean collision time τ are related as,

$$\tau_r = \frac{\tau}{1 - \langle \cos\theta \rangle}$$

For isotropic scattering or symmetrical scattering $\langle\cos\theta\rangle = 0$ Then $\tau_r = \tau$



LATTICE SCATTERING

Mean collision time (τ): The average time that elapses between two consecutive collisions of an electron with the lattice points is called mean collision time.

$$\tau = \lambda/v$$

where 'λ' is the mean free path, $v \approx v_{th}$ is velocity same as combined effect of thermal & drift velocities.