CONDUCTOR & SEMI – CONDUCTOR

The electrons in the outermost orbitals of the atoms, which constitute the solid, determine its electrical properties. The electron theory of solids aims to explain the structures and properties of solids through their electronic structure. The electron theory is applicable to all solids both metals & non – metals. It explains the electrical, thermal and magnetic properties of solids etc. The theory has been developed in three main stages.

i) The classical free electron theory

ii) The Quantum free electron theory

iii) the zone theory

The classical free electron theory was developed by Drude & Lorentz in 1900. According to this theory, the metals containing free electrons obey the laws of classical mechanics.

Sommerfeld developed the Quantum free electron theory during 1928. According to this theory, free electrons obey quantum laws.

The zone theory was stated by Bloch in 1928. According to this theory, the free electrons move in periodic field provided by the lattice. This theory is also called 'Band theory of solids'.

Important Definitions :

Mean free path :

The average distance travelled by an electron between two successive collisions insid e a metal in the presence of applied field is known as mean free path.

Ekectron – lattice scattering :

When the electrons move in crystal lattice, they collide with positive ions in the lattice loose their momentum and energy. Again they are accelerated by the applied field and collide with ions and so on. This process of electron scattering is called electron – lattice scattering.

Relaxation Time:

Relaxation time can be defined as the time taken for the drift velocity of electron to decay to 1/e of its initial value.

Drift velocity of electrons:

When electrons move in a crystal lattice, they collide with positive ions in the lattice and look their momentum, Again, they are accelerated by the applied field and collide with ions and so on. The average velocity acquired by an electron after steady state is reached in the presence of an electric field is called drift velocity of electrons.

Mobility of electrons:

In addition to thermal motion, electrons drift due to the applied field. The magnitude of the drift velocity per unit field is defined as the mobility of electrons.

i.e., $\mu = \frac{V_d}{E}$

Electrical conductivity:

Electrical conductivity is defined as the current density per unit electric field. In terms of electron mobility μ, electrical conductivity.

σ = ne μ

Fermi – Dirac distribution function :

The probability F (E) of an electron occupying an energy level E is given by Fermi – Dirac distribution function.

$$F(E) = \frac{1}{1+\exp\left(\frac{E-E_F}{kT}\right)}$$

Where E_F is called Fermi energy.

The probability F (E) of an electron occupying an energy level E is given by

F (E)

In metals, at 0 K

if $E < E_F$, all levels are filled with electrons i.e. F(E) = 1

if $E > E_F$, all levels are empty.

i.e. F (E) = 0

If T > 0 k, at E_F, F (E) = $\frac{1}{2}$

Fermi level :

The Fermi – level is that state at which the probability of electron occupation is 1/2 at any temperature above 0 K and also it is the level of maximum energy of the filled states at 0 k.

Fermi Energy :

Fermi energy is the energy of the state at which the probability of electron occupation is 1/2 at any temperature above 0 K. It is also the maximum energy of filled states at 0 K.

The main difference between classical free electron theory and band theory.

According to classical free electron theory, electron move inside constant field where as according to band theory they move inside periodically varying lattice field.

Effective mass of electron.

When an electron in a periodic potential of lattice is accelerated by an electric or magnetic field, then the mass of electron is called effective mass of electron (m*). If there is a strong binding force between the electron and the lattice, it will be difficult for the electrons to move. This means that the electron has acquired a large effective mass.

Concept the hole. :

When an electron moves in a periodic potential of lattice beyond the inflexion point K acceleration is negative. In this region the lattice exerts a large retarding force on electron. This means that in this region of K the electron behaves as a positively charged particle referred to as a hole.

Intrinsic semiconductors ;

Intrinsic semiconductors are those material having an energy gap of the order of 1 ev. Charge carriers are generated due to breaking of covalent bonds. Ge and Si are some examples of intrinsic semiconductors.

With increase of temperature the conductivity of semiconductor increases while that of metals decreases :

Reasons :

With increase of temperature more and more charge carriers are created and hence the conductivity of semiconductors increases. In case of metals with increase of temperature the concentration of charge carriers remains the same. But due to increase of thermal energy the electrons make frequent collisions with lattice ions and hence the resistivity increased and conductivity decreases.

Extrinsic semiconductors :

A semiconducting material in which the charge carriers originate from impurity atoms added to the material is called extrinsic semiconductor. The addition of impurity increases the carrier concentration and hence the conductivity of the conductor.

Examples : Phosphorus, arsenic or antimony (pentavalent impurity elements) added to either germanium or silicon gives n-types semi conductors while aluminium, gallium, or indium (trivalent impurity elements) added results in p – type semiconductors.

Electrical conductivity of an intrinsic semiconductor :

$\sigma = n_i e(\mu_e + \mu_h)$

where n_i = intrinsic carrier concentration

μ_e – mobility of electrons

μ_h – mobility of holes.

Electrical conductivity of an intrinsic semiconductor interms of forbidden energy gap :

$\sigma_i A \exp\left(\frac{-E_g}{2kT}\right)$

where A is a constant

Elemental semiconductors :

Pure semiconductor elements from fourth column are called elemental semiconductors, when doped with pentavalent or trivalent impurity elements, we get n-type or p-type entrinsic semiconductors. These intrinisic and extrinsic semiconductors are known as elemental semi-conductors.

Example : Silicon and Germanium

Compound semiconductors :

Semiconductors formed by combinations of equal atomic fractions of fifth and third column or sixth and second column elements are called compound semiconductors.

GaAs and InP are two examples of III – V compounds

MgO and CdS are two examples of II – VI compounds.

Hall effect :

When a piece of conductor (metal or semiconductor) carrying a current is placed in a transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both the current and the magnetic field. This phenomenon is known as Hall effect and the generated voltage is known as Hall voltage.

For an N-type semiconductor the Hall coefficient is negative whereas for a P-type semiconductor is positive. Thus from the direction of the Hall voltage developed, we can find out the type of semiconductor.

Applications of Hall effect :

1. Determination of type of semiconductor.
2. Measurement of carrier concentration.
3. Determination of mobility of charge carries.
4. Measurement of magnetic flux density using a semiconductor sample of known hall coefficient.