Unit-V

Semi Conductors and Super Conductors

Semi Conductors :- Introduction - Instrinsic Semi Conductors - Density of charge carriers - Electrical Conductivity - Fermi Level - Extrinsic semiconductors - Density of charge carriers - Dependence of Fermi energy on carrier concentration and temparature - Drift and diffusion currents - Einstein's Equation - Direct and Indirect Band gap semiconductors - Hall effect - Hall coefficient - Applications of Hall Effect.

Super Conductors :- Introduction - Properties of super conductors - Meissner effect - Type-I and Type-II semiconductors - BCS Theory - Josephson effect (AC and DC) - High T_c semiconductors - Applications of superconductors.

Semi Conductors

Semi Conductor :-

A substance which has resistivity in between conductors and insulators is known as semiconductor. semiconductors are classified into two categories.

(i) Intrinsic semi conductor - pure SC's

(ii) Extrinsic semi Conductor. - Impure SC. → P-type SC, n-type SC

Intrinsic Semi Conductor :-

Pure semi conductors are known as intrinsic semi-conductors.

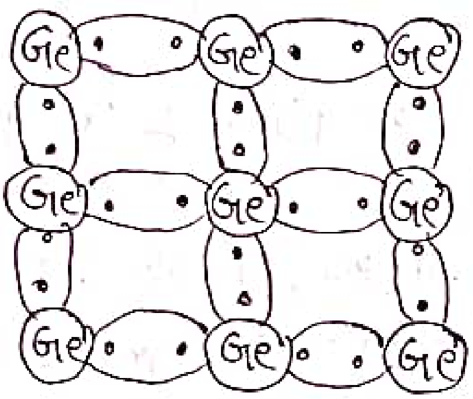
Ex :- Pure Ge, Pure Si.

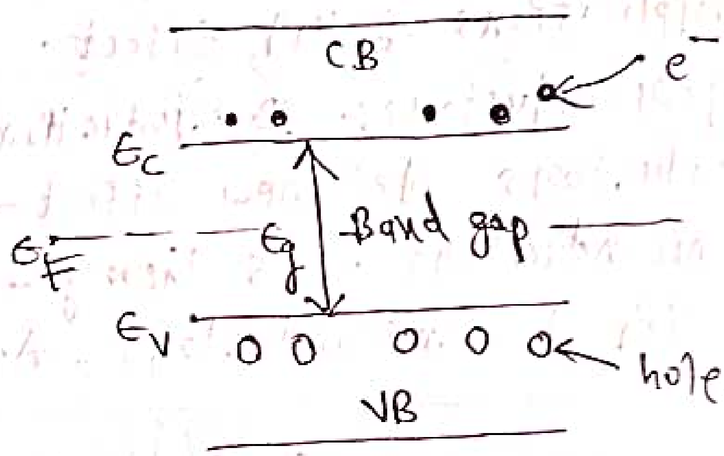
At low temperature all the valency electrons are bound to the atoms through covalent bonds.

At high temperature, thermal energy becomes comparable with the bond energy. Some of the covalent bonds will be broken and e^--hole pairs will be generated.

The e^- can occupy the CB and holes will be created in the VB.

Each broken covalent bond generates one e^- and hole pair. Thus the e^- and hole density in an intrinsic semi conductor will be equal.





Intrinsic Carrier Concentration:-

Let n be the number of electrons per unit volume (or) Electron-carrier concentration in the CB.

Let p be the number of holes per unit volume (or) Hole-carrier concentration in the VB.

For an intrinsic SC, $n = p = n_i$

where, n_i = Intrinsic Carrier Concentration.

Electron concentration in the CB is

$$n = N_c \, e^{-(E_C - E_F)/k_B T}$$

Hole concentration in the VB is $p = N_V e^{-(E_F - E_V)/k_B T}$

where, N_C, N_V are the pseudo-constants

k_B = Boltzman constant.

T = absolute temperature.

$$n_i^2 = np$$

$$n_i^2 = N_C e^{-(E_C - E_F)/k_B T} \times N_V e^{-(E_F - E_V)/k_B T}$$

$$n_i^2 = N_C . N_V . e^{(-E_C + \cancel{E_F} - \cancel{E_F} + E_V)/k_B T}$$

$$n_i^2 = N_C . N_V . e^{-(E_C - E_V)/k_B T}$$

But $E_F = E_C - E_V \Rightarrow E_g = E_C - E_V$.

$$n_i^2 = N_C . N_V \, e^{-E_g/k_B T}$$

$$n_i = \sqrt{N_C N_V} \, e^{-E_g/2k_B T}$$

From the above relation, it is clear that

(i) The intrinsic carrier concentration is independent of the Fermi level.

(ii) The intrinsic carrier concentration is a function of the band gap (E_g).

(iii) n_i depends on the temperature (T).

Fermi Level :-

The Fermi level indicates that the probability of occupation of $\bar{e}$ in the energy levels VB and the CB.

For an intrinsic SC, hole and e^- concentrations are equal and it indicates that the probability of occupation of energy levels in CB and the VB are equal.

Thus, the Fermi level lies in the middle of the energy gap (E_g)

For an intrinsic SC, $n = p$.

$$N_C \cdot e^{-(E_C - E_F)/k_B T} = N_V \, e^{-(E_F - E_V)/k_B T}$$

$$\frac{N_V}{N_C} = \frac{e^{-E_C + E_F / k_B T}}{e^{-E_F + E_V / k_B T}}$$

$$\frac{N_V}{N_C} = e^{-E_C + E_F / k_B T} \times e^{(E_F - E_V)/k_B T}$$

$$\frac{N_V}{N_C} = e^{[2E_F - (E_C + E_V)]/k_B T}$$

Taking log on both sides,

$$\log\left(\frac{N_V}{N_C}\right) = \frac{2E_F - (E_V + E_C)}{k_B T}$$

$$E_F = \frac{1}{2} k_B T \log\left(\frac{N_V}{N_C}\right) + \frac{E_C + E_V}{2}$$

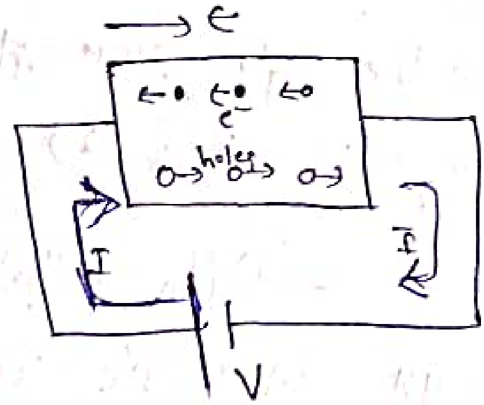
when, $N_V = N_C$ then,

$$E_F = \frac{E_C + E_V}{2}$$

$\log\left(\frac{\cancel{N_V}}{\cancel{N_C}}\right) = \log 1 = 0$

Thus the fermi energy level in an intrinsic SC lies in the middle (or) centre of the energy gap.

Intrinsic Conductivity :-



Consider an intrinsic semi conductor to which a potential difference (V) is applied.
It establishes an electric field and current will be generated.
The charge carriers are forced to drift in their respective directions. The drift velocity is given by

$$v_d = \mu E$$

where, μ = Mobility of the charge carriers.

Let n be the electron carrier concentration in the sc. Then, the current density due to an electron is given by

$$J_n = nev_d = ne\mu_n E.$$

lly, for hole, current density is given by

$$J_p = pe\mu_p E$$

where, p = Hole carrier concentration.
μ_p = Mobility of the hole.
μ_n = mobility of the e^-

Total current density, $J = J_n + J_p$

$$J = ne\mu_n E + pe\mu_p E$$

$$J = (n\mu_n + p\mu_p) e E \longrightarrow (1)$$

But, the total current density is $J = \sigma E \rightarrow (2)$

Comparing (1) & (2) we get

$$\sigma = (n\mu_n + p\mu_p)e$$

For an intrinsic semi conductor, $n = p = n_i$

$$\sigma = (\mu_n + \mu_p) n_i e$$

But $n_i = \sqrt{N_c N_v}\, e^{-E_g/2K_BT}$

$$\sigma = (\mu_n + \mu_p) e \cdot \sqrt{N_c N_v}\, e^{-E_g/2K_BT}$$

$$\sigma = A \cdot e^{-E_g/2K_BT} \longrightarrow (3)$$

where, $A = \sqrt{N_c N_v} \cdot e(\mu_n + \mu_p)$.

Determination of Energy Band Gap:-

Let E_g be the energy gap b/w VB and the CB.

from eqn (3), $\rho = \frac{1}{\sigma} = \frac{1}{A} \cdot e^{E_g/2K_BT} = B\, e^{E_g/2K_BT}$

where, $B = \frac{1}{A}$

$$\rho = B e^{E_g/2K_BT}$$

Taking log on both sides.

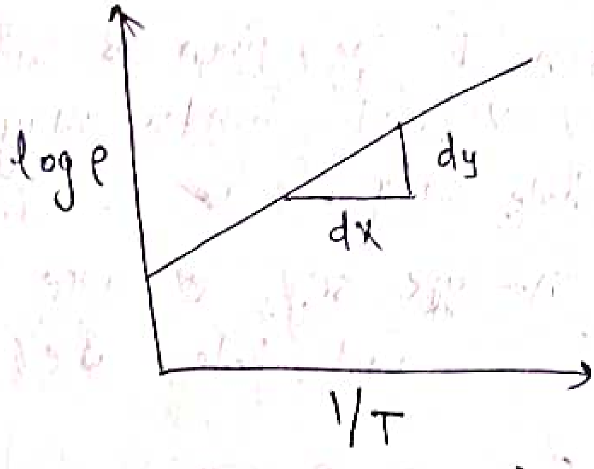
$$\log \rho = \log B + \frac{E_g}{2K_BT}$$

Now, plotting $\log \rho$ on y-axis and $\frac{1}{T}$ on x-axis we get a SL. The slope of the line gives the E_g of the SC.

from the figure,

$$\frac{E_g}{2K_B} = \frac{dy}{dx}$$

$$\boxed{E_g = 2K_B \cdot \frac{dy}{dx}}$$



Extrinsic Semi Conductor:-

Impure semi conductors are known as extrinsic semiconductors

(or)

When impurities are added to an intrinsic semi conductors then it becomes an extrinsic semiconductor.

Depending upon the type of impurity extrinsic SC are two types.

(i) n-type extrinsic SC

(ii) P-type extrinsic SC.

n-type extrinsic SC:-

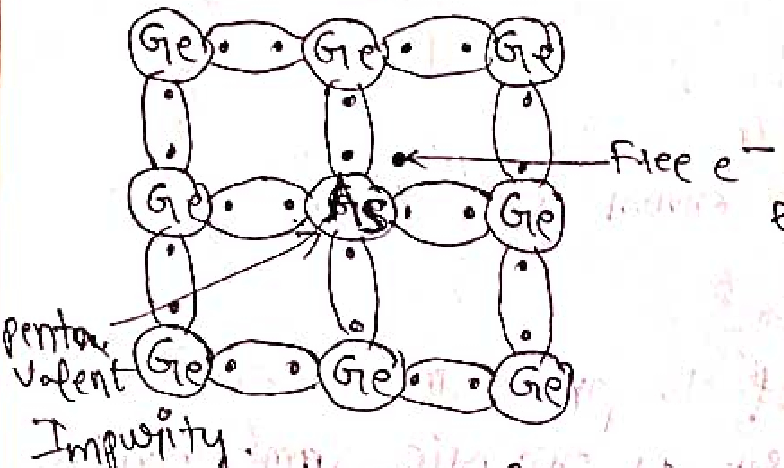
When pentavalent impurities are added to an intrinsic semiconductor, then n-type SC are formed.

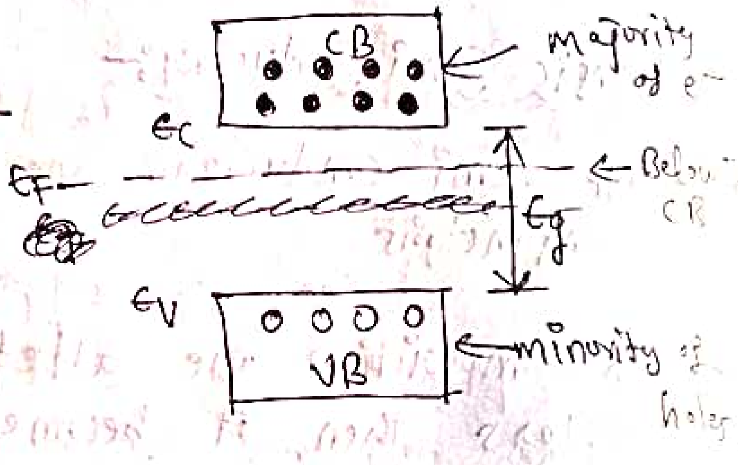
When pentavalent impurities such as P, As, Sb, Bi are added to the pure Ge (or) Si atoms then form 4 covalent bonds with neighbouring Ge atoms. The 5th e^- is free. Here, the impurity Si atom donating a free e^- so these atoms are called donor atoms.

At room temperature, donor level is so close to ~~CB~~. the bottom of the CB.

When 'T' is given to that ~~n-type~~-SC, breaking of covalent bonds may occur which will generate e^--hole pair.

In n-type SC, e^- are majority charge carriers and holes are minority charge carriers.





at T > 0 K.

P-type extrinsic SC:-

When trivalent impurities are added to an intrinsic SC, then p-type SC are formed.

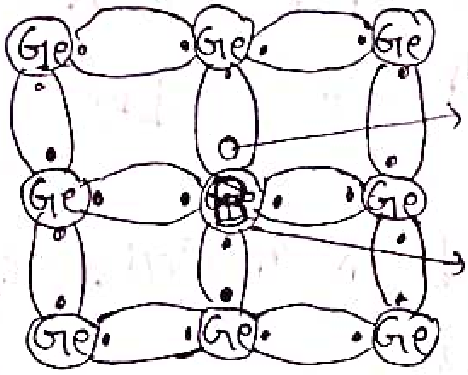
When trivalent impurities such as B, Al, Ga, In are added to the pure Ge or Si atoms then form 3 covalent bonds with neighboring Ge atom.

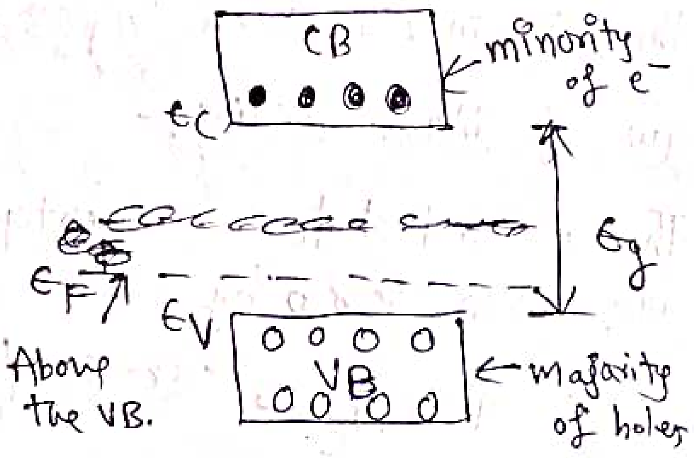
The impurity atom Ge will need one more electron to complete its bond. The hole will be created.

Since, impurity atom accepts one extra electron. So it is called acceptor impurity energy level.

When 'T' is given to that SC, breaking of covalent bonds may occur which will generate e^--hole pair.

In p-type SC, holes are majority charges carriers and e^- are minority charge carriers.





Fermi Level:-

For an n-type SC, the Fermi energy is

$$\epsilon_F = \epsilon_c - K_B T \log\left(\frac{N_c}{N_D}\right)$$

where, N_D = Concentration of donor atoms

It is clear that for n-type SC, Fermi level lies below the CB.

For a p-type SC, the Fermi level is

$$E_F = E_V + K_B T \log\left(\frac{N_V}{N_A}\right).$$

where, N_A = Concentration of acceptor atoms.

It is clear that for p-type SC, Fermi level lies above the VB.

Effect of 'T' on E_F (Fermi Energy Level):-

In n-type SC, as 'T' increases, more number of e^- hole pairs are formed.

At very high 'T', the concentration of the e^- in the CB will be greater than the concentration of the e^- in the VB.

When 'T' increases, In n-type and P-type sc's the E_F moves close to CB and VB respectively.

Law of Mass Action:-

The $\bar{e}$ and hole concentrations of an intrinsic sc are given by

$$n = N_c \, e^{-(E_c - E_F)/k_BT}$$

$$p = N_v \, e^{-(E_F - E_v)/k_BT}$$

As, $n = p = n_i$

$$n_i = \sqrt{N_c N_v} \; e^{-E_g/2k_BT}$$

The above relation shows that, for any arbitary value of E_F, the product of n and p is constant. This is known as law of mass action.

The $\bar{e}$ and hole concentrations of an extrinsic sc are given by

for n-type sc,
$$n_n = N_c \, e^{-(E_c - E_F)/k_BT}$$
$$p_n = N_v \, e^{-(E_F - E_v)/k_BT}$$

$$n_n \cdot p_n = N_c \cdot N_v \cdot e^{-E_g/2k_BT}$$

$$\therefore n_n p_n = n_i^2 \longrightarrow (1)$$

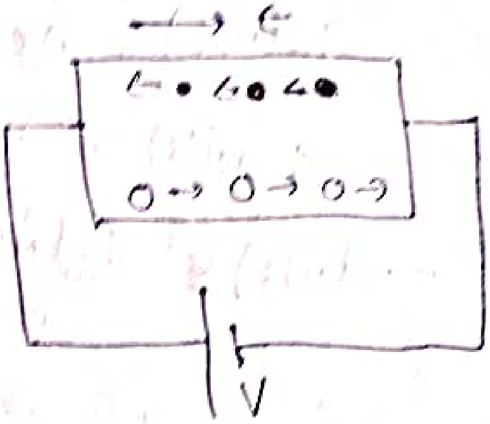
lly for p-type sc, $\therefore p_p n_p = n_i^2 \rightarrow (2)$

from (1) & (2), $n_i^2 = n_n p_n = n_p p_p$

The above reln shows that, the product of majority and minority charge carriers concentrations in an extrinsic SC at particular 'T' is equal to the square of intrinsic carrier concentration at that 'T'

Drift and Diffusion Currents:-

Drift:-



Under the influence of an external electric field the charge carriers are forced to move in a particular direction. This phenomena is known as drift.

Let 'n' be the number of e^- in a SC.
E be the electric field and V_d be the drift velocity.

Then the current density, $J = ne V_d$

$$\sigma = \text{Conductivity} = \frac{J}{E} = \frac{neV_d}{E} \qquad J = \sigma E$$

The drift velocity is also given by, $V_d = \mu_n E$

Now, $J = ne\mu_n E$

$$\sigma = \frac{J}{E} = \frac{ne\mu_n \cancel{E}}{\cancel{E}} = ne\mu_n.$$

In case of a SC, the drift current density due to the e^- is $J_n(\text{drift}) = ne\mu_n E$

The drift current density due to hole is
$J_p(\text{drift}) = pe\mu_p E$.

Total drift current density,

$$J(\text{drift}) = J_n(\text{drift}) + J_p(\text{drift})$$

$$J(\text{drift}) = ne\mu_n E + pe\mu_p E$$

$$J(\text{drift}) = (n\mu_n + p\mu_p)eE$$

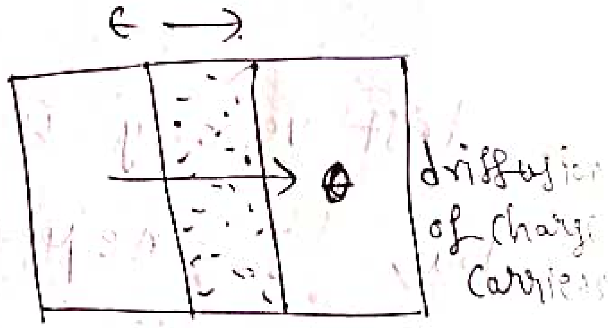
$$\sigma(\text{drift}) = \frac{J(\text{drift})}{E} = \frac{(n\mu_n + p\mu_p)e\cancel{E}}{\cancel{E}} = e(n\mu_n + p\mu_p)$$

For an intrinsic SC, $n = p = n_i$ then

$$\sigma_i(\text{drift}) = n_i e(\mu_n + \mu_p)$$

Diffusion:-

Due to non-uniform carrier concentration, the charge carriers moves from a region of higher concentration to a region of lower concentration. This process is known as diffusion of charge carriers.



Let Δn be the excess e^- concentration.

A/c to Fick's law,

The rate of diffusion of $e^- \propto -\frac{\partial}{\partial x}(\Delta n)$

$$= -D_n \frac{\partial}{\partial x}(\Delta n)$$

where, D_n = Diffusion coefficient of electrons.

The diffusion current density due to electrons is given by $J_n(\text{diffusion}) = -e\left(-D_n \frac{\partial}{\partial x}(\Delta n)\right)$

$$J_n(\text{diffusion}) = e D_n \frac{\partial}{\partial x}(\Delta n)$$

The diffusion current density due to hole is given by

$$J_p(\text{diffusion}) = e\left[-D_p \frac{\partial}{\partial x}(\Delta p)\right] = -e D_p \frac{\partial}{\partial x}(\Delta p)$$

where, Δp be the excess hole concentration.

Total ~~diffusion~~ current density, for electrons

$$\cancel{J_n(\text{diffusion}) = J_n(\text{drift}) + J_n(\text{diffusion})}$$

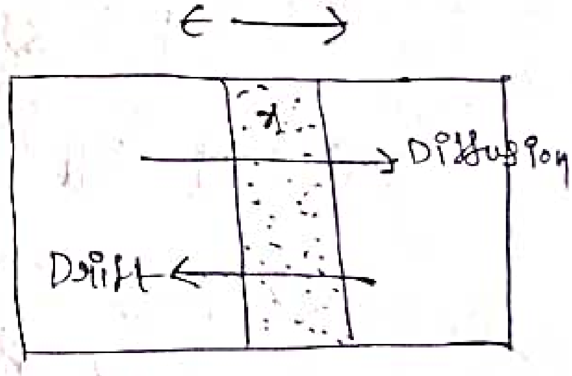
$$\cancel{J(\text{diffusion})} \Rightarrow J_n = J_n(\text{drift}) + J_n(\text{diffusion})$$

$$J_n = ne\mu_n \epsilon + e D_n \frac{\partial}{\partial x}(\Delta n)$$

lly for holes, total current density is

$$J_p = pe\mu_p \epsilon - e D_p \frac{\partial}{\partial x}(\Delta p)$$

Einstein's Relation:-



The relation b/w mobility μ and the diffusion coefficient D of the charge carriers in a SC is known as Einstein's Relation.

At equilibrium with no applied electric field, if the charge distribution uniform, there is no net current flow.

Any disturbance in equilibrium state leads to diffusion current, which creates an internal electric field.

This field causes the drifting of charge carriers resulting in a drift current.

Let Δn be the excess electron concentration of a sc.
At equilibrium condition, the drift and diffusion current densities are equal due to excess electrons.

i.e, drift current density = diffusion current density

$$(\Delta n) e \cdot \mu_n E = e D_n \frac{\partial}{\partial x}(\Delta n) \longrightarrow ①$$

The force on excess electrons is equal to the product of excess charge and electric field.

i.e, $F = (\Delta n) e E$.

from eq ①,
$$F = \frac{e D_n \frac{\partial}{\partial x}(\Delta n)}{\mu_n} \longrightarrow ②$$

From Kinetic theory of gases, the force on gas molecule is given by

$$F = K_B T \frac{\partial}{\partial x}(\Delta n) \longrightarrow ③$$

Comparing eq ② & ③, we get

$$K_B T = \frac{e D_n}{\mu_n}$$

$$\frac{D_n}{\mu_n} = \frac{K_B T}{e} \longrightarrow ④$$

lly for holes, $\frac{D_p}{\mu_p} = \frac{K_B T}{e} \longrightarrow ⑤$

from eq's ④ & ⑤ we get

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p}$$

$$\therefore \frac{D_n}{D_p} = \frac{\mu_n}{\mu_p}$$

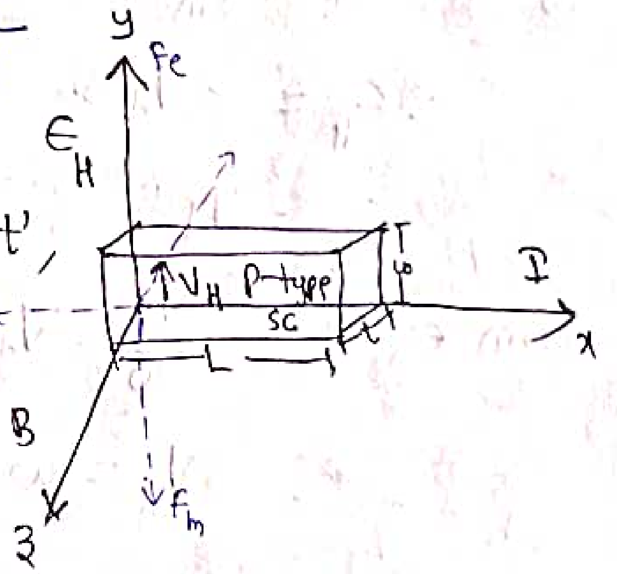
∴ This eq is known as Einstein relation.

Hall Effect:-

If a SC carrying current is placed in a magnetic field with the direction of field ⊥ to the direction of current, then a potential difference is developed across the SC in a direction ⊥ to both current and magnetic field. This phenomenon is called "Hall Effect" and the potential developed is called "Hall Potential (V_H)".

Expression for Hall Potential (V_H):-

Consider a P-type SC of length L, width w, and thickness 't' and carrying current 'I' along x-direction as shown in the figure.



Let 'B' be the magnetic field applied ⊥ to the directions of current along z-direction.

Due to the magnetic field the holes experiences a magnetic force, $F_m = eV_dB \longrightarrow (1)$

where, V_d = drift velocity

A/c to Fleming's left hand rule, the direction of this magnetic force is downwards. (along -ve -y-axis).

An electric potential called Hall potential (V_H). is developed across the SC in the upward direction (+ve, y-axis).

The Hall potential gives an electric field called "Hall field".

$$E_H = \frac{V_H}{w} \longrightarrow (2)$$

Due to this field the holes experiences an electric force, $F_e = eE_H \longrightarrow (3)$

The direction of this electric force is upwards (+ve, y-axis)

At equilibrium condition,

$$F_e = F_m$$

$$\cancel{e} E_H = \cancel{e} V_d B.$$

$$E_H = V_d B$$

from eq (2), $\frac{V_H}{w} = V_d B$

$$V_H = w V_d B \longrightarrow (4)$$

we know current density, $J = peV_d \rightarrow (5)$, for hole

current density is also given by, $J = \frac{I}{A} = \frac{I}{wt} \rightarrow (6)$

where, A = area of cross section

from eq's (5) & (6).

$$\frac{I}{wt} = peV_d \Rightarrow V_d = \frac{I}{pewt} \longrightarrow (7)$$

from eq's ④ & ⑦.

$$V_H = \cancel{w} \cdot \frac{I}{pe\cancel{w}t} B$$

$$V_H = \frac{IB}{pet} \rightarrow ⑧$$

Eq-8 is expression for Hall potential.

$$p = \frac{IB}{V_H et} \rightarrow ⑨$$

Using above expression the concentration of holes (or) (the concentration of free e^-) can be determined.

<u>Hall Coefficient (R_H):-</u>

It is defined as the Hall field per unit current density per unit magnetic induction.

$$R_H = \frac{\epsilon_H}{J \cdot B}$$

we know, $\epsilon_H = \frac{V_H}{w}$, $J = \frac{I}{wt}$

Now, $R_H = \dfrac{\frac{V_H}{w}}{\frac{I}{wt} B} \Rightarrow R_H = \frac{V_H}{\cancel{w}} \times \frac{\cancel{w}t}{IB}$

$$R_H = \frac{V_H t}{IB}$$

we now, $V_H = \frac{IB}{pet}$

$$R_H = \frac{\frac{IB}{pet} \cdot t}{IB} \Rightarrow R_H = \frac{\cancel{IB}\cancel{t}}{pe\cancel{t}\cancel{IB}} \Rightarrow R_H = \frac{1}{pe} \rightarrow ⑩$$

To find mobility (μ_p or μ_n) of holes or electrons:-

The cunductivity 'σ' is given by

$$\sigma = pe\mu_p$$

$$\mu_p = \frac{\sigma}{pe}$$

we know, $R_H = \frac{1}{pe}$ then $\mu_p = \sigma R_H$

$$\text{Ily, } \mu_n = \sigma R_H \longrightarrow (10)$$

Applications of Hall effect:-

(i) To determine the nature of SC. (whether p-type or n-type).

If V_H is +ve $\Rightarrow$ p-type SC

If V_H is -ve $\Rightarrow$ n-type SC.

(ii) To determine the concentration of charge carriers.

$$p = \frac{IB}{V_H et} \quad , \quad n = \frac{IB}{V_H et}$$

(iii) To determine the mobility of holes or electrons.

$$\mu_p = \sigma R_H \quad , \quad \mu_n = \sigma R_H$$

(iv) Strong magnetic field can be measured by Hall Effect.

(v) Hall effect quite helpful in understanding the electrical conduction in metals and SC.

Super Conductors

Super Conductors:-

The electrical resistivity of many metals and alloys drops suddenly to zero, when the materials are cooled to a sufficient low temparature called critical / transition temparature. This phenomenon is known as super conductivity.

Super conductivity was first observed in 1911 by Dutch physicist, H.K. Onnes of his experiment on measuring the electrical conductivity of metals at low temparature.

Transition / Critical Temparature:-

The 'T' at which the normal conductor loses its resistivity and becomes a super conductor is known as transition temparature.

Properties of Super Conductors:-

(i) Super Conductivity is a low temparature phenomenon.

(ii) Electrical resistance is zero. But, It can conduct the current even in the absence of an applied voltage.

(iii) The critical / Transition temparature (T_c) value of a super conductor is found to vary with its isotopic mass of single superconductor.

$$T_c \propto \frac{1}{\sqrt{M}}$$

(iv) Super conducting substance is not disappearing even by adding impurities.

(v). If strong magnetic field is applied to a superconductors below its T_c, the super conductors undergoes a transition from super conducting state to normal state.

(vi) Transition metals having odd number of valency electrons are favourable to superconductivity.

(vii) Metals having even number of valency electrons are not favourable to superconductivity.

(viii). Certain materials exhibits superconductivity on increasing the pressure in superconductors, the increase in the stress results in increase of the T_c value.

Critical Magnetic Field (H_c):-

The minimum magnetic field is required to destroy the superconducting state is called the critical magnetic field (H_c).

$$H_c = H_0 \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

Important Factors to define a Superconducting state:-

The superconducting state is defined by three very important factors.

(i) Critical Temparature (T_c).
(ii) Critical Field (H_c).
(iii) Critical current (I_c).

Meissner Effect:-

When a weak magnetic field is applied to a superconducting material at a temparature below transition temparature (T_c), the magnetic flux lines are expelled. The material acts as an ideal diamagnet. This effect is called Meissner Effect.

This effect is reversible. Under this condition, the magnetic induction inside the specimen/material is given by

$$B = \mu_0 (H + M)$$

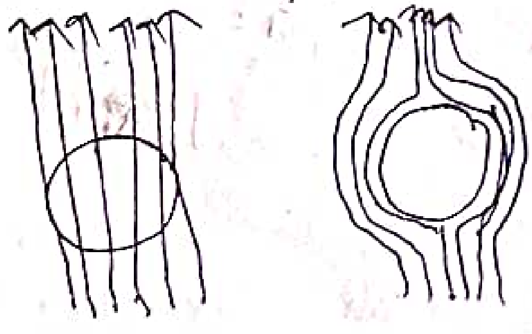
where, H = External applied magnetic field.

M = Magnetization.

When the material is superconducting a/c to Meissner effect, inside the bulk, $B = 0$.

Hence, $0 = \mu_0 (H + M)$

$$M = -H$$



$T > T_c$

$T < T_c$

Meissner effect

Thus, the material is perfectly diamagnetic.

Magnetic Susceptibility $= \chi = \frac{M}{H} = \frac{-\cancel{H}}{\cancel{H}} = -1$

London Penetration depth:-

Consider a super conductor for which a magnetic field (H_0) is applied.

To obey, Meissner effect, it will not allow magnetic lines to pass through it.

In practice, a small portion of H_0 penetrates to a small distance into the super conductor.

The penetrating field at a distance 'x' is given by,

$$H = H_0 e^{-x\lambda}$$

where, λ = Penetrating depth.

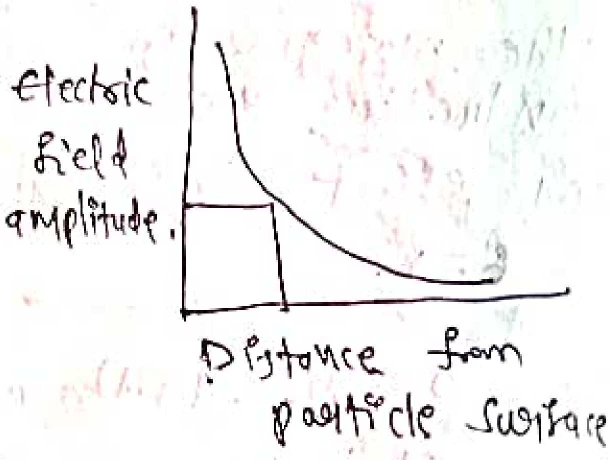
When, $x = \lambda$, then $H = H_0 e^{-\lambda^2}$.

The λ is the distance inside the super conductor at which the penetrating magnetic field is equal to times the applied magnetic field H_0.

λ Ranges from 10 nm to 100 nm.

The variation of λ with temperature 'T' is given by

$$\lambda = \frac{\lambda_0}{\sqrt{\left(1-\frac{T}{T_c}\right)^4}}$$



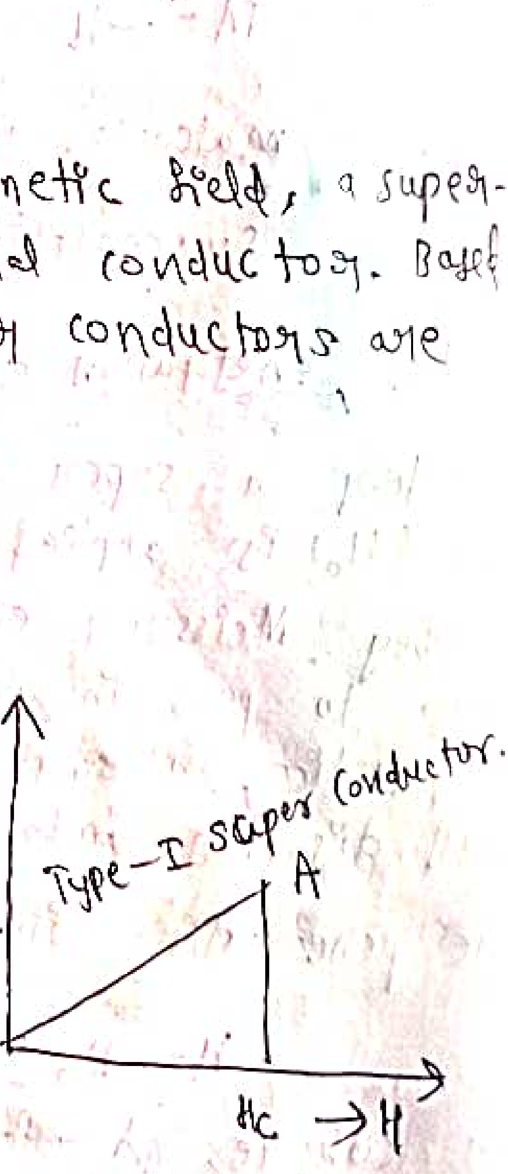
Types of Super Conductor:-

In the presence of critical magnetic field, a super-conductor converts into a normal conductor. Based on the conversion process, super conductors are classified into two types.

(i) Type-I super Conductor.
(ii) Type-II Super Conductor.

Type-I Super Conductor:-

Consider a cylindrical super conductor to which a magnetic field 'H' is applied along the x-direction. It will not allow the magnetic lines and obeys Meissner effect.



Inside the super conductor, the magnetization acting opposite to magnetic field (H).

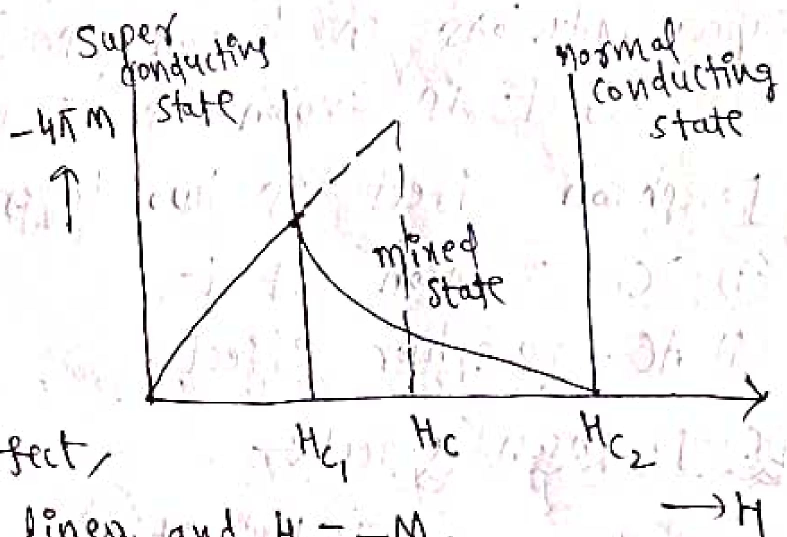
When the magnetic field is equal to the critical field, then immediately, M becomes zero and converts into normal conductor.

i.e, $H = H_c$ then $M = 0$.

This conversion is fast and is known as Type-I super conductor. It is also known as soft super conductor.

Ex:- Sn, Hg, Nb, V, etc.

Type-II Super Conductor:-



Consider a sphericle super conductor to which a magnetic field is applied along the x-axis.

As per the Meissner effect, it allows the magnetic lines and $H = -M$.

In H_{c_1} (lower critical field), it behaves as a super conductor.

when the magnetic field is exceeds H_{c_1}, Then the penetration starts. As a result (-M) values decreases and the penetrated portion loses superconductivity and becomes a normal conductor.

This conversion is completed at H_{c_2}.

H_c is the mixed state of ~~super conducting~~ b/w H_{c_1} and H_{c_2}.

After H_{c_2} it is converted in to normal conductor.

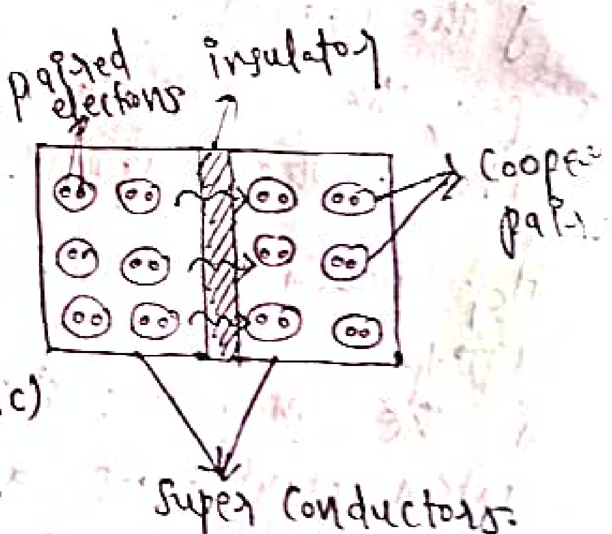
This conversion is slow, and is known as Type-II super conductor. It is also known as hard super conductor.

Ex:- Nb_3, Sn, Nb_3Ge, etc

Josephson Effect:-

Consider two super conductors which are joined togeth with the help of a thin insulating layer.
These super conductors consist of paired electrons kn as cooper pairs in the super conducting state.
These cooper pairs will try to penetrate through the thin insulator and constitute a small super current.
The insulator which forms the junctions b/w super conductors is known as Josephson junction and this effect is known as Josephson effect.
Josephson effect is two types
(i) DC - Josephson effect
(ii) AC - Josephson effect.

DC-Josephson effect:-



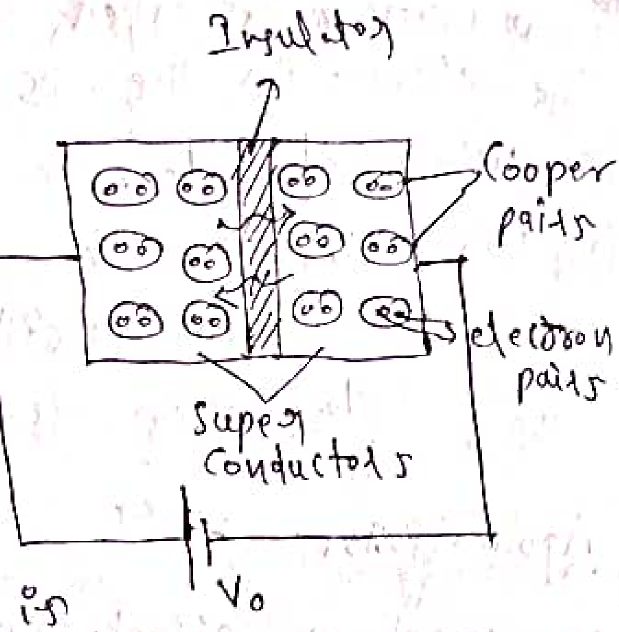
Without any applied voltage across the junction due to tunneling of cooper pairs, a small direct super current (dc) will flows across the junction.
This is known as DC-Josephson effect.

The propagation of cooper pair be in the form of wav
The phase difference b/w the two parts of the waves on either side of the junctions in terms of wave function is. $\phi_0 = \phi_2 - \phi_1$.

The tunneling current is given by, $I = I_0 \sin\phi_0$.

where, I_0 = Maximum current.

AC - Josephson Effect:-



When a potential V_0 is applied across the junction then the cooper pairs start oscillating through the insulating layer. As a result, an (ac) current flows through the junction. This effect is known as AC- Josephson effect.

Due to Vo, an additional phase difference of $\Delta\phi = \epsilon \frac{t}{h}$ is introduced for the cooper pairs.

where, ϵ = Energy of the cooper pairs

$$\epsilon = 2eV_0.$$

$$\Delta\phi = \frac{2eV_0 t}{h}.$$

The tunneling current is given by,

$$I = I_0 \sin \phi_0 + \Delta\phi$$

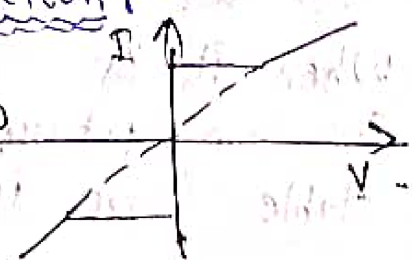
$$I = I_0 \sin \phi_0 + \frac{2eV_0 t}{h}$$

$$\omega = \frac{2eV_0}{h}$$

$$I = I_0 \sin \phi_0 + \omega t$$

where, ω = Angular frequency.

V-I characteristics of Josephson junction:-



(i) When $V_0 = 0$, there is a constant flow of DC - current (I_c) through the junction.

this current is called super conducting current and the effect is the DC- Josephson effect.

(ii) when, $V_0 < V_c$, a constant DC- current (I_c) flows

(iii) when $V_0 > V_c$, the junction has finite resistance and the current oscillates with a frequency, of $\omega = \frac{2eV_0}{h}$. This effect is the AC- Josephson effect.

Applications:-

(i) Josephson effect is used to generate microwaves with frequency, $\omega = \frac{2eV_0}{h}$.

(ii) The AC- Josephson effect is used to define/standard voltage.

(iii) Josephson effect is used to switching of signals from one circuit to another.

BCS Theory:-

Bardeen, Cooper and Schrieffer proposed a microscopic theory known as BCS theory.

It explains the super conducting state of a super condu-

This theory involves the electron interactions through phonon as mediators.

In normal conductor, the e^- will be moving randomly. when they are vibrated the repulsive force predominant than the attractive force. As a result they get scattered and resistance comes into existence.

when it is converted into super conductor by decreasing its temparature below the critical 'T' and to maintain stable state the e^- get paired up are known as cooper

The electrons are travelling in a solid and interact with lattice vibration by electrostatic forces b/w them. This interaction is called e^--phonon interaction, which leads to scattering of e^- and cause a change in the electrical resistivity.

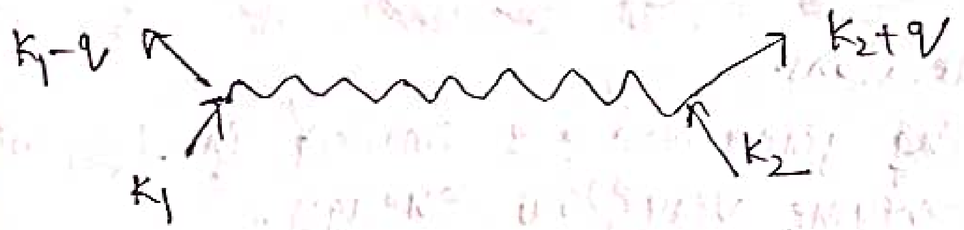
The resistivity is sensitive with T, since the number of phonons increases with 'T'.

From the BCS theory, the e^--phonon interaction produces an attractive interaction b/w two electrons.

The BCS theory is also known as $e^- - e^-$ interaction (or) e^--phonon interaction.

For attractive interaction, the wave vector and spin are represented as $K\uparrow$ and $K\downarrow$.

The two e^- interacting attractively in the phonon field are called cooper pairs.



High T_c Superconductors:-

For most of the super conductors, super conductivity occurs only at low critical temparatures (T_c) values. For attaining low 'T' we should use liq. He, which is costly process.

In attaining the superconductivity at high temparature, (or) To discover high 'T' super conductors scientists made the following steps.

(i) Super conductivity was discovered on a thin film of niobium and germanium at 23.2K.
(Nb). (Ge).

(ii) Compound form of $Ba-PbBi-O_3$ was found to be super conductor at 38K.

(iii) Oxide compound form of $Y_1Ba_2Cu_3O_7$ (123 Super Conductor) was found to be super conductor at 92K.

(iv) Oxide compound form of $Bi-Sr-Ca-Cu-O$ was found to be super conductor at 115K.

(v) The form $Ti-Ba-Ca-Cu-O$ was found to be super conductor at 125K.

Properties:-

(i) They are highly anisotropic.
(ii) They have the presence of CuO_3 layers.
(iii) They have inherent metallic properties.

Applications of Super Conductors:-

(i) Electric Generators
Super conducting generators are smaller in size, with less weight, consume very low energy.

(ii) Magnetic Levitation.
This is used for high speed transportation.

(iii) Transformers & Low loss transmission lines.
Super conducting wires are used as electric cables the transmission losses are minimized.
Super conductors are used for winding of transformers, the power losses will be very small.

(iv) Generation of high magnetic fields.

Super conducting materials are used for producing high magnetic fields.

(v) Fast electrical switching.

when the magnetic field > ~~critical field~~ (Hc), changes the super conducting state to normal state.

(vi) Logic and storage functions in computers.

The C-V characterstics of Josephson effect is used for memory elements in computers.

(vii) SQUIDS – Super Conducting Quantum Interface Devices.

Two Josephson junctions mounted on a superconducting ring form SQUID. These are used to study tiny magnetic signals from the brain and heart

(viii) Super Conducting magnets.

Super conducting magnets consists of coils of wires made up of super conductors. These coils are used in electric machines, transformers.

Wave Optics

① Interference:-

when two (or) more light waves are super imposed in the medium then a/c to super position principle, the resultant displacement at any point is equal to the algebraic sum of the displacements of the individual waves.
The resultant displacement of the resultant wave is given by $y = y_1 + y_2$.
The variation in the resultant displacement influences amplitude variation, which causes intensity variation. This modification in the distribution of intensity in the region of super position is known as "Interference".

② Constructive Interference:-

The resultant amplitude is equal to the sum of the amplitudes of the two light waves is called constructive interference. $y = y_1 + y_2$

③ Distructive Interference:-

The resultant amplitude is equal to the difference of the amplitudes of the two light waves is called distructive interference. $y = y_1 - y_2$.

④ Coherence:-

If the two light waves are said to be coherent they have same frequency and wavelength. The process of maintaining constant phase relation is known as coherence.

⑤ Temparal Coherence:-

It is possible to predict the phase relation at a point on the wave w r to another point on the same wave. It is known as temparal coherence.