Semi Conductors :-

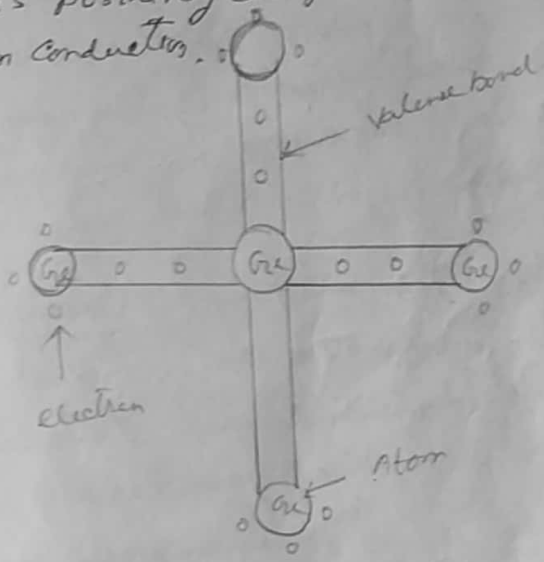
A Semi Conductor is a material which is neither a good conductor of electricity nor a good insulator. Its conductivity lies midway between a conductor and an insulator. The resistivity of Semi Conductors varies from 10^{-5} to 10^{-4} ohm m as compared to the values ranging from 10^{-8} to 10^{-6} ohm m for conductor and 10^{8} to 10^{8} ohm m for insulator. Example of such substances are the crystalline forms of the fourth group of the periodic table. Germanium (Ge) and Silicon are two very typical substances showing this behaviour. In addition there are certain compound Semi Conductors such as gallium arsenide (GaAs), Indium phosphide (InP), Cadmium Sulphide (CdS) etc. which are formed from the combination of group (III) and (V) or group (II) and (VI).

The band gap of Semi Conductors varies from 0.2 to 2.5 eV which is quite small as compared to that of insulators. For example the band gap of diamond (insulator) is 6 eV. The valence band and conduction band of metals may even overlap.

Intrinsic Semi Conductor :- The intrinsic Semi Conductors like Si and Ge are pure Semi Conductors. The electrical conductivity of an intrinsic Semi Conductors is ~~solely~~ determined by thermally generated charge carriers, as ~~explained below~~.

A Semi Conductor which is pure element (pure Germanium or Silicon) is called intrinsic Semi Conductor.

There are four valence electrons in the outer most orbit of an atom of Germanium (or silicon). The four valence electrons of each atom of ~~other~~ Germanium are shared with nearest four valence electrons of another atom and formed a covalent bond. The free electrons are not available at absolute zero for conduction due to this configuration. Hence the semiconductor behaves as an insulator at this temperature. When heat energy is supplied to it, some valence bonds break up ~~and~~ electrons become free to move randomly. When an electron leaves the valence bond, an empty space is created. This empty space is called hole. The hole is positively charged. Both the hole and electron take part in conduction.



Extrinsic Semi Conductor:- The intrinsic semi conductors are not of much use due to their small and fixed conductivity. The conductivity of a semi conductor can be considerably improved by adding a small amount of impurity. Such semi-conductors are known as impurity semi-conductor or extrinsic semiconductor or doped semiconductor. As the intrinsic semiconductors are generally elements of group (IV) i.e they have 4 electrons in the outermost electronic orbit, the impurity element chosen as 5 electrons in the outermost orbit, group (V) i.e one more than that required to completely fill the outer most shell of the outermost

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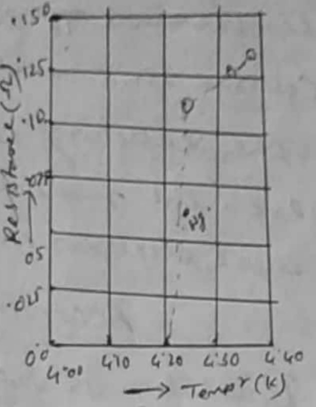
Super Conductivity

Shell of the intrinsic Semi Conductor.

The impurity atoms of group (V) are known as donor or n-Type and give rise to n-Type Semi Conductor. The impurity atoms of group (III) are known as acceptor or p-Type and give rise to p-type Semi Conductor.

SUPERCONDUCTIVITY

In 1911 Kamerlingh Onnes first observed the phenomena of superconductivity during his experiment on the electrical resistivity of many metals and alloys at sufficiently low temperature. The study of variation of resistance of mercury with Tempr is shown in the fig.



It was observed that the resistance falls sharply near 4.2 K and vanished completely below this temperature as shown in the fig. The resistance is small and finite above this Tempr, but below this Tempr it becoms zero. Hence the phenomenon in which the electrical resistivity of the material suddenly falls to nearly zero when it is cooled to a very low Tempr is known as superconductivity and the material under this condition is called superconductor.

Critical Temperature (T_c):— The Tempr at which the material undergoes a phase transition from a state of normal conductor to superconductor is known as critical Tempr. This is also called transition Tempr.

The superconductivity can be explained by free electron model as follows.

The resistivity of the ~~model~~ metal is given by

$$\rho = \frac{m}{ne^2\tau} \quad \text{——— (1)}$$

where m = mass of an electron

e = charge of an electron

n = number of electron per unit volume

and τ = Collision time.

As the temperature decreases, the vibration of the ions in a crystal decreases. Thus the ~~probability~~ probability of an electron-ion collision decreases or we can say that collision time τ increases. Hence it is clear from ① that ρ decreases as τ increases or Tempr decreases.

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From ① we can also say that ρ tends to zero if temp approaches zero. Thus the resistivity vanishes completely for infinite value of τ at sufficiently low temperature. When the temp of the specimen is below the critical temperature T_c the major part of electrons have infinite collision time and they become superconducting. The scattering is not possible for these electrons even the material may contain some impurities. Thus these electrons are the cause of superconductivity.

According to Onnes the conducting superconducting transition is reversible. If the superconducting specimen is heated, the normal resistivity at temp T_c is again obtained.

Occurrence of superconductivity :—

Superconductivity has been found in different metallic elements of the periodic system, alloys, intermetallic compounds and semiconductors. It is matter to notice that some best conductors like gold and copper etc are not superconductors while some materials which are semiconductors at normal temp become superconductors at sufficiently low temp.

Now-a-days the range of transition temp exceeds from 23.2 K for the alloy Nb_3Ge to 0.01 K for few semiconductors.

Characteristic properties of superconductivity :—

(i) persistent currents :— A current can be induced in a superconductor by electromagnetic induction when it has the form of ring. Now the ring is cooled in a magnetic field from temp above T_c to below this temp and after some time the field is removed. It was found that this

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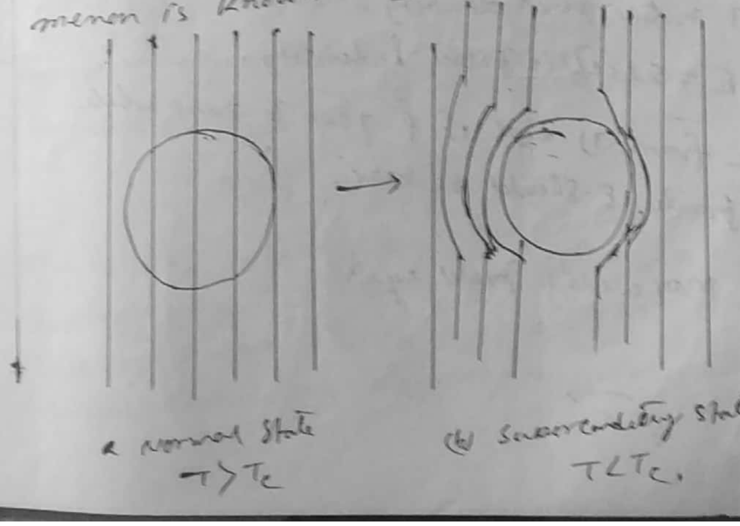
current continues to persist without attenuation in a superconducting rings for more than a year. This current is known as 'persistent current'. This current decays with time which is represented by the formula $I = I_0 e^{-\frac{R}{L}t}$ where R/L is called the time constant. When $R \to 0$, $\frac{L}{R}$ i.e time constant should be equal to infinity. Hence the current in a ring should flow for infinite period till the temper remains same. Due to this nature it is called persistent current.

① Effect of magnetic field:— When a magnetic field is applied across a superconductor, its superconductivity is destroyed. That a strong magnetic field which is also known as critical field, is applied across a superconducting sample, the sample becomes normal conductor. If $H_c(T)$, which is function of temper denote the critical value of the applied magnetic field for destruction of superconductivity. Then it can be given by the relation

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

where H_0 represents the critical field at absolute zero. It is clear from ① that when $T = 0^\circ K$, the value of H_c becomes maximum and when $T = T_c$ i.e at critical temper, $H_c = 0$.

(iii) Meissner Effect:— In 1933 Meissner and Ochsenfeld observed that when a long superconductor is cooled in a magnetic field below the value of transition temperature, then at transition the lines of induction are pushed out of the specimen of the superconductor as shown in the fig. This phenomenon is known as Meissner Effect.



(a) normal state $T > T_c$

(b) superconducting state $T < T_c$.

(VII) Size :- when the size of ~~the~~ a specimen of super conductor is reduced ~~to~~ below 10^{-4} cm, some of its properties are modified, Ex. the magnetic permeability of a very small specimen is non zero and increases further as the temp approaches T_c .

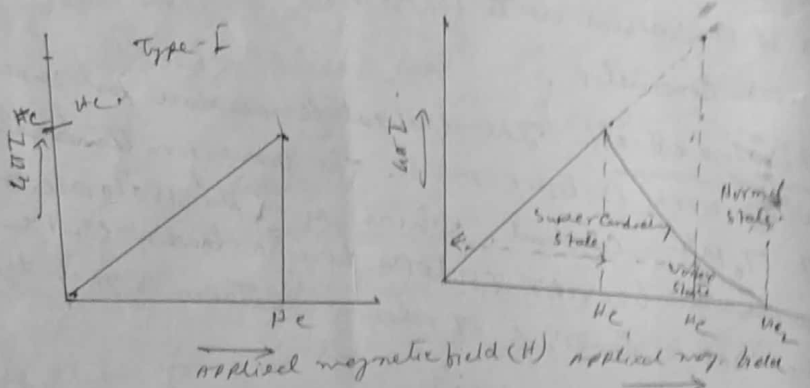
(VIII) Impurity :- The introduction of impurities modifies almost all the super conducting properties.

(IX) Thermal Conductivity :- The thermal Conductivity of a material changes discontinuously during the transfer from normal to super conducting state and vice versa

(X) Crystal structure :- The crystal lattice remains unchanged during transition from normal to super conducting state.

Type-I and Type-II super conductor

Type-I super conductor :- The specimens of many materials which are completely diamagnetic and through which flux is excluded are known as type-I super conductor. The magnetisation curve for type-I super conductor is shown in the fig below.



Type-II Super Conductor :- The specimen of other materials which shows the magnetisation curve of the form fig (6) are called type II super conductor.

In the Case of these Super-conductors, when the magnetic field is applied below the value of H_{c_1}, the Sample of materials is diamagnetic and thus the flux is entirely excluded in this range of magnetic field. Here H_{c_1} is known as lower critical field. The flux begins to penitrate the substance at H_{c_1} and the penetration increases till H_{c_2}. The value of magnetisation becomes zero at H_{c_2} and the substance behaves as normal Conductor. Here H_{c_2} is known as upper critical field. We can say that the magnetisation of such groups of super Conductors decreases gradually with increase of applied magnetic field and vanishes at H_{c_2}. Between H_{c_1} and H_{c_2}, the value of $B \neq 0$ and hence the Meissner effect is said to be incomplete. The super Conductor is threaded by flux lines between the region H_{c_1} and H_{c_2}. Such region is known as Vortex State. Type II Super Conductors are known as hard super Conductor.