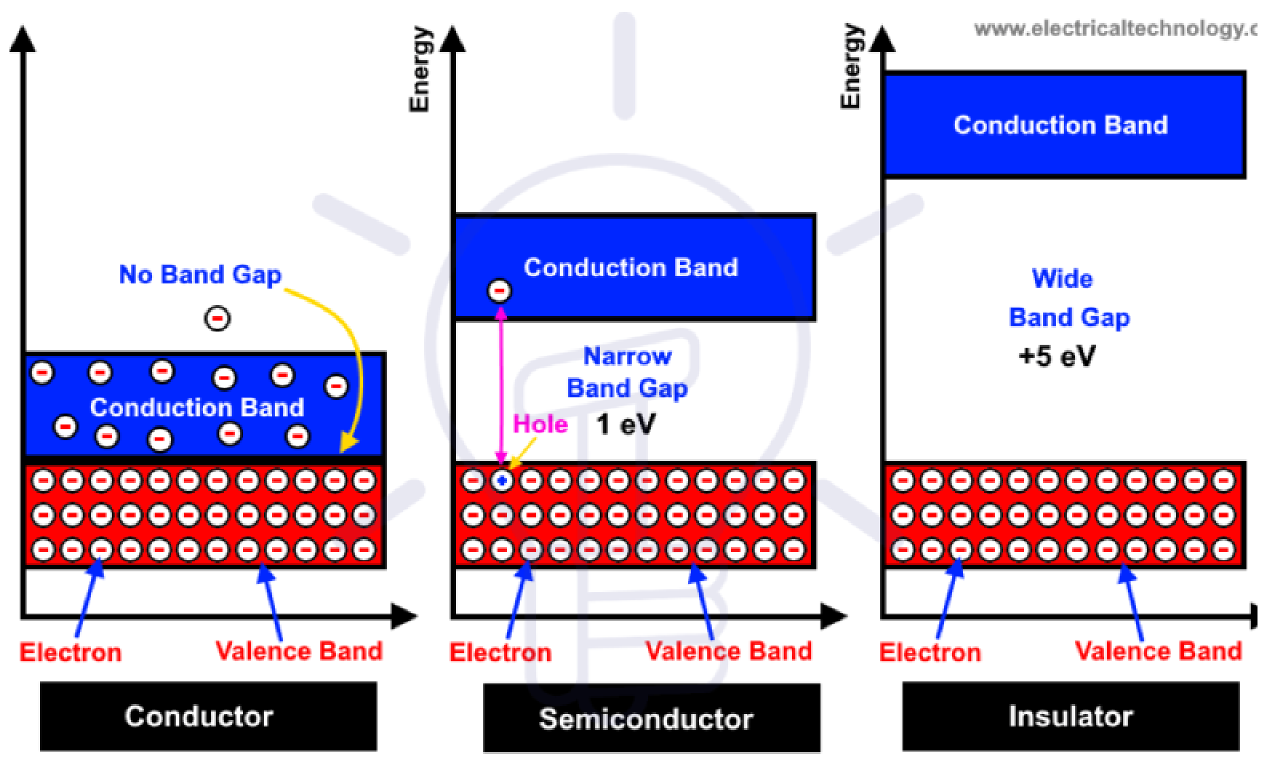
Semiconductor and Superconductor

Semiconductors:-

Semiconductors are materials having four valance electrons and whose electric conductivity lies between the conductivity of good conductors and insulator. E.g. silicon, Germanium etc.

At absolute zero, a semiconductor acts as an insulator, when temperature increases some of the valence electron are able to cross the small forbidden gap and reach the conduction band. Hence conductivity increases as temperature increases. Therefore it has negative temperature coefficient of resistance [R decreases with T]. The forbidden band gap does not exist in metal, it is narrow in semiconductor and wide in insulator.



Currents in Semiconductor:-

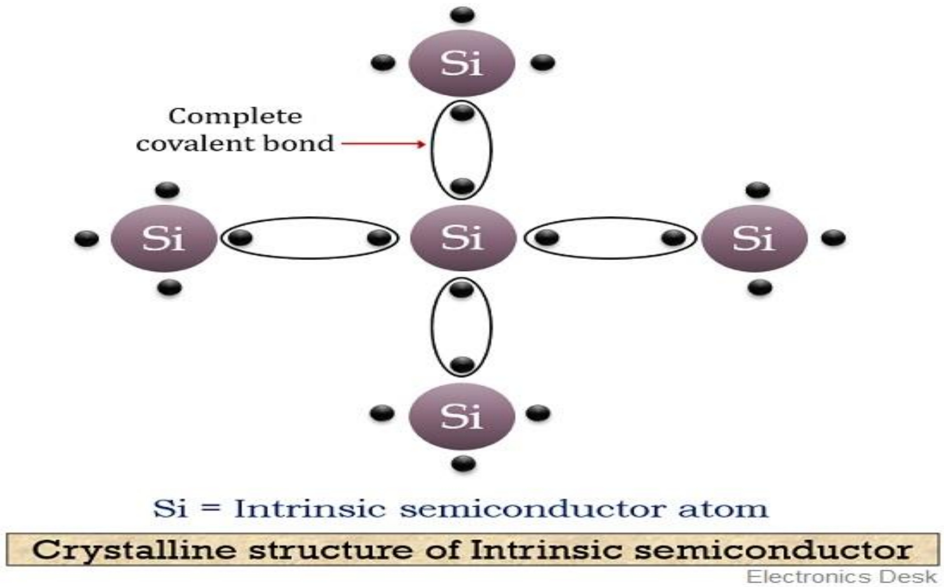
Current in semiconductor is due to motion of both electron in conduction band and motion of holes in valance band.

1. **Electron current:-**
   At room temperature conduction electrons are present in semiconductor. They move in random manner. Under the action of external field these electron acquire an additional force in the direction of electric field, and move towards anode thus forming the electron current. The electron current is same as that in pure conductor.

2. **Hole current:-**
   When a semiconductor is at normal temperature, some of the electrons in valence band jump to conduction band and create hole in valence band, when an external field is applied, the valence electron move from the end of negative potential to the end of positive potential. The electron jump forward to the succeeding hole by creating a hole behind. Again the later electron jump to succeeding hole by creating a hole behind. In this way there occurs a movement of electron from one hole to another. It seems as a movement of hole in the direction opposite to that of electron. This movement of hole constitutes a current called hole current.

Types of semiconductor:-

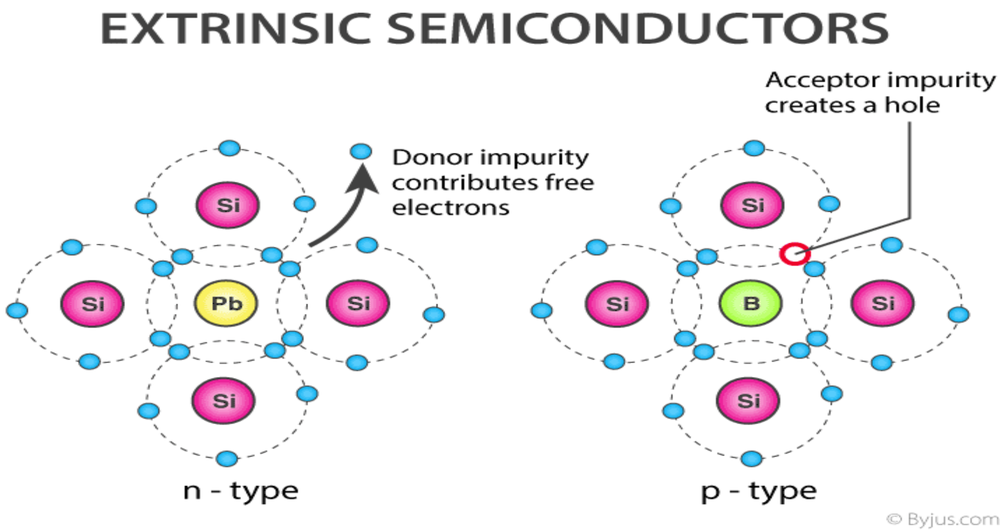
1. Intrinsic semiconductor:-



A pure semiconductor is called an intrinsic semiconductor. In any intrinsic semiconductor the thermally generated electrons and holes are so few, that we can't get any useful current. So its conductivity is poor. The thermally generated electrons and holes are so few that it can be consider as an insulator.

2. Extrinsic semiconductor:-

The conductivity of semiconductors rises when some impurities are added on it. The addition of impurity causes to increase either electron concentration or hole concentration. Such semiconductors which are doped with some impurity and having higher conductivity is called extrinsic semiconductor. There are two types of extrinsic semiconductor;



I. N-type semiconductor:-

When a pentavalent impurities like arsenic (As), phosphorous (P) and antimony (Sb) is added to pure semiconductor, a N-type semiconductor is formed. The four electrons out of five valance electron of these impurities make a covalent bond with four valance electron of Si or Ge. So one electron remains free on every add of impurity. Since, the concentration of electron increases in this semiconductor, so it is called N-type semiconductor.

II. P-type semiconductor:-

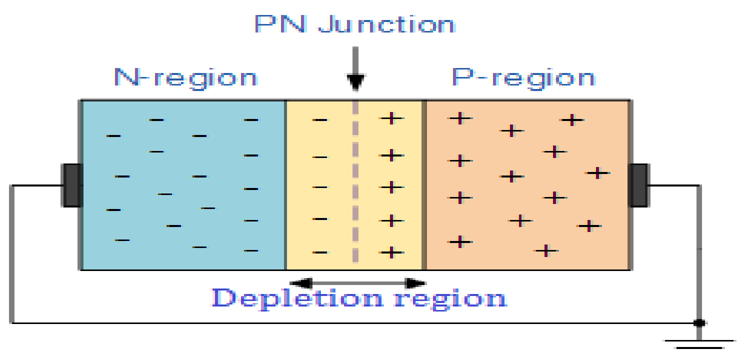
When a trivalent impurities such as boron (B), Aluminum (Al) or Gallium (G) is added to pure Silicon or Germanium, a P-type semiconductor is formed. The three valance electron of these impurities make a covalent bond with four valance electron of Si or Ge. So there is deficiency of one electron to form fourth bond. So one hole is created on every add of trivalent impurity.

In this way the concentration of hole can be raise to desired level without increasing the concentration of electron.

P-N junction:-

When one P-type semiconductor and one N-type semiconductor are placed in contact as shown in figure below, the resulting semiconductor device is called P-N junction diode and the plane of contact is called junction of diode.

When P-type and N-type crystal are placed in contact the recombination of electron and holes take place at the junction. This continues till a potential barrier is developed at the junction of the diode. This region of potential barrier is called depletion layer.



Mobility:-

The magnitude of drift velocity per unit applied electric field is called mobility of electron.

$$i.e.\ \mu = \frac{v_d}{E} \ldots\ldots\ldots (1)$$

$$\text{Since, } J = nev_d$$

$$\text{And, } J = \sigma E$$

$$nev_d = \sigma E$$

$$or, \frac{v_d}{E} = \frac{\sigma}{ne}$$

$$\therefore \mu = \frac{\sigma}{ne}$$

$$and, \sigma = ne\mu \ldots\ldots\ldots (2)$$

$$\text{Also, } \sigma = \frac{ne^2\tau}{m} \ldots\ldots\ldots (3)$$

From equation (2) and (3)

$$ne\mu = \frac{ne^2\tau}{m}$$

$$\therefore \mu = \frac{e\tau}{m} \ldots\ldots\ldots. (4)$$

Where, τ is called average time between collision (relaxation-time).

Conductivity of Semiconductor:-

In case of semiconductor, the current is due to flow of both electrons and holes. If σ_e and σ_h are conductivity of a semiconductor due to electrons and holes respectively, the total conductivity is given by;

$$\sigma = \sigma_e + \sigma_h$$

We know that; $\sigma = ne\mu$

$\therefore$ For electron; $\sigma_e = n_e e\mu_e$, where, n_e is number of electrons per unit volume and μ_e is mobility of electron.

And for holes; $\sigma_h = n_h e\mu_h$, where, n_h is number of holes per unit volume and μ_h is mobility of holes.

$$\therefore \ \sigma = (n_e e\mu_e + n_h e\mu_h)$$

$$\text{or}, \sigma = e(n_e\mu_e + n_h\mu_h)$$

$\therefore$ Resistivity is given by;

$$\sigma = \frac{1}{\rho} = e(n_e\mu_e + n_h\mu_h)$$

For an intrinsic semiconductor, $n_e = n_h = n$ (say)

$$\therefore \ \sigma = ne(\mu_e + \mu_h)$$

According this equation, conductivity increases with 'n'. As temperature increases the free charge carriers increase in semiconductor. So conductivity of semiconductor increases with temperature.

Electrical conduction in metals, insulators and semiconductor according to bond theory of solids:-

The electrical conduction properties of different elements and compounds can be explained in terms of number of electron present in conduction band. The electrons lying in the valence band no part in the conduction process.

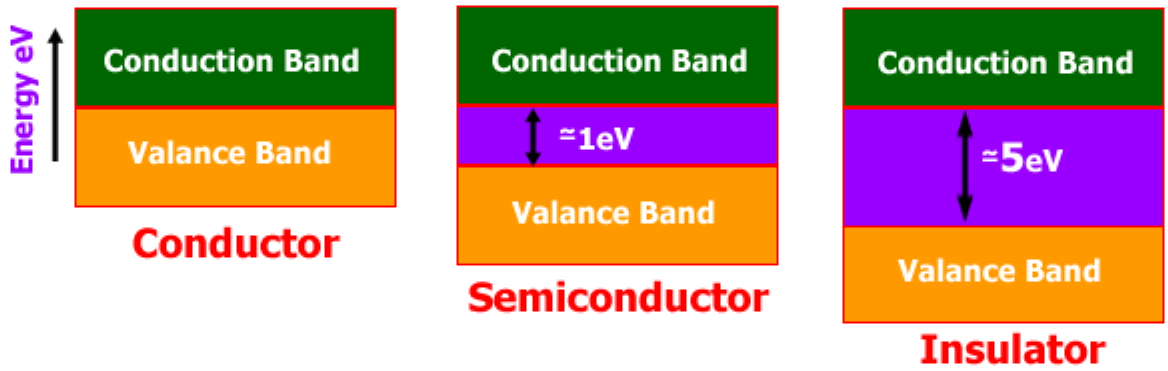


Fig: Classification of Solids on the basis of electricity Conduction

a. Conductor (metals):-

Metals are those in which large numbers of electrons are available for electrical conduction. Therefore metals are excellent conductors. In terms of energy bands, conductors are those which have overlapping valence and conduction bands or no forbidden band. Due to the absence of forbidden energy gap, there is no possibility of establish holes. The total current is simply a flow of electrons.

b. Insulators:-

An insulator has wide forbidden energy gap. The valence band is completely filled with electrons and the conduction band is completely empty. The valence electrons are bound very tightly to their parent atom. For conduction to take place, electrons must be given sufficient energy to jump from the valence band to conduction band. Increase in temperature enables some electrons to go to conduction band which accounts for the negative coefficient of resistance of insulators.

c. **Semiconductors:-**

The electrical conductivity of semiconductor lies in between those of insulators and conductors. At room temperature, they have partially field conduction band and partially filled valence band. The valence band is very narrow in the order of nearly 1eV. At absolute zero, there are no electrons in conduction band and valence band is completely filled. With increase in temperature, width of forbidden gap decreases so that some of the electrons are liberated in to the conduction band. This means the conductivity of semiconductor increases with temperature. So they have negative temperature coefficient of resistance.

Superconductors:-

The electrical resistance of metal and alloys decreases as the temperature is lower. If we study the variation of resistance with temperature, the resistance becomes immeasurable. The resistivity of mercury becomes zero below the temperature of 4 Kelvin. This property of material being of zero resistivity below certain temperature is called superconductivity. Such materials are called superconductor and this temperature is called critical temperature. Below the critical temperature the material is in superconducting state and above the critical temperature the material is in normal state.

In perfect conductors, the interior magnetic field must remain fixed but can have a zero or nonzero value. In real superconductors, all magnetic flux is expelled during the phase transition to superconductivity, and the magnetic field is always zero within the bulk of superconductor.

Properties of superconductor:-

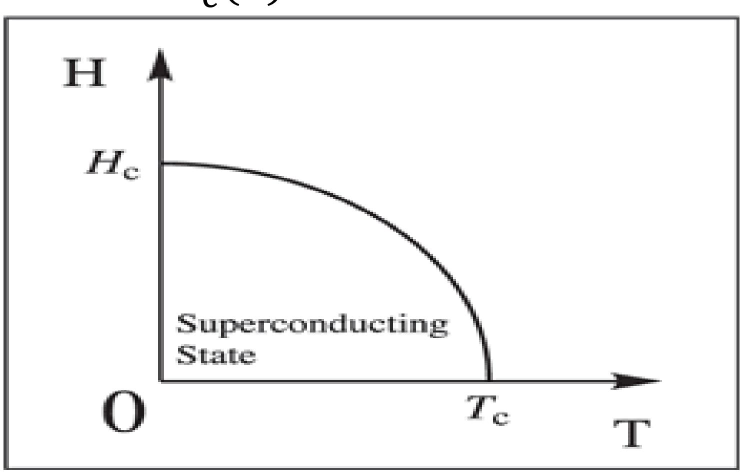
1. Critical magnetic field:-

A sufficiently strong magnetic field can destroy superconductivity. The critical value of applied magnetic field which can destroy superconductivity is called critical magnetic field $H_c(T)$.

At critical temperature, the critical field is zero, i.e. $H_c(T) = 0$. The variation of critical field with temperature is as shown in figure. The nature of curve is parabolic and can be represented by the relation.

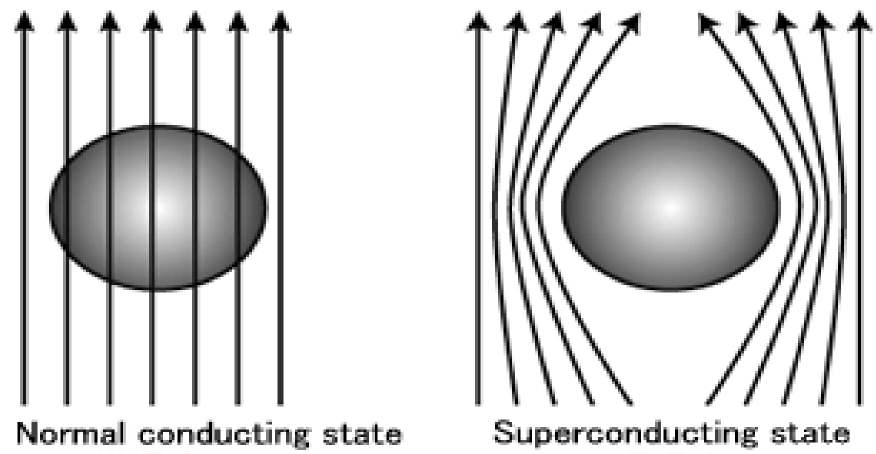
$$H_c(T) = H_c(0)\left(1 - \frac{T^2}{T_c^2}\right),$$

where $H_c(0)$ is critical field at 0 K.



2. **Meissner Effect:-**

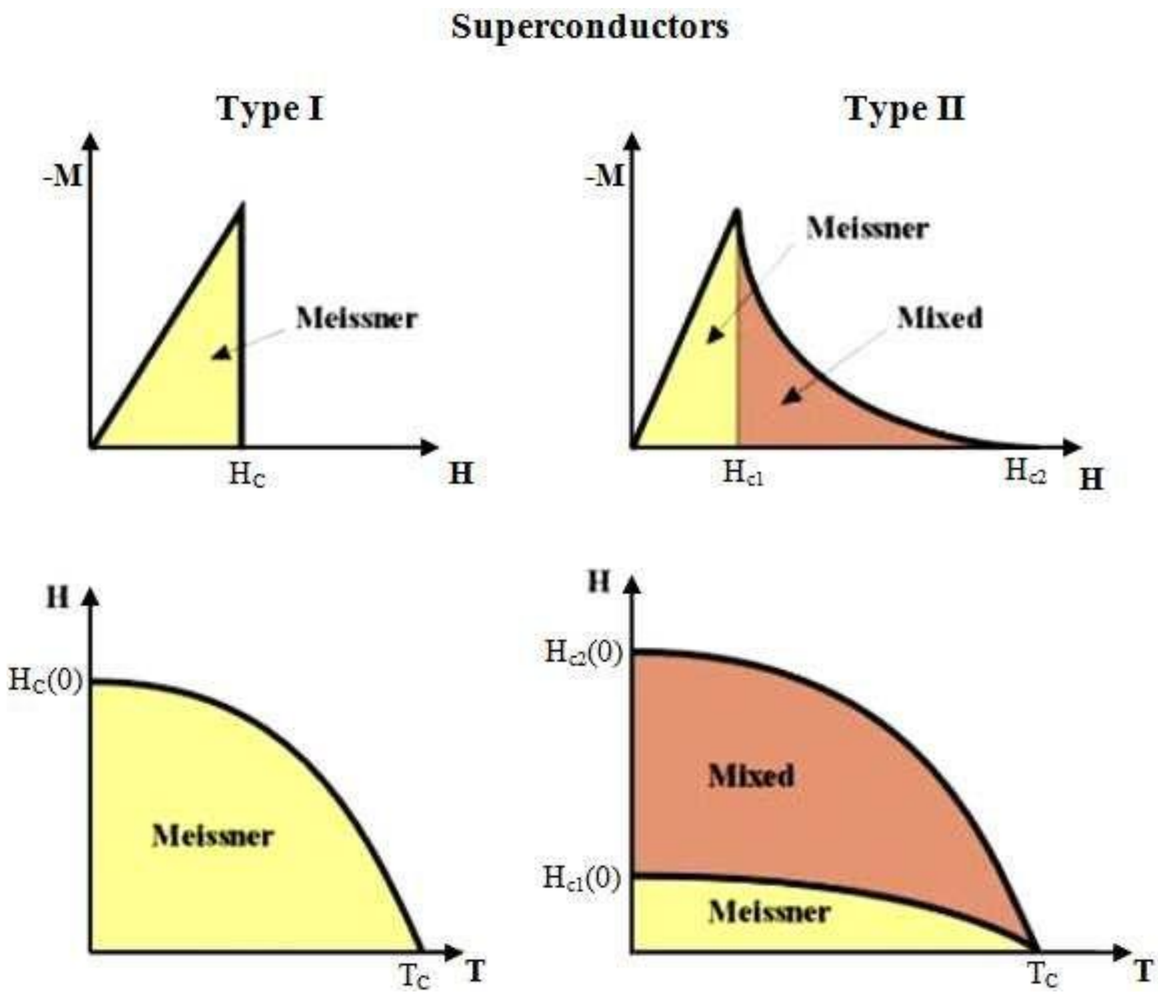
The Meissner effect is the expulsion of a magnetic field from a superconductor during its transition to the superconducting state when it is cooled below the critical temperature.



Meissner in 1935, found that if a superconductor is cooled in a magnetic field down to critical temperature, the lines of induction of magnetic field (B) are pushed out. This phenomenon is called meissner effect. This means superconductor shows perfect diamagnetic effect i.e magnetic field inside the superconductor is zero i.e. $B = 0$.

Classification of Superconductors:-

On the basis of magnetizing behavior, superconductors can be classified as type – I (or soft) and type –II (or hard) superconductors.



Type - I superconductor:-

This type of superconductor obeys complete Meissner's effect up to critical field. They are completely diamagnetic. The magnetization curve for type-I material is as shown in figure. At, the critical magnetizing field, the magnetization decreases abruptly and the material becomes normal state.

Type - II superconductor:-

This type of superconductor looses magnetization gradually as shown in figure. For applied field below the critical magnetic field, the material is diamagnetic and hence the field is completely excluded.

Here Hc_1 is called the lower critical field. Above Hc_1, the field starts penetrating in to the material until the upper critical field H_{C2} is reached. Between the two critical magnetic field H_{C2} and H_{C1}, the material is said to be in mixed state or vortex state. Above the magnetic field H_{C2}, the material becomes conductor.

Uses of Superconductor:-

1. It is used in supercomputer.
2. It is used in generation and transmission of electric power.
3. It is used in medical diagnosis (Magnetic Resonance Imaging (MRI) in strong magnetic fields).

Exercise:-

1. Explain superconductivity and its types with examples. Write the difference between superconductor and perfect conductor.
2. What is superconductor? Explain critical magnetic field. Describe the characteristics of superconductor.
3. Differentiate between semiconductors and superconductors. Discuss about critical magnetic field in superconductors. Also prove that superconductors are diamagnetic in nature.
4. What are superconductors? How they differ from the perfect conductors? Give basic properties and uses of superconductors.