

# MEI, Pampore

## UNIT 1: - THE SOLID STATE

The existence of a substance in any physical state is determined by two factors.

1. Intermolecular forces ( attraction )
2. Thermal Energy.

At sufficiently low temperature, the thermal energy is low and intermolecular forces bring them so close that they cling to one another and occupy fixed positions. These can still oscillate about their mean position and the substance exists in solid state.

The following are the general characteristic properties of the solid state.

1. Intermolecular distance are short and intermolecular forces are strong
2. Their constituent particles, ( atoms, molecules, or ions) have fixed positions and can oscillate about their mean position .
3. They are incompressible and rigid.
4. They do not possess translation motion.
5. They have definite mass, volume and shape.

### CLASSIFICATION OF SOLIDS:

Solids can be classified on the basis of nature of order present in the arrangement of constituent particles ( Atoms , Molecules ) into two types as.

1. Crystalline solids
  2. Amorphous solids
1. **CRYSTALLINE SOLIDS**:- Solids like Cu, Ag, NaCl besides being incompressible and rigid, have also characteristic geometrical forms . Such substances are said to crystalline solids .

The X- ray diffraction studies reveal that their ultimate particles ( viz molecules, atoms or ions ) are arranged in a definite pattern throughout the entire 3- dimensional network of a crystal . This definite and high ordered arrangement of constituent particles extends over a large distance . This is termed as long range order . They are called true solids .

#### Characteristic properties of crystalline solids

- a) The Crystalline solids have definite characteristic shape.
- b) They have sharp and characteristic melting point
- c) They have a definite and characteristic Enthalpy of fusion
- d) They are an isotropic means their physical properties are different in different direction . For e. g the velocity of light passing through a crystal varies with the direction in which it is measured . Thus a ray of light entering such a crystal may split into two components each following a different velocity . This phenomenon is called as double refraction ( except cubic)
- e) When cut with a sharp edged tool, they split into two pieces and the newly generated surfaces are plain and smooth ( regular geometry)
- f) They possess fixed density. Viz, Cu, Ag, Fe, NaCl, Zn, KNO<sub>3</sub> et

**AMORPHOUS SOLIDS** :- There is another category of solids such as glass , rubber, and plastics, which possess properties of incompressibility and rigidity to certain extent, but do not have definite geometric forms. Such substances are called amorphous solids . they are called pseudo. They possess short range order.

#### Characteristic features:-

1. They have random arrangement of constituent particles called short range order.

2. They have variable density
3. The amorphous solids have irregular shapes.
4. They do not have sharp melting point and they gradually soften over a range of temperature.
5. They do not possess definite enthalpy of fusion.
6. Their physical properties such as electric conductivity, thermal conductivity, mechanical strength and refractive index are the same in all directions. Amorphous substances are therefore said to be isotropic.
7. They are called pseudo solids and super cooled liquids  
E. g Glass, rubber. Plastics etc

### CLASSIFICATION OF CRYSTALLINE SOLID:-

According to attractive force which hold crystal together are generally of four types and thus crystal can be classified into four types:

#### **Ionic crystals**

The lattice points in ionic crystals consist of alternative positive and negative ions in equivalent amount arrangement in an order so that the potential energy is minimum. Such crystals are normally found in ionic compounds. E.g.  $\text{NaCl} \longrightarrow \text{Na}^+ + \text{Cl}^-$ .

#### **Covalent crystals**

In covalent crystals, atoms at their lattice point are held together by shared pair of electrons between them. The covalent bonding extends throughout the crystals in spatial direction. These are very hard except graphite. Their covalent bonding extends in all directions that is why they are network solids.

#### **Molecular crystals**

In molecular crystals, the repeating unit is chemically identifiable atoms or molecules which do not carry a net charge. Such solids may be classified into two types:-

- (a) *Polar molecular solids*:- They are formed from unsymmetrical molecules containing polar covalent bonds. The polar molecules which constitute the crystal are held together by fairly strong dipole-dipole interaction e.g. ice. These solids do not have high melting points and are fairly volatile.
- (b) *Non polar molecular solids*:- These solids consist of non polar molecules which are held together by weak van der Waals' forces e.g. solid  $\text{CO}_2$ , naphthalene and iodine etc. They are soft and possess low melting points and such solids vapourise readily.

#### **Metallic crystals**

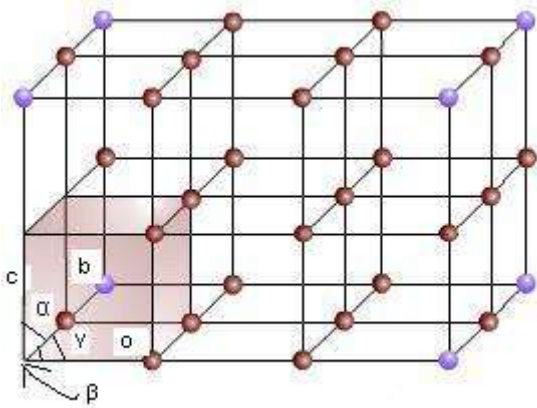
These are the solids which consist of positive ions surrounded by mobile electrons commonly known as electron gas. These units are held together by fairly strong electrostatic forces between the positive metal ions and the mobile electrons which move freely within the boundaries of the crystal e.g. Na, K, Cu, Ag etc. Metallic solids exhibit bright surface known as metallic luster. They are good conductors of heat and electricity. Their boiling and melting points are high.

## STUDY OF CRYSTALS

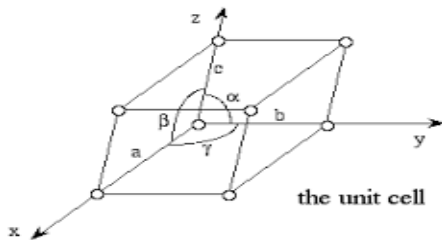
**CRYSTAL**:- A crystal is a homogeneous portion of a solid substance made by regular pattern of structural units bonded by plane surface making definite angles with each other.

**Lattice points**:- The constituent particle which generate the unit cell and hence the space lattice are called lattice points.

**Space lattice or crystal lattice**:- The arrangement of constituents like atoms, ions, and molecules in different sites in three dimensional space is called space lattice.



**Unit cell:**-The smallest repeating unit in space lattice which when repeated over and over again, results in a lattice crystal of the given substance called unit cell.



**Face:**-The plane surface of the crystal is called a face.

**Edge:**- An edge is formed by the intersection of two faces.

**Interfacial angles:**-The angles between any two adjacent faces in a crystal is called interfacial angles. The interfacial angle remains constant for a crystal, no matter what is the size of unit cell. This statement is called 'Law of constancy of interfacial angles.'

### Types of unit cell.

**Primitive unit cell:**- Lattice points are present only at corners.e.g simple cubic unit cell. :- In this arrangement, the points are present at all the corners of a cube. The atom present at each corner contributes  $1/8$  to each cube because it is shared by 8 cubes. Now, there are 8 atoms at the corners.

Thus the no. of atoms present in each unit cell = 8 corner atoms  $\times$   $1/8$  atom per unit cell  
= 1 atom

Thus, simple cube has one atom / unit cell.

**Non- primitive unit cell:** Lattice points are present not only corners, but also at some other specified positions. On the basis on the position of lattice points, it is further divided into following types.

**BODY CENTERED CUBIC :-** It has points at all the corners as well as at the centre of the cube. These are eight atoms at the corners and each is shared by 8 unit cells so that the contribution of each atom at corner is  $1/8$ . In addition there is one atom in the body of the cube which is not shared by any other cube. . The no. of atoms present at the corners / unit cells =  $8 \times 1/8 = 1$

The no. of atoms present at the centre of the cube = 1

Therefore total no. of atoms in BCC arrangement =  $1 + 1 = 2$

Thus a body centered cube has two atoms / unit cell.

**Face centered Cubic :-** It has points at all the corners as well as at the centre of each of the six faces. Atom present at each corner contributes  $1/8$  to each cube as it is shared by 8 cubes. In addition there are six atoms at the faces of the cube and each is shared by two unit cells.

Therefore the contribution of each atom at the Face/ unit cell is  $1/2$ . Thus the no.

Of atoms present at corners/ unit cells =  $8 \times 1/8 = 1$

The no. of atoms present at faces / unit cell =  $6 \times 1/2 = 3$

Therefore Total no. of atoms in ccp or Fcc arrangement =  $1 + 3 = 4$

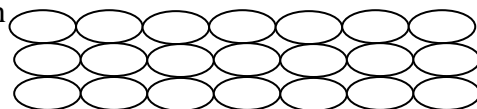


**Packing of constituent particles in solid :-** When a crystal is made to grow, it involves atoms, ions or molecules which are considered as identical spheres. The particles of solids attract each other strongly and pack together as closely as possible in order to attain stability. Thus use the available space most economically and a state of maximum possible density is obtained.

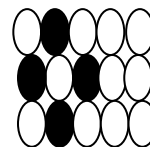
**Edge Development :-** If a number of spheres are placed in a horizontal row so that they touch each other and their centres lie along a straight line, this row of spheres is known as an edge of the crystal



**Crystal plane Development :-** When the rows of spheres are combined, a crystal plane is developed. These can be only two methods in which the crystal planes can be found.

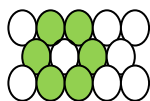


1, **Square planer arrangement:-** when particles are joined in such a way that their adjacent rows shows a horizontal as well as vertical alignment and form squares, it is called a square planer arrangement. Each particular sphere touches four neighboring spheres giving rise to a square planer arrangement.



2, **Hexagonal close packing :-** In this arrangement, the spheres in the 2<sup>nd</sup> row lie in the depressions between spheres of the first row. Spheres in the 3<sup>rd</sup> row lie in the depressions between the spheres of the 2<sup>nd</sup> row but they are vertically aligned with those in the first row and so on. Each particular sphere touches six neighboring spheres.

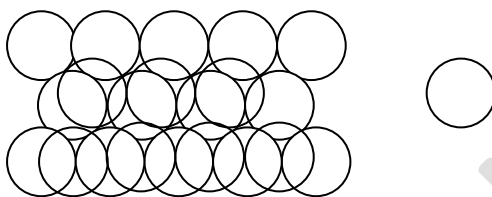
It is seen that the void space in the 2<sup>nd</sup> arrangement is lesser than that in the 1st arrangement. This means that hexagonal packing is more efficient and is more probable.



**CO-ORDINATION NO.:-** Number of spheres touching a particular sphere in a given arrangement is called Co-ordination number. The co-ordination no. in a hexagonal packing is 6. It depends upon the structure of the crystal.

Hexagonal close packing Involving 3 dimensional packing.

Let us consider 1st layer of spheres designated by 'a' and the 2<sup>nd</sup> layer designated by 'b'. Each sphere of the layer 'b' is situated at the depression created by the centers of the three touching spheres of the 1st layer. Each sphere in the 1st layer has six depressions surrounding it. Out of them, three are marked as 'A' and three alternate positions are marked as 'B'. In the 2<sup>nd</sup> layer, the spheres are situated in such a manner that they occupy the positions marked as 'B'. While as depressions marked as 'A' remain unoccupied. Each sphere thus touches nine other spheres. These depressions 'A' remain unoccupied because the holes 'A' and 'B' cannot be occupied at the same time due to shortage of space between the two adjacent holes. Thus either all 'A' or all 'B' holes can be occupied at one time by the 2<sup>nd</sup> layer. The Third layer can be packed on the top of the 2<sup>nd</sup> layer 'b' by two arrangements.



i) *Hexagonal close packing (hcp) arrangement* :- In hcp arrangement, the third layer is packed in such a way that each sphere is directly aligned above a sphere in layer 'a' in every respect. A fourth layer can be placed in such a way so that it resembles layer 'b' in every respect. This alternate pattern of 'a' and 'b' layers can be represented upwards upto a desired extent and is designated as 'ab, ab, ab,.....' Pattern. In this pattern each sphere touches 12 other spheres giving coordination no. of 12 and this arrangement is called (hcp) arrangement.

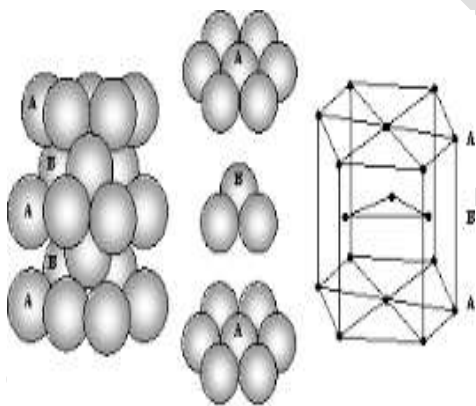


Fig. 5.9. Hexagonal close packing (hcp) in three dimensions

ii) *Cubic close packing arrangement (CCP)* :- In ccp arrangement the atoms are arranged at the corner and at the centres of all the six faces of a cube. Here the two layers of spheres 'a' and 'b' are arranged one upon the top of the other, The third layer 'c' can be kept on the layer 'b' so that the spheres of the layer 'c' are not directly aligned above the spheres in layer 'a'. In this case the layer 'c' is different from either of two layers 'a' and 'b'. The spheres of this layer are placed over the depressions 'B' of the 1st layer. The fourth layer can be directly kept above the layer 'a' and the fifth above the layer 'b' so that the pattern can be represented as 'abc, abc, abc,.....'. This arrangement is called (CCP). In this case also, the Co-ordination no. is 12. The CCP type packing resembles fcc type packing. Ccp and hcp arrangements are efficient in use of space. In both cases 74% of the available volume is occupied by the spheres. The 26% unoccupied space is regarded as holes or voids in the crystal lattice.

Majority of the metals have either hcp or ccp arrangement e.g. Be, Mg, Mo crystallize in hcp structure while as Ar, Fe, Ni, Cu, Ag and Au crystallize in ccp structure.

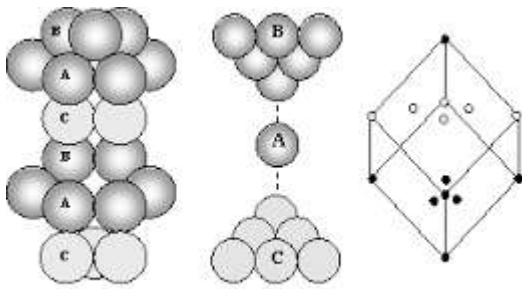
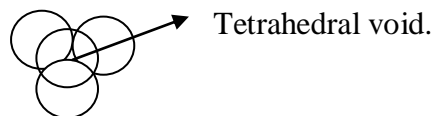


Fig. 5.10. Cubic close packing (ccp or fcc) in three

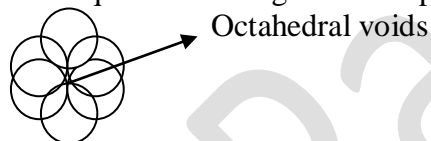
### Interstitial sites or voids

In the close packing of spheres, certain hollows are left vacant. These holes in the crystals are called interstitial sites or voids. Two important interstitial sites are tetrahedral and Octahedral sites.

i) Tetrahedral site :- A sphere in the second layer is placed above three spheres touching one another in the first layer. The centres of these spheres lie at the apices of a tetrahedron. The shape of the void is not tetrahedral, but the arrangement around this void is tetrahedral. Thus the vacant space among four spheres having tetrahedral arrangement is called tetrahedral site.



ii) Octahedral site :- This type of site is formed at the centre of six spheres. Each octahedral site is produced by two sets of a equilateral triangles which point in opposite directions. Thus, The void formed by two equilateral triangles with apices in opposite direction is called Octahedral site.



**Density of unit cell:**-It is defined the ratio of mass per unit cell to the total volume of unit cell.

$$\text{Density } (\rho) = \frac{\text{Mass of unit cell}}{\text{volume of unit cell}}$$

$$\text{Mass of unit cell} = \text{No. of atoms in a unit cell } (z) \times \text{Mass of each atom}(m).$$

$$\text{Mass } (m) = \frac{M}{N_A} \text{ where } M = \text{Atomic mass}, N_A = \text{Avogadro no.}$$

$$\text{Therefore Density } (\rho) = \frac{z \times M}{a^3 \times N_A}$$

Q:-Ag crystallize in Fcc arrangement, having edge length 460pm. Calculate the density of the crystal? (M= 108gmol<sup>-1</sup>)

$$\begin{aligned} \text{Solution ; Length of edge, } a &= 460\text{pm} \\ &= 460 \times 10^{-10} \text{ cm} \end{aligned}$$

Since it is Fcc arrangement,

No. of atoms in the unit cell, Z = 4

Atomic mass of the element, M = 108g mol<sup>-1</sup>

$$\text{Density } (\rho) = \frac{z \times M}{a^3 \times N_A}$$

$$4 \times 108 \text{ g/mol}$$

$$= \frac{1}{(460 \times 10^{-10} \text{cm})^3 \times (6.023 \times 10^{23} \text{mol}^{-1})}$$

$$= 7.37 \text{g cm}^{-3}$$

### EFFICIENCY OF PACKING OR PACKING EFFICIENCY

Packing efficiency of a solid may be defined as the percentage of total space occupied by the particles. Higher the packing efficiency, lesser are the voids present and thus higher is the density of the crystal.

$$\text{Packing efficiency} = \frac{\text{Volume occupied by particles}}{\text{Total volume of the unit cell}} \times 100$$

$$= \frac{Z \times \frac{4}{3} \pi r^3}{a^3}$$

Z = no. of particles per unit cell

$\frac{4}{3} \pi r^3$  = vol. of particle(sphere)

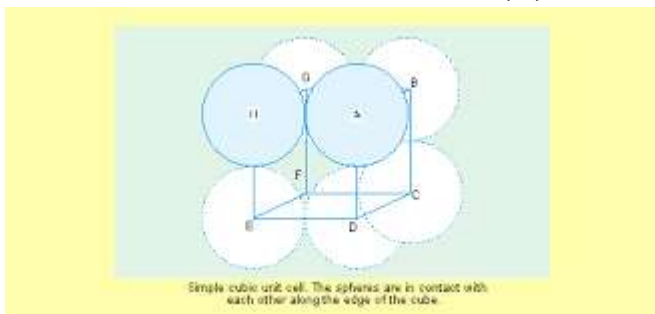
$a^3$  = Total vol. of unit cell

$$= \frac{4}{3} Z \pi (r/a)^3 \times 100$$

#### (a) Simple cubic unit cell:

No. of atoms per unit cell = 1

$$a = 2r \text{ therefore, P.F} = \frac{1 \times \frac{4}{3} \pi r^3}{(2r)^3} = 0.52 \text{ or } \% \text{ P.F} = 52$$



$$\% \text{ of voids} = 100 - 52 = 48 \% \text{ [loose packing]}$$

#### (b) Body centered cubic unit cell:

No. of atoms per unit cell =  $8 \times \frac{1}{8} + 1 = 2$

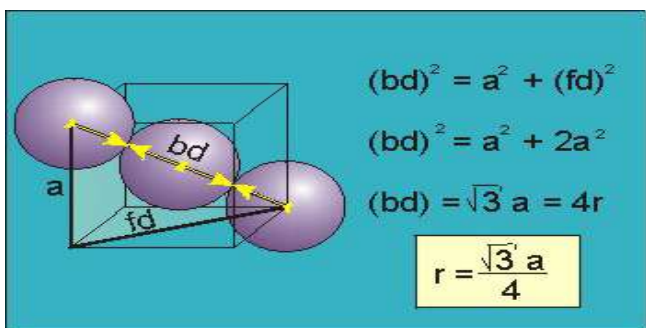
$$r = \frac{\sqrt{3}}{4} a$$

$$\text{or } a = \frac{4r}{\sqrt{3}}$$

$$\text{P.F} = \frac{2 \times \frac{4}{3} \pi r^3}{(4r/\sqrt{3})^3}$$

$$= 0.68 \text{ or } \% \text{ P.F} = 68 \%$$

$$\% \text{ of voids} = 100 - 68 = 32 \% \text{ \{ loose packing \}}$$



(c) **Face centered cubic unit cell:**

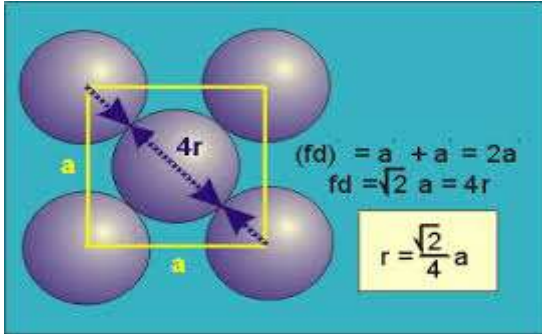
No. of atoms per unit cell = 4

$$r = \frac{\sqrt{2}}{4} a \quad \text{or} \quad a = \frac{4r}{\sqrt{2}}$$

$$\text{P.F} = 4 \times \frac{4}{3} \pi r^3$$

$$\frac{\text{P.F}}{(4r/\sqrt{2})^3} = 0.74 \quad \text{\%P.F} = 74\%$$

$$= \text{\% of voids} = 100-74 = 26\% \{ \text{close packing} \}$$



**Co-ordinations no. and Radius Ratio:-**

The cations and anions in an ionic solid are held together by strong electrostatic forces and for stability. There should be maximum electrostatic attractions and minimum electrostatic repulsion between the oppositely charged ions, Co-ord, no. and geometry of the crystals largely depends upon the the relative sites of the ions,

The ratio of the radius of the cation to the radius of the anion is called radius ratio .

$$\text{Radius ratio} = \frac{\text{Radius of the cation}}{\text{Radius of the anion}} = \frac{r_+}{r_-}$$

The effect of the ratio in determining the co-ordination no. and the shape of an ionic solid is known as Radius ratio effect

<b>Radius ratio</b>	<b>CO- Ord . No</b>	<b>Crystal Shape</b>	<b>Examples</b>
0 --- 0.155	2	Linear	$F^8 H^8 F^8$
0.155---- 0.225	3	Trigonal Planer	$B_2 O_3$
0.225 ---- 0.414	4	Tetrahedral	Zns
0.414----- 0.732	6	Octahedral	NaCl
0.732 ----- 1.000	8	Cubic ( Body centred )	CsCl

Longer cations are surrounded by maximum an Ioms and smaller cations by lesser anions. Eg in CsCl Crystal Cs + has large size , hence surrounded by 8 Cl anions ( C. No =8 ) while as in NaCl. Crystal , Na + has small size .

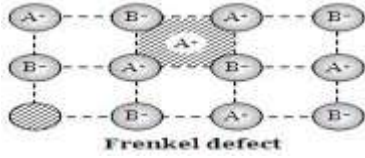
**IMPERFECTIONS or DEFECTS IN SOLIDS**

In the actual formation of a solid often some irregularities or imperfections remain in its crystal lattice . These are called solid defects or solid imperfections. In other words solid defects are deviations from the ideal structures or patterns. These defects in solids are important in certain cases because they import some new proportion to the solids. Imperfections in solids are caused mainly due to temperature, presence of impurities at the time of growth of a crystal , missing of lattice points etc. At absolute temperature ( 0 K) most of the





defect is a combination of a vacancy and an extra interstitial ion. These defects are common in ionic solids most preferably in those in which anions are much larger than cations and whose co-ordination no. are low. e.g AgCl, AgBr, ZnS etc. In these cases cations are smaller than anions. In pure alkali metal halides, Frenkel defects are generally absent, because these ions (due to larger cationic size) do not get into interstitial sites.



In case of Frenkel defect the density of crystal remains same because ions (usually cations) are not absent but are dislocated somewhere in the lattice. This defect normally causes an increase in the Dielectric constant of the medium because of the closeness of similar charges.

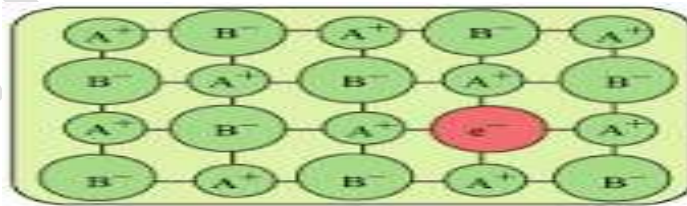
Schottky and Frenkel defects are collectively called as thermodynamic or intrinsic defects. Schottky defect appears more than Frenkel defect because the energy needed to cause Schottky defect is much less than the Frenkel defect.

**Point Defects in Non-Stoichiometric crystals :-** The compounds in which the ratio of positive and negative ions present in the compound differs from that required by ideal chemical formula of the compound are called non-stoichiometric compounds. The defects in these compounds are called non-stoichiometric defects. There are of two types depending upon whether positive ions are in excess or negative ions are in excess. These are also known as metal excess defects and metal deficiency defects respectively.

i) **Metal Excess Defects :-** In these defects, the positive ions are in excess. These may arise due to the following two ways :-

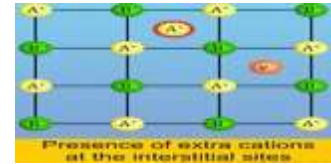
Anion Vacancies :- In this case, negative ions may be missing from their lattice sites leaving holes in which the electrons remain entrapped to maintain the electrical neutrality. Evidently, there is an excess of +ve (metal) ions. This type of defect is observed in those crystals which are likely to form Schottky defects. eg in alkali metal halides. Anion vacancies are produced when alkali metal halide crystals are heated in the atmosphere of the alkali metal vapours. The metal atoms get deposited on the surface of the crystal, halide ions move into that surface and combine with metal atoms. The electrons thus produced by the ions of the metal atoms diffuse into the crystal and get trapped at the anion vacancies.

The electrons trapped in anion vacancies are referred to as F centre. These give very interesting properties. e.g. the excess of K in KCl makes the crystal violet, excess of Li in LiCl makes the crystal appear pink.



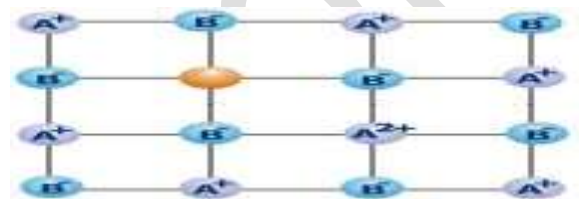
Excess cations occupying interstitial sites :- In this case, these are extra +ve ions occupying interstitial sites and also electrons at interstitial sites to maintain electrical neutrality. The defect may be visualized as the loss of non-metal atoms which leave their electrons behind. The excess metal ions occupy interstitial positions. This type of defect is found in crystals which are likely to develop

Frenkel defect. e.g. ZnO (yellow)



2) **Metal Deficiency Defects** :- These are the defects in which negative ions are in excess. They may also arise in two ways.

a) **Cation vacancies**:- In some cases, the positive ions may be missing from their lattice sites. The extra negative charge may be balanced by some nearby metal ion which are converted to higher oxidation state. E.g. Fe<sub>3</sub>O<sub>4</sub>, Nickel Oxide.



B) **Extra anions occupying interstitial sites**:-

In this case, the extra anions may be occupying interstitial sites.

The extra negative charge is balanced by the extra charges on the adjacent metal ions. Such type of defect is not common because the -ive ions are usually very large and they cannot easily fit into the interstitial sites.

**ELECTRICAL PROPERTIES OF SOLIDS**:- On the basis of electrical conductivity, solids can be classified into three types :

i) Conductors (metals) ii) Insulators and iii) Semiconductors

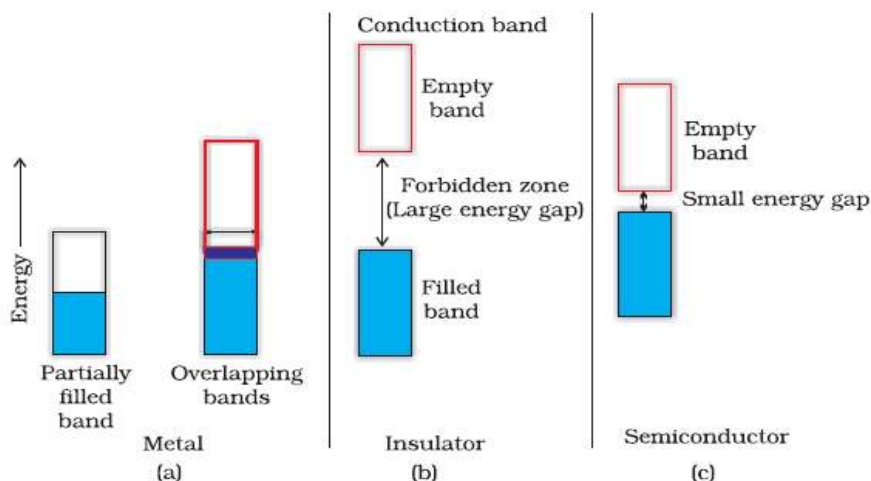
i) **Conductors** :- The electrical conductivity of metals is very high and is of the order of  $10^6$  --  $10^8$  ohm<sup>-1</sup> cm<sup>-1</sup>. The solids which allow the passage of electric current are called conductors. These are of two types: metallic conductors and electrolytic conductors >

a) **Metallic conductors**:- are those conductors which allow the electricity to pass through them without undergoing any chemical change e.g. Cu, Ag, etc. In these conductors, the conduction is due to the movement of electrons under the influence of an applied electric potential.

b) **Electrolytic conductors** are those which allow the electricity to pass through them by undergoing a chemical change. The conduction in ionic solids is due to the migration of ions or other charged particles under the applied field. Due to strong electrostatic forces the ionic solids do not conduct electricity when they are in molten state or in the form of their aqueous solutions e.g. NaCl

ii) Insulators :- In some materials the electrons are tightly bound to their respective atoms and are not in a position to move through the solid. Such materials do not allow electricity to pass through them, hence called insulators. Their conductivity value is of the order of  $10^{-12} \text{ ohm}^{-1} \text{ cm}^{-1}$  at room temperature and have no free electrons or ions to conduct electricity. Wood, diamond, plastic, polythene, glass etc are insulators

ii) Semi conductors :- There is a class of conductors whose conductivity value lies in between the conductors and insulators ( $10^2$ ----  $10^9 \text{ ohm}^{-1} \text{ cm}^{-1}$ ). Their conductivity increases with increase in temperature. The electrical conductivity of semi conductors arises due to the presence of impurities and defects in these crystals, the electricity and holes produced by ionization of defects contribution to conduction in these solids.



### Semi conductors may be intrinsic and extrinsic

**Intrinsic semi conductors :-** These are certain crystals like pure Si, Ge etc. which act as insulators at 0K because electrons fixed in covalent bonds are not available for conduction. However, at higher temperature some of the covalent bonds are broken and the electrons so released become free to move in the crystal and thus conduct electric current when electric field is applied.

**Extrinsic semiconductors :-** In this case the guest atoms are doped in the host crystal. If gr. 15 elements impurities (As, P) are doped in group 14 elements crystals (Si, Ge), the conduction of electricity is caused by the one excess electron of gr. 15 element. Hence gives rise to an electronic current. This conductor is called n-type semi conductor (n stands for negative)

If group 13 element impurities (B, Al) are doped in group 14 element crystals (Si, Ge) the conduction of electricity is caused by an electron deficient or hole, hence give rise to a hole current. This conductor is called p-type semi conductor (p stands for +ive)

The behavior of transition metal oxides towards conduction is as follows :

Metallic conductors =  $\text{TiO}$ ,  $\text{VO}$ ,  $\text{CrO}_3$  etc .

Metallic to insulator (semi-conduction)  $\text{TiO}_3$ ,  $\text{VO}_2$ ,  $\text{VO}_3$  etc

Insulators =  $\text{TiO}_2$ ,  $\text{Mn}^0$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{V}_2\text{O}_5$ ,  $\text{MnO}_2$ .

**Magnetic properties :-** The magnetic properties of solids are also related to the electronic structures.

Materials can be divided into the following types depending upon their response to magnetic field.

i) **Diamagnetic materials :-** The substances which are weakly repelled by the magnetic fields are known as diamagnetic substances. Diamagnetism arises when all electrons are paired. Being paired, the magnetic moment of one electron is compensated by the equal and opposite magnetic moment of the other electron, E.g  $\text{C}_6\text{H}_6$ ,  $\text{NaCl}$  etc

2) **Paramagnetic materials** :- The substances which have permanent magnetic dipoles and are attracted by the magnetic field are known as paramagnetic substances. They lose their magnetism in the absence of magnetic field. These consist of atoms, ions or molecules having one or more unpaired electrons. The random orientations of the magnetism moments of the unpaired electrons cancel each others effect. But, in the presence of external magnetic field these unpaired electrons are aligned and the substances shows temporary magnetism eg  $O_2$ ,  $Cu^{2+}$ ,  $Fe^{3+}$ , Al, Mn etc

3) **Ferromagnetic substances** :- The substances which are strongly attracted by the magnet and show permanent magnetism even in absence of the magnetism field is called ferromagnetic substances.

A ferromagnetic substance if once magnetized retains its magnetism permanently evens When the magnetic field is removed. This occurs due to unpaired electron in the same direction, Eg Fe, Ni, Co,  $CrO_2$ ,  $Fe_3O_4$ .

4) **Anti – Ferromagnetic substances** :- These are substances in which the alignment of magnetic moment is equal and in opposite direction, so that the net magnetic moment is zero . Thus, anti Ferro magnetic substances show reduced paramagnetic than expected eg  $MnO$ ,  $Mn_2O_3$ ,  $O_3$ ,  $V_2O_3$ , etc

5) **Ferrimagnetic substances** :- Their magnetic effect lies in between the ferro and anti ferro magnetic substances. These are the substances in which the alignment of magnetic moments in opposite directions are not equal . This results in the net magnetic moment of the substance called ferromagnetic substance . The magnetism developed by this is called ferrimagnetisms .

Ferrimagnetisms substances show fairly good paramagnetic character eg  $FeO_4$  ( ferrites ).

6) **Di electric properties** :- A substances through which there is no net flow of electric charge when placed under an applied electric field is called as dielectric material. This is due to the electrons in the d electric material are tightly held by individual atoms . or ions . An insulator is a dielectric having no conducting electrons. A dielectric becomes conductive by heating it or high temperature or when very high voltage is applied to it. . A few example of dIelectrics are glass, porcelain (pure water chemically),  $CH_3Cl$  etc .

7) **Superconductors**:- Super conductors materials are those which offers no resistance to the passage of electricity. Electrical resistance decrease with decrease in temperature and become almost zero near the absolute zero. Most metals become superconducting at very low temperature (2-5K). Superconductors are used in electronics, building magnets, power transmissions , levitation transportation, (trains- which move in air without rails).