

Syllabus

1.1	Introduction	1.6	Packing of particles in crystal lattice
1.2	Types of solid	1.7	Packing efficiency
1.3	Classification of crystal and solid	1.8	Crystal defects or imperfections
1.4	Crystal structure	1.9	Electrical properties solids
1.5	Cubic system	1.10	Magnetic properties of solids

Can you recall ?

1. What are the three most common states of matter ?

Ans : Solid, liquid and gases are the three most common states of matter.

2. How does solid state differ from the other two states ? (Answer with to volume, shape, effect of temperature and pressure on these and the motion of constitute particles and interparticle forces.)

Ans :

Reference	Solid	Liquid	Gases
Volume	Has definite volume	Has definite volume	Takes volume of the container
Shape	Has definite shape	Takes the shapes of the container	Takes the shape of the container
Effect of change in temperature	Small change in volume	Moderate change in volume	Large change in volume
Effect of change in pressure	Practically incompressible	Compressible to small extent	Compressible
Motion of constituent particle	Particle occupy fixed position	Can move a small distance within the liquid	Particles are in random continuous motion
Interparticle forces	Strong	Moderately strong	Very weak or negligible

1.1 Introduction

Q.1 What factors effects the shape and volume of a definite solid ?

Ans : Solids have definite shape and volume, which change only slightly with change in temperature and pressure.

Q.2 What are the smallest constituent particles of solids ?

Ans : The smallest constituent particle of various solids are atoms, ions or molecules.

1.2 Types of Solid

Q.3 Name two types of solids.

Ans : The two types of solids are :

- (i) Amorphous solid and (ii) Crystalline solid.

Q.4 Give the characteristic properties of crystalline solids.

Ans : The crystalline solids possess following characteristic properties :

- i. There is a regularity and periodicity in the arrangement of constituent particles in crystalline solids. The ordered arrangement of particles extends over a long range.
- ii. Crystalline solids have sharp melting point, that is they melt at a definite temperature.
- iii. All crystalline substance except those having cubic structure are anisotropic. In other words their properties like refractive index, thermal electrical conductivity, etc. are different in different directions.

Q.5 Give examples of crystalline solids.

Ans : Ice, salts such as NaCl, metals such as sodium, gold, copper and materials such as diamond, graphite, ceramics are examples of crystalline solids.

Q.6 Give characteristic properties of amorphous solids.

Ans : Amorphous solids have following characteristics :

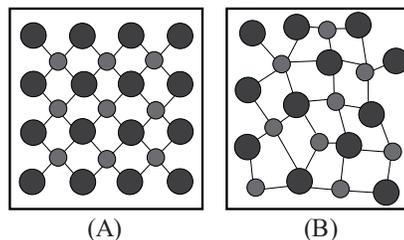
- i. The constituent particles in amorphous solids are randomly arranged. The particles do not have long range ordered structure but they do have a short range order.
- ii. Amorphous solids do not have sharp melting points. They melt gradually over a temperature interval. On heating, amorphous solids gradually and continuously soften and start to flow.
- iii. These solids are isotropic. In other words, their properties such as refractive index, conductivity are all independent of direction of measurement. They exhibit the same magnitude for any property in every direction.

Q.7 Give examples of amorphous solids.

Ans : Glass, plastic, rubber, tar and metallic glass (metal-metalloid alloys) are a few examples of amorphous solids.

+Q.8 Use your brain power

Identify the arrangements A and B as crystalline or amorphous.



Ans : Arrangement A is crystalline solid
Arrangement B is Amorphous solid.

Q.9 Give distinguish between crystalline solid and amorphous solid.

Ans :

	Crystalline Solid	Amorphous Solid
i.	There is a regularity and periodicity in the arrangement of constituent particles.	The constituent particles are randomly arranged.
ii.	They have a sharp melting point, that is they melt at a definite temperature.	They do not have sharp melting point, they melt over a range of temperature.
iii.	They are anisotropic solids. i.e., their properties like refractive index, electrical conductivity etc are different in different direction.	They are isotropic solids. i.e., their properties like refractive index and conductivity are same in every direction.
iv.	Example : NaCl, diamond, graphite ect	Example : Glass, plastic, rubber, tar etc.

Q.10 Write a short note on

1. **Isomorphism**
2. **Polymorphism**

Ans :

1. **Isomorphism :**

- i. Two or more substances having the the same crystal structure are called as

isomorphous.

- ii. In these substances the chemical composition has the same atomic ratio.
- iii. For example :
 - a. NaF and MgO
 - b. NaNO_3 and CaCO_3 are isomorphous pairs and have the same atomic ratios, 1 : 1 and 1 : 1 : 3 respectively of the constituent atoms.

2. Polymorphism :

- i. A single substance that exists in two or more forms or crystalline structure is said to be polymorphous.
- ii. Polymorphs of a substance are formed under different conditions.
- iii. For example :
 - a. Calcite and aragonite are two forms of calcium carbonate.
 - b. α -quartz, β -quartz and cristobalite are three of the several forms of silica.

Q.11 What is meant by allotropy ?

Ans : Polymorphism occurring in elements is called allotropy.

For example : Three allotropic forms of carbon are diamond, graphite and fullerene.

Do you know ?

Many crystalline forms of silica (SiO_2) are found in nature. Three of them are α -quartz, β -quartz and cristobalite.

1.3 Classification of crystalline solids

Q.12 What are the four main classes of crystalline solids ?

Ans : The four main classes of crystalline solids are :

- i. Ionic solids
- ii. Covalent network solids
- iii. Molecular solids
- iv. Metallic solids.

Q.13 Write the characteristics of ionic crystals ?

Ans : Ionic crystals have the following characteristics :

- i. The constituent particles of ionic crystals are charged ions. The cations and anions may differ

in size.

- ii. Each ions of a given sign of charge is bonded to ions of opposite charge around it by coulomb force. In other words, the particles of ionic crystals are held by electrostatic force of attraction between oppositely charged ions.
- iii. Ionic crystals are hard and brittle. They have high melting points.
- iv. These are non-conductors of electricity in solids state. However, they are good conductors when melted or dissolved in water.
For example : NaCl, K_2SO_4 , CaF_2 , KCl are ionic crystals.

Q.14 Give the characteristics of covalent network crystals.

Ans : Characteristics of covalent network crystals are as follows :

- i. The constituent particles in covalent network solids are atoms.
- ii. The atoms in these crystals are linked by a continuous system of covalent bonds. The result is a rigid three dimensional network that forms a giant molecule. The entire crystal is a single molecule.
- iii. As a result of rigid and strongly bonded structure, covalent network crystals are very hard. In fact they are the hardest and most incompressible of all the materials. These crystals have high melting and bonding points.
- iv. The electrons are localised in covalent bonds and hence are not mobile. As a result, covalent solids are poor conductors of heat and electricity.
For examples : Diamond, quartz (SiO_2), boron nitride, carborandum are covalent network solids.

Do you know ?

Diamond is the hardest known material.

Try this

+Q.15 Graphite is a covalent solid and good conductor of electricity. Explain.

- Ans :**
- i. In graphite, each carbon is covalently bonded

- to 3 other carbon atom in hexagonal arrangement.
- ii. The fourth valence electron of each carbon atom is free to move in the delocalised molecular orbitals giving good electrical conductivity.

Q.16 State the properties of molecular crystals.
Ans :

- i. The constituent particles of molecular solids are molecules (or unbonded single atoms) of the same substance.
- ii. The bonds within the molecules are covalent. The molecules are held together by various intermolecular forces of attraction. for example:
 - a. Weak dipole-dipole interactions
 - b. Very weak dispersion or London forces
 - c. Intermolecular hydrogen bonds.
- iii. Because of weak intermolecular attractive forces, molecular solids are usually soft substances with low melting points.
- iv. These solids are poor electrical conductors and are good insulators.

***Q.17 Distinguish between ionic solids and molecular solids.**
Ans :

	Ionic Solids	Molecular Solids
i.	The constituent particles are charged ions like cations and anions.	The constituent particles are monoatomic or polyatomic molecules.
ii.	The constituent particles are held together by electrostatic force of attraction between oppositely charged ions.	The constituent particles are held together by intermolecular forces of attraction for e.g. Dipole-dipole forces, hydrogen bonding, London forces.
iii.	They are hard and brittle.	They are soft.
iv.	They are nonconductors of electricity in solid state. However, they are good conductors when melted or dissolved in water.	They are poor conductor of electricity and are good insulators.
v.	They have high melting point. (600 °C to 3000 °C)	They have low melting point. (-272 °C to 400 °C)
vi.	Example : NaCl, K ₂ SO ₄ , CaF ₂ , KCl etc.	Example : CH ₄ , CO ₂ , O ₂ and Cl ₂ etc.

Q.18 State the properties of metallic crystals.
Ans : Metallic crystals have the following properties:

- i. Metals are malleable, that is, they can be hammered into thin sheets.
- ii. Metals are ductile, that is, they can be drawn into wires.
- iii. Metals have good electrical and thermal conductivity.
Examples : metals such as Na, K, Ca, Li, Fe, Au, Ag, Co, etc.

Q.19 What are the various types of intermolecular forces that held the molecules in a molecular crystals together ?

Ans :

Property \ Type	Ionic solids	Covalent network solids	Molecular solids	Metallic solids
Particles of unit cell	Cations and anions	Covalently bonded atoms	Monoatomic or polyatomic molecules.	Metallic ions in a sea of electrons
Interparticle forces	Electrostatic	Covalent bonds	London, dipole dipole forces and/or hydrogen bonds	Metallic bonds (attraction between cations and mobile valence electrons)
Hardness	Hard and brittle	Very hard	Soft	Variable from soft to very hard
Melting points	High 600 °C to 3000 °C	High 1200 °C to 4000 °C	Low (-272 °C to 400 °C)	Wide range (-39 °C to 3400 °C)
Thermal and electrical conductivity	Poor electrical conductors in solid state. Good conductors when melted or dissolved in water	Poor conductors Exceptions : i. Graphite : good conductor of electricity. ii. Diamond : good conductor of heat	Poor conductor of heat and electricity	Good conductor of heat and electricity
Examples	NaCl, CaF ₂	diamond, silica	ice, benzoic acid	Na, Mg, Cu, Au

★ Q.20 What are the types of particles in each of the four main classes of crystalline solids ?

Ans : The types of particles in each of the four main classes of crystalline solids are :

- Ionic solids : The constituent particles are cations and anions.
- Covalent solids : The constituent particles are atoms.
- Molecular solids : The constituent particles are monoatomic or polyatomic molecules.
- Metallic solids : The constituent particles are positive ions in a sea of electrons.

★ Q.21 A solid is hard brittle and electrically nonconductors. Its melt conducts electricity. What type of solid it is ?

Ans : Ionic solids are hard, brittle and nonconductor of electricity in solid state. However, they are good conductor when melt or dissolved in water. Therefore, the given solid is an ionic solid.

1.4 Crystal Structure

Q.22 What is lattice ?

Ans : Lattice is geometrical arrangement of points in a three dimensional periodic array.

Lattice and basis are the two terms namely used to describe the ordered three dimensional arrangement of particles in a crystals.

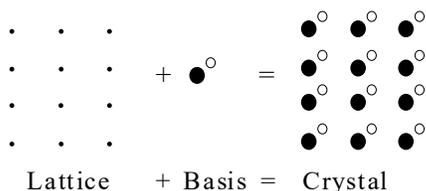
Q.23 Explain the term basis ?

Ans : Basis of the crystal lattice is the constituent particles that are attached to the lattice points.

Q.24 Explain how crystal structure is obtained from lattice and basis ?

Ans :

- A crystal structure is obtained by attaching a constituent particle (or basis) to each of the lattice point.
- Such constituent particles (or basis) that are attached to the lattice points forms the basis of the crystal lattice.
- Crystal lattice is also called space lattice of crystal.
- Thus, crystal is the structure that results by attaching a basis to each of the lattice points.



★Q.25 What is the unit cell ?

Ans : The smallest repeating structural unit of a crystalline solid is called unit cell.

Q.26 Explain : Unit cell.

Ans : The smallest repeating structural unit of a crystalline solid is called unit cell.

Q.27 Describe different types of unit cells.

Ans : There are four types of unit cells.

- Primitive or simple unit cell :** In primitive unit cell, the constituent particles are present at its corners only.
- Body-centred unit cell :** In this type of unit cell, one constituent particle is present at the centre of its body in addition to the corner particles.
- Face-centred unit cell :** This unit cell consists of particles at the centre of each of the faces in addition to the corner particles.
- Base-centred unit cell :** This unit cell consists of particles at the centre of any two of its opposite faces in addition to the corner particles.

Q.28 Explain Bravais lattice in crystal structure.

Ans :

- By mathematical analysis, it has been proved that only fourteen different kinds of space

lattices are possible.

- In other words, there are only 14 ways in which similar points can be arranged in a three dimensional order. These 14 lattices, which describe the crystal structure, are called Bravais lattices.
- Fourteen Bravais lattices are divided into seven crystal systems. The possible combinations of lattice point spacings (a , b and c) along three axes and the angles (α , β and γ) between these axes give rise to seven crystal systems.
- In other words, seven crystal systems are associated with 14 Bravais lattices also called 14 unit cells.

Q.29 Give the names of seven crystal structure.

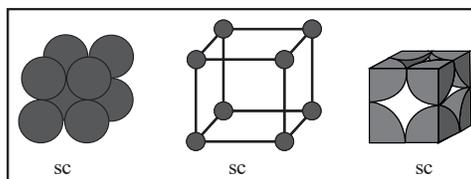
Ans : The seven crystal systems are named as cubic, tetragonal, orthombic rhombohedral, monoclinic, triclinic and hexagonal system.

1.5 Cubic System

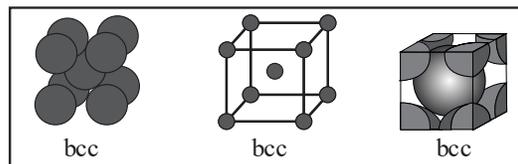
Q.30 Name and explain three kinds of unit cells in cubic system with the help of diagram

Ans : There are three kinds of unit cells in cubic system : primitive or simple cubic (sc), body-centred cubic (bcc) and face-centred cubic (fcc).

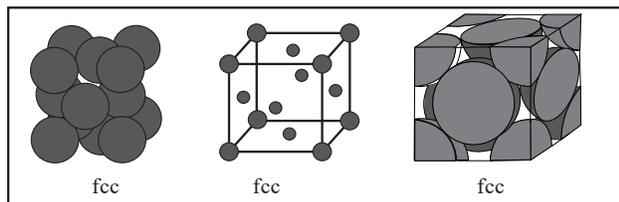
- Simple cubic unit cell (sc)** it has a particle at each of the eight corners of a cube.



- Body-centred cubic unit cell (bcc)** it has particles at its eight corners and an additional particle in the center of the cube.



- Face-centred cubic unit cell (fcc)** it has particle at the centre of each of six faces in addition to the particles at eight corners of the cube.



Q.31 Calculate the number of particles in primitive or simple cubic unit cell.

Ans :

- A simple cubic cell has particles at its eight corner.
- Particle at each corner of a given unit cell is shared with seven other neighbouring cubes that comes together at that corner.
- As a result, the corner particle contribute only $1/8$ to a single unit cell.
- Therefore, a simple cubic cell has $\frac{1}{8} \times 8 = 1$ particle per unit cell.

Q.32 Calculate the number of particles in body-centred cubic unit cell (bcc)

Ans :

- A bcc unit cell has eight corner particles and an additional particles at the centre of the cube.
- Particle at each corner of a given unit cell is shared with several other neighbouring cubes that comes together at that corner.
- The particle at the centre of a given cube is not shared by any other cube.
- Thus, bcc unit cell has one particle in the centre of the cube $= \frac{1}{8} \times 8 + 1$ making total of 2 particles per bcc unit cell.

***Q.33 Calculate the number of atoms in face-centred cubic unit cell (fcc).**

Ans :

- A fcc unit cell has particles at the eight corners plus particles at the centre of its six faces.
- Particle at each corner of a given unit cell is shared with several other neighbouring cubes that comes together at that corner.
- Each particle at the centre of that six faces is shared with one neighbouring cube.
- Thus, $1/2$ of each face particle belongs to the

given unit cells. From six face, $\frac{1}{2} \times 6 = 3$ particles belong to the given unit cell.

- Therefore, fcc unit cell has one corner particle plus 3 face particles total 4 particles per unit cell.

Remember

Each corner particle of a cube is shared by 8 cubes, each face particle is shared by 2 cubes and each edge particle is shared by 4 cubes.

Q.34 Obtain the relationship between density of a substance and the edge length of unit cell.

Ans :

- If edge length of cubic unit cell is a , the volume of unit cell is a^3 .
- Suppose that mass of one particle is m and that there are n particles per unit cell.
Mass of unit cell = $m \times n$... (i)
- The density of unit cell (ρ), which is same as density of the substance is given by

$$\rho = \frac{\text{mass of unit cell}}{\text{volume of unit cell}}$$

$$= \frac{m \times n}{a^3} = \text{density of substance} \quad \dots \text{(ii)}$$

- Molar mass of the substance is given by
 $M = \text{mass of one particle} \times \text{number of particles per mole}$
 $= m \times N_A$ (N_A is Avogadro number)
Therefore, $m = M/N_A$... (iii)
- Combining Eq. (i) and (ii), gives

$$\rho = \frac{nM}{a^3 N_A}$$

Type - 1

Numerical based on density

Formula used

$$\rho = \frac{nM}{a^3 N_A}$$

- *1. When gold crystallizes, it forms face-centred cubic cells. The unit cell edge length is 408 pm. Calculate the density of gold. Molar mass of gold is 197 g/mol.**

Data : Edge length (a) = 408 pm

Molar mass of gold (M) = 197 g/mol

Number of atoms (n) = 4

Avogadro's number (N_A)
= 6.022×10^{23} atom mol⁻¹

To find : Density of the gold (ρ)

Formula : $\rho = \frac{nM}{a^3 N_A}$

Solution :

Since it is an fcc lattice number of atoms in an unit cell is 4.

$$\rho = \frac{nM}{a^3 N_A}$$

$$\rho = \frac{197 \text{ g mol}^{-1} \times 4 \text{ atom}}{(4.08 \times 10^{-8})^3 \text{ cm}^3 \times 6.022 \times 10^{23} \text{ atom mol}^{-1}}$$

$$= \frac{197 \times 4}{(4.08 \times 10^{-8})^3 \times 6.022 \times 10^{23}}$$

$$= \frac{197 \times 4}{(4.08)^3 \times 10^{-24} \times 6.022 \times 10^{23}}$$

$$= \frac{197 \times 4}{(4.08)^3 \times 6.022 \times 10^{-1}}$$

$$= \frac{1970 \times 4}{(4.08)^3 \times 6.022}$$

$$= \frac{1970 \times 4}{(4.08)^3 \times 6.023}$$

$$= \text{Antilog} [\log (1970) + \log (4)] - [3 \log 4.08 + \log 6.023]$$

$$= \text{Antilog} [3.2944 + 0.6020] - [3(0.6106) + (0.7798)]$$

$$= \text{Antilog} [3.8984] - [1.3318 + 0.7798]$$

$$= \text{Antilog} [3.8964] - [2.6116]$$

$$= \text{Antilog} [1.2848]$$

$$= 19.27 \text{ g/cm}^3$$

$$= 19.27 \times 10^3 \text{ kg/m}^3$$

Ans : Density of gold is $19.27 \times 10^3 \text{ kg/m}^3$.

★2. An element with molar mass 27 g/mol forms cubic unit cell with edge length of 405 pm. If density of the element is 2.7 g/cm³. What is the nature of cubic unit cell ?

Data : Molar mass (M) = 27 g/mol
Edge length (a) = 405 pm
Density (ρ) = 2.7 g/cm³

To find : Nature of cubic unit cell

Formula : $\rho = \frac{nM}{a^3 N_A}$

Solution : $\rho = \frac{nM}{a^3 N_A}$

$$n = \frac{\rho N_A a^3}{M}$$

$$= \frac{2.7 \text{ g/cm}^3 \times 6.022 \times 10^{23} \text{ atom/mol}}{(4.05 \times 10^{-8})^3 \text{ cm}^3}$$

$$= \frac{27 \text{ g/mol}}{27 \text{ g/mol}}$$

$$= 0.1 \times 6.022 \times 10^{23} \times (4.05)^3 \times 10^{-24}$$

$$= 10^{-1} \times 6.022 \times 10^{23} \times (4.05)^3 \times 10^{-24}$$

$$= 6.022 \times (4.05)^3 \times 10^{23} \times 10^{-25}$$

$$= 6.022 \times (4.05)^3 \times 10^{-2}$$

$$= \text{Antilog} [\log (6.022) + 3 \log (4.05)] \times$$

$$10^{-2}$$

$$= \text{Antilog} [0.7797 + 3(0.6074)] \times 10^{-2}$$

$$= \text{Antilog} [0.7797 + 1.8222] \times 10^{-2}$$

$$= \text{Antilog} (2.6019) \times 10^{-2}$$

$$= 399.8 \times 10^{-2}$$

$$= 3.998$$

$$n \approx 4$$

Number of atoms in a unit cell = 4

Since, the unit cell consist of 4 atoms, it has face-centred cubic (fcc) structure.

Ans : The nature of given cubic unit cell is face-centred cubic (fcc).

Problem for Practice

- An element with density 10 g cm^{-3} forms a cubic unit cell with edge length $3 \times 10^{-8} \text{ cm}$. What is the nature of the cubic unit cell if the atomic mass of the element is 81 g/mol .

Ans : (BCC unit cell)

- An element with atomic mass 93 g mol^{-1} has density 11.5 g cm^3 . If the edge length of its unit cell is 300 pm . Identify the type of unit cell.

Ans : (BCC unit cell)

1.6 Packing of Particles in Crystal Lattice

Q.35 Explain the term : Coordination number.

Ans :

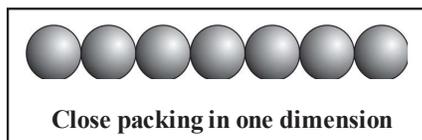
- The number of neighbouring spheres that touch any given sphere is its coordination number.

- ii. Magnitude of the coordination number is a measure of compactness of spheres in close-packed structures.
- iii. The larger the coordination number, the closer are the spheres to each other.

[Note : Constituent particles of a crystalline solid are close packed. While describing the packing of particles in a crystal, the individual particles are treated as hard spheres. The closeness of particles maximize the interparticle attractions.]

Q.36 Explain one dimensional closed packing in solids.

Ans : A close packed one dimensional structure results by arranging the spheres to touch each other in a row.



The coordination number of one dimensional closed packing is two.

Q.37 Explain two dimensional closed packing in solids.

Ans :

i. Close packing in two dimensions : A close packed two dimensional (planar) structure results by stacking the rows together such that they are in contact with each other. There are two ways to obtain close packing in two dimensions.

ii. Square close packing :

- a. One dimensional rows of close packed spheres are stacked over each other such that the spheres align vertically and horizontally.
- b. If the first row is labelled as 'A' type, being exactly same as the first row, the second row is also labelled as 'A' type.
- c. Hence this arrangement is called A, A, A, A..... type two dimensional arrangement. In this arrangement, every sphere touches four neighbouring spheres.
- d. Hence, two dimensional coordination

number, here, is 4.

- e. A square is obtained by joining the centres of these four closest neighbours.
- f. Therefore, this two dimensional close packing is called square close packing in two dimension.

iii. Hexagonal close packing :

- a. Close packed one dimensional row shows that there are depressions between the neighbouring spheres.
- b. If the second row is arranged in such a way that its spheres fit in the depressions of the first row, a staggered arrangement results.
- c. If the first row is called 'A' type row, the second row, being different, is called 'B' type.
- d. Placing the third row in staggered manner in contact with the second row gives rise to an arrangement in which the spheres in the third row are aligned with the spheres in the first row. Hence the third row is 'A' type.
- e. Similarly spheres in the fourth row will be aligned with the spheres in the second row and hence the fourth row would be 'B' type.
- f. The resulting two dimensional arrangement is 'ABAB...' type.
- g. In this arrangement each sphere touches six closest neighbours. Thus, the two dimensional coordination number in this packing is 6.
- h. A regular hexagon is obtained by joining the centres of these six closest spheres.
- i. Hence, this type of two dimensional close packing is called hexagonal close packing in two dimensions.

Q.38 Distinguish between square close packing in two dimension and hexagonal close packing in two dimension.

Ans :

	Square close packing in two dimension	Hexagonal close packing in two dimension
i.	Spheres are over each other such that the spheres align vertically and horizontally.	The spheres of second row fits in the depression of the first row, results in a staggered arrangement.
ii.	The arrangement is called AAAA.... type two dimensional arrangement.	The arrangement is called ABAB.... type two dimensional arrangement.
iii.	The coordination number in this type of packing is 4.	The coordination number in this type of packing is 6.

iv.	A square is obtained by joining the centres of the closest neighbours.	A regular hexagon is obtained by joining the centres of the closed neighbours.
v.	The square close packing is less efficient close packing.	The hexagonal close packing is more efficient the square close packing.
vi.	The free space in this arrangement is more.	The free space in this arrangement is less.

Q.39 Which are the two types of voids seen in hexagonal close packing ?

Ans : Two types of apex of the triangular voids in alternate rows pointing upwards and downwards are seen in hexagonal close packing.

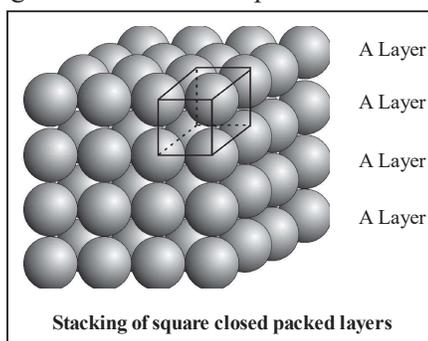
Q.40 Explain three dimensional close packing in solids.

Ans : **Close packing in three dimensions :** Stacking of two dimensional layers gives rise to three

dimensional crystal structures. Two dimensional square close packed layers are found to stack only in one way to give simple cubic lattice. Two dimensional hexagonal close packed layers are found to stack in two distinct ways. Accordingly two crystal structures, namely, hexagonal close packed (hcp) structure and face centred cubic (fcc) structure are formed.

i. Stacking of square close packed layers :

- Stacking of square close packed layers generates a three dimensional simple cubic structure.
- Here, the second layer is placed over the first layer so as to have its spheres exactly above those of the first layer.
- Subsequent square close packed layers are placed one above the other in the same manner.
- In this arrangement, spheres of all the layers are perfectly aligned horizontally as well as vertically.
- Hence, all the layers are alike, and are labelled as 'A' layers. This arrangement of layers is described as 'AAAA...' type.
- The structure that results on stacking square close packed layers is simple cubic.
- Its unit cell is the primitive cubic unit cell.

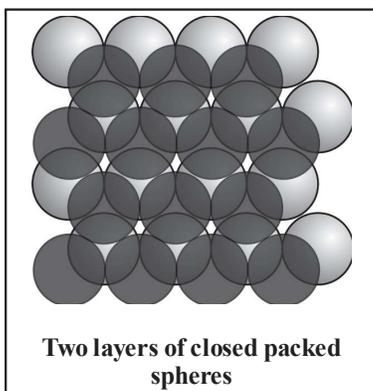


h. It can be seen that in the simple cubic structure, each sphere touches six neighbouring spheres, four in its own layer, one in the layer above and one in the layer below.

i. Hence, coordination number of each sphere is 6.

j. Polonium is the only metal that crystallizes in simple cubic closed packed structure.

- ii. **Stacking of two hexagonal close packed layers :**
- To generate a close packed three dimensional structure, hexagonal close packed layers are arranged in a particular manner.
 - In doing so, spheres of the second layer are placed in the depression of the first layer.
 - If the first layer is labelled as 'A' layer, the second layer is labelled as 'B' layer because the two layers are aligned differently.
 - It is evident from the that all triangular voids of the first layers are not covered by the spheres of the second layer.
 - The triangular voids that are covered by spheres of the second layer generate tetrahedral void.
 - A tetrahedral void is surrounded by four spheres.
 - On joining the centres of these four spheres a tetrahedron is formed which encloses the tetrahedral voids.
 - The remaining triangular voids of the first layer have above them the triangular voids of the second layer.
 - The overlapping triangular voids from the two layers together form an octahedral void which is surrounded by six spheres.



- iii. **Placing third hexagonal close packed layer :**
- There are two ways of placing the third hexagonal close packed layer on the second.
 - One way of doing this is to align the spheres of the third layer with the spheres

- of the first layer.
- The resulting pattern of the layers will be 'ABAB....'. This arrangement results in hexagonal close packed (hcp) structure.
- Metals such as Mg, Zn, have hcp crystal structure.
- The second way of placing the third hexagonal close packed layer on the second is to cover the octahedral voids by spheres of the third layer.
- In such placing, the spheres of the third layer do not align with the spheres of the second or the spheres of the first layer.
- The third layer is, therefore, called 'C' layer.
- The spheres of the fourth layer get aligned with the spheres of the first layer.
- Hence, the fourth layer is called 'A' layer.
- This pattern of stacking hexagonal close packed layers is called 'ABCABC....'.
- This arrangement results in cubic close packed (ccp) structure.
- This is same as fcc structure. Metals such as copper and Ag have ccp (or fcc) crystal structure.

Q.41 How are the the spheres arranged in the first layer of simple cubic closed. Packed structures ? How are the successive layers of spheres placed above this layers ?

Ans :

- In simple cubic closed pack structures is obtained by staking spheres in the form of square closed packing.
- The spheres in the first layer of simple cubic closed-packed structure are arranged in AAAA type arrangement.
- The successive layer is placed exactly one above the another touching four neighbouring spheres.

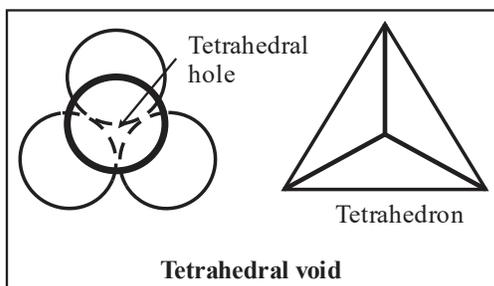
★Q.42 Third layer of sphere is added to second layer so as to hcp or ccp structure. What is the difference between the additional of third layer to form these hexagonal closed-packed structures ?

Ans :

- In hcp or ccp structure, the third layer is not aligned with those of the first layer or second layer.
- Therefore, the third layer is called as 'C' layer.
- The spheres of the fourth layer get aligned like the sphere of the first layer.
- Therefore, the fourth layer is called 'A' layer. Therefore, the resulting arrangement is called ABCABC type of arrangement.

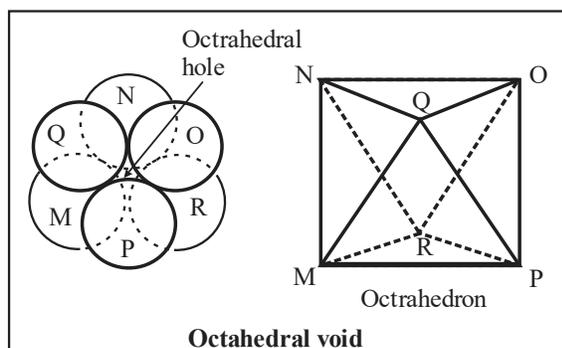
★Q.43 Draw a tetrahedral void.

Ans :



Q.43 Draw an octahedral void.

Ans :



★Q.44 How are tetrahedral and octahedral voids formed ?

Ans :

- Two dimensional hexagonal closed packed layer has trigonal void formed by three spheres covered.
- When a sphere is placed on the triangular void of the first layer, tetrahedral void is formed. A tetrahedral void is surrounded by four spheres.
- An octahedron is formed when three closed pack spheres forming a triangular void is placed over another set of three closed pack spheres forming a triangular void. An octahedral void is surrounded by six spheres.

Q.45 Explain the co-ordination of the following

structures

- Simple cubic (sc) crystal**
- In hcp and ccp/fcc structure.**

Ans :

- In the simple cubic (sc) crystal structure, that results from stacking of square close packed layers, each sphere is surrounded by 6 neighbouring spheres, 4 in its own layer, 1 above and 1 below. Hence coordination number of any sphere in sc is 6.
- In both hcp and ccp/fcc structures that result from stacking of hexagonal close packed layers in two different ways, each sphere is surrounded by 12 neighbouring spheres, 6 in its own layer, 3 above and 3 below. Hence, the coordination number of any sphere in hcp or ccp/fcc structure is 12.

Q.46 What are the number of voids per atom in hcp and ccp ?

Ans : The tetrahedral and octahedral voids occur in hcp and ccp/fcc structures. There are two tetrahedral voids associated with each atom. The number of octahedral voids is half that of tetrahedral voids. Thus, there is one octahedral void per atom.

[Note : If N denotes number of particles, then number of tetrahedral voids is 2N and that of octahedral voids is N.]

1.7 Packing Efficiency

Q.47 Explain : Packing Efficiency.

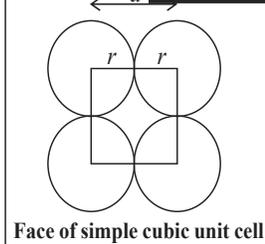
Ans :

- The magnitude of packing efficiency gives a measure of how tightly particles are packed together.
- Packing efficiency is the fraction or a percentage of the total space occupied by the spheres (particles).
Packing efficiency =

$$\frac{\text{volume occupied by particle in unit cell}}{\text{total volume of cell}}$$

Q.48 Calculate the packing efficiency of metal crystal in simple cubic lattice.

Ans :



Packing efficiency of metal crystal in simple cubic lattice is obtained by the following steps.

Step 1 : Radius of sphere : In simple cubic unit cell, particles (spheres) are at the corners and touch each other along the edge. A face of simple cubic unit cell is shown in figure. It is evident that

$$a = 2r \text{ or } r = a/2 \quad \dots \text{ (i)}$$

where r is the radius of atom and 'a' is the length of unit cell edge.

Step 2 : Volume of sphere : Volume of a sphere = $\left(\frac{4\pi}{3}\right)(r^3)$ Substitution for r from Eq. (i) gives.

$$\text{Volume of one particle} = \left(\frac{4\pi}{3}\right)(a/2)^3 = \frac{\pi a^3}{6} \quad \dots \text{ (ii)}$$

Step 3 : Total volume of particles : Because simple cubic unit cell contains only one particle, volume occupied by particle in unit cell

$$= \frac{\pi a^3}{6}$$

Step 4 : Packing efficiency :

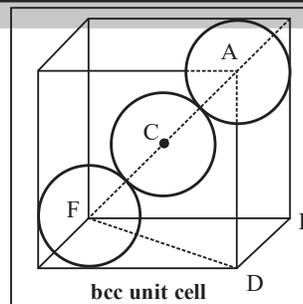
$$\text{Packing efficiency} = \frac{\text{volume occupied by particle in unit cell}}{\text{total volume of cell}} \times 100$$

$$\begin{aligned} &= \frac{\pi a^3}{6} \times 100 = \frac{100\pi}{6} \\ &= \frac{100 \times 3.142}{6} = 52.36\% \end{aligned}$$

Thus, in simple cubic lattice, 52.36 % of total space is occupied by particles and 47.64% is empty space, that is, void volume.

Q.49 Calculate the packing efficiency of metal crystal in body-centred cubic (bcc) lattice.

Ans :



Packing efficiency of metal crystal in body-centred cubic (bcc) lattice can be obtained by the following steps :

Step 1 : Radius of sphere (particle) : In bcc unit cell, particles occupy the corners and in addition one particle is at the centre of the cube. The figure shows that the particle at the centre of the cube touches two corner particles along the diagonal of the cube. To obtain radius of the particle (sphere) Pythagoras theorem is applied.

For triangle FED $\angle FED = 90^\circ$.

$$\therefore FD^2 = FE^2 + ED^2 = a^2 + a^2 = 2a^2 \quad \text{(because } FE = ED = a) \quad \dots \text{ (i)}$$

For triangle AFD, $\angle ADF = 90^\circ$

$$\therefore AF^2 = AD^2 + FD^2 \quad \dots \text{ (ii)}$$

Substitution of Eq (i) into Eq. (ii) yield

$$AF^2 = a^2 + 2a^2 = 3a^2 \quad \text{(because } AD = a)$$

$$\text{or } AF = \sqrt{3} a \quad \dots \text{ (iii)}$$

The figure shows that $AF = 4r$.

Substitution for AF from equation (iii) gives

$$\sqrt{3} a = 4r \text{ and hence, } r = \frac{\sqrt{3}}{4} a \quad \dots \text{ (iv)}$$

Step 2 : Volume of sphere : Volume of sphere particle = $\frac{4}{3} \pi r^3$. Substitution for r from Eq. (iv)

$$\begin{aligned} \text{volume of one particle} &= \frac{4}{3} \pi \left(\frac{\sqrt{3}}{4} a\right)^3 \\ &= \frac{4}{3} \pi \times \frac{(\sqrt{3})^3}{64} a^3 \\ &= \frac{\sqrt{3} \pi a^3}{16} \end{aligned}$$

Step 3 : Total volume of particles : Unit cell bcc contains 2 particles. Hence, volume occupied by particles in bcc unit cell.

$$= 2 \times \frac{2\sqrt{3} \pi a^3}{16}$$

$$= \frac{\sqrt{3}\pi a^3}{8} \quad \dots (v)$$

Step 4 : Packing efficiency

Packing efficiency

$$= \frac{\text{volume occupied by particles in unit cell}}{\text{total volume of unit cell}} \times 100$$

$$= \frac{\sqrt{3}\pi a^3}{8a^3} \times 100 = 68\%$$

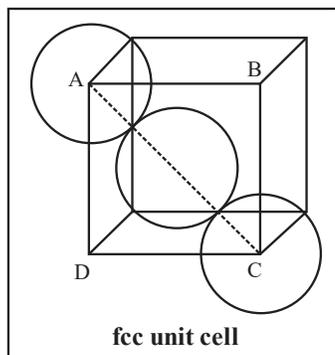
Thus, 68 % of the total volume in bcc unit lattice is occupied by atoms and 32 % is empty space or void volume.

Q.50 Calculate packing efficiency of metal crystal in body-centred cubic (bcc) lattice.

Ans : Packing efficiency of metal crystal in body-centred cubic (bcc) lattice can be obtained by the following steps :

Step 1 : Radius of particle/sphere : The corner particles are assumed to touch the particle at the centre of face ABCD as shown in figure. The triangle ABC is right angles with $\angle ABC = 90^\circ$. According to Pythagorus theorem,

$$AC^2 = AB^2 + BC^2 = a^2 + a^2 = 2a^2$$



(because $AB = BC = a$)

$$\text{Hence, } AC = \sqrt{2} a \quad \dots (vi)$$

Figure shows that $AC = 4r$. Substitution for AC from Eq. (vi) gives

$$\sqrt{2} a = 4r \text{ or } r = \frac{\sqrt{2}}{4} a = \frac{a}{2\sqrt{2}} \quad \dots (vii)$$

Step 2 : Volume of sphere : Volume of one particle

$$= \frac{4}{3} \pi r^3. \text{ Substitution for } r \text{ from Eq. (vii) gives.}$$

$$\begin{aligned} \text{Volume of one particle} &= \frac{4}{3} \pi \left(\frac{a}{2\sqrt{2}} \right)^3 \\ &= \frac{4}{3} \pi a^3 \times \left(\frac{1}{2\sqrt{2}} \right)^3 \\ &= \frac{\pi a^3}{12\sqrt{2}} \end{aligned}$$

Step 3 : Total volume of particles : The unit cell of fcc lattice contains 4 particles. Hence, volume of occupied by particles in fcc unit cell

$$= 4 \times \frac{\pi a^3}{12\sqrt{2}} = \frac{\pi a^3}{3\sqrt{2}}$$

Step 4 : Packing efficiency : Packing efficiency

$$= \frac{\text{volume occupied by particles in unit cell}}{\text{total volume of unit cell}} \times 100$$

$$= \frac{\pi a^3}{3\sqrt{2}} \times 100 = \frac{\pi}{3\sqrt{2}} \times 100 = 74\%$$

Thus in fcc/hcp crystal lattice, 74 % of the total volume is occupied by particles and 26 % is void volume or empty space.

Q.51 Which of the three lattice, sc, bcc and fcc has the most efficient packing of particles ? Which one has the least efficient packing ?

Ans : Out of the three lattices, face-centred cubic (or ccp or hcp) has the most efficient packing of 74 % of the total volume is occupied by particles, while simple cubic system (sc) has the least efficient packing of 52.36 % of the total volume is occupied by particles.

Unit cell	Relation between a and r	Volume of one particle	Total volume occupied by particles in unit cell
sc	$r = a/2 = 0.5000a$	$\pi a^3/6 = 0.5237a^3$	$\pi a^3/6 = 0.5237a^3$
bcc	$r = \sqrt{3}a/4 = 0.4330a$	$\sqrt{3}\pi a^3/16 = 0.34a^3$	$\sqrt{3}\pi a^3/8 = 0.68a^3$
fcc	$r = \sqrt{2}a/4 = 0.3535a$	$\pi a^3/12\sqrt{2} = 0.185a^3$	$\pi a^3/3\sqrt{2} = 0.74a^3$

★Q.52 Which of the three types of packing used by metals making the most efficient the least efficient space and which makes the least

efficient use ?

Ans : Out of the three types of packing face-centred cubic (or ccp or hcp) lattice makes the most efficient use of space while simple cubic lattice makes the least efficient use of space.

★ Q.53 Mention two properties that are common to both hcp and ccp lattices.

Ans : Common properties of both hcp and ccp lattices are same coordination number 12 and same packing efficiency of 74 %.

Lattice	Coordination number of atoms	Packing efficiency
sc	6 : four in the same layer, one directly above and one directly below	52.40%
bcc	8 : four in the layer below and four in the layer above	68%
fcc/ccp/hcp	12 : six in its own layer, three above and three below	74%

Coordination number and packing efficiency in systems

Q.54 Derive the formula for the number of particles and number of unit cells in x g of metallic crystal.

Ans : Density (ρ) and molar mass (M) of a metal are related to each other through unit cell parameters as shown below :

$$\rho = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{\text{number of particles in unit cell}}{\text{volume of unit cell}} \times \frac{M}{N_A}$$

$$\therefore \rho = \frac{n}{a^3} \times \frac{M}{N_A}$$

$$\therefore M = \rho \frac{a^3 N_A}{n}$$

where 'n' is the number of particles in unit cell

and ' a^3 ' is the volume of unit cell.

Number of particles in 'x' g metal :

\therefore Molar mass, M , contains N_A particles

\therefore x g of metal contains $\frac{xN_A}{M}$ particles.

substitution of M gives

$$\text{Number of particles in 'x' g} = \frac{xN_A}{\rho a^3 N_A / n}$$

$$= \frac{xn}{\rho a^3}$$

Number of unit cells in 'x' g metal :

\therefore 'n' particles correspond to 1 unit cell

$\therefore \frac{xn}{\rho a^3}$ particles correspond to $\frac{xn}{\rho a^3} \times \frac{1}{n}$ unit cells.

\therefore Number of unit cells in 'x' g metal $\frac{x}{\rho a^3}$.

Q.55 Write the formula to calculate the number of unit cells in volume 'V' of a metal.

Ans : Number of unit cells in volume 'V' of metal

$$= \frac{V}{a^3}.$$

Here, a^3 is the volume of unit cell.

Type - 2

Numerical based on voids, atomic radius and edge length

Formula used

- For scc unit cell : $r = 0.5 a$
- For bcc unit cell : $r = 0.4330 a$
- For fcc unit cell : $r = 0.3535 a$

- Density $\rho = \frac{n}{a^3} \times \frac{M}{N_A}$

- Number of atom in x gram of metal = $\frac{xn}{\rho a^3}$

- Number of unit in x gram of metal = $\frac{x}{\rho a^3}$

+1. A compound made of elements C and D crystallizes in fcc structure. Atoms of C are present at the corners of the cube. Atoms of D are at the centres of faces of the cube. What is the formula of the compound ?

- Given :**
- Element C and D forms fcc structure
 - Atom C present at the corner
 - Atom D are the centre of faces

To find : Formula of the compound

Solution :

- C atoms are present at the 8 corners. The contribution of each corner atom to the unit cell is $1/8$ atom. Hence, the number of C atom that belongs to the unit cell $= 8 \times (1/8) = 1$
- D atoms are present at the centres of six faces of unit cell. Each face-centre atom is shared between two cubes. Hence, contribution of each face centre atom to the unit cell is $1/2$ atom. The number of D atoms that belong to unit cell $= 1/2 \times 6 = 3$
There are one C atom and three D atoms in the unit cell.
Formula of compound $= CD_3$.

- +2. A compound is formed by two elements A and B. The atoms of element B forms ccp structure. The atoms of A occupy $1/3$ rd of tetrahedral voids. What is the formula of the compound ?**

- Given :**
- Atom of element B forms ccp structure
 - Atom A occupy $1/3$ rd of tetrahedral voids

To find : Formula of the compound

Solution : The atoms of element B form ccp structure. The number of tetrahedral voids generated is twice the number of B atoms.

Thus, number of tetrahedral voids $= 2B$

The atoms A occupy $(1/3)$ of these tetrahedral voids.

Hence, number of A atoms $= 2B \times 1/3$

Ratio of A and B atoms $= 2/3 B : 1B$

$= 2/3 : 1 = 2 : 3$

Formula of compound $= A_2B_3$.

- ★3. Cesium chloride crystallizes in cubic unit cell with Cl^- ions at the corners and a Cs^+ ion in the centre of the cube. How many CsCl molecules are there in the unit cell ?**

- Given :**
- Cl^- ions are at the corners of the cube
 - Cs^+ ions are in the centres of the cube

To find : Number of CsCl molecules in the unit cell

Solution : Cl^- ions are present on the 8 corners of a cube.

Atoms present on the corner, contributes $1/8$ to the unit cell.

Therefore, the number of atoms present in a

$$\text{unit cell} = \frac{1}{8} \times 8 = 1$$

Cs^+ ion is at the centre of the unit cell.

Atom present in the centre of a unit cell contributes completely.

Therefore, the number of Cs^+ ion present in a unit cell $= 1$.

In a unit cell, there is one Cl^- atom and one Cs^+ ion.

Therefore, number of CsCl molecule in the unit cell $= 1$.

Ans : Number of CsCl molecule in the unit cell $= 1$.

- ★4. In an ionic crystalline solid atoms of element y from hcp lattice. The atoms of the element x occupy one third of tetrahedral voids. What is the formula of the compound ?**

- Given :**
- Atoms of element y forms hcp lattice.
 - Atoms of element x occupy one third of tetrahedral voids.

To find : Formula of the compound.

Solution : The atoms of element y form hcp lattice. The number of tetrahedral voids generated is twice the number of y atoms.

Therefore, the number of tetrahedral voids $= 2y$.

The atoms of element x occupy $1/3$ of these tetrahedral voids.

$$\text{Number of atoms} = 2y \times (1/3) = \frac{2y}{3}$$

The ratio of x and y atoms $= 2/3y : 1y$

$= 2/3 : 1$

$= 2 : 3$

Formula of compound $= 2 : 3$.

Ans : Therefore, the formula of the compound is $2 : 3$.

- +5. A compound forms hcp structure. What is the number of (a) octahedral voids (b) tetrahedral voids (c) total voids formed in**

0.4 mol of it ?

Given : Compound forms hcp structure

Number of moles = 0.4 mol

To find : i. Number of octahedral voids
ii. Number of tetrahedral voids
iii. Total number of voids

Solution :

Number of atoms in 0.4 mol = $0.4 \times N_A$
= $0.4 \times 6.022 \times 10^{23} = 2.4098 \times 10^{23}$

(a) Number of octahedral voids = number of atoms = 2.4098×10^{23}

(b) Number of tetrahedral voids
= 2 × number of atoms
= $2 \times 2.4098 \times 10^{23}$
= 4.818×10^{23}

(c) Total number of voids
= $2.409 \times 10^{23} + 4.818 \times 10^{23}$
= 7.227×10^{23} .

★6. Cu crystallizes in fcc unit cell with edge length of 495 pm. What is the radius of Cu atom ?

Given : Type of unit cell is fcc

Edge length of unit cell (a) = 495 pm

To find : Radius of Cu atom (r)

Formula : For fcc unit cell, $r = 0.3535 a$

Solution : According to the formula

$r = 0.3535 a$
= 0.3535×495
= $\text{Antilog}_{10} [\log_{10} 0.3535 + \log_{10} 495]$
= $\text{Antilog}_{10} [(-0.4516) + 2.6946]$
= $\text{Antilog}_{10} (2.243)$
= 174.98
 $r = 175 \text{ pm}$

★7. The density of iridium is 22.4 g/cm³. The unit cell of iridium is fcc. Calculate the radius of iridium atom. Molar mass of iridium is 192.2 g/mol.

Given : Density of iridium (P) = 22.4 g/cm³.

Type of unit cell is fcc.

Molar mass of iridium (M) = 192.2 g/mol

To find : Radius of iridium atom.

Formula : i. $\text{Density (P)} = \frac{M \times n}{a^3 \times N_A}$

ii. $r = 0.3535 \times a$

Solution : In a fcc unit cell (n) = 4

According to formula (i)

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

$$22.4 \text{ g/cm}^3 = \frac{192.2 \text{ g/mol} \times 4 \text{ atom}}{a^3 \times 6.022 \times 10^{23} \text{ atom mol}^{-1}}$$

$$a^3 = \frac{192.2 \times 4}{22.4 \times 6.022 \times 10^{23}}$$

$$\text{Antilog} [(\log 192.2 + \log 4) - (\log 22.4 + \log 6.022 + \log 10^{23})]$$

$$\text{Antilog} [(2.2837 + 0.6020) - (1.3504 + 0.7797 + 23)]$$

$$\text{Antilog} [2.8857 - 25.1301] \\ = \text{Antilog} (-22.2444)$$

$$a^3 = 5.6963 \times 10^{-23}$$

$$a = \sqrt[3]{5.6963 \times 10^{-23}}$$

$$a = \sqrt[3]{59.963 \times 10^{-24}}$$

$$a = \sqrt[3]{59.963} \times 10^{-8} = (59.963)^{1/3} \times 10^{-8}$$

$$a = \text{Antilog} \left[\frac{1}{3} \log_{10} 59.963 \right] \times 10^{-8}$$

$$= \text{Antilog} \left[\frac{1}{3} \times 1.7555 \right] \times 10^{-8}$$

$$= \text{Antilog} (0.58516) \times 10^{-8}$$

$$a = 3.847 \times 10^{-8} \text{ cm}$$

$$a = 384.7 \text{ pm}$$

According to formula (ii)

$$r = 0.3535 a$$

$$r = 0.3535 \times 384.7 \text{ pm}$$

$$= \text{Antilog} (\log 0.3535 + \log 384.7)$$

$$= \text{Antilog} (-0.4516 + 2.5851)$$

$$= \text{Antilog} (2.1335)$$

$$r = 135.9$$

$$r = 136 \text{ pm}$$

Ans : Radius of iridium atom (r) is 136 pm.

+8. The unit cell of metallic silver is fcc. If radius of Ag atom is 144.4 pm, calculate (a) edge length of unit cell (b) volume of Ag atom, (c) the percent of the volume of a unit cell, that is occupied by Ag atoms, (d) the percent of empty space.

Given : Type of unit cell is fcc

Radius of silver (Ag) atom (r) = 144.4 pm

To find : i. Edge length of unit cell
ii. Volume of silver (Ag) atom
iii. Percent of the volume of a unit cell that is occupied by silver atoms.
iv. Percent of empty space

Formula : i. $r = 0.3535 a$

ii. Volume of an atom $= \frac{4}{3} \pi r^3$

iii. Percent of volume occupied by silver atom

$$= \frac{\text{Volume occupied by atoms in unit cell}}{\text{Total volume at unit cell}} \times 100$$

Solution :

(a) For fcc unit cell, $r = 0.3535 a$
 $r = 144.4 \text{ pm} = 144.4 \times 10^{-12} \text{ m}$
 $= 144.4 \times 10^{-10} \text{ cm}$

$$a = \frac{r}{0.3535} = \frac{144.4 \times 10^{-10} \text{ cm}}{0.3535}$$

$$= 1.261 \times 10^{-23} \text{ cm}^3$$

(c) In fcc unit cell, there are 4 Ag atoms

Volume occupied by 4 Ag atoms

$$= 4 \times 1.26 \times 10^{-23} \text{ cm}^3$$

$$= 5.044 \times 10^{-23} \text{ cm}^3$$

Total volume of unit cell $= a^3$

$$= (4.085 \times 10^{-8} \text{ cm})^3$$

$$= 6.817 \times 10^{-23} \text{ cm}^3$$

Percent of volume occupied by Ag atoms

$$= \frac{\text{volume occupied by atoms in unit cell}}{\text{total volume of unit cell}} \times 100$$

$$= \frac{5.044 \times 10^{-23} \text{ cm}^3}{6.817 \times 10^{-23} \text{ cm}^3} = 74\%$$

(d) Percent empty space $= 100 - 74 = 26\%$.

+9. Niobium forms bcc structure. The density of niobium is 8.55 g/cm^3 and length of unit cell edge is 330.6 pm . How many atoms and unit cells are present in 0.5 g of niobium ?

Given : Type of unit cell is bcc
 Density of niobium (P) $= 8.55 \text{ g/cm}^3$
 Length of unit cell edge (a) $= 330.6 \text{ pm}$
 Mass of niobium (x) $= 0.5 \text{ g}$

To find : i. Number of atoms in 0.5 g of niobium
 ii. Number of unit cells in 0.5 g of niobium.

Formula : i. Number of atom in x gram of metal

$$= \frac{xn}{\rho a^3}$$

ii. Number of unit in x gram of metal

$$= \frac{x}{\rho a^3}$$

Solution:

i. Number of atoms in $x \text{ g}$ niobium $= \frac{xn}{\rho a^3}$

$x = 0.5 \text{ g}$, $n = 2$ (for bcc structure),

$r = 8.55 \text{ g/cm}^3$,

$a = 330.6 \text{ pm} = 3.306 \times 10^{-8} \text{ cm}$.

Number of atoms in 0.5 g of niobium

$$= \frac{0.5 \text{ g} \times 2}{8.55 \text{ g cm}^{-3} \times (3.306 \times 10^{-8} \text{ cm})^3}$$

$$= 3.25 \times 10^{21}$$

ii. Number of unit cells in $x \text{ g} = \frac{x}{\rho a^3}$

Number of unit cells in 0.5 g of niobium

$$= \frac{0.5 \text{ g} \times 2}{8.55 \text{ g cm}^{-3} \times (3.306 \times 10^{-8})^3}$$

$$= 1.62 \times 10^{21}.$$

★ 10. An element has a bcc structure with unit cell edge length of 288 pm . How many unit cells and number of atoms are present in 200 g of the element ?

Density of an element $= 14.44 \text{ g/cm}^3$.

Given : Type of unit cell is bcc
 Unit cell edge length (a) $= 288 \text{ pm}$
 Mass of element (x) $= 200 \text{ g}$

To find : i. Number of atoms in 200 g of element
 ii. Number of unit cell in 200 g of element

Formula : i. Number of atoms in x gram of element

$$= \frac{xn}{\rho a^3}$$

ii. Number of unit cell in x gram of

$$\text{element} = \frac{x}{\rho a^3}$$

Solution : Since it is an bcc unit cell $n = 2$.

According to formula (i)

Number of atoms in 200 g elements

$$= \frac{xn}{\rho a^3}$$

$$\begin{aligned}
 &= \frac{200 \text{ g} \times 2 \text{ atom}}{14.44 \text{ gm}^{-3} \times (2.88 \times 10^{-8} \text{ cm})^3} \\
 &= \frac{400}{14.44 \times (2.88 \times 10^{-8})^3} \\
 &= \frac{4 \times 10^2}{14.44 \times (2.88)^3 \times (10^{-24})} \\
 &= \frac{4 \times 10^2 \times 10^{24}}{14.44 \times (2.88)^3} \\
 &= \frac{4}{14.44 \times (2.88)^3} \times 10^{26} \\
 &= \text{Antilog} [\log 4 - (\log 14.44 + \log (2.88)^3)] \\
 &\quad \times 10^{26} \\
 &= \text{Antilog} [\log 4 - (\log 14.44 + 3 \log 2.88)] \\
 &\quad \times 10^{26} \\
 &= \text{Antilog} [0.6020 - (1.1595 + 3(0.4593))] \\
 &\quad \times 10^{26} \\
 &= \text{Antilog} [0.6020 - (1.1595 + 1.3779)] \\
 &\quad \times 10^{26} \\
 &= \text{Antilog} [0.6020 - 2.5374] \times 10^{23} \\
 &= \text{Antilog} (-1.9354) \times 10^{26} \\
 &= 1.16 \times 10^{-2} \times 10^{26} \\
 &= 1.16 \times 10^{24} \\
 &\text{According to formula (ii)} \\
 &\text{Number of unit cells in 200 g of element} \\
 &= \frac{200 \text{ g}}{14.44 \text{ cm}^{-3} \times (2.88 \times 10^{-8} \text{ cm})^3} \\
 &= \frac{200}{14.44 \times (2.88)^3 \times 10^{-24}} \\
 &= \frac{2 \times 10^2 \times 10^{24}}{14.44 \times (2.88)^3} \\
 &= \frac{2}{14.44 \times (2.88)^3} \times 10^{26} \\
 &= \text{Antilog} [\log 2 - (\log 14.44 + \log (2.88)^3)] \\
 &\quad \times 10^{26} \\
 &= \text{Antilog} [\log 2 - (\log 14.44 + 3 \log 2.88)] \\
 &\quad \times 10^{26} \quad (\log a^b = b \log a) \\
 &= \text{Antilog} [0.3010 - (1.1545 + 3(0.4593))] \\
 &\quad \times 10^{26} \\
 &= \text{Antilog} [0.3010 - (1.1595 + 1.3779)] \times 10^{26} \\
 &= \text{Antilog} [0.3010 - 2.5374] \times 10^{26} \\
 &= \text{Antilog} (-2.2364) \times 10^{26} \\
 &= 5.802 \times 10^{-3} \times 10^{26}
 \end{aligned}$$

$$= 5.802 \times 10^{23}$$

- Ans :** i. Number of atoms in 200 g of element is 1.16×10^{24} .
 ii. Number of unit cells in 200 g of element is 5.80×10^{23} .

★ 11. Aluminium crystallizes in cubic close packed structure with unit cell edge length of 353.6 pm. What is the radius of Al atom ? How many unit cells are there in 1.00 cm³ of Al ?

Given : Type of unit cell is ccp.
 Unit cell edge length (a) = 353.6 pm
 $= 3.536 \times 10^{-8} \text{ pm}$
 Volume (V) of aluminium = 1.00 cm³.

To find : i. Radius of aluminium atom (Al)
 ii. Number of unit cells in 1.00 cm³ of Al.

Formula : i. For ccp or fcp unit cell $r = 0.3535 a$
 ii. Number of unit cells in volume (v) of

$$\text{metal} = \frac{v}{a^3}$$

Solution : According to formula (i)

$$\begin{aligned}
 r &= 0.3535 a \\
 &= 0.3535 \times 353.6 \text{ pm} \\
 &= \text{Antilog} (\log 0.3535 + \log 353.6) \\
 &= \text{Antilog} (-0.4516 + 2.5485) \\
 &= \text{Antilog} (2.0969) \\
 &= 124.99
 \end{aligned}$$

$$r = 125 \text{ pm}$$

According to formula (ii)

Number of unit cells in volume (v) of

$$\begin{aligned}
 \text{metals} &= \frac{v}{a^3} \\
 &= \frac{1.00 \text{ cm}^3}{(3.536 \times 10^{-8} \text{ cm})^3} \\
 &= \frac{1.00}{(3.536)^3 \times 10^{-24}} \\
 &= \frac{1 \times 10^{24}}{(3.536)^3}
 \end{aligned}$$

$$= \text{Antilog} [\log_{10} 1 - \log (3.536)^3] \times 10^{24}$$

$$= \text{Antilog} [\log_{10} 1 - 3 \log (3.536)] \times 10^{24}$$

$$= \text{Antilog} [0 - 3(0.5485)] \times 10^{24}$$

$$= \text{Antilog} [-1.645] \times 10^{24}$$

$$= 0.0226 \times 10^{24}$$

$$= 2.26 \times 10^{22}$$

- Ans :** i. Radius of Al atom (r) is 125 pm.

- ii. Number of unit cells in 1.00 cm^3 of Al of 2.26×10^{22} .

Problem for Practice

1. A compound is formed by two elements X and Y. Atoms of the element Y make ccp and those of element X occupy all the octahedral voids. What is the formula of this compound ?

Ans : XY

2. In a cubic closed packed structure of mixed oxides, the lattice is made up of oxide ions one-sixth of tetrahedral voids are occupied by cation A while one third of octahedral voids are occupied by cation B. What is the formula of oxide ?

Ans : ABO_3

3. An element has body-centred cubic (bcc) structure with unit cell edge length of 288 pm. The density of the element is 7.2 g cm^{-3} . How many atoms are present in 208 g of the element ?

Ans : 24.17×10^{23} atoms

4. A metal crystallizes of fcc structure and the unit cell has a length of edge $3.72 \times 10^{-8} \text{ cm}$. Calculate the density of the metal. Given the atomic mass of metal as 68.5 g mol^{-1}

Ans : Density of metal = 8.83 g/cm^3

5. Sodium crystallizes in bcc structure. If the atomic radius of sodium is 186 pm. Find (i) edge length (a)
(ii) volume of the unit cell and
(iii) density of sodium crystal.

The atomic mass of sodium is 23 g/mol

Ans : i. Edge length (a) = 430 pm

ii. Volume of a unit cell = $79.4 \times 10^{-24} \text{ cm}^3$

iii. Density of sodium = 0.962 g/cm^3

6. Copper crystallizes in fcc type unit cell. The edge length of a unit cell is 360.8 pm. The density of metallic copper is 8.92 g/cm^3 . Determine the atomic mass of copper

Ans : Atomic mass of copper = 63.07 g/mol^{-1}

1.8 Crystal defect or imperfection

Q.56 Define crystal defect or imperfection.

Ans : The irregularities in the arrangement of constituent particles of a solid crystal are called defect or imperfections.

Q.57 Write a short note on crystal defect or imperfections.

Ans :

i. The irregularities in the arrangement of constituent particles of a solid crystal are called defect or imperfections.

ii. The real, naturally occurring crystalline substances do not have perfect crystalline structures.

iii. They have some disorders or irregularities in the stacking of atoms.

iv. Defects are created during the process of crystallization. The imperfections are more if the crystallization occurs at a faster rate.

v. It means that the defects can be minimized by carrying out crystallization at a slower rate.

vi. An ideal crystals with no imperfections are possible only at the absolute zero of temperature.

vii. Above this temperature no crystalline materials are 100 % pure. They contain defects.

viii. Whatever be the nature of a crystal defect, electrical neutrality of the solid is maintained.

[Note : Sometimes defects are to be intentionally created for manipulating the desired properties in crystalline solids.]

Q.58 Name three points defects ? Give the name of its major classes.

Ans : There are three types of defects :

- Point defects
- Line defects and
- Plain defects.

Q.59 What is point defects ? Give the name of its major classes.

Ans : These defects are irregularities produced in the arrangement of basis at lattice points in crystalline solids.

There are three major classes of point defects: stoichiometric point defects, impurity defects and nonstoichiometric point defects.

Q.60 Write a short note on stoichiometric points defects.

Ans : **Stoichiometric point defects :**

- Chemical formula of a compound shows fixed ratio of number of atoms or number of cations and anions.
- This fixed ratio is the stoichiometry of the compound.
- In stoichiometric defect, the stoichiometry remains unchanged.
- In other words, the ratio of number of atoms or number of cations and anions of compound remains the same as represented by its chemical formula.
- There are four types of stoichiometric point defects: vacancy defect, self interstitial defect, Schottky defect and Frenkel defect.

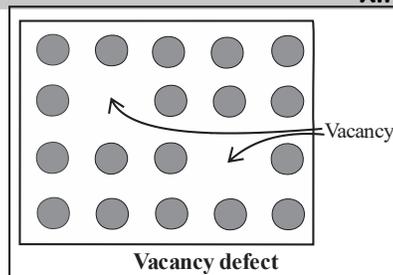
Q.61 What are the four types of stoichiometric point defects ?

Ans : There are four types of stoichiometric points defects :
Valency defect, Self interstitial defect, Schottky defect and Frenkel defect.

Q.62 Explain valency defect with suitable diagram.

Ans :

- During crystallization of a solid, a particle is missing from its regular site in the crystal lattice.
- The missing particle creates a vacancy in the lattice structure. Thus, some of the lattice sites are vacant because of missing particles as shown in figure.

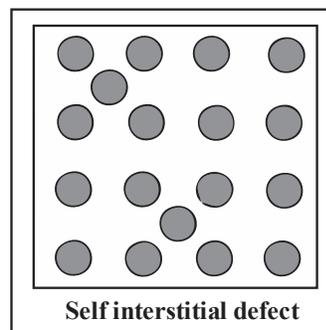


- The crystal is, then, said to have a vacancy defect.
- The vacancy defect can also be developed when the substance is heated.
- Due to the absence of particles, the mass of the substance decreases.
- However, the volume remains unchanged.
- As a result the density of the substance decreases.

Q.63 Explain self-interstitial defect with the help of a suitable diagram.

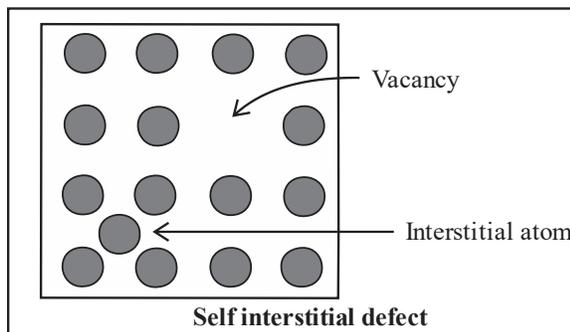
Ans :

- Interstitial sites in a crystal are the spaces or voids in between the particles at lattice points.
- When some particles of a crystalline elemental solid occupy interstitial sites in the crystal structure, it is called self interstitial defect.
- This defect occurs in the following two ways :
 - Firstly, an extra particle occupies an empty interstitial space in the crystal structure as shown in figure.



- This extra particle is same as those already present at the lattice points.
- The extra particles increase the total mass of substance without increasing volume. Hence its density increases.
- Secondly, in an elemental solid a particle gets shifted from its original lattice point and occupies an interstitial space in the crystal as

shown in the figure.

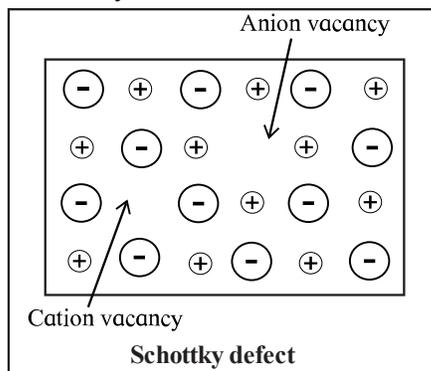


- vi. Because of the displacement of a particle a vacancy defect is created at its original regular lattice site.
- vii. At the same time interstitial defect results at its new position.
- viii. We can, therefore, say that in this defect there is a combination of vacancy defect and self interstitial defect.
- ix. This defect preserves the density of the substance because there is neither loss nor gain in mass of a substance.

Q.64 Explain : Schottky defect.

Ans :

- i. In an ionic solid, equal number of cations and anions are missing from their regular positions in the crystal lattice creating vacancies as shown in figure.
- ii. It means that a vacancy created by a loss of cation is always accompanied by a vacancy formed by a loss of anion.



- iii. Thus, there exist two holes per ion pair lost, one created by missing cation and the other by a missing anion.
- iv. Such a paired cation-anion vacancy defect is a

Schottky defect.

Q.65 Give the condition for the formation of Schottky defect.

Ans : Schottky defect is found in ionic compounds with the following characteristics :

- i. High degree of ionic character.
- ii. High coordination number of anion
- iii. Small difference between size of cation and anion. The ratio r_{cation}/r_{anion} is not far below unity.

★Q.66 What are the consequences of Schottky defect ?

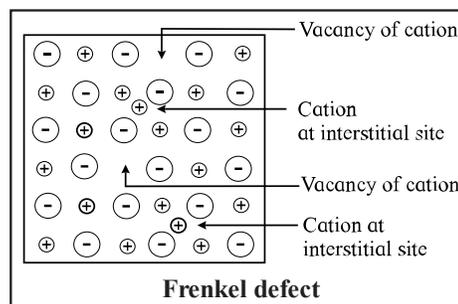
Ans : **Consequences of Schottky defect**

- i. As the number of ions decreases, mass decreases. However, volume remains unchanged. Hence, the density of a substance decreases.
- ii. The number of missing cations and anions is equal, the electrical neutrality of the compound is preserved.
This defect is found in ionic crystals such as NaCl, AgBr and KCl.

Q.67 Describe Frenkel defect in detail with help of diagram.

Ans :

- i. Frenkel defect arises when an ion of an ionic compound is missing from its regular lattice site and occupies interstitial position between lattice points as shown in figure.
- ii. The cations are usually smaller than anions.
- iii. It is, therefore, more common to find the cations occupying interstitial sites.
- iv. It is easier for the smaller cations to accommodate the interstitial spaces.
- v. It is important to note that the smaller cation is displaced from its normal site to an interstitial space.



- vi. It, therefore, creates a vacancy defect at its

original position and interstitial defect at its new location in the same crystal.

- vii. Frenkel defect can be regarded as the combination of vacancy defect and interstitial defect.

[Note : Frenkel defect is not found in pure alkali metal halides because cations of alkali metals due to large size cannot occupy interstitial space.]

Q.68 What are the consequence and conditions for the formation of Frenkel ?

Ans :

i. Conditions for formation of Frenkel

- Frenkel defect occurs in ionic compounds with large difference between sizes of cation and anion.
- The ions of ionic compounds must be having low coordination number.

ii. Consequences of Frenkel defect

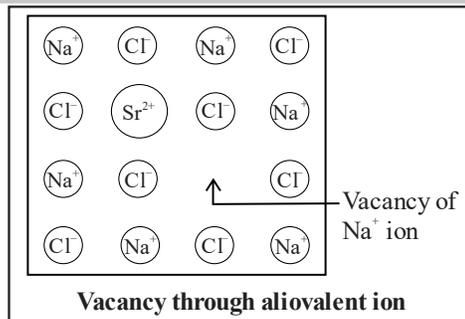
- As no ions are missing from the crystal lattice as a whole, the density of solid and its chemical properties remain unchanged.
- The crystal as a whole remains electrically neutral because the equal numbers of cations and anions are present.

[Note : This defect is found in ionic crystals like ZnS , $AgCl$, $AgBr$, AgI , CaF_2 .]

★Q.69 What is an impurity defect ? What are its types ? Explain the formation of vacancies through aliovalent impurity with example.

Ans :

- Impurity defect arises when foreign atoms, that is, atoms different from the host atoms, are present in the crystal lattice.
- There are two kinds of impurity defects : Substitutional and interstitial impurity defects.
- Vacancies are created by the addition of impurities of aliovalent ions (that is, ions with oxidation state (O.S.) different from that of host ions) to an ionic solid.

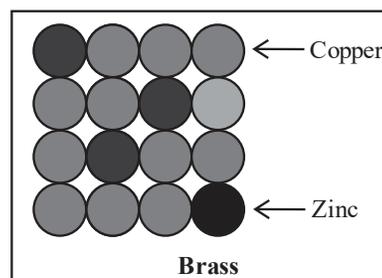


- Suppose that a small amount of $SrCl_2$ impurity is added to $NaCl$ during its crystallization.
- The added Sr^{2+} ions (O.S. + 2) occupy some of the regular sites of Na^+ host ions (O.S.+1).
- In order to maintain electrical neutrality, every Sr^{2+} ion removes two Na^+ ions.
- One of the vacant lattice sites created by removal of two Na^+ ions is occupied by one Sr^{2+} ion.
- The other site of Na^+ ion remains vacant as shown in figure.

Q.70 Describe substitutional impurity defect using a suitable example.

Ans :

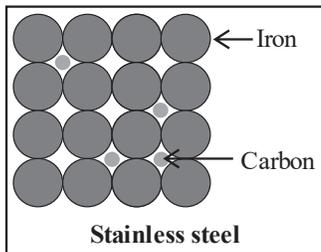
- In this defect, the foreign atoms are found at the lattice sites in place of host atoms.
- The regular atoms are displaced from their lattice sites by impurity atoms.
- For example :
Solid solutions of metals (alloys) : Brass is an alloy of Cu and Zn . In brass, host Cu atoms are replaced by impurity of Zn atoms. The Zn atoms occupy regular sites of Cu atoms as shown in figure.



Q.71 With help of a suitable diagram describe interstitial impurity defect.

Ans :

- i. In this defect, the impurity atoms occupy interstitial spaces of lattice structure.
- ii. For example in steel, Fe atoms occupy normal lattice sites.
- iii. The carbon atoms are present at interstitial spaces, as shown in figure.



Q.72 What are nonstoichiometric defects and name their types.

Ans :

- i. Nonstoichiometric defect arises when the ratio of number of atoms of one kind to that of other kind or the ratio of number of cations to anions becomes different from that indicated by its chemical formula.
- ii. In short, stoichiometry of the compound is changed.
- iii. It is important to note that the change in stoichiometry does not cause any change in the crystal structure.

There are two types of nonstoichiometric defects :

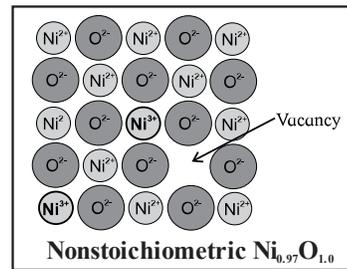
- a. Metal deficiency defect
- b. Metal excess defect.

Q.73 Explain metal deficiency defect using a suitable example.

Ans :

- i. **Metal deficiency defect :** This defect is possible only in compounds of metals that show variable oxidation states.
- ii. In some crystals, positive metal ions are missing from their original lattice sites. The extra negative charge is balanced by the presence of cation of the same metal with higher oxidation state than that of missing cation.
- iii. For example, in the compound NiO one Ni²⁺ ion is missing creating a vacancy at its lattice

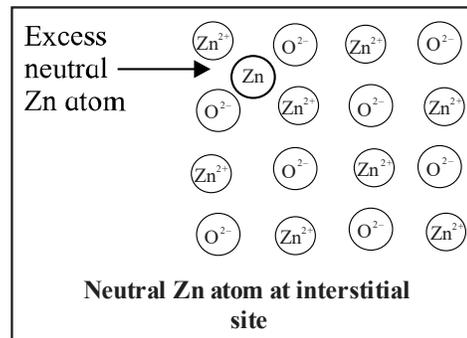
site. The deficiency of two positive charges is made up the presence of two Ni³⁺ ions at the other lattice sites of Ni²⁺ ions as shown in fig. The composition of NiO then becomes Ni_{0.97}O_{1.0}.



Q.74 Explain the types of metal excess defect.

Ans : There are two types of metal excess defects.

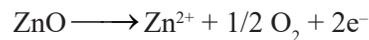
- i. A neutral atom or an extra positive ion occupies interstitial position : ZnO presents two ways of metal excess defect. In the first case in ZnO lattice one neutral Zn atom is present in the interstitial space as shown in the below.



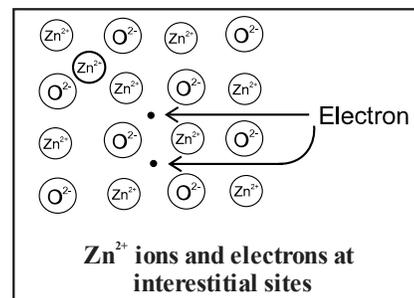
Neutral Zn atom at interstitial site

Zn²⁺ ions and electrons at interstitial sites

In the second case, when ZnO is heated it decomposes as :



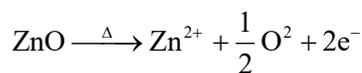
The excess Zn²⁺ ions are trapped in interstitial site in the lattice. The electrons also diffuse in the crystal to occupy interstitial sites as shown in the figure below.



- In both the cases, nonstoichiometric formula of ZnO is $Zn_{1+x}O_{1.0}$.
- ii. By anion vacancies (Colour or F-centres)
This type of defect impart colour to the colourless crystal. For example, when NaCl crystal is heated in the atmosphere of sodium vapour, sodium atoms are deposited on the crystal surface.
 Cl^- ions diffuse to the crystal surface creating vacancies at their regular sites. These Cl^- ions combine with Na atoms on the surface to form NaCl, by releasing electron from sodium atom.
 $Na + Cl^- \longrightarrow NaCl + e^-$
The electrons released diffuse into the crystal and occupy vacant sites of anions as shown in the figure. The anion vacant sites occupied by electrons are F-centres or colour-centres.
An F-centre in a crystal
NaCl shows yellow colour due to the formation of F-centre. The crystal of NaCl has excess Na. The nonstoichiometric formula of NaCl is the $Na_{1+x}Cl_{1.0}$

Q.75 When ZnO is heated it turns yellow and return back to original white colour on cooling. What could be the reason ?

Ans : ZnO decomposes to Zn^{2+} ion, free electrons and oxygen on heating



ZnO shows metals excess defect where the excess Zn^{2+} ion occupies the interstitial sites and the electrons occupy the neighbouring interstitial sites.

By absorbing Me energy the electrons get excited to higher energy level from visible light and therefore the compound appears coloured.

1.9 Electrical properties of solids

Q.76 How are solids classified on the basis of their electrical conductivity?

Ans : Solids show very wide range of electrical conductivity. Accordingly solids are classified into the following three categories :

conductors, insulators and semiconductors.

Q.77 Explain the following terms

- i. Conductors
- ii. Insulators
- iii. Semiconductors

Ans.

- i. **Conductors :**
Solids having electrical conductivities in the range 10^4 to $10^7 \text{ Ohm}^{-1}\text{m}^{-1}$ are called conductors.
- ii. **Insulators :**
Solids having low electrical conductivities in the range 10^{-20} to $10^{-10} \text{ Ohm}^{-1}\text{m}^{-1}$ are insulators. Most nonmetals and molecular solids belong to this category.
- iii. **Semiconductors :**
Solids having electrical conductivities in the range 10^{-6} to $10^4 \text{ Ohm}^{-1}\text{m}^{-1}$ are semiconductors. This range is intermediate between conductors and insulators. Metalloids like silicon, germanium belong to this category.

Q.78 Write a short note on band theory.

Ans :

- i. Electrical conductivities of solid metals, nonmetals and metalloids are explained in terms of band theory.
- ii. A band is made of closely spaced electronic energy levels.
- iii. Band formation can be correlated to formation of molecular orbitals (MOs) by interaction of atomic orbitals.
- iv. According to MO theory interaction of atomic orbitals of combining atoms results in formation of equal number of MOs which spread over the entire molecule.
- v. Similar to this, interaction of energy levels of electrons in the closely spaced constituent atoms in solids result in formation of bands. Band theory considers formation of two types of bands, namely, conduction band and valence band.
- vi. The energy difference between valence band and conduction band is called band gap.

★Q.79 What are valence band and conduction

band ?

Ans : **Conduction band :**

- The highest energy band containing electrons is the conduction band.
- It is formed by interaction of the outermost energy levels of closely spaced atoms in solids.
- Conduction band may be partially occupied or vacant.
- Electrons in conduction band are mobile and delocalized over the entire solid. They conduct electricity when electrical potential is applied.

Valence band

- The band having lower energy than conduction band is the valence band.
- The electrons in valence band are not free to move because they are tightly bound to the respective nuclei.

Q.80 Explain : Band gap

Ans.

- The energy difference between valence band and conduction band is called band gap.
- Size of the band gap decides whether electrons from valence band can be promoted to vacant conduction band or not when band gap is too large to promote electrons from valence band to vacant conduction band by thermal energy, it is called forbidden zone.
- When band gap is small, electrons from higher energy levels in valence band can be promoted to conduction band by absorption of energy (such as thermal, electromagnetic).

Do you know ?

The band gap energy values of a few solids are as shown here.

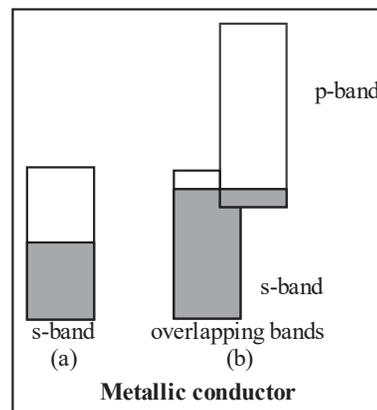
Solid	E_{gap} eV
Diamond	5.47
Sodium	0
Silicon	1.12
Germanium	0.67

Q.81 Explain conductivity of metal on me basis

of band theory.

Ans : The electrical properties of metallic conductors, insulators and semiconductors are explained in terms of band theory as follows :

- Metals are good conductors of electricity.
- The outermost electrons of all the atoms in the metallic crystal occupy conduction band.
- The number of electrons in conduction band of metals is large.
- Hence metals are good conductors of electricity.
- The conduction bands in metals can be further labelled as 's' band in fig., overlapping s and p bands in figure (b) and so on.
- This depends on the atomic orbitals involved in band formation.
- Band formation in metallic conductors, thus, results in delocalization of the outermost electrons of all the metal atoms leaving behind metal ions.
- This is described as 'cations of metal are immersed in the sea of electrons'.



Q.82 Why the conductivity of metal decreases with increase in temperature

Ans :

- The cations of metal atoms occupying lattice sites vibrate about their mean positions.
- At higher temperatures, metal cations undergo increased vibrational motion about their lattice sites.
- The flow of electrons is interrupted by increased vibrational motion.

- iv. As a result conductivity of metals decreases with increase in temperature.

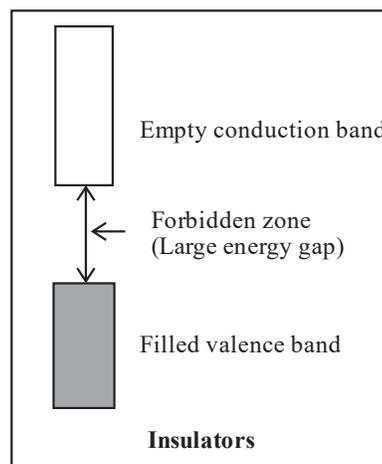
Do you know

- i. Metallic sodium is an example of conductor where the conduction band is partially filled and there is no band gap. Electronic configuration of Na is $[\text{Ar}]3s^1$. Interaction of the partially filled 3s AOs of all the Na atoms gives rise to same number of MOs. All these closely spaced MOs together form a continuous band of energies which is called 3s band. Lower half of 3s band corresponds of BMOs and is filled while the upper half of 3s band corresponds to AMOs and is empty. There is no gap between these two halves. The 3s band in sodium is the conduction band which contains same number of electrons as the sodium atoms. This is responsible for the high conductivity of metallic sodium.
- ii. Metallic magnesium is an example of conductor with overlapping bands. Electronic configuration of Mg is $[\text{Ar}]3s^23p^0$. Interaction of completely filled 3s AOs of all the Mg atoms gives rise to the same number of MOs all of which are filled. These together form the 3s band which is a completely filled band. Interaction of vacant 3p AOs of all the Mg atoms gives rise to the same number of vacant MOs together called 3p band. This is the vacant band. The filled 3s band and vacant 3p band overlap each other. As a result, higher energy electrons move from 3s band to 3p band.

Q.83 Explain the electrical conductivity of insulator on the basis of band theory

Ans : Insulators :

- i. In insulators the valence band is completely filled with electrons and the conduction band is empty.

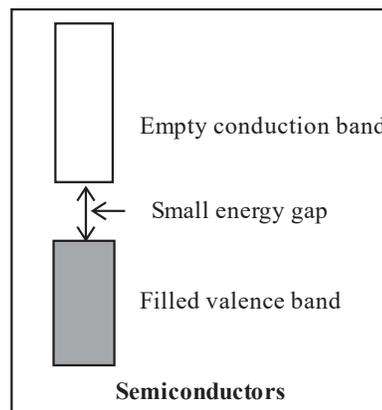


- ii. The valence band and conduction band in insulators are separated by a large energy gap called forbidden zone.
- iii. Thermal energy is insufficient to promote electrons from valence band to conduction band.
- iv. As a result the conduction band remains vacant. The material is, therefore, an insulator.

Q.84 Explain the electrical conductivity at semiconductors on the basis of band theory.

Ans : Semiconductor

- i. Electrical conductivity of a semiconductor material is intermediate between that of metals and insulators.
- ii. The metalloids Si and Ge are semiconductors.
- iii. Like insulators, the valence band in semiconductor is completely filled with electrons and conduction band is empty. However, the energy gap between the two bands is smaller than that in an insulator.



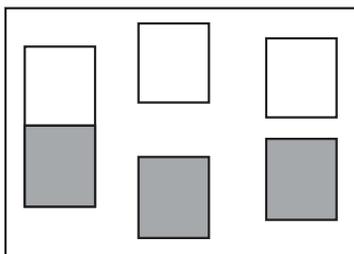
- iv. At a temperature above absolute zero a few electrons in the valence band have enough thermal energy to jump through the small band gap and occupy higher energy conduction band.
- v. The conduction band, thus, becomes partially filled and the valence band becomes partially empty.
- vi. The electrons in conduction band are free to move.
- vii. When electric potential is applied to a semiconductor, it conducts a small amount of electricity.
- viii. Such a pure semiconductor material which has a very low but finite electrical conductivity is called intrinsic semiconductor.

Q.85 How does electrical conductivity of a semiconductor change with temperature? Why?

Ans :

- i. The electrical conductivity of a semi-conductor increases with increasing temperature.
- ii. This is because, the number of electrons with sufficient energy so as to get promoted to the conduction band increases as temperature rises.
- iii. Thus, at higher temperatures, there are more mobile electrons in the conduction band and more vacancies in the valence band than at lower temperature.

***Q.86 The following picture shows show population bands for materials having different electrical properties. Classify them a insulator, semiconductor or a metal.**



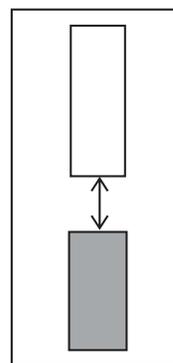
Ans : The picture on the left represents a metal. The picture in the middle represents an insulator and the picture in the right represent a semiconductors.

***Q.87 Distinguish with the help of diagrams metal conductors, insulators and semiconductors from each other.**

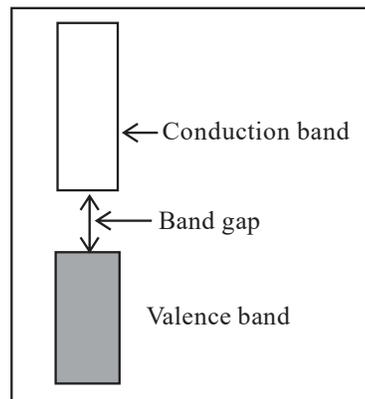
Ans :

Metal conductors	Insulators	Semiconductors
Metal are good conductors of electricity	Insulators are non conductors of electricity	Electrical conductivity of a semiconductor is intermediate between that of metals and insulators
In metal conductors, there is no band gap or there is overlapping between valence band and conduction band	The valence band and conduction band in insulators are separated by a large energy	The valence band in semiconductor is completely filled with electrons and conduction band is empty. However, the energy gap between the two bands is smaller than that in an insulator

***Q.88 The picture represents bands of MOs for Si. Label valence band, conduction band and band gap.**



Ans :



Q.89 Define the following.

i. Doping ii. Dopant

Ans : **Doping :** The process of addition of minute quantity of impurities to a semiconductor to increase its conductivity is called doping.

Dopant : The added impurity to a semiconductor to increase its conductivity is called dopant.

Q.90 How can we increase the conductivity of a semiconductor ?

Ans : The conductivity of a semiconductor can be increased by doping.

Q.91 What are the two types of extrinsic semiconductor ?

Ans : There are two types of extrinsic semiconductors, namely, n-type and p-type semiconductors.

Can you tell ?

+Q.92 Let a small quantity of phosphorus be doped into pure silicon.

Will the resulting material contain the same number of total number of electrons as the original pure silicon ?

Will the material be electrically neutral or charged ?

Ans :

- i. No the resulting material will not contain the same number of total number of electrons as the original pure silicon.
- ii. The material will be electrically charged.

***Q.93** What are n-type semiconductors ? Why is the conductivity of doped n-type semiconductor higher than that of pure semiconductor ? Explain with diagram.

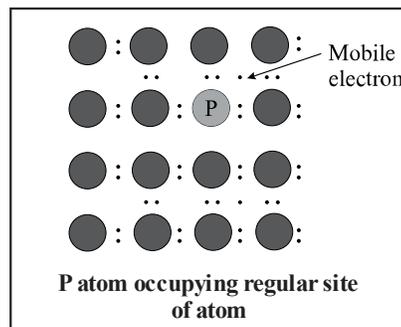
Ans :

i. n-type semiconductor : n-type semiconductor contains increased number of electrons in the conduction band.

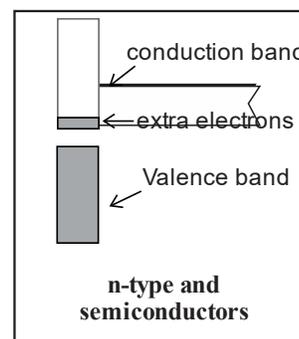
An n-type semiconductor is obtained by adding group 15 element to intrinsic semiconductor which belongs to group 14.

Consider, for example, doping of Si with phosphorus.

Si has a crystal structure in which each Si atom is linked tetrahedrally to four other Si atoms. When small quantity of phosphorous is added to pure Si, the P atoms occupy some vacant sites in the lattice in place of Si atoms, as shown in figure.



The overall crystal structure of Si remains unchanged.

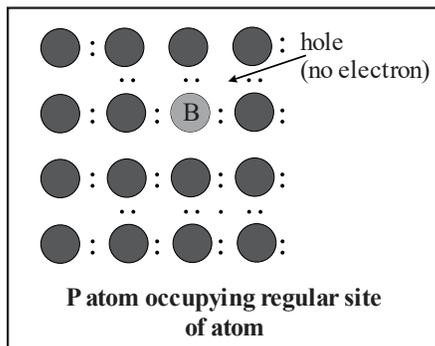


Q.94 What are p-type semiconductor ? Why is the conductivity of p-typed semiconductor higher than that of p-type semiconductor ? Explain with diagram

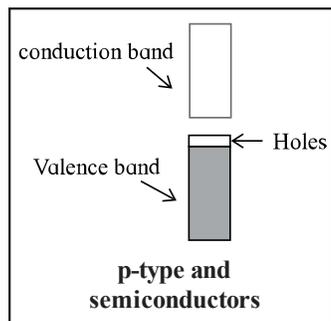
Ans :

p-type semiconductor :

- i. A p-type semiconductor is produced by doping a pure semiconductor material (Si or Ge) with an impurity of group 13 elements.
- ii. These elements contain less number of valence electrons than that of the pure semiconductor.
- iii. Consider, for example, pure Si doped with boron. The B atoms occupy normal positions of some of the Si atoms in the lattice as shown in figure below.



- iv. Boron atom has only three valence electrons. It does not have enough electrons to form bonds with its four Si neighbours.
- v. B atom forms bonds with three Si atoms only. The missing fourth electron creates an electron vacancy. It is called a hole.
- vi. the holes in the valence band of p-type semiconductor.



- vii. A hole of tendency to accept electron from its close vicinity. Thus, a hole behaves as if it has a positive charge.
- viii. The electrons in partially filled valence band move under the influence of an applied potential. The holes move in the opposite direction.
- ix. Because the charge carriers are holes which behave like positive charge, the Si or Ge doped with group 13 elements like B, Ga or In, is a p-type semiconductor.

Remember

1. Whether intrinsic or extrinsic semiconductor, the material is electrically neutral.
2. An n-type semiconductor such as Si doped with P has more electrons than those needed for bonding and thus has electrons in the partially filled conduction band.

3. A p-type semiconductor such as Si doped with B has the less electrons than needed for bonding and thus has vacancies (holes) in the band.

1.10 Magnetic property of Solids

Q.95 Explain magnetic property of solids in detail.

Ans :

- i. Magnetic properties of solids can be understood easily in terms of classical picture of electron.
- ii. The electron spin about their own axis.
- iii. The spinning electrons act like tiny magnets because their spinning action generates magnetic field.
- iv. If an orbital contains one electron, the unbalanced spin exhibits magnetism.
- v. However, when electrons are paired their spin is balanced and no magnetic property is observed.
- vi. On the basis of magnetic properties solids are classified into three major classes : diamagnetic, paramagnetic and ferromagnetic.

Q.96 Name the three major classes of magnetic properties of solids.

Ans : On the basis of magnetic properties solids are classified into three major classes : diamagnetic, paramagnetic and ferromagnetic.

Q.97 What are diamagnetic substances ?

Ans : The substances with all electrons paired, are weakly repelled by magnetic fields. These substances are said to be diamagnetic.

Q.98 Write short not on diamagnetic substances.

Ans :

- i. The substances with all electrons paired, are weakly repelled by magnetic fields.
- ii. These substances are said to be diamagnetic.
- iii. Pairing of electrons balances the spins and hence, cancels their magnetic moments.
- iv. N_2 , F_2 , $NaCl$, H_2O and benzene are some

examples of diamagnetic substances.

Q.99 What are paramagnetic substances ? Give its examples.

Ans :

- i. The substances with unpaired electrons are weakly attracted by magnetic field.
- ii. These substances are called paramagnetic substances.
- iii. For examples :
Oxygen (O_2), Cu^{2+} , Fe^{3+} , Cr^{3+} .

Q.100 Give a short note on paramagnetic solids.

Ans :

- i. The substances with unpaired electrons are weakly attracted by magnetic field.
- ii. These substances are called paramagnetic substances.
- iii. The spinning of unpaired electron gives rise to a magnetic moment.
- iv. The substance is attracted by magnetic field because of magnetic moment.
- v. It is important to understand that these substances exhibit magnetism in presence of external magnetism in presence of external field only.
- vi. They lose magnetism when the external magnetic field is removed.
- vii. Oxygen (O_2), Cu^{2+} , Fe^{3+} , Cr^{3+} are some examples of paramagnetic substances.

Q.101 What are ferromagnetic substances ?

Ans : The substances containing large number of unpaired electrons are attracted strongly by magnetic field. These substances are said to be ferromagnetic.

Q.102 Write a short note on ferromagnetism.

Ans :

- i. The substances containing large number of unpaired electrons are attracted strongly by magnetic field.
- ii. These substances are said to be ferromagnetic.
- iii. These substances can be permanently magnetised.

iv. They retain magnetism even after the removal of external magnetic field.

vii. Some example of ferromagnetic substances are Fe, Co, Ni, Gd, CrO_2 .

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