2. THE SOLID STATE

Synopsis: **INTRODUCTION:**

- Solids are characterized by their high density and low compressibility as compared to those of the gas phase.
- The properties of solids indicate that the molecule (or ions) in them are relatively close together.
- Solids can be broadly classified into two categories, namely, crystalline and amorphous solids. The main characteristics of these are described in the following.
- **Crystalline Solids:** The outstanding characteristics of a crystal are its sharp melting point, its flat faces and sharp edges.
- These properties are due to a high degree of internal order which extends throughout the crystal (a definite pattern constantly repeating in space). This is know as long-range order.
- **Amorphous Solids:** Amorphous solids do not have the long-range order but have a short-range order.
- This characteristics may not be found around a similar atom placed at a distance from the other atom.
- Examples of amorphous solids are glass, used silica, rubber and polymers.
- Amorphous solids do not have the characteristics as possessed by crystalline solids.
- In many ways, they are more closely related to liquids than to the crystalline solids and are, therefore, regarded as supercooled liquids with high viscosity.
- A given material may be converted into the amorphous or glassy form by rapidly cooling the melt or freezing the vapour.

CLASSIFICATION OF CRYSTALS BASED ON BOND TYPE

- The properties of most of the crystals are found to conform to one of the four general types of chemical bonds, in terms of which it is possible to classify them into four categories as described in the following.
- **Molecular Crystals (or van der Waals Crystals):**Molecular crystals are those in which the crystalline state is composed of an aggregate of discrete molecules held together by van der Waals forces.
- Because of these weaker forces, molecular crystals are soft and posses comparatively low melting points.
- Examples are CO_2, CCl_4, Ar and most of the organic compounds.
- **Ionic Crystals:** Ionic crystals involve electrostatic forces amongst their structural units.
- Because of stronger forces, ionic crystals are strong and likely to be brittle.
- The melting points are high, which decease with increasing size of the ions.
- In ionic crystals, some of the atoms may be held together by covalent bonds to form ions having definite positions and orientations in crystal lattice.
- **Covalent Crystals:** Covalent crystals involve forces of chemical nature (covalent bonds) extended in three dimensions. These forces are strong, and consequently the crystals are strong and hard, with high melting points. Examples are diamond, silicon, etc.
- **Metallic crystals:** Electrons are held loosely in these type of crystals. They are god conductors or electricity. Metallic crystals are strong and can be bent.
- **Hydrogen bonded crystals**
- Molecules having H atom bonded to more electronegative atoms like F, O, N exhibit strong hydrogen bonding
- Crystals of H_2O, HF, NH_3 and amino acids are some examples of hydrogen bonded crystals.
- **CRYSTAL SYSTEMS : -**
- There are 230 crystal forms possible. These forms may be classified into 32 classes on the basis of their symmetry.

- On the basis of inter facial angles and axes crystal systems are 7 types.
- The crystal structures depends on the set of crystallographic parameters

System	Axial angular characteristics	Examples of common substance	Symmetry elements possible
Cubic	a= b =c; $\alpha=\beta=\gamma=90^0$	*NaCl* Diamond Pb, Hg, Ag; Alum Zns; CaF_2; FeS_2	Four 3 folds axis Six 2 folds axis
Tetragonal	a= b ≠ c; $\alpha=\beta=\gamma=90^0$	SnO_2, TiO_2, white Sn, $NiSO_4$ $K_4[Fe(CN)_6]$	One 4 fold axis
Orthorhombic or rhombic	a≠ b ≠ c; $\alpha=\beta=\gamma=90^0$	KNO_3; $MgSO_4.7H_2O$ α – S; K_2SO_4; $BaSO_4$, $PbCO_3$	Three 2 fold axis 2 fold axis Two Perpendicular planes
Hexagonal	a= b ≠ c; $\alpha=\beta=90^0$ $\gamma=120^0$	Graphite, ice Quartz, Mg, Zn, HgS; PbI_2	One 6 fold axis
Trigonal or Rhombohehral	a= b =c; $\alpha=\beta=\gamma\neq90^0$	Calcite; $NaNO_3$; $KMnO_4$, Bi, Sb; As	One 3 fold axis
Monoclinic	a≠ b ≠ c; $\alpha=\gamma=90^0$ $\beta\neq90^0$	Monoclinic S: $CaSO_4.2H_2O$; $Na_2SO_4.10H_2O$; $NaHCO_3$; $FeSO_4.7H_2O$	One 2 fold axis one plane
Triclinic	a≠ b ≠ c; $\alpha\neq\beta\neq\gamma\neq90^0$	$CuSO_4.5H_2O$ $K_2Cr_2O_7.H_3BO_3$	……

- Ice may give hexagonal or trigonal crystals
- Quartz may give hexagonal or trigonal crystals
- **BRAVAIS LATTICES : -**
- Bravais showed that there are 14 different possible kinds of three dimensional lattices.
- The geometric shape of the crystal lattice must be same as that of solid crystal itself.
  Ex : If unit lattice is having cubical structure the crystal is also a cube.
- From fundamental laws of crystallography there are 14 basic arrangements known as Bravais Lattices.
- These 14 Bravais lattices are grouped into seven crystal system based on unit cell symmetry .
- These seven crystal systems are

Crystal System	No.of Bravais lattices	Common names of these lattices
Cubic	3	Simple cubic, fcc and bcc
Tetragonal	2	Primitive; body centred tetragonal prisms
Rhombic	4	Primitive, body centred, face - centred and endcentred
Hexagonal	1	Primitive Hexagonal prism
Trigonal	1	Rhombohedral (or) primitive
Monoclinic	2	Primitive & end centered
Triclinic	1	Triclinic primitive(or) primitive

Bragg's Equation:

- If the waves are in phase, then constructive interference takes place.
- If the waves are not in phase, they undergo destructive interference.
- If the two waves are to be present in phase, the path difference must be equal to the wavelength(λ) or an integral whole multiple of wavelength ($n\lambda$).
- Bragg's equation is $n\lambda = 2d \sin\theta$
  n = order of reflection (1, 2, 3, …….)
  λ = wavelength of x-ray
  d = distance between planes
  θ = angle of incidence
- At the Bragg's experiment, as the intensity of diffracted x-ray increase, the degree of ionisation also increase.
- It Bragg's angle (θ), intensity of the diffracted x-ray is maximum and maximum value is recorded in electrometer.
- The NaCl crystal has the d values in the ratio 1 : 0.703 : 1.134. from this it is conformed the crystal has **fcc** system.
- In the powder method, the holes and the ends of the photographic film are inlet and the outlets of the x-rays.

Packing of identical spheres:

- There are two types of packing. 1) Close packing and 2) not close packing.
- Close packing of spheres leads two types of lactices
  a) **hcp** (hexagonal close packing) and
  b) **fcc** or **ccp** (cubic close packing)
- Not close packing type leads **bcc** (body centred cubic lattice)

HCP:

- It has ABABAB ….. type of layers.

- Co-ordination number is 12
- Packing fraction is 0.74.
- In one unit cell of HCP, on average 6 spheres are present and 6 octahedral voids and 12 tetrahedral voids are present.
- Examples: Mg, Zn, Ce, Ti etc.

CCP or FCC:

- It has ABCABC ….. type of layers.
- Co-ordination number is 12
- Packing fraction is 0.74.
- In one unit of **ccp** or **fcc**, on average 4 spheres are present and 4 octahedral voids and 8 tetrahedral voids are possible.
- Metals having this lattice are more meleable.
- Examples: Al, Cu, Ag, Au etc.

BCC:

- It is not a close packing and it has ABAB … type of layers.
- Co-ordination number is 8
- Packing fraction is 0.68.
- Examples: Li, Na, K etc.
- Two tetrahedral voids are present above and below each atom and the octahedral void is present midway between the two close-packed layers.

Ionic crystals:

- In ionic crystals, it is not possible for both cations and anions to have close-packed structures due to their different sizes.
- However, if one of the ions is bigger than the other, it is common for the bigger ions (usually anions) alone to approach a closed-packed structure and smaller ions to fit into holes (or voids) in this structure.
- The limiting sizes of cations that can fit into the voids without disturbing the closest packing of anions are as follows.

Octahedral void $\frac{r_c}{r_a} = 0.414$

Tetrahedral void $\frac{r_c}{r_a} = 0.225$

- A few common ionic lattices are described below.
- **Rock-Salt Structure:** In such a structure, anions form a face-centred cubic unit cell and cations occupy octahedral voids.
- There are four anions and four cations per unit cell of this structure, and hence, the formula of ionic compound is A_4B_4 or simply AB.
- Examples are NaCl, KCl, MgO, CaO and SrO.
- **Anti-Fluorite Structure:** In this, anions form a cubical-closest packing arrangement and cations occupy tetrahedral voids.
- There are four anions and eight cations per unit cell of this structure and hence the formula of the ionic compound is A_8B_4 or simply A_2B.
- Examples are Li_2O, Na_2O, K_2O and Rb_2O.

- **Zinc-Blende Structure:** In such a structure, anions form cubical closest – packed structure and cations are present in the half of the tetrahedral holes.
- There are four anionsand four cations per unit cell of this structure, and hence the formula of an ionic compound is A_4B_4 or simply AB.
- Examples are BeO and ZnS.
- **Body-Centred Cubic Structure:** In this structure, the cation is located at the body centre of a cube of anions, and the anion is located at the body centre of a cube of cations.
- There is one cation and one anion present per unit cell, and hence, the formula of an ionic compound is AB.
- In this structure, each ion has eight positively charged ions as its next nearest neighbours. Hence, the coordination number of each cation and anion is eight.
- Examples are CsCl, CsBr and CsI.
- **Fluorite Structure:** In this structure, cations form cubical-closest packing and anions occupy tetrahedral holes. Here

  Coordination number of cations = 8

  Coordination number of anions = 4

  General formula: $M_{1/8}X_{1/4}$ or MX_2.
- Examples include UO_2, ThO_2 and CaF_2.
- **Corundum Structure:** In this structure, anions form hexagonal closest packing and cations are present in 2/3 of the octahedral holes. The general formula of the compound is $M_{2/3}X$ or M_2X_3.
- Examples include Fe_2O_3, Al_2O_3 and Cr_2O.
- **Spinel structure:** In this structure, oxides are arranged in cubical-closest packing, one-eight of the tetrahedral holes are occupied by divalent metal ion (A^{2+}) and one-half of the octahedral holes are occupied by trivalent metal ions (B^{3+}). In a unit cell, we have

  Number of divalent metal ions, $A^{2+} = \frac{1}{8}(8) = 1$

  Number of trivalent metal ions, $B^{3+} = \frac{1}{2}(4) = 2$

  Number of oxide ions, $O^{2-} = 4$

  Hence, General formula of the compound: AB_2O_4

  Examples are $ZnAl_2O_4$, $MgAl_2O_4$ and $ZnFe_2O_4$.
- **Stability of ionic Structure:** Broadly, speaking the stability of ionic structures depends upon the radius ratio of r_c and r_a. The structures predicted from the value of r_c/r_a are as follows.

Ratio	Structure	Coordination number
$\frac{r_c}{r_a} > 0.732$	Body-centred cube	8
$0.732 \geq \frac{r_c}{r_a} \geq 0.414$	Face-centred cubic i.e. octahedral	6
$0.414 \frac{r_c}{r_a} \geq 0.225$	Tetrahedral	4

For example, chlorides of Li, K and Rb crystallize in the face-centred cubic lattice whereas the chloride of Cs crystallize in the body-centred cubic lattice.

- **CALCULATION OF THE CONTRIBUTION OF LATTICE POINTS PER UNIT CELL OF A SUBSTANCE.**
- A three dimensional crystal lattice is built up by the unit cells arranged in three directions .
- The unit cells have different shapes depending on the arrangement of the component atom (or) ions in space lattice.
- Each lattice point and the component particle contribute fraction to the unit cell because they are shared by vicinal unit cells.
- The atoms, molecules (or) ions that are making up the crystal are present at the lattice points and are represented by points.

Unit cell	Contribution of lattice points			Net no.of constituent particles
	Corners (1/8)	Face Center (1/2)	Body Center (1)	
Simple unit cell	$8\times\frac{1}{8}=1$	-	-	1
Face centered unit cell	$8\times\frac{1}{8}=1$	$6\times\frac{1}{2}=3$	-	4
Body centered unit cell	$8\times\frac{1}{8}=1$	-	$1\times1=1$	2
End face centre unit cell	$8\times\frac{1}{8}=1$	$2\times\frac{1}{2}=1$	-	2

- A lattice point at the corner of a unit cell is shared by 8 vicinal unit cells.
- A face centered point is shared by two adjacent unit cells.
- A edge centered point is shared by four adjacent unit cells
- A body centered lattice point belongs completely to a specific unit cell.
- Total contribution of lattice points can be calculated from the unit cell..

- **CALCULATION OF DENSITY OF UNIT CELL**
- Knowing the unit dimensions, the density of a crystalline substance can be calculated from the formula

$$\rho=\frac{ZM}{N_0a^3}1 \qquad \text{or} \quad \rho=\frac{ZM}{N_0V}$$

- Where ρ = density
- Z = No. of atoms (or) formula units per unit cell
- M = Molecular weight of the lattice particle (Atomic wt / formula wt)
- unit cell length. v = volume

- **PACKING OF SOLIDS AND VOIDS**
- In solids constituent particles are arranged as spheres in close structure.
- In close packed structure, maximum space is occupied by constituent particles and leave minimum vacant space
- When the spheres are closely packed the different crystal systems are generated.
- As a consequence of this close packing in different pattern one gets the face centred cubic, body centred cubic and hexagonal closed packed structure etc.
- In such packings a central sphere, present in two dimensional array touches six nearest spheres in hexagonal close packing. In a square packing, a central sphere touches four neighbouring spheres
- Hexagonal close packing is more compact and occupies 74% volume and the remaining 26% space is void.
- In a cubic close packing it is 74% occupied space.

- **INTERSTIAL VOIDS :**
- The empty spaces between the three dimensional layers are known as holes or voids. The holes are also refered as interstices. There are three types of holes possible.

(A) TETRAHEDRAL HOLES :

- A hole formed by three spheres in contact with each other of a layer. The hole is capped by a sphere from an upper layer.(Planar triangle with vertex down wards)
- A hole formed by three spheres of a layer in contact with each other and also with a sphere of a next lower layer (planar triangles with vertex upward)
- Note : In the above types of holes the four spheres are arranged at the vertices of a regular tetrahedron.
- If 'X' spheres form a solid there are a total of '2X' tetrahedral holes. Out of them 'X' holes are of the type (1) and the remaining 'X' holes belong to type(2).

(B) OCTAHEDRAL HOLE : It is the vacant space between a group of three spheres in a layer and another set of three spheres of a next layer. These six spheres surrounding the hole, lie at the vertices of a regular octahedron.

- If there are 'X' atoms in a close packed structure, there are 'X' octahedral holes present.
- Thus number of tetrahedral holes is double the number of octahedral holes. The size of these holes depends on the size of the spheres producing them.
- Octahedral holes are larger than tetrahedral holes.

- **POINT DEFECTS IN CRYSTALS**
- Stoichiometric compounds are called Daltanides, non-stoichiometric compounds are called Berthollides.
- Point defects are the irregularities or deviations from ideal arrangement around a point or an atom in a crystalline substance
- Properties like density, entropy and heat capacity are influenced by crystal defects to a lesser extent.
- The defects in the crystal influence the properties like mechanical strength, electrical conductivity and chemical activity of the solids to a greater extent.
- Thermodynamically all solids possess a tendency to acquire defects because defects result in disorder and hence increase the entropy of the system
- Electron micro scope is used to know the defects in a solid crystal
- The defects in the crystals can be devided in to different kinds

- **TYPES OF CRYSTAL DEFECTS**
- **INTRINSIC DEFECTS *:*** These are seen in pure crystals
- **EXTRINSIC DEFECTS :** These are due to the impurities in the solids
- **POINT DEFECTS :** These occur at the lattice points or sites in the crystals
- **EXTENDED DEFECTS :** These are present in one or more dimensions
- In stoichiometric compounds two types of defects are observed

(A) SCHOTTKY DEFECT(SCHOTTKY-WAGNER DEFECTS)

- This defect arises due to a vacancy at cation sites and equal number of vacancies at anion sites
- In ionic crystals electrical neutrality is to be maintained
- This type of defect occurs in ionic compounds with (a) High co-ordination numbers and
- (b) Where the positive and negative ions are of similar size i.e., $\frac{r^+}{r^-} \cong 1$

  Ex : NaCl, CsCl
- Schottky defect is found in highly ionic compounds
- Large number of vacancies in the lattice lower the density

(B) FRENKEL DEFECT

- This type of defect arises due to a vacancy at a cation site. Actually, The cation moves to another position between two layers (interstitial position) and it is surrounded by a greater number of anions
- Frenkel defect is favoured by a large difference in sizes between cation and anion
- Compounds having ions of different sizes i.e $\frac{r^+}{r^-}$ is low since positive ions are smaller than negative ions, generally the positive ions are found in interstitial positions
- In these compounds the coordination number is low(usually 4 or 6)
  Ex : ZnS, AgBr, AgI, AgCl.
- Some ionic crystals have both the Schottky as well as Frenkel defects
  Ex : AgBr

- **ELECTRICAL AND MAGNETIC PROPERTIES**
- Properties of solids depending on the nature of bonding or cohesive forces present in them
- In ionic solids cohesive forces are due to the lattice energy and they originated from Coulombic forces of attractions between the two ions
- In metals electrons are essentially mobile and so the properties of metals can be explained in terms of electron bands formed by molecular orbitals.
- Crystals can possess various structures, these structures can be studied by X-ray diffraction methods.
- Pure crystalline solids are also imperfect arrangements. These defects in solids cause changes in the properties of the solids.
- Crystalline solids exhibit a wide range of properties namely, Electrical, Mechanical, Magnetic and other properties.
- The physical properties of solid, its structure and its chemical composition are all closely interrelated.

- **ELECTRICAL PROPERTIES :**
- Based on electrical conductivity, solids can be broadly classified into three types

- They are Metals, Semi-conductors and Insulators or Non-conductors
- Metals are conductors and have conductivity of the order of 10^3 to 10^8 $ohm^{-1}cm^{-1}$
- Insulators have very low conductivity of the order of 10^{-10} to 10^{-22} $ohm^{-1}cm^{-1}$
- The solids whose conductivity lies between those of Metallic conductors and insulators are called Semi-conductors. The order of semic conductors 10^{-6} to 10^4 $ohm^{-1}cm^{-1}$
- The electrical conductivity that is observed is usually related to defects in the crystal.
- In such defective crystal the migration of ions or charge imperfections(in case of Ionic conductivity) or the motion of electrons and shifting of holes(increase of electronic conductivity) relate the conductivities.
- The mechanism of electrical conductivity may be given in terms of
- a) Vacancy Mechanism b) Interstitial Mechanism and c) Interstitialcy Mechanism
- The Magnitude of electrical conductivity strongly depends on the number of electrons available to participate in the conduction process.
- In Metals the conductivity depends on the number of valence electrons present per atom.
- when a large number of atoms unite their wave functions interact.
- This results in a large number of molecular orbitals or energy levels, some Bonding and some antibonding.
- These energy levels are closely spaced energy levels and are known as bands.
- The number of energy levels is equal to the number of Atomic orbitals interacting.
- One half of these resulting orbitals have lowered energy levels and are known as bonding orbitals. They are of similar energies and form a continuous band of orbitals.
- The other half of resultant orbitals have raised energy levels are known as Antibonding energy levels or orbitals.
- At all real temperatures the band has a large number of half filled energy levels. Electrons can flow readily through these bands only when the band is incompletely filled with electrons or when electronic band(filled energy levels) is very close to vacant molecular orbitals.
- At laboratory temperatures the conductivity of the metals is nearly independent of impurities and the lattice defects.
- At low temperatures the mobility due to vibrations in the lattice is quite negligible and as a result the conductivity becomes infinitely large.
- The conductivity of metals generally decrease with an increase in temperature. This is probably due to increased vibrations in the lattice points the resistance to the flow of electrons increases.
- The impurities in the metal and the imperfections in the lattice also contribute to the conductivity.
- Measurement of the resistance of the metal as resistance ratio explain the purity of the metal.
- The conductivity of semi conductors varies completely in the opposite way to that of the metals.
- Semi conductors conductivities increases with increase in temperature. This is due to the fact that the electrons from the valence band jump to the conduction band.
- Pure semi conductors which exhibit this property are known as intrinsic semi conductors.
- The temperature zone where the conductivity depends on the thermal electrons and the holes in the lattice of the semi conductors is known as intrinsic region.
- At low temperature the conductivity is mainly determined by the concentrations of the electron donors and the acceptors. This region is known as extrinsic region.

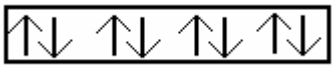
- ***Doping : -***
- Addition of B $(IIIA Group)$ (or) P (or) As $(VA \text{ Group})$ element to alter the conductivity of $Ge(or)$ Si is called as doping.

- Pure $Si(or)Ge$ are intrinsic semiconducters
- In doping, group $IIIA$ element behaves as electron acceptor and group VA$(15 group\ elements)$ element behaves as donor.
- When VA (or) 15th group element is added to , the crystal lattice does not change, but few atoms are replaced by group VA (or) 15th group elements, it forms covalent bonds with the fifth electron is delocalised, therefore becomes electrical conductor.
- Silicon doped with VA (or) 15th group element is known as 'n' type semi conductor (n = negatively charged electrons are responsible for conductivity)
- In doping VA (or) IIIA group element is called as dopant
- When IIIA (or) 13th group ;element like (or) or is added to the substitution of few atoms by group $IIIA$ takes place
- $IIIA$ group element has only 3 valence electrons. One more electron is required, it is left as a vacant place on the atom. This is called as electron vacancy or a hole.
- This electron vacancy in the crystal structure migrates from one atom to another. This is responsible for electrical conductivity of Si.
- 'Si' doped with IIIA (or) 13th group element is called p – type semiconductor
- n – type and p – type semi conductors both are used in electronic devices
- Example : Diode, pnp or npn type semiconductors are used in transistors.
- These transistors are used to detect (or) amplify radio or audo signals
- In the conversion of radiant energy into electrical energy solar cell (p – n type) is used
- Many solid state semiconductors are prepared by combining IIIA or 13th group elements with VA or 15th group elements and IIB or 12th group elements with VIA or 16th group
- In this type of conductors bond is not pure covalent nature of the bond depends on electronegativities of two elements.
- Transition metal oxides shows wide variation in this electrical properties.
- Metal sulphides of transition elements also exhibits wide variation in their electrical properties.

- **MAGNETIC PROPERTIES :**
- The substances can be classified into five types depending on their response to an applied magnetic field.

(A) DIAMAGNETIC MATERIALS : The substances which are weakly repelled by magnetic field examples NaCl, KCl, TiO_2 ZnO_2 Benzene etc.

- Alignment of magnetic moments in diamagnetic substances



(B) PARAMAGNETIC MATERIALS: The substances which are attracted by magnetic field due to the presence lone electrons on atoms, ions or molecules.

- They lose their magnetic property when the applied filed is removed
  Ex : O_2, Cu^{++}, Fe^{++}, Na, Ti_2O_3, VO_2 , NO etc

(C) FERROMAGNETIC MATERIALS *:* The substances which are strongly attaracted by magnetic field.

- These substances contain domains of magnetization. All of them are oriented in the same direction. They retain their magnetism even after withdrawal of applied field.
  Ex : Fe, Co, Ni, CrO_2 etc.
- Fe, Co, Ni, are the only three elements which show ferromagnetism at room temperature.
- The alignment of magnetic moments in these substances is



(D) Anti Ferromagnetism : It is due to compensatory alignment of moments. The net moment is Zero. The alignment in these substance is



Ex : MnO_2, V_2O_3, NiO etc.

(E)Ferrimagnetism : It is due to the unequal number of alignement of moments in parallel and antiparllel directions. It results in the net moment.



Fe_3O_4, $MgFe_2O_4$, $CuFe_2O_4$, $ZnFe_2O_4$etc.

- All the magnetically ordered solids transfroms to the paramagnetic state at elevated temperatures due to the randomization of spins
  Ex : V_2O_3 changes to paramagnetic at 150 K and NiO at 523 K
- Every substance has some type of magnetic property, these magnetic properties are measured in terms of magnetic susceptibility and magnetic moment.
- Magnetic subsceptibility is expressed in gram susceptibility, volume susceptibility or molar susceptibility.

- **BRAIN TWISTING CONCEPTS**
- Length of face diagonal - $\sqrt{2}a$
- Length of body diagonal - $\sqrt{3}a$
- For fcc lattice of an ionic crystal of NaCl type edge length, $a = 2\left(r_c + r_a\right)$
- Packing fraction = $\dfrac{\textbf{volume of atoms in the cube}}{\textbf{volume of the cube}}$

- Percentage of volume occupied by aotms in a packing = packing fraction $\times$ 100

S.-N-O	Cubic system	Density (d)	Edge length (a)	Radius (r)	Distance between two spheres
1	Simple Cube	$\frac{M}{N_0.a^3}$	2r	a/2	a
2	Face centred cube	$\frac{4M}{N_0.a^3}$	$\frac{4r}{\sqrt{2}}$	$\frac{a}{2\sqrt{2}}$	$\frac{a}{\sqrt{2}}$
3	Body centred cube	$\frac{2M}{N_0.a^3}$	$\frac{4r}{\sqrt{3}}$	$\frac{\sqrt{3}a}{4}$	$\frac{\sqrt{3}a}{2}$