Solid State

(MHT-CET/JEE/NEET)

Introduction

- Solid, liquid and gas are three physical states of matter. effecting changes in conditions of temperature and pressure. The physical slate of matter is the result of interplay of intermolecular forces of attraction like dipole-dipole interactions, dipole-induced dipole interactions, London forces, hydrogen bonding, etc.
- The form of matter which possesses rigidity, does not flow and hence, has a definite shape and a definite

Classification of Solids

- The presence or absence of orderly arrangement of the constituent panicles of the solid distinguishes the solids into two types:

Crystalline solids

- A crystalline solid is a homogeneous solid in which the constituent particles (atoms, ions or molecules) are arranged in a definite repeating pattern. They are also called true solids.
- They are further classified as :
  Isomorphous : Two or more substances having the same crystal structure are said to be isomorphous. e.g.,
  (i) NaF and MgO (atoms in the ratio 1:1)
  (ii) $NaNO_3$ and $CaCO_3$ (atoms in the ratio 1:1:3)
  (iii) K_2SO_4 and K_2SeO_4 (atoms in the ratio 2:1: 4).
  (iv) Cr_2O_3 and Fe_2O_3 (atoms in the ratio 2:3)
  Polymorphous :A single substance that crystallises in two or more forms under different conditions is called polymorphous
  e.g.,
  (i) Carbon has two polymorphic forms i.e., graphite and diamond.
  (ii) Sulphur has two polymorphic forms i.e., rhombic and monoclinic sulphur.
  (iii) Calcium carbonate and silicon dioxide also exist in nature in two polymorphic forms.

Amorphous solids

- The substances that appear like solids but do not have well developed perfectly ordered crystalline structure are called amorphous (no form) solids.
- They are also called pseudo solids or super-cooled liquids.

Distinction between Crystalline Solids and Amorphous Solids

Crystalline solids	Amorphous solids
The solids have definite characteristic shape due to orderly regular long range arrangement of constituent particles.	The solids have irregular shape due to orderly arrangement of constituent particles. The order is **only** short range
These are true solids.	These are pseudo solids or supercooled liquids.
Crystalline solids may or may not *be* isotropic. They are anisotropic (physical properties have different values in different directions).	Amorphous solids are isotropic (physical properties have same values in different directions) like liquids.
Heat of fusion is definite and depends upon arrangement of particles in the crystalline solids.	Heat of fusion is not definite.
Ca,As,NaF,NaCl,NaNO₃, etc.	Glass, Rubber, Plastics, Tar, Butter, etc.

Glass

- Glass is an optically transparent material produced by fusing together silicon oxide with sodium oxide, boron oxide and a trace amount of transition metal oxide is added to impart colour to the glass.

Different types of glass

- By changing the compositions almost eight hundred different types of glasses are manufactured.
- **Quartz glass:** Obtained from silicon dioxide only.
- **Pyrex glass :** Obtained by fusing together 60 to 80% SiO_2, 10 to 25% B_2O_3 and remaining amount of Al_2O_3.

- **Soda lime glass** : Obtained by fusing 75% SiO_2, 15% Na_2O and 10% CaO.
- **Red glass**: Contains trace amount of gold and copper.
- **Yellow glass**: Contains UO_2.
- **Blue glass**: Contains CoO or CuO.
- **Green glass**: Contains Fe_2O_3 or CuO.

Classification of Crystalline Solids

- Most of the solids are crystalline in structure. Metallic solids like gold, platinum, silver, copper, zinc, etc. are crystalline solids. Inorganic salts like sodium chloride, magnesium sulphate, potassium bromide, copper sulphate, cesium chloride, etc. are all crystalline solids. Non-metallic solids like sulphur, phosphorus, iodine are crystalline solids. Organic substances like benzoic acid, oxalic acid, camphor, naphthalene, etc. are also crystalline solids.
- Crystalline solids are classified into four main types depending on nature of bonds : 1.3.1 Molecular solids 1.3.2 Ionic solids 1.3.3 Metallic solids 1.3.4 Covalent solids

Characteristics of Various Types of Solids (Crystals)

Sr. No.	Characteristics	Molecular solids	Ionic solids	Metallic solids	Covalent solids
1.	Constituent particles present in lattice sites	molecules (Polar or non-polar)	positive and negative ions	positive ions in a sea of delocalised electrons	atoms
2.	Bonding forces	weak van der Waals forces, or hydrogen bonding	electrostatic attraction between ions	electrostatic attraction between cations and sea of electrons (metallic bonds)	Strong covalent bonds
3.	Hardness	very soft	hard	variable (hard or soft)	very hard, except graphite which is soft
4.	Brittleness	low	brittle	very low	medium
5.	Melting point	low	high	moderate to high	very high
6.	Electrical conductivity	bad conductors	bad conductors (conductors in molten state or in aqueous solutions)	good conductors	bad conductors except graphite
7.	Solubility	some are soluble and some are insoluble in both polar as well as non-polar solvents	soluble in polar and insoluble in non-polar solvents	insoluble in polar as well as non-polar solvents	insoluble in polar and usually soluble in non-polar solvents
8.	Examples	CH_4, H_2, CO_2, H_2O, sugar, etc.	NaCl, ZnS, KNO_3, CaO, $BaCl_2$, etc.	all metals and alloys	diamond, graphite, fullerence, etc.

Crystalline Alltropes of Carbon

Allotrope	Properties
Diamond	A rigid three-dimensional network of sp^3 hybridised carbon atoms, hardest substance known and used as an abrasive.
Graphite	Most stable allotrope', having layered structure in which each layer has sp hybridised carbon atoms in hexagonal rings and adjacent layers are held together by weak van der Waals forces, soft, slippery, conductor of electricity and used as lubricant in machines
Fullerene	Pure form of carbon, consists mainly of C_{60}, have shape like soccer ball (also called Buckminster fullerene) which contains 20 six-membered rings and 12 five-membered rings and all carbon atoms are sp^2 hybridised, used as high strength materials, electric conductors, molecular sensors, semiconductors and form a superconductor with potassium ($K_{35}C_{60}$).

Unit Cell and Two and Three Dimensional Lattices

- A unit cell is the smallest repeating structural unit of a crystalline solid.
- When unit cells of the same crystalline substance are repeated in space in all directions, a crystalline solid is formed.
- Unit cell of a crystalline solid and its extension in three dimensional space are shown in figures (a) and (b).
- Each point at the intersection of the lines in the unit cell represents constituent particles, i.e., an ion or an atom or molecule of the crystalline solid.
- Any point at the intersection of lines is called a *lattice point*.
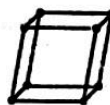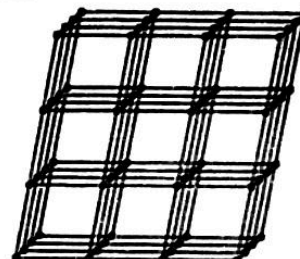

Fig.: (a) Unit cell Fig.: (b) Extension of unit cells in three dimension

- The collection of all the points in the crystal having similar environment is called space lattice.
- French mathematician Bravais proved that lattice points can be arranged in maximum of fourteen types. The arrangement is called Bravais lattices.
- The fourteen lattices corresponding to seven crystal systems are as follows:

S. No.	Crystal system	Type	Edge length	Angle	Example
1.	Cubic	Simple/primitive	$a = b = c$	$\alpha = \beta = \gamma = 90°$	Polonium
2.	Cubic	Body centred	$a = b = c$	$\alpha = \beta = \gamma = 90°$	Fe, Rb, Na, Ti, W, U, Zr
3.	Cubic	Face centred	$a = b = c$	$\alpha = \beta = \gamma = 90°$	Cu, Al, Ni, Au, Ag, Pt
4.	Tetragonal	Primitive	$a = b \neq c$	$\alpha = \beta = \gamma = 90°$	SnO_2
5.	Tetragonal	Body centred	$a = b \neq c$	$\alpha = \beta = \gamma = 90°$	Ti, O_2, $CaSO_4$
6.	Orthorhombic	Primitive	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$	Rhombic sulphur
7.	Orthorhombic	Body centred	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$	KNO_3
8.	Orthorhombic	Face centred	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$	$BaSO_4$
9.	Orthorhombic	End centred	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$	$MgSO_4 \cdot 7H_2O$
10.	Monoclinic	Primitive	$a \neq b \neq c$	$\alpha = \beta = 90°, \gamma \neq 90°$	Monoclinic sulphur
11.	Monoclinic	End centred	$a \neq b \neq c$	$\alpha = \beta = 90°, \gamma \neq 90°$	$Na_2SO_4 \cdot 10H_2O$
12.	Triclinic	Primitive	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90°$	$K_2Cr_2O_7, H_3BO_3$
13.	Hexagonal	Primitive	$a = b \neq c$	$\alpha = \beta = 90°, \gamma = 120°$	ZnO, BeO, CoS, SnS
14.	Rhombohedral or trigonal	Primitive	$a = b = c$	$\alpha = \beta = \gamma \neq 90°$	Calcite, $NaNO_3, FeCO_3$

Calculation of number of atoms per unit cell

- Total number of constituent units (spheres) per unit cell

$$= \frac{1}{8} \times \text{Occupied corners} + \frac{1}{2} \times \text{Occupied face centres}$$

$$+ \text{Occupied body centre} + \frac{1}{4} \times \text{Occupied end centres}$$

Unit cell	No. of atoms and their contribution per unit cell			Total no. of atoms per unit cell
	at corners	at faces	in centre	
Simple cubic	$8 \times \frac{1}{8}$	0	0	1
Body-centred cubic	$8 \times \frac{1}{8}$	0	1	$1 + 1 = 2$
Face-centred cubic	$8 \times \frac{1}{8}$	$6 \times \frac{1}{2}$	0	$1 + 3 = 4$

Packing in Solids

Close Packing in Crystals

- **Hexagonal close packing (hcp)** : $ABAB$...... type. i.e., spheres in every third layer are vertically aligned with the first layer spheres.
- **Cubic close packing (ccp) or face-centred cubic (fcc)** : $ABCABC$....... type. i.e., spheres in every fourth layer are vertically aligned.
- Both these types of close packing are highly efficient (with % occupied space = 74%) and have coordination number (number of nearest neighbours) 12.

Simple cubic unit cell	Face-centred cubic or cubic close-packing	Body-centred cubic
$Z = 1$	$Z = 4$	$Z = 2$
$d = a = 2r, r = \frac{a}{2}$	$d = 2r = \frac{a}{\sqrt{2}}$, $r = \frac{a}{2\sqrt{2}}$	$d = 2r = \frac{\sqrt{3}a}{2}$, $r = \frac{\sqrt{3}a}{4}$
Packing efficiency = 52.4%	Packing efficiency = 74%	Packing efficiency = 68%
Coordination No. = 6	Coordination No. = 12	Coordination No. = 8

- For *bcc* structure of pure elements, $Z = 2$ but for *bcc* structure of ionic compounds like NaCl, CsCl, $Z = 1$.
- **Tetrahedral void** : It is a simple triangular void surrounded by four spheres. In *ccp*, tetrahedral voids are located on body diagonals, two on each.

- **Octahedral void** : It is a double triangular void surrounded by six spheres. In *ccp*, octahedral voids are located at the body centre and edge centres.
- If N is the number of close packed spheres, then the number of octahedral voids generated = N, the number of tetrahedral voids generated = $2N$
- Radius (r) of tetrahedral void = $0.225 R$
- Radius (r) of octahedral void = $0.414 R$, where R is the radius of the spheres in close packing.

Density of Unit Cells

Calculations involving Unit Cell Dimensions

- $$\rho = \frac{Z \times M}{a^3 \times N_A \times 10^{-30}} \text{ g cm}^{-3}$$

  where Z = no. of atoms per unit cell, a = edge length in pm, ρ = density of solid, M = molar mass and N_A = Avogadro's no.

Illustration : Calculate the radius of molybdenum atom if the element crystallizes as body-centred cubic crystal. Given: Density of Mo = 10.3 g cm^{-3} and molar mass of Mo = 95.94 g mol^{-1}.

Soln.: In a body-centred cubic unit cell, there are two atoms per unit cell.

Hence, from the expression, $\rho = \frac{Z}{a^3}\left(\frac{M}{N_A}\right)$.

$$a^3 = \frac{Z}{\rho}\left(\frac{M}{N_A}\right) = \frac{2}{10.3} \times \frac{95.94}{6.023 \times 10^{23}} = 3.09 \times 10^{-23} \text{ cm}^3$$

$a = 3.13 \times 10^{-8}$ cm = 313 pm

Now, since in the body-centred cubic unit cell, atoms touch each other along the cross diagonal of the cube, we have

$$4r = \sqrt{3}a \text{ or } r = \frac{\sqrt{3}}{4}a = \frac{\sqrt{3}}{4} \times 313 = 135.5 \text{ pm}$$

Illustration : Iron crystallizes in a *bcc* system with a lattice parameter of 3.289 Å. Calculate the density of iron in the *bcc* system.

(Given : atomic weight of Fe = 56, $N_A = 6.023 \times 10^{23}$ mol^{-1})

Soln.: Density, $\rho = \frac{Z \times M}{N_A \times a^3}$. For *bcc*, $Z = 2$

$$\therefore \rho_{Fe} = \frac{2 \times 56.0 \text{ g mol}^{-1}}{6.023 \times 10^{23} \text{ mol}^{-1} \times (3.289 \times 10^{-8} \text{ cm})^3}$$

$$= 5.226 \text{ g cm}^{-3}$$

Packing in Voids of Ionic Solids

- Ionic solids are formed from cations and anions. The number of oppositely charged ions are appropriately adjusted such that the charges are balanced and the compound formed is electrically neutral.
  - ▶ If the cation is relatively small then it occupies tetrahedral hole.
  - ▶ Bigger cations occupy octahedral holes.
  - ▶ In case if the size of the cation is too large to be accommodated in the small space of octahedral hole, the packing of the anions are modified, anions are appropriately separated from one another and larger cations are accommodated in larger cubic hole as shown in the figure.

Fig.: Larger cation in larger cubic hole

Illustration : A compound formed by elements A and B crystallizes in cubic structure where A atoms are at the corners of a cube and B atoms are at the face-centre. What is the formula of the compound ?

Soln.: A atoms are at eight corners of the cube.

Therefore, the number of A atoms in the unit cell $= \dfrac{8}{8} = 1$
B atoms are at the face-centre of six faces.

Therefore, its share in the unit cell $= \dfrac{6}{2} = 3$
The formula is AB_3.

Illustration : In a cubic lattice, the closed packed structure of mixed oxides of the lattice is made up of oxide ions; one eighth of the tetrahedral voids are occupied by divalent ions (A^{2+}) while one half of the octahedral voids are occupied by trivalent ions (B^{3+}). What is the formula of the oxide?

Soln.: Let there be 80 O^{2-} in the crystal.
Octahedral voids = 80, Tetrahedral voids = 160
A^{2+} ions $= \dfrac{1}{8} \times 160 = 20$; B^{3+} ions $= \dfrac{1}{2} \times 80 = 40$
$A^{2+} : B^{3+} : O^{2-} = 20 : 40 : 80 = 1 : 2 : 4$
Thus, the formula is AB_2O_4.

- **Radius ratio rule for ionic compounds :** For the stability of an ionic compound, each cation should be surrounded by maximum number of anions and *vice versa* (for maximum electrostatic forces of attraction).

- Radius Ratio $= \dfrac{\text{Radius of the cation } (r^+)}{\text{Radius of the anion } (r^-)}$

r^+/r^- Values, Coordination Numbers and Examples

C. No.	Radius ratio	Types of hole occupied	Example
3	0.155 – 0.225	Planar triangular	Boron trioxide (B_2O_3)
4	0.225 – 0.414	Tetrahedral	Sphalerite (ZnS)
6	0.414 – 0.732	Octahedral	Rock salt (NaCl)
8	> 0.732	Cubic	Caesium chloride (CsCl)

Illustration : The radii of Zn^{2+} and S^{2-} ions are 72 and 184 pm respectively. Predict the probable type of coordination for Zn^{2+} ions.

Soln.: Given that : Radius of $Zn^{2+} = 72 \times 10^{-12}$ m;
Radius of $S^{2-} = 184 \times 10^{-12}$ m

∴ Ratio of radius of cation to radius of anion
$\dfrac{r_{(Zn^{2+})}}{r_{(S^{2-})}} = \dfrac{r_c}{r_a} = \dfrac{72}{184} = 0.391$

∴ Zn^{2+} occupies tetrahedral voids, having coordination number 4. As compound of Zn^{2+} and S^{2-} will have equimolar quantities of the two ions, therefore coordination number of Zn^{2+} will also be 4.

Structures of Ionic Compounds

Compound	Description	Coordination number	Other examples
NaCl (Rock salt)	ccp arrangement of Cl^- ions and Na^+ ions occupy all the octahedral voids	$Na^+ = 6$ $Cl^- = 6$	LiCl, KCl, AgCl AgBr, CaO, MgO
CsCl	Simple cubic arrangement of Cl^- ions and Cs^+ ions in the cubic sites	$Cs^+ = 8$ $Cl^- = 8$	CsBr, CsI
ZnS (Zinc Blende)	ccp arrangement of S^{2-} ions and Zn^{2+} ions in the alternate tetrahedral voids	$Zn^{2+} = 4$ $S^{2-} = 4$	CuCl, CuI, BeO, AgI
ZnS (Wurtzite)	hcp arrangement of S^{2-} ions and Zn^{2+} ions in the alternate tetrahedral voids	$Zn^{2+} = 4$ $S^{2-} = 4$	AgI, BeS, CuBr
CaF₂ (Fluorite)	ccp arrangement of Ca^{2+} ions and F^- ions in all the tetrahedral voids	$Ca^{2+} = 8$ $F^- = 4$	BaF₂, SrF₂

TiO_2 (Rutile)	Distorted *bcc* of Ti^{4+} ions and O^{2-} ions in the octahedral voids	$Ti^{4+} = 6$ $O^{2-} = 3$	MgF_2, ZnF SnO_2, PbO_2
Na_2O (Anti-fluorite)	*ccp* arrangement of O^{2-} ions and Na^+ ions in all the tetrahedral voids	$Na^+ = 4$ $O^{2-} = 8$	Li_2O, K_2S

Defects in Crystal Structure

- Any deviation from the perfectly ordered arrangement of constituent particles is called *defect* or *imperfection*.
- **Types of defects :** There are two types of defects :
  - **Line defect :** The defect is due to irregularity in a complete line, a row of lattice points of constituent particles.
  - **Point defect :** The defect is due to a fault produced in the arrangement of a point *i.e.*, a constituent particle like atom, ion or molecule in a crystalline solid.

Types of point defects : There are three types of point defects :

(i) **Vacancy defect :** Sometimes during crystallisation some of the places of the constituent particles remain unoccupied in crystal lattice and the defect generated is called *vacancy defect*.

(ii) **Schottky defect :** The defect produced due to vacancies caused by absence of equal number of anions and cations in the crystal lattice is called *Schottky defect*.

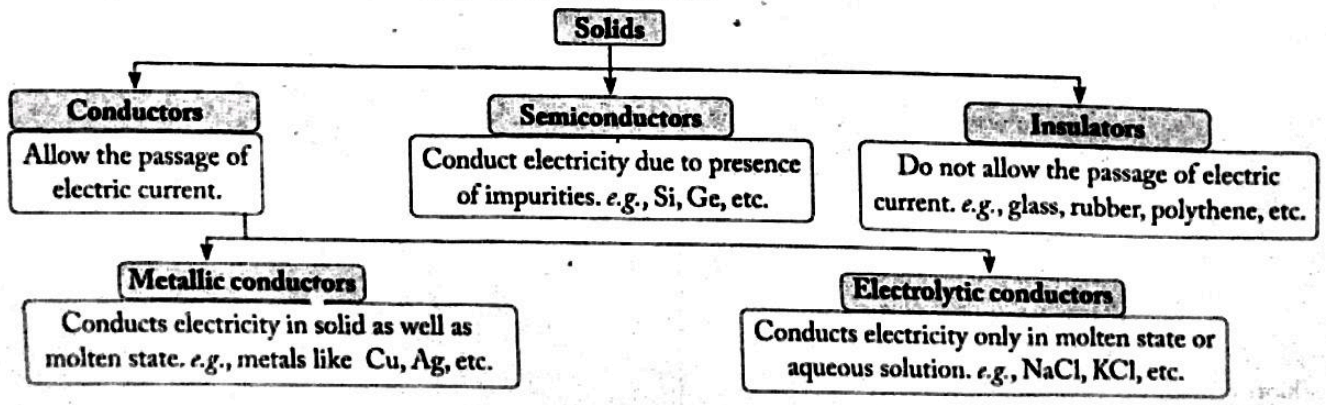**Conditions favouring Schottky defect :** The Schottky defect is noticed in ionic compounds,
  - with high coordination numbers.
  - in which cations and anions have almost identical sizes.
    e.g.; alkali metal halides such as NaCl, KCl, CsCl, KBr, etc. normally show this defect.

Consequences of Schottky defect :
  - The defect increases the electrical conductivity of the crystalline solid.
  - The presence of holes because of the missing ions lowers the density of the crystal.
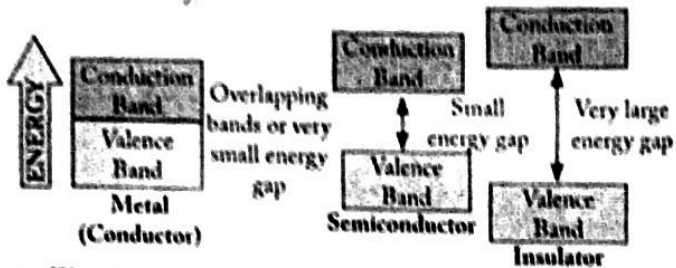
Electrical Properties

  - Due to the presence of large number of holes, stability of the crystal decreases.
  - It also lowers the lattice energy of the crystal.

(iii) **Interstitial or Frenkel defect :** This defect occurs when cation or anion from ionic solid leaves its regular site and moves to occupy a place between the lattice sites called *interstitial position*.

Conditions favouring Frenkel defect : Generally it is observed in the ionic compounds where,
  - crystal structure possesses low coordination number.
  - the anions are much larger than cations.

Consequences of Frenkel defect :
  - Presence of this defect does not alter the density of the solid.
  - Frenkel defects are responsible for conduction of electricity in crystals.
  - They are responsible for phenomenon of diffusion in solids.
  - They decrease the stability of the crystal.
    e.g.; AgCl because of Ag^+ ions or ZnS because of Zn^{2+} ions shows this defect.

- **Impurity defect :** When a regular cation of the crystal is replaced by some different cation then the defect generated is called *impurity defect*.

Types of impurity defects : There are two types :

(i) **Substitution impurity defect :** If the impurity cation is substituted in place of regular cation then it is called *substitution impurity defect*.
    e.g.; brass is a substitution alloy formed by substituting copper metal by zinc metal in the ratio 3 : 1.

(ii) **Interstitial impurity defect :** If the impurity is present in the interstitial positions then it is called *interstitial impurity defect*.
    e.g.; stainless steel is an interstitial alloy formed by introducing carbon atoms as impurity.

- On the basis of electrical conductivity solids are classified as :

Solids

Conductors
Allow the passage of electric current.

Semiconductors
Conduct electricity due to presence of impurities. *e.g.*, Si, Ge, etc.

Insulators
Do not allow the passage of electric current. *e.g.*, glass, rubber, polythene, etc.

Metallic conductors
Conducts electricity in solid as well as molten state. *e.g.*, metals like Cu, Ag, etc.

Electrolytic conductors
Conducts electricity only in molten state or aqueous solution. *e.g.*, NaCl, KCl, etc.
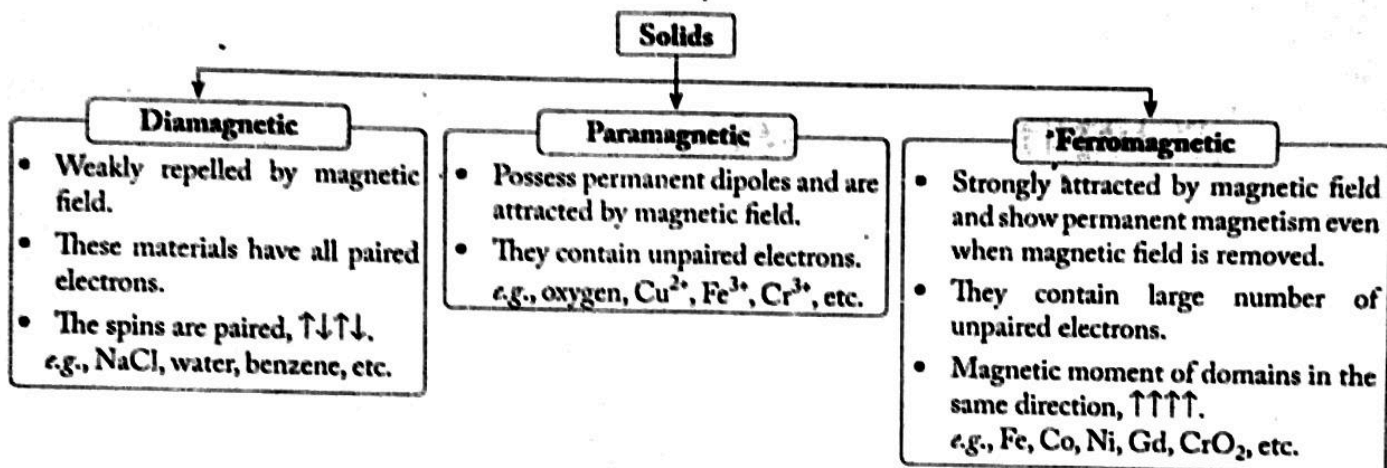
- **Band theory :**

- Electrical conductivity of semiconductors increases with rise in temperature because more electrons can jump to the conduction band.
- The conductivity of semiconductors can be increased by adding an appropriate amount of suitable impurity (*Doping*).
- By adding electron rich impurities, like P and As (group 15 elements) to Si or Ge, free electrons become available which increase conductivity. Such solids are called *n-type semiconductors*.
- By adding electrons deficit impurities like B, Al (group 13 elements) to Si or Ge, holes are created. Electrons move to occupy the holes. Thus, holes move towards negatively charged plate as if they carry positive charge. These are called *p-type semiconductors*.

Magnetic Properties

- Magnetic moment arises due to orbital motion of the electron around the nucleus and spin of electron around its own axis. The magnetic properties of solids are related to the electronic structure and on the basis of response towards magnetic field, solids are divided as follows :

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                    Solids
    ┌─────────────────┼──────────────────┐
Diamagnetic      Paramagnetic      Ferromagnetic
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Diamagnetic
- Weakly repelled by magnetic field.
- These materials have all paired electrons.
- The spins are paired, $\uparrow\downarrow\uparrow\downarrow$.
  e.g., NaCl, water, benzene, etc.

Paramagnetic
- Possess permanent dipoles and are attracted by magnetic field.
- They contain unpaired electrons.
  e.g., oxygen, Cu^{2+}, Fe^{3+}, Cr^{3+}, etc.

Ferromagnetic
- Strongly attracted by magnetic field and show permanent magnetism even when magnetic field is removed.
- They contain large number of unpaired electrons.
- Magnetic moment of domains in the same direction, $\uparrow\uparrow\uparrow\uparrow$.
  e.g., Fe, Co, Ni, Gd, CrO_2, etc.

Determination of magnetic property (Guoy's method) :

- The method consists of weighing the substances in and out of magnetic field.
  ▸ If the substance is diamagnetic then it weighs less in the magnetic field.

▸ If the substance is paramagnetic then it weighs more in the magnetic field because the substance is pulled in the magnetic field.

▸ If the substance is ferromagnetic then it weighs more than that of paramagnetic in the magnetic field because the substance is pulled more in the magnetic field.

SOLID STATE

A solid is a state of matter which possesses definite shape and volume. They are characterised by incompressibility, rigidity and mechanical strength.

Classification of Solids

Amorphous Solids : The substances whose constituent particles are not arranged in any regular arrangement are called *amorphous solids.* These solids have a random, disordered arrangement of constituents. They do not have definite shape.

Crystalline Solids : The substances whose constituent particles are arranged in a definite geometric pattern in three dimensional space are called *crystalline solids.* These solids have a definite regular arrangement, definite shape and high melting points. These are of following types:

1. Molecular solids
2. Ionic solids
3. Metallic solids
4. Covalent solids

Crystal Lattice and Unit Cell

Crystal Lattice : It is the regular arrangement of constituent particles of a crystalline solid in three dimensional space.

Unit Cell : A unit cell is the smallest repeating unit in space lattice which when repeated over and over again produces the complete crystal lattice.

sc : Particles at the corners only (Z = 1)

fcc : Particles at the corners as well as face centres (Z = 4)

bcc : Particles at the corners and body centre (Z = 2)

Cubic System :

$$d = \frac{Z \times M}{a^3 \times N_A} \ \text{g cm}^{-3}$$

Relation between d, a and r :

	Simple cubic	fcc	bcc
$r = \frac{a}{2}$	$r = \frac{a}{2} = \frac{a}{2\sqrt{2}}$	$r = \frac{a}{2} = \frac{\sqrt{3}a}{4}$	

Size and No. of Voids :

Type	Size	No. of Voids
Octahedral	0.414 R	N
Tetrahedral	0.225 R	2N

Coordination Number and Packing Efficiency :

Type	Simple cubic	bcc	fcc
C. No.	6	8	12
Packing efficiency	52.4%	68%	74%

Imperfections (Defects) in Solids

Line defects : The defects arise due to irregularity in a complete line, a row of lattice points of constituent particles.

Point defects : The defects which arise due to the irregularity or deviations from ideal arrangement of atoms around a point or an atom in a crystalline substance are called *point defects.*

Vacancy defects : Sometimes during crystallisation some of the places of the constituent particles remain unoccupied in crystal lattice and the defect generated is called *vacancy defect.*

Schottky defects : Characterized by missing of equal number of cations and anions from their lattice sites and electrical neutrality is maintained.

Frenkel Defects : An ion shifts from its original lattice site to the interstitial site. Electrical neutrality and stoichiometry are maintained.

Impurity defects : Arise when foreign atoms are present at the lattice site in place of host atoms (substitutional solid solutions) or at the vacant interstitial sites (interstitial solid solutions).

Properties of Solids (Crystals)

Electrical Properties : Solids may be classified into three categories depending upon their values of electrical conductivity.

- **Conductors :** Allow the passage of electric current. e.g., metals, NaCl, KCl(aq), etc.
- **Insulators :** Do not allow the passage of electric current. e.g., glass, rubber, polythene, etc.
- **Semiconductors :** Conduct electricity due to presence of impurities. e.g., Si, Ge, etc.
  - *n*-type semiconductors : Group 14 elements (Si, Ge) doped with group 15 elements, free electrons increase conductivity.
  - *p*-type semiconductors : Group 14 elements (Si, Ge) doped with group 13 elements, holes increase conductivity.

Magnetic Properties : Solid substances are classified into following categories depending upon their behaviour towards magnetic field.

- **Diamagnetic** substances are weakly repelled by external magnetic field e.g., NaCl, benzene, water, etc.
- **Paramagnetic** substances are weakly attracted by external magnetic field e.g., O_2, Cu^{2+}, Fe^{3+}, Cr^{3+}, etc.
- **Ferromagnetic** substances are strongly attracted by external magnetic field e.g., Fe, Co, Ni, Gd, CrO_2, etc.