1 The Solid State

Facts that Matter

Solids: The substances having definite shape, mass and volume, are called solids.

Characteristic properties of solid:

- They have definite mass, volume and shape.
- The intermolecular distances are short.
- The intermolecular forces are strong.
- Their constituent particles have fixed positions and can only oscillate about their mean positions.
- They are incompressible and rigid.

Types of Solids: On the basis of the arrangement of the constituent particles, they are of two types:

- Crystalline solids
- Amorphous solids

1. Crystalline solids

- In a crystalline solid, the particles (atoms, molecules or ions) are arranged in a regular and repetitive three-dimensional arrangement.
- These solids have sharp melting point.
- These solids are **Anisotropic.**

  Note: Anisotropic substances/solids are the substances which have different values of physical properties (such as electrical conductivity, refractive index, thermal expansion etc.) in different directions. (Phenomenon of showing different values of all physical properties in different directions is known as **Anisotropism.**)
- These solids can undergo a clean cleavage.
- These solids are generally incompressible.

Examples: All the **metallic elements** like iron, copper and silver; **Non-metallic elements** like sulphur, phosphorus and iodine and **Compounds** like sodium chloride, zinc sulphide and naphthalene.

2. Amorphous solids

- In an amorphous solid, the particles (atoms, molecules or ions) are arranged in an irregular and non-repetitive three-dimensional arrangement.
- Rapidly solidified liquids are amorphous substances, *e.g.* glass, rubber, etc.
- These solids are generally **Isotropic.**

  Note: Isotropic substances/Solids are the substances which have the same values of physical properties (such as electrical conductivity, refractive index, thermal expansion etc.) in all directions.

  (Phenomenon of showing same values of all physical properties in all directions is known as **Isotropism**.)
- These solids on cleavage form smaller pieces with non-planar faces.
- These solids do not have sharp melting point and boiling point, *i.e.* they melt gradually over a temperature range.
- These solids are compressible.

Crystalline solids can be classified into the following categories on the basis of the intermolecular forces acting between the constituent particles

Types of solids	Constituent particles	Attractive forces	Examples	Physical nature	Electrical conductivity	Melting point
1. Molecular solids	Molecules					
(*a*) Non-polar		Dispersion or London forces	Ar, CCl_4, H_2 I_2, CO_2	Soft	Insulator	Very low
(*b*) Polar		Dipole-dipole interactions	HCl, SO_2	Soft	Insulator	Low
(*c*) Hydrogen bonded		Hydrogen bonding	H_2O (ice)	Hard	Insulator	Low
2. Ionic solids	Ions	Coulombic or electrostatic	NaCl, MgO ZnS, CaF_2	Hard but brittle	Insulator in solid state but conductors in molten state and in aqueous solutions	High
3. Metallic solids	Positive ions in a sea of delocalised electrons.	Metallic bonding	Fe, Cu, Ag Mg	Hard but malleable and ductile	Conductors in solid state as well as in molten state	Fairly high
4. Covalent or network solid	Atoms	Covalent bonding	SiO_2 (quartz) SiC, Diamond AlN,	Hard	Insulators	Very high
			C (Graphite)	Soft	Conductor	

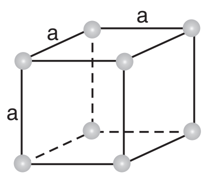
Lattice point: This is a constituent particle (*i.e., ion, atom, molecule*) of a crystal.

Space lattice or crystal lattice: A regular three-dimensional arrangement of points in space is called space lattice or crystal lattice. The points represent the constituent particles of the crystal.

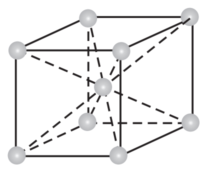
Unit cell: A unit cell is the smallest portion of the crystal lattice. When it is moved repeatedly to a distance equal to its own dimension along each direction, a three-dimensional crystal lattice is generated.

Types of unit cell: The unit cells are of four types:

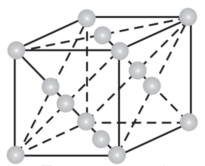
1. **Simple/Primitive unit cell:** It has lattice points (*i.e.,* ions, atoms, molecules) at all the corners of a cube. (Therefore, it has total 8 points)
2. **Body-centred unit cell:** It has one lattice point at the centre of the cube along with all the points at the corner of a cube. (Therefore, it has total 9 points)
3. **Face-centred unit cell:** It has lattice points at the centre of each face along with all the points at the corner of a cube. (Therefore, it has total 14 points)



Primitive (or simple)



Body-centred



Face-centred

Rank of unit cell (z): The number of particles as points in a unit cell is known as rank. To calculate rank, these points should be noted:

- A point at each corner of unit cell is counted as $\frac{1}{8}$ because it countributes to 8 unit cells.
- The points on an edge are counted as $\frac{1}{4}$ because it contributes to 4 unit cells.
- The points at each face are counted $\frac{1}{2}$ because it contributes to 2 units cells.
- The points within the unit cell is counted as 1.
  The rank of unit cell of:

  (1) Primitive/simple cube = $\frac{1}{8} \times 8 = 1$ (2) Body-centred cubic = $\frac{1}{8} \times 8 + 1 = 2$

  (3) Face-centred cubic = $\frac{1}{8} \times 8 + \frac{1}{2} \times 6 = 4$

Co-ordination number: It is the number of atoms or spheres that surrounds the single sphere/atom in a crystal.
C.N. of tetragonal arrangement = 3
C.N. of tetrahedral arrangement = 4
C.N. of octahedral arrangement = 6
C.N. of body centered cubic arrangement = 8
Any close (tight) packing having C.N. = 12 *i.e.,* hcp and ccp (fcc) having C.N.= 12

Void/Hole/Interstices: The space which is left in between the closed pack arrangement is called void. In close packing two types of voids are created viz. tetrahedral and octahedral voids.

Relationship between edge length (a) and radius of the sphere (r) in unit cell:

For fcc, $a = 2\sqrt{2}\,r$ For bcc, $a = \frac{4}{\sqrt{3}}\,r$ For simple cubic, $a = 2\,r$

(**Note:** Sphere = Atom, molecule, ion or any constituent).

Relationship between 'd', 'a' and 'r'

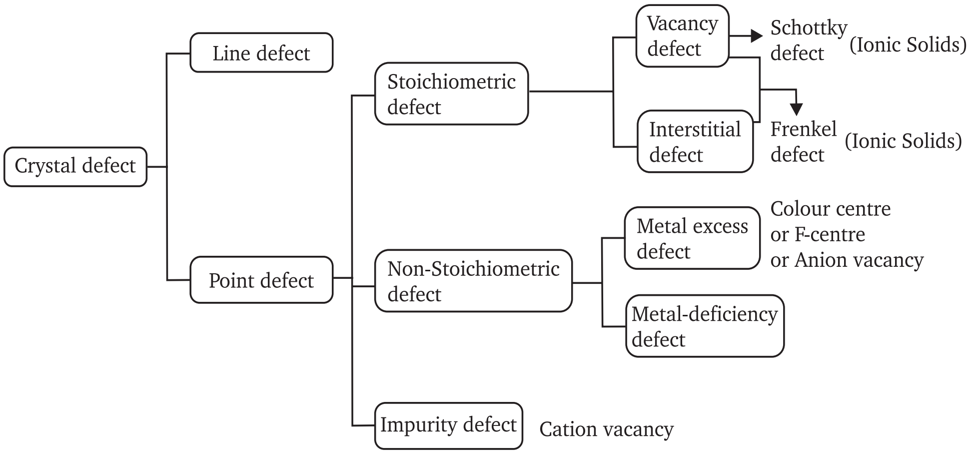
S.No.	Type of unit cell	d (nearest neighbour distance) and a (edge length)	a (Edge length) and r (atomic radius)
1.	Simple	d = a	r = a/2
2.	bcc	d = a × 0.866	r = a × 0.433
3.	fcc	d = a × 0.707	r = a × 0.3535

Efficiency of packing: This is the space occupied by the spheres in a particular unit cell. It is generally shown in %.

1. The % of packing fraction in **Simple Cubic** = 52.36%
2. The % of packing fraction in **Body Centred Cubic** = 68%
3. The % of packing fraction in **Face Centred Cubic** = 74%

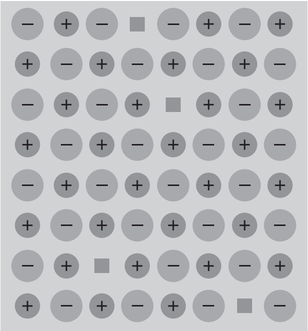
Crystals defect: Internal irregularities of crystals is known as crystals defect.

The following defects are found in crystals:

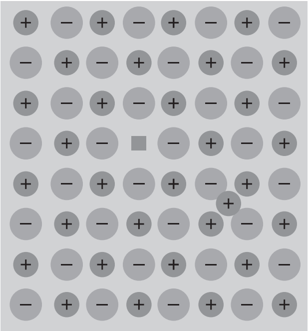


- Single crystals are formed when the process of crystallization occurs at extremely slow rate.
- **Line defects** are the irregularities or deviations from ideal arrangement in entire rows of lattice points.
- **Point defects** are the irregularities or deviations from ideal arrangement around a point or an atom in a crystalline substance.
- **Stoichiometric defect:** Point defects that do not disturb the stoichiometry of the solid is known as *stoichiometric defect* or *intrinsic defect* or *thermodynamic defect.*
- **Vacancy defect:** When some of the lattice sites are vacant, the crystal is said to have vacancy defect. This results in decrease in density of the substance. This defect develops when a substance is heated.
- **Interstitial defect:** When some constituent particles occupy an interstitial site, the crystal is said to have interstitial defect. This defect increases the density of the substance.
- **Schottky defect**
  (1) It occurs when a pair of ions of opposite charge are missing from the ideal lattice.
  (2) The presence of a large number of Schottky defect in a crystal lowers its density.
  (3) This defect occurs if cation and anion having similar size with high coordination number.
  (4) It is found in NaCl. There is one schottky defect for 10^{16} ions.
- **Frenkel defect**
  (1) When an ion leaves its position in the lattice and occupy interstitial site leaving a gap in the crystal *i.e.,* it creates a vacancy defect and interstitial defect.
  (2) This defect will occur if size of cation is smaller than anion, with low coordination number.
  (3) Frenkel defects are **not found in pure alkali halide.** Due to larger size of cations, ions cannot accommodate in interstitial site.
  (4) Frenkel defects are found in silver halide (AgX), because silver ions are smaller in size and can get into the interstitial site.
  (5) The Frenkel defect does not change the density of the solid.
  (6) In AgBr, AgCl both Schottky and Frenkel defects are found.

Differences between Schottky and Frenkel defects: (These defects are classified under stoichiometric defects *i.e.,* ionic ratio of compound remains same.)



Schottky defect

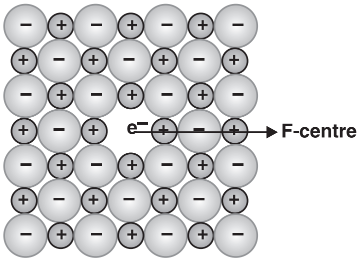


Frenkel defect

Schottky defects	Frenkel defects
Ions leave the lattice structure.	Ions slip into voids in the lattice structure.
Electrical neutrality is maintained.	Electrical neutrality is maintained.
Density of crystal decreases.	Density of crystal remains the same.
Found in compounds with higher coordination no.	Found in compounds with lower coordination no.
Ionic size should be same *e.g.,* NaCl, CsCl, AgBr, AgCl etc.	Ionic size difference is more, Frenkel defect is found in silver halides (AgX), because silver ions are smaller in size and can get into the interstitial site *e.g.,* AgBr, AgCl, etc.

Note:—In AgBr, AgCl both Schottky and Frenkel defects are found.

- **Metal excess defect:**
  - (*a*) **F-centres (here F means Farbe *i.e.,* colour):** When there is an excess of metal ions in non-stoichiometric compounds, the crystal lattice has vacant anion site. The anion sites occupied by electrons are called **F-centres.**
    - ← The F-centres are associated with the colour of the compounds. Excess of K in KCl makes the crystal violet. Excess of Li in LiCl makes the crystal pink.
    - ← Solids containing F-centres are paramagnetic, because the electrons occupying the F-centres are unpaired.
    - ← When the crystal having F-centres are exposed to light, they become photoconductor.



F-centres and their importance

'F' centres: F-centres are sites in an imperfect crystal where electrons are trapped in the anion vacancies.

Importance of 'F' centres: F-centres are responsible for imparting colour to the crystals.

(*b*) **Metal excess defect due to the presence of extra cation at the interstitial site:** Zinc oxide is white in colour at room temperature. On heating, it loses oxygen and turns yellow.

$$ZnO \xrightarrow{\text{heating}} Zn^{2+} + \frac{1}{2}O_2 + 2e^-$$

Now, there is excess of zinc in the crystal and its formula becomes $Zn_{1+x}O$, the excess zinc ions move to interstitial site and the electrons to neighbouring interstitial site.

- **Metal deficiency defect:** FeO, mostly found with a composition of $Fe_{0.95}O$ *i.e.,* range from $Fe_{0.93}O$ – $Fe_{0.96}O$. In crystals of FeO, some Fe^{2+} ions are missing and the loss of positive charge is made up by the presence of required number of Fe^{3+} ions.
- **Impurity defect:** This defect arises due to cation vacancies. In some ionic compounds presence of impurity produce some defects, called impurity defects.

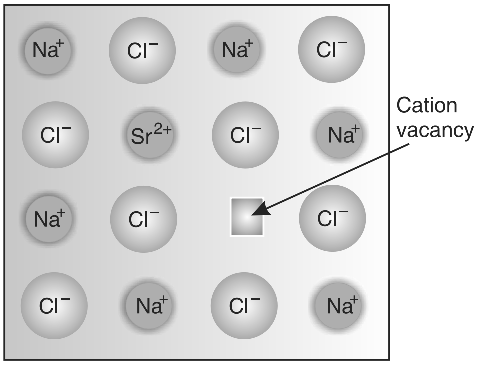
  e.g. 1. Presence of Cd^{++} ion as impurity in AgCl.
  2. Presence of Sr^{++} ion as impurity in NaCl.

  Doping: The process of adding impurities to a crystal so as to change its electrical properties is called **Doping**.

  e.g., Mixing of $SrCl_2$ in solid NaCl.

  Note: 1. Doping increases the conductivity of crystal.
  2. Doping is a kind of impurity defect.

  For example, if we mix strontium chloride ($SrCl_2$) with sodium chloride, some strontium (Sr^{2+}) ions occupy the lattice sites of sodium ions (Na^+) and equal number of sodium (Na^+) sites remain vacant. Such vacancies in the crystal increase the electrical conductivity because certain ions from the neighbouring sites can move into these vacant holes. In this defect the number of positive ions are less as compared to negative ions. Crystals with such defects also act as semiconductor. Since the conductivity is due to holes, these are known as *p*-type semiconductors.



Doping of $SrCl_2$ in NaCl

- **Semiconductor:** These are solids whose conductivity lies in between those of conductors and insulators. The conductivity of semiconductors increases with increase of temperature.
- **Intrinsic semiconductor:** An insulator capable of conducting electric current at higher temperature or when irradiated with electromagnetic radiations, are known as intrinsic semiconductors. This happens because certain covalent bonds are broken and the released electrons are in a position to conduct electric current. *e.g.,* Silicon, Germanium.
- **Extrinsic semiconductor:** These are formed when impurities of certain elements are added (doped) to an insulator.
- ***n*-type semiconductors:** It is obtained by doping group-14 elements with group-15 elements.

  Suppose Si (having 4 valence electrons) is doped with P (with 5 valence electrons), out of 5 valence electrons of P, only 4 valence electrons are involved in bond formation. The 5th electron is not bound anywhere and can be easily promoted to the conduction band. The conduction is thus mainly caused by the movement of electrons.
- ***p*-type semiconductors:** It is obtained by doping group-14 elements with group–13 elements.

Suppose Si (having 4 valence electrons) is doped with Ga (which has 3 valence electrons), 3 valence electrons are involved in bond formation with the neighbouring Si atom.

A vacancy is left which can be filled by the transfer of a valence electron from a neighbouring Si atom. The movement of electron into the vacancy leaves behind a hole which carries positive charge. Another electron from a neighbouring Si atom can move into the hole leaving behind another hole. It appears as if the hole has moved through the lattice.

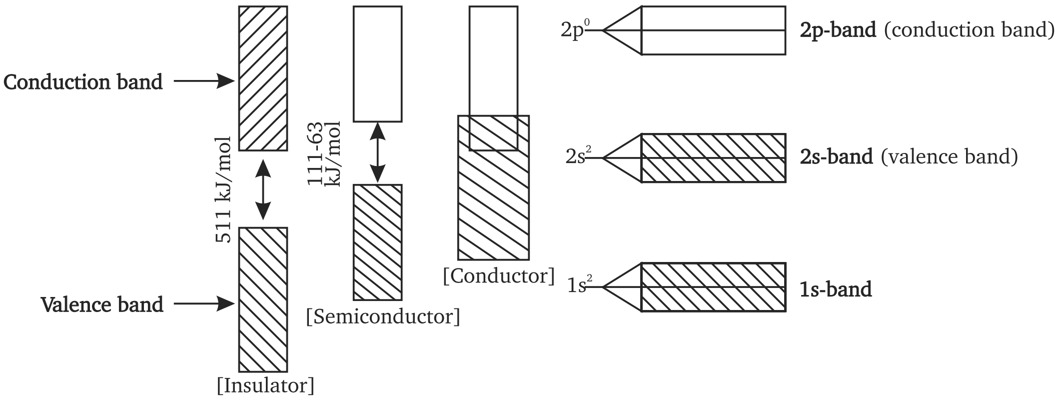
The movement of these positively charged holes is responsible for the conduction of charge.

12–16 and 13–15 compounds: Combination of elements of Gr – 13 and Gr – 15 or Gr – 12 and Gr – 16 produce compounds which stimulate average valency of four as in Ge or Si.

12 – 16 compounds $\longrightarrow$ ZnS, CdS, CdSe, HgTe

13 – 15 compounds $\longrightarrow$ InSn, AlP, GaAs

Band theory to explain electrical properties: The band model of metal is based on molecular orbital theory. When a large no. of molecular orbitals (formed by atomic orbitals) overlap in metal, it results a continuous energy level which is called the Energy Band.



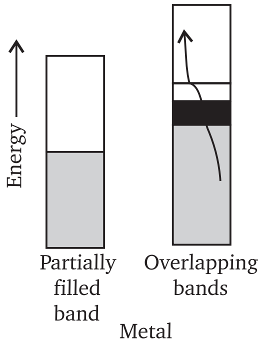
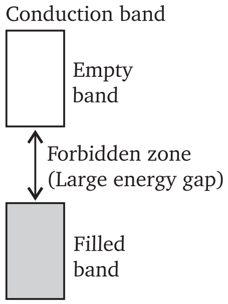
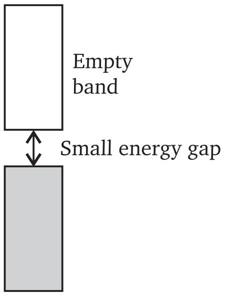
Conductivity of Insulator $\Rightarrow 10^{-20} - 10^{-16}$ ohm^{-1} m^{-1}
Semiconductor $\Rightarrow 10^{-6} - 10^{4}$ ohm^{-1} m^{-1}
Conductor $\Rightarrow 10^{4} - 10^{7}$ ohm^{-1} m^{-1}

The lowest unoccupied energy band is known as **conduction band.**
The highest occupied energy band is known as **valence band.**
The energy difference between the top of valence band and the bottom of the conduction band is known as **energy gap** or **forbidden zone.**

Electrical properties of solids: There are three kind of electrical properties (*i.e.,* solids may be classified into three categories on the basis of their electrical properties):

1. Conductors
2. Insulators
3. Semiconductors

Conductors–Substances which allow electricity to pass through them easily. e.g.,–Metals	**Insulators–**Substances which do not allow electricity to pass through them easily. e.g.,–Rubber, wood, glass	**Semiconductors–**Substances which allow electricity to pass through them partially. e.g.,–Doped Silicon

		
Conductors: The solids having no gap (there is no forbidden zone) between conduction band and filled band. Since energy gap is not there, therefore electrons can easily/freely move from one band to another band.	**Insulators:** There is large gap (large forbidden zone) between conduction band and filled band. Electrons cannot move easily/freely.	**Semiconductors:** There is small gap (Small forbidden zone) between conduction band and filled band. Electrons can move/jump when energy is supplied.

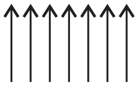
Magnetic properties:

(1) **Diamagnetic Property/Substance/Solids:** Diamagnetic substances are the substances which are weakly repelled by a magnetic field. The electrons in diamagnetic substances are all paired. They do not contain unpaired electrons. *e.g.* TiO_2, NaCl, C_6H_6, N_2, Zn, etc.

(2) **Paramagnetic Property/Substance/Solids:** Paramagnetic substances are those which are attracted by a magnetic field but they lose their magnetism in the absence of magnetic field. These substances have permanent magnetic dipole, due to the presence of atoms, molecules or ions containing unpaired electrons. *e.g.,* Cu^{2+}, Fe^{3+}, O_2, NO, CuO, etc.

Substances containing unpaired electrons are further classified as:

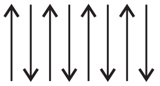
(*a*) **Ferromagnetic Property/Substance/Solids:** Ferromagnetic substances are those substances which are strongly attracted by a magnetic field and can be made into permanent magnets. These substances show magnetism even in the absence of a magnetic field. The large magnetism in these substances is due to the spontaneous alignment of magnetic moment, *i.e.*, unpaired electron in the same direction. These substances lose ferromagnetism and become paramagnetic at a certain temperature on heating. (This particular temperature is called **Curie Temperature**)



Example: Iron, cobalt, nickel, gadolinium and CrO_2.

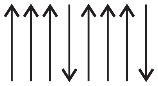
CrO_2 is used to make magnetic tapes for audio recording.

(*b*) **Anti-ferromagnetic Property/Substance/Solids:** Anti-ferromagnetic substances are those substances in which equal number of magnetic moments are aligned in opposite directions so as to give zero net magnetic moment.



Example: MnO, MnO_2 and Mn_2O_3

(*c*) **Ferrimagnetic substances:** Ferrimagnetism is observed when the magnetic moments of the domains in the substance are aligned in parallel and anti-parallel directions in unequal numbers. They are weakly attracted by magnetic field as compared to ferromagnetic substances. *e,g.,* Fe_3O_4 (magnetite) and ferrites like $MgFe_2O_4$ and $ZnFe_2O_4$.



These substances lose ferrimagnetism and become paramagnetic at a certain temperature (called Curie Temperature) on heating.

NCERT IN-TEXT QUESTIONS SOLVED

1.1. Why are solids rigid?

Ans. In a solid, the constituent particles are very closely-packed. Hence, the forces of attraction among these particles are very strong, that is why they are rigid.

1.2. Why do solids have a definite volume?

Ans. The constituent particles of a solid have fixed positions and are not free to move *i.e.*, they possess rigidity. That is why they have a definite volume.

1.3. Classify the following as amorphous or crystalline solids: Polyurethane, naphthalene, benzoic acid, teflon, potassium nitrate, cellophane, polyvinyl chloride, fibre glass, copper.

Ans. Amorphous solids: Polyurethane, teflon, cellophane, polyvinyl chloride, fibre glass.
Crystalline solids: Benzoic acid, naphthalene, potassium nitrate, copper.

1.4. Why is glass considered as super cooled liquid?

Ans. Glass is an amorphous solid. Like liquids it has a tendency to flow, though very slowly. The proof of this fact is that glass panes in the windows or doors of old buildings are invariably found to be slightly thicker at the bottom than at the top.

1.5. Refractive index of a solid is observed to have the same value along all directions. Comment on the nature of this solid. Would it show cleavage property?

Ans. As the solid has same value of refractive index along all directions, this means that it is isotropic and hence amorphous. Being an amorphous solid, it would not show a clean cleavage when cut with a knife. Instead it would break into pieces with irregular surfaces.

1.6. Classify the following solids in different categories based on the nature of intermolecular forces operating in them: Potassium sulphate, tin, benzene, urea, ammonia, water, zinc sulphide, graphite, rubidium, argon, silicon carbide. (*AI CBSE* 2017)

Ans. Types of solids and their nature:

Potassium sulphate	Ionic
Tin	Metallic
Benzene	Molecular (non polar)
Urea	Molecular (polar)
Ammonia	Molecular (hydrogen bonded)
Water	Molecular (hydrogen bonded)
Zinc sulphide	Ionic
Graphite	Covalent or Network
Rubidium	Metallic
Argon	Molecular (non polar)
Silicon carbide	Covalent or Network

1.7. Solid A is a very hard electrical insulator in solid as well as in molten state, and melts at extremely high temperature. What type of solid is it?

Ans. Covalent or Network solid like SiO_2 (quartz) or SiC or C (diamond).

1.8. Ionic solids conduct electricity in molten state but not in solid state. Explain.

Ans. In the molten state, ionic solids dissociate to give free ions and hence can conduct electricity. However in the solid state, as the ions are not free to move but remain held together by strong electrostatic forces of attraction, so they cannot conduct electricity in the solid state.

1.9. What type of solids are electrical conductors—metallic or ductile?

Ans. Metallic solids.

1.10. Give the significance of a 'lattice point'.

Ans. Each Lattice point represents one constituent particle of the solid. The constituent particle may be an atom, a molecule (group of atom) or an ion.

1.11. Name the parameters that characterise a unit cell.

Ans. A unit cell is characterised by (*i*) its dimensions along the three edges a, b and c. These edges may or may not be mutually perpendicular, (*ii*) angles between the edges, α (between b and c), β (between a and c) and γ (between a and b).

Thus, a unit cell is characterised by six parameters a, b, c, α, β and γ.

1.12. Distinguish between

(*i*) Hexagonal and monoclinic unit cell

(*ii*) Face-centred and end-centred unit cell.

Ans. (*i*) For hexagonal unit cell $a = b \neq c$, $\alpha = \beta = 90°$, $\gamma = 120°$

For monoclinic unit cell, $a \neq b \neq c$, $\alpha = \gamma = 90°$, $\beta = 90°$

(*ii*) A face-centred unit cell has one constituent particle present at the centre of each face in addition to the particles present at the corners.

An end-centred unit cell has one constituent particle each at the centre of any two opposite faces in addition to the particles present at the corners.

1.13. Explain how much portion of an atom located at: (i) corner and (ii) body-centre of a cubic unit cell is part of its neighbouring unit cell.

Ans. (*i*) An atom at the corner is shared by eight adjacent unit cells. Hence, portion of the atom at the corner that belongs to one unit cell $= \dfrac{1}{8}$

(*ii*) The atom at the body centre of a cubic unit cell is not shared by other unit cell. Hence, it belongs fully to the unit cell.

1.14. What is the two dimensional coordination number of a molecule in square close-packed layer?

Ans. In the two dimensional square close-packed layer, the atom touches 4 nearest neighbouring atoms. Hence, its coordination number = 4.

1.15. A compound forms hexagonal close-packed structure. What is the total number of voids in 0.5 mol of it? How many of these are tetrahedral voids?

Ans. No. of atoms in the close packing = 0.5 mol

$$\begin{aligned} &= 0.5 \times 6.022 \times 10^{23} = 3.011 \times 10^{23} \\ \text{No. of octahedral voids} &= \text{No. of atoms in the packing} \\ &= 3.011 \times 10^{23} \\ \text{No. of tetrahedral voids} &= 2 \times \text{No. of atoms in the packing} \\ &= 2 \times 3.011 \times 10^{23} = 6.022 \times 10^{23} \\ \text{Total no. of voids} &= 3.011 \times 10^{23} + 6.022 \times 10^{23} = 9.033 \times 10^{23} \end{aligned}$$

1.16. A compound is formed by two elements M and N. The element N forms ccp and atoms of M occupy $\frac{1}{3}$rd of the tetrahedral voids. What is the formula of the compound?

Ans. Suppose the atoms N in the *ccp* = n

$\therefore$ No. of tetrahedral voids = $2n$

As $\frac{1}{3}$rd of the tetrahedral voids are occupied by atoms M, therefore,

No. of atoms $\quad M = \dfrac{2n}{3}$

$\therefore \quad$ Ratio of $M : N = \dfrac{2n}{3} : n = 2 : 3$

Hence, the formula is M_2N_3

1.17. Which of the following lattices has the highest packing efficiency:
(*i*) Simple cubic (*ii*) body-centred cubic (*iii*) hexagonal close-packed Lattice?

Ans. Packing efficiency for simple cubic = 52.4%
Body-centred cubic = 68%
Hexagonal close-packed = 74%
$\therefore$ Hexagonal close packed lattice has the highest packing efficiency.

1.18. An element with molar mass 2.7×10^{-2} kg mol^{-1} forms a cubic unit cell with edge length 405 pm. If the density is 2.7×10^{3} kg m^{-3}, what is the nature of the cubic unit cell?

Ans. Density, $d = \dfrac{z \times M}{a^3 \times N_A}$

$$\therefore \quad z = \frac{d \times a^3 \times N_A}{M} = \frac{(2.7\times10^{3}\,\text{kg}\,\text{m}^{-3})(4.05\times10^{-10}\,\text{m})^3(6.022\times10^{23}\,\text{mol}^{-1})}{2.7\times10^{-2}\,\text{kg}\,\text{mol}^{-1}}$$

$$= 3.99 \approx 4$$

Thus, there are 4 atoms of elements present per unit cell, hence, the cubic unit cell must be face-centred or cubic close-packed (*ccp*).

1.19. What type of defect can arise when a solid is heated? Which physical property is affected by it and in what way?

Ans. When a solid is heated, vacancy defect is produced in the crystal. This is because on heating some atoms or ions leave the lattice site completely, some lattice sites become vacant. As a result of this defect the density of the substance decreases because some atoms/ions leave the crystal completely.

1.20. What type of stoichiometric defect is shown by (*i*) ZnS (*ii*) AgBr?

Ans. (*i*) **ZnS** shows Frenkel defect because its ions have a large difference in size.
(*ii*) **AgBr** shows both Frenkel and Schottky defects.

1.21. Explain how vacancies are introduced in an ionic solid when a cation of higher valence is added as an impurity in it.

Ans. Two or more cations of lower valency are replaced by a cation of higher valency to maintain electrical neutrality. Hence, some cation vacancies are created. For example, if in the ionic solid, Na^+Cl^- impurity of Sr^{2+} is added (as $SrCl_2$) then twice the Na^+ lattice sites will become vacant and one of these will be occupied by Sr^{2+} ion and other will remain vacant.

1.22. Ionic solids, which have anionic vacancies due to metal excess defect develop colour. Explain with the help of suitable example.

Ans. Taking the example of NaCl, when its crystals are heated in presence of sodium vapour some chloride ion leave their lattice sites to combine with sodium to form NaCl. For this reaction to occur Na atoms lose electrons to form Na^+ ions. The electron that has been released diffuses into the crystal to occupy the anion vacancies created by Cl^- ions. The crystal now has excess of sodium. The sites occupied by unpaired electrons are called F-centres. They impart yellow colour to the crystal because they absorb energy from the visible light and get excited.

1.23. A group 14 element is to be converted into *n*-type semiconductor by doping it with a suitable impurity. To which group should this impurity belong?

Ans. *n*-type semiconductor means conduction due to the presence of excess of negatively charged electrons. Hence, to convert group 14 element into *n*-type semiconductor, it should be doped with group 15 element.

1.24. What type of substances would make better permanent magnets—ferromagnetic or ferrimagnetic? Justify your answer.

Ans. Ferromagnetic substances make better permanent magnets. This is because the metal ions of a ferromagnetic substances are grouped into small regions called 'domains'. Each domain acts as a tiny magnet. These domains are randomly oriented. When the substance is placed in a magnetic field all the domains get oriented in the direction of the magnetic field and a strong magnetic field is produced. This ordering of domains persists even when the external magnetic field is removed. Hence, the ferromagnetic substance becomes a permanent magnet.

NCERT TEXTBOOK QUESTIONS SOLVED

1.1. Define the term 'amorphous'. Give a few examples of amorphous solids.

Ans. Amorphous means no form. An amorphous solid consists of particles of irregular shape. The arrangement of constituent particles in such a solid has only short range order. The structure of amorphous solids is similar to that of liquids. Few examples are—glass, rubber and plastics.

1.2. What makes a glass different from a solid such as quartz? Under what conditions could quartz be converted into glass?

Ans. Glass is an amorphous form of silica. In glass, SiO_4 tetrahedra are randomly joined to each other. It does not have a long range regular structure and no sharp melting point. On heating it softens and melts over a wide range of temperature.

Quartz is a crystalline form of silica. In quartz, SiO_4 tetrahedra are regularly joined to each other and have long range regular arrangement. It has a sharp melting point.

On melting quartz and then cooling it rapidly. It is converted into glass.

1.3. Classify each of the following solids as ionic, metallic, molecular, network (covalent) or amorphous.

(*i*) Tetra phosphorous decoxide (P_4O_{10}) (*ii*) Ammonium Phosphate $(NH_4)_3PO_4$
(*iii*) SiC (*iv*) I_2 (*v*) P_4 (*vi*) Plastic
(*vii*) Graphite (*viii*) Brass (*ix*) Rb (*x*) LiBr
(*xi*) Si

Ans. (*i*) Tetraphosphorous decoxide (P_4O_{10}) = Molecular solid
(*ii*) Ammonium phosphate $(NH_4)_3\ PO_4$ = Ionic solid
(*iii*) SiC = Covalent solid (*iv*) I_2 = Molecular solid
(*v*) P_4 = Molecular solid (*vi*) Plastic = Amorphous solid
(*vii*) Graphite = Covalent solid (*viii*) Brass = Metallic solid
(*ix*) Rb = Metallic solid (*x*) LiBr = Ionic solid
(*xi*) Si = Covalent solid

1.4. (*i*) What is meant by the term 'coordination number'.

(*ii*) What is the coordination number of atoms:

(*a*) In a cubic close-packed structure?

(*b*) In a body-centred cubic structure?

Ans. (*i*) The number of nearest neighbours of a particle in a closed packed structure is called its coordination number. For example, in hexagonal close packing (hcp) in three dimensions each atom (or constituent particle) is touching 12 other atoms. So, its coordination number is 12.

(*ii*) (*a*) In cubic close-packed structure each atom is in direct contact with 12 other atoms. Hence, its coordination number is 12.

(*b*) In body centred cubic structure coordination number is 8.

1.5. How can you determine the atomic mass of an unknown metal if you know its density and the dimension of its unit cell? Explain.

Ans. Let d = density of the unit cell

volume of the unit cell = a^3(in case of cubic crystal)

Mass of an atom present in the unit cell

$$m = \frac{M}{N_A}$$

$$M = \text{molar mass}$$

Therefore, density of the unit cell = $\frac{\text{mass of unit cell}}{\text{volume of unit cell}}$, $\boxed{d = \frac{z \times M}{a^3 \times N_A}}$

By this formula we can calculate $\boxed{M = \frac{d \times a^3 \times N_A}{z}}$

Where, z = No. of atoms in unit cell

N_A = Avogadro number

1.6. Stability of a crystal is reflected in the magnitude of its melting point. Comment. Collect melting point of solid water, ethyl alcohol, diethyl ether and methane from a data book. What can you say about the intermolecular forces between these molecules?

Ans. Higher the melting point, greater are the forces holding the constituent particles together and hence greater is the stability.

Melting point of the substances are given below:

Substance	**Melting point**
Solid water	273 K
Ethyl alcohol	155.7 K
Diethyl ether	156.8 K
Methane	90.5 K

Higher melting point of solid water (i.e., ice) than alcohol shows that hydrogen bonding in ethyl alcohol molecules is not as strong as in water molecules.

Diethyl ether is a polar molecule. Methane is a non polar molecule.

Methane has only weak van der Waals forces (London dispersion forces).

1.7. How will you distinguish between the following pairs of terms:

(*i*) Hexagonal close packing and cubic close packing?

(*ii*) Crystal lattice and unit cell?

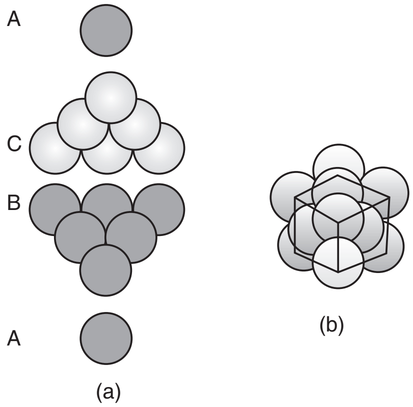
(*iii*) Tetrahedral void and octahedral void?

Ans. (*i*)

Hexagonal close packing	**Cubic close packing**
(*a*) In this case, the spheres of the third layer are exactly aligned with those of the first layer. Thus the pattern of the sphere can be written as AB AB - - - -	(*a*) In cubic close packing, the spheres of the third layer are not aligned with those of the first layer or second layer. Only when fourth layer is placed, its spheres are aligned with the first layer. This pattern is often written as ABC ABC - - - - .
(*b*) In hexagonal closed packing, tetrahedral voids of the second layer may be covered by the spheres of the third layer.	(*b*) In cubic close packing, third layer may be placed above the second layer in a manner such that its spheres cover the octahedral voids.

(*ii*) **Crystal lattice and unit cell:** If the three-dimensional arrangement of constituent particles in a crystal is represented diagrammatically in which each particle is depicted as a point, the arrangement is called a 'crystal lattice' whereas unit cell is the smallest portion of a crystal lattice which when repeated in different directions generates the entire lattice.

(*iii*) **Tetrahedral void and octahedral void:** A simpler triangular void in a crystal surrounded by four spheres is called a tetrahedral void or a hole. Whereas octahedral void is a double triangular void and is surrounded by six spheres.



(*a*) ABCABC....arrangement of layers when octahedral void is covered
(*b*) fragment of structure formed by this arrangement resulting
in cubic closed-packed (*ccp*) or face-centred cubic (*fcc*) structure

1.8. How many lattice points are there in one unit cell of each of the following lattice?

(*i*) Face-centred cubic (*ii*) Face-centred tetragonal

(*iii*) Body-centred

Ans. (*i*) Lattice points in face-centred cubic lattice = 8 (at corners) + 6 (at the face centre) = 14

(*ii*) Face centred tetragonal = 8 (at corners) + 6 (at the face centre) = 14

(*iii*) Lattice points in body-centred cube
= 8 (at corners) +1 (at the body centre)
= 9

1.9. Explain:

(*i*) The basis of similarities and differences between metallic and ionic crystals.

(*ii*) Ionic solids are hard and brittle.

Ans. (*i*) **Similarities:**

- Both ionic and metallic crystals have electrostatic forces of attraction.
- In ionic crystals these forces are between oppositely charged ions. In metals, these forces are among the valence electrons and positvely charged kernels.
- Both have high melting point.

Differences:

- Ionic bond is strong due to electrostatic forces of attraction whereas metallic bond may be weak or strong depending upon the number of valence electrons and the size of kernels.
- In ionic bond, ions are not free to move. Hence, they cannot conduct electricity in solid state. They can do so only in molten state or in aqueous solution.
  In metals, electrons are free to move. Hence, they conduct electricity in solid state.

(*ii*) Ionic crystals are hard due to strong electrostatic forces between them. They are brittle because ionic bond is non-directional.

1.10. Calculate the efficiency of packing in case of a metal crystal for:

(*i*) Simple cubic (*ii*) body-centred cubic

(*iii*) Face-centred cubic (with the assumptions that atoms are touching each other).

Ans. (*i*) **Packing efficiency in simple cubic lattice:** In a simple cubic lattice the atoms are located only on the corners of the cube.

The particles touch each other along the edge, thus the edge length or side of the cube '*a*' and the radius of each particle, *r* are related as:

$$a = 2r$$

The volume of the cubic unit cell = $a^3 = (2r)^3 = 8r^3$

Since a simple cubic unit cell contains only 1 atom

Thus, volume of the occupied space $= \frac{4}{3}\pi r^3$

$$\therefore \quad \text{Packing efficiency} = \frac{\text{Volume of one atom}}{\text{Volume of cubic unit cell}} \times 100\,\%$$

$$= \frac{\frac{4}{3}\pi r^3 \times 100}{8r^3} = \frac{\pi}{6} \times 100 = 52.4\%$$

(*ii*) **Packing efficiency in body-centred cubic lattice:** It is clear that atom at the centre will be in touch with the other two atoms diagonally arranged.

In ΔEFD

$$b^2 = a^2 + a^2 = 2a^2$$

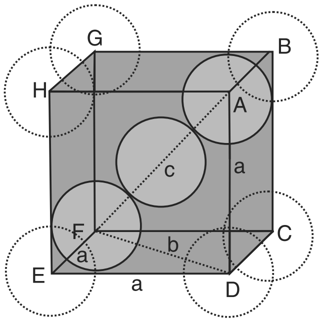
$$b = \sqrt{2}a$$

Now in ΔAFD

$$c^2 = a^2 + b^2 = a^2 + 2a^2 = 3a^2$$

$$c = \sqrt{3}a$$

The length of the body diagonal *c* is equal to 4*r*, where *r* is the radius of the sphere (atom), as all the three spheres along the diagonal touch each other.



Therefore, $\sqrt{3}a = 4r, \qquad a = \frac{4r}{\sqrt{3}}$

Also we can write, $r = \frac{\sqrt{3}}{4}a$

In this type of structure, total number of atoms is 2 and their volume is $2\times\frac{4}{3}\pi r^3$

Volume of the cube, $a^3 = \left(\frac{4r}{\sqrt{3}}\right)^3$

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

$$= \frac{2\times\frac{4}{3}\pi r^3\times 100}{\left(\frac{4r}{\sqrt{3}}\right)^3}\% = \frac{{}^{8}\!/_{3}\,\pi r^3\times 100}{\frac{64}{3\sqrt{3}}r^3}\%=68\%$$

(*iii*) **Packing efficiency in face-centred cubic lattice** (with the assumptions that atoms are touching each other):

Let us calculate the efficiency in *ccp* or *fcc* structure.

Let the unit cell edge length be '*a*' and face diagonal AC = *b*

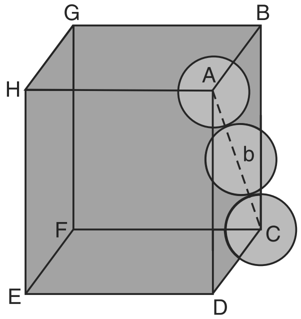
In ΔABC

$$AC^2 = b^2 = BC^2 + AB^2$$
$$b^2 = a^2 + a^2 = 2a^2$$
$$b = \sqrt{2}a$$

If *r* is the radius of the sphere

We find $b = 4r$

$$4r = \sqrt{2}a$$
$$a = \frac{4r}{\sqrt{2}} = 2\sqrt{2}r$$



We know that in *fcc* structure there are effectively 4 spheres.

Total volume of the four spheres is equal to $4\times\frac{4}{3}\pi r^3$

and the volume of the cube $a^3 = \left(2\sqrt{2}r\right)^3$

$$\text{Therefore, Packing efficiency} = \frac{\text{Volume occupied by four spheres in unit cell}\times 100}{\text{Total volume of the unit cell}}\%$$

$$= \frac{4\times\frac{4}{3}\pi r^3\times 100}{\left(2\sqrt{2}r\right)^3}\% = \frac{{}^{16}\!/_{3}\,\pi r^3\times 100}{16\sqrt{2}r^3}\% = 74\%$$

1.11. Silver crystallises in fcc lattice. If edge length of the cell is 4.07×10^{-8} cm and density is 10.5 g cm^{-3}, calculate the atomic mass of silver. [*CBSE Delhi* 2014]

Ans. $$M = \frac{d \times a^3 \times N_A}{z}$$

where d = Density of the material

a = Length of the edge of the cell

N_A = Avogadro number

z = No. of atoms

$$M = \frac{10.5\ g\,cm^{-3} \times \left(4.07 \times 10^{-8} cm\right)^3 \times \left(6.023 \times 10^{23}\,mol^{-1}\right)}{4}$$

$\therefore$ Atomic mass of silver, $M = 107.08 g\ mol^{-1}$

1.12. A cubic solid is made of two elements P and Q. Atoms of Q are at the corners of the cube and P at the body centre. What is the formula of the compound? What are the co-ordination numbers of P and Q?

Ans. As atoms of Q are present at the 8 corners of the cube. Therefore number of atoms of Q in the unit cell: $= \frac{1}{\cancel{8}} \times \cancel{8} = 1$ b

As atoms of *P* are present at the body centre, therefore number of atoms of *P* in the unit cell = 1

$\therefore$ Ratio of atoms = P : Q = 1 : 1

Hence, the formula of the compound is PQ. Atoms at the body-centre would be in contact with all the atoms at the corners. Hence, the coordination number of P would be 8. Similarly, coordination number of Q is also 8.

1.13. Niobium crystallises in body-centred cubic structure. If density is 8.55 g cm^{-3}, calculate atomic radius of niobium. Atomic mass of niobium = 93 *u*

Ans. In a body centred cubic structure, the number of atoms per unit cell = 2

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

$$a^3 = \frac{M \times z}{d \times N_A \times 10^{-30}}\ g\ cm^{-3} = \frac{2 \times 93}{6.02 \times 10^{23} \times 10^{-30} \times 8.55}$$

$$= 3.61 \times 10^7$$

$$a = 3.305 \times 10^2\ pm = 330.5\ pm$$

But in body-centred cubic unit cell body diagonal is equal to 4 times the radius of atom.

$$4\,r = \sqrt{3}a = \sqrt{3} \times 330.5$$

$\therefore$ $r = 143$ pm

$\therefore$ radius of niobium atom = 143 pm

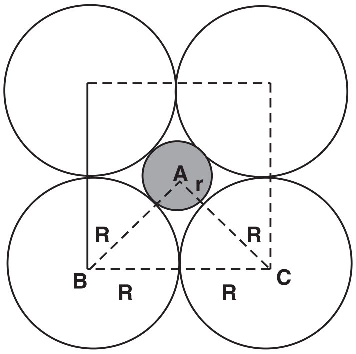
1.14. If the radius of the octahedral void is r and the radius of the atoms in close packing is R, derive relation between r and R.

Ans. A sphere fitting into the octahedral void is shown by shaded circle. ABC is a right angle triangle. Applying Pythagoras theorem,

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

$$(2R)^2 = (R + r)^2 + (R + r)^2$$

$$= 2\,(R + r)^2$$



or $$\frac{(2R)^2}{2} = (R + r)^2$$

or $$\sqrt{\frac{(2R)^2}{2}} = R + r$$

or $$\sqrt{2R^2} = R + r$$

or $$\sqrt{2}R = R + r$$

$$r = \sqrt{2}R - R$$

$$r = R\left(\sqrt{2} - 1\right) = R\,(1.414 - 1) = 0.414\,R$$

1.15. Copper crystallises into a fcc lattice with edge length 3.61×10^{-8} cm. Show that the calculated density is in agreement with its measured value of 8.92 g cm^{-3}.

Ans. $$d = \frac{z \times M}{a^3 \times N_A}$$

No. of atoms in *fcc* lattice $z = 4$

$$= \frac{4 \times 63.5\ \text{mol}^{-1}}{\left(3.61 \times 10^{-8}\ \text{cm}\right)^3 \times \left(6.02 \times 10^{23}\ \text{mol}^{-1}\right)}$$

$$\text{Atomic mass of unit cell} = \frac{4 \times 63.5}{6.02 \times 10^{23}}\,g = 4.22 \times 10^{-22}\,g$$

$$\text{Density} = \frac{\text{Mass of unit cell}}{\text{Vol. of unit cell}}$$

$$= \frac{4.22 \times 10^{-22}}{47.4 \times 10^{-24}\ \text{cm}^2} = 8.9\text{g cm}^{-3} = 8.9\ \text{g cm}^{-3}$$

which is in close agreement with the measured value.

1.16. Analysis show that nickel oxide has the formula $Ni_{0.98}\,O_{1.00}$. What fractions of nickel exist as Ni^{2+} and Ni^{3+} ions?

Ans. The formula $Ni_{0.98}\,O_{1.00}$ shows that

$$Ni : O = 0.98 : 1.00 = 98 : 100$$

Thus if there are 100 oxygen atoms, then

Ni atoms = 98

Charge on O^{2-} ions = $100 \times (-2) = -200$

Suppose Ni atoms as $Ni^{2+} = x$,

$Ni^{3+} = 98 - x$

Total charge on Ni^{2+} and Ni^{3+} $= (+2)x + (+3)\,(98 - x)$

$= +2x + 294 - 3x = 294 - x$

As metal oxide is neutral, total charge on cations = Total charge on anions

$$294 - x = 200$$

$$-x = -294 + 200$$

$$-x = -94$$

$$\% \text{ of Ni as } Ni^{2+} = \frac{94}{98}\times 100 = 95.918\%$$

$$\% \text{ of Ni as } Ni^{3+} = \frac{98-x}{98}\times 100 = \frac{98-94}{98}\times 100 = \frac{4}{98}\times 100 = 4.082$$

1.17. What is a semiconductor? Describe the two main types of semiconductors and contrast their conduction mechanism.

Ans. Substance whose conductance lies in between that of metals (conductors) and insulators are called semiconductors. There are two main types of semiconductors:

(*i*) ***n*-type semiconductors:** Silicon and germanium belong to group 14 of the periodic table and have four valence electrons each. In their crystals each atom forms four covalent bonds with its neighbours. When doped with a group 15 element like P or As, which contains five valence electrons, they occupy some of the lattice sites in silicon or germanium crystal. Four out of five electrons are used in the formation of four covalent bonds with the four neighbouring silicon atoms. The fifth electron is extra and becomes delocalised.

These delocalised electrons increase the conductivity of doped silicon (or germanium). Here the increase in conductivity is due to the negatively charged electron, hence silicon doped with electron rich impurity is called *n*-type semiconductor.

(*ii*) ***p*-type semiconductor:** Silicon or germanium can also be doped with a group 13 element like B, Al or Ga which contains only three valence electrons. The place where the fourth valence electron is missing is called *electron hole* or *electron vacancy*. An electron from a neighbouring atom can come and fill the electron hole, but in doing so it would leave an electron hole at its original position. If it happens it would appear as if the electron hole has moved in the direction opposite to that of the electron that filled it under the influence of electric field. Electrons would move towards the positively charged plate through electronic holes, but it would appear as if electron holes are positively charged and are moving towards negatively charged plate. This type of semiconductors are called *p*-type semiconductors.

1.18. Non-stoichiometric cuprous oxide, Cu_2O can be prepared in laboratory. In this oxide, copper to oxygen ratio is slightly less than 2 : 1. Can you account for the fact that this substance is a *p*-type semiconductor?

Ans. The Cu : O ratio is less than 2 : 1 in Cu_2O shows that some cuprous (Cu^+) ions have been replaced by (Cu^{2+}) ions. To maintain electrical neutrality, every two Cu^+ ions will be replaced by one Cu^{2+} ion. Thereby creating a hole. As conduction will be due to these positive holes, hence it is a *p*-type semiconductor.

1.19. Ferric oxide crystallises in a hexagonal close-packed array of oxide ions with two out of every three octahedral holes occupied by ferric ions. Derive the formula of the ferric oxide.

Ans. Suppose the number of oxide ions (O^{2-}) in the packing = N

$\therefore$ As $\frac{2}{3}^{rd}$ of the octahedral voids are occupied by ferric ions, therefore number of ferric ions present $= \frac{2}{3}\times N = \frac{2N}{3}$

$$\text{Ratio of } Fe^{3+} : O^{2-} = \frac{2N}{3} : N = 2 : 3$$

Hence, the formula of ferric oxide = Fe_2O_3.

1.20. Classify each of the following as being either a *p*-type or a *n*-type semiconductor.

(*i*) Ge doped with In (*ii*) Si doped with B.

Ans. (*i*) *Ge* is group 14 element and *In* is group 13 element. Hence an electron deficit hole is created and therefore it is *p*-type.

(*ii*) *Si* is group 14 element and *B* is group 13 element. Hence an electron deficient hole is created and therefore it is also *p*-type.

1.21. Gold (atomic radius = 0.144 nm) crystallises in a face-centred unit cell. What is the length of a side of the cell?

Ans. Radius of gold atom, r = 0.144 nm

In face centred unit cell, face diagonal $= 4r = \sqrt{2}\, a$

$$a = \frac{4r}{\sqrt{2}} = 2\sqrt{2r} = \frac{4 \times 0.144\,\text{nm}}{1.414} = 0.407 \text{ nm}$$

1.22. In terms of band theory, what is the difference (*i*) between a conductor and an insulator (*ii*) between a conductor and a semiconductor?

Ans. (*i*) **Difference between Conductor and insulator:** In case of conductors the gap between valence band and conduction band is very small or overlaps. That is why under an applied electric field the conductor (metals) shows conductivity (electron can flow easily) whereas in insulators the gap between filled valence band and the next higher energy unoccupied band (conduction band) is large, therefore electron cannot jump to it and such substances has very small conductivity and they behave as an insulator.

(*ii*) **Difference between a Conductor and a Semiconductor:** In case of semiconductors, the gap between the valence band and conduction band is small, therefore some electrons may jump to the conduction band and shows some conductivity.

In a conductor the band is partially filled or it overlaps with the high energy unoccupied conduction band, so that electrons can flow easily under an applied electric field.

1.23. Explain the following terms with suitable examples:

(*i*) Schottky defect (*ii*) Frenkel defect (*iii*) Interstitial defect (*iv*) F-centres

Ans. (*i*) **Schottky defect:** It is basically a vacancy defect in ionic solids. In order to maintain electrical neutrality the number of missing cations and anions are equal. Like simple vacancy defect, schottky defect also decreases the density of the substance. Schottky defect is shown by ionic substances in which the cation and anion are of almost similar sizes. For example, NaCl, KCl, CsCl and AgBr.

(*ii*) **Frenkel defect:** This defect is shown by ionic solids. The smaller ion (usually cation) is dislocated from its normal site to an interstitial site. It creates a vacancy defect at its original site and an interstitial defect at its new location.

Frenkel defect is also called dislocation defect. It does not change the density of the solid. It is shown by ionic substances in which there is a large difference in the size of ions, for example ZnS, AgCl, AgBr and AgI due to small size of Zn^{2+} and Ag^{+} ions.

(*iii*) **Interstitial defect:** When some constituent particles (atoms or molecules) occupy an interstitial site the crystal is said to have interstitial defect. This defect increases the density of the substance. Non ionic solids show this type of defect.

(*iv*) **F - centres:** Alkali halides like NaCl and KCl show this type of defect when crystals of NaCl are heated in a atmosphere of sodium vapour, the sodium atoms are deposited on the surface of the crystal. The Cl^- ions diffuse to the surface of the crystal and combine with Na atoms to give NaCl. This happens by the loss of electrons by sodium atoms to form Na^+ ions. The released electron diffuses into the crystal and occupy anionic sites. As a result crystal has now excess of sodium. The anionic sites occupied by unpaired electrons are called F-centres. They impart yellow colour to the crystal of NaCl. The colour results by the excitation of these electrons when they absorb energy from the visible light falling on the crystals.
Another examples are: LiCl, KCl, etc.

1.24. Aluminium crystallises in a cubic close-packed structure. Its metallic radius is 125 pm. [*CBSE* 2011]

(*i*) What is the length of the side of the unit cell?

(*ii*) How many unit cells are there in 1.00 cm^3 of aluminium?

Ans. In *ccp* or *fcc,*

(*i*) $$a = 2\sqrt{2}r = 2 \times 1.414 \times 125 \text{ pm} = 354 \text{ pm}$$

(*ii*) $$\text{volume of one unit cell} = (a)^3 = (354 \times 10^{-8}\text{cm})^3$$

$$\text{Unit cells in } 1\text{cm}^3 = \frac{1}{(3.54\times10^{-8})^3} = 2.26 \times 10^{22}$$

1.25. If NaCl is doped with 10^{-3} mol % of $SrCl_2$. What is the concentration of cation vacancies?

Ans. Doping of NaCl with 10^{-3} mol % $SrCl_2$ means that 100 moles of NaCl are doped with 10^{-3} mol of $SrCl_2$

$$\therefore \text{ 1 mole of NaCl is doped with } SrCl_2 = \frac{10^{-3}}{100} \times 6.02\times10^{23} = 6.02\times10^{18}$$

1.26. Explain the following with suitable examples:

(*i*) ferromagnetism (*ii*) paramagnetism (*iii*) ferrimagnetism

(*iv*) antiferromagnetism (*v*) 12–16 and 13–15 group compounds.

Ans. (*i*) **Ferromagnetism:** A few substances like iron, cobalt, nickel, gadolinium and CrO_2 are attracted very strongly by a magnetic field. Such substances are called ferromagnetic substances.
Besides strong attraction, these substances can be permanently magnetised.

(*ii*) **Paramagnetism:** These substances are weakly attracted by a magnetic field. They lose their magnetism in the absence of magnetic field. Paramagnetism is due to presence of one or more unpaired electrons which are attracted by the magnetic field. O_2, Cu^{2+}, Fe^{3+}, Cr^{3+} ions are some examples of such substances.

(*iii*) **Ferrimagnetism:** Ferrimagnetism is observed when the magnetic moments of the domains in the substance are aligned in parallel and anti-parallel directions in unequal numbers. They are weakly attracted by magnetic field as compared to ferromagnetic substances. Fe_3O_4 (magnetite) and ferrites like $MgFe_2O_4$ and $ZnFe_2O_4$ are examples of such substances. These substances lose ferrimagnetism on heating and become paramagnetic.

(*iv*) **Antiferromagnetism:** When magnetic moments are aligned in such a way that net magnetic moment is zero then magnetism is called antiferromagnetism. For example, MnO.

(*v*) **12–16 Group compounds:** Compounds formed between group 12 elements with elements of group 16 are called 12–16 compounds. *e.g.,* ZnS, Hg, Te, etc.
13–15 Group compounds: Compounds formed between elements of group 13 with group 15 elements are called 13–15 compounds. *e.g.,* Ga, As, AlP, etc.

ADDITIONAL QUESTIONS SOLVED

I. Very Short Answer Type Questions

(1 Mark)

Q1. What is the total number of atoms per unit cells in a face-centred cubic (fcc) structure? [*CBSE* 2008, 2013]

Ans. Total number of atoms per unit cell in a fcc structure = 4 atoms.

Q2. What is the number of atoms per unit cell in a body-centred cubic structure? [*CBSE* 2007]

Ans. Total number of atoms per unit cell in a body-centred cubic structure = 2 atoms.

Q3. What is the coordination number in rock salt type structure? [*Foreign* 2007]

Ans. The coordination number of each ion in rock salt type structure = 6.

Q4. Name an element with which silicon can be doped to give an n-type semiconductor. [*CBSE* 2007 F]

Ans. Gallium

Q5. A cubic solid is made of two elements X and Y. Atoms Y are at the corners of the cube and X at the body centre. What is the formula of the compound? [*CBSE* 2006]

Ans. No. of atoms of Y in the unit cell

$$= \frac{1}{\cancel{8}} \times \cancel{8} = 1$$

As X atoms are present at the body centre. Therefore, number of atoms of X in the unit cell = 1

∴ Ratio of atoms X : Y = 1 : 1

Hence formula of the compound = XY.

Q6. What is the effect of Schottky and Frenkel defects on the density of crystalline solids? [*AI* 2006 (*C*)]

Ans. Schottky defect decreases the density of the substance. In Frenkel defect there will be no change in the density of the solids.

Q7. What makes the crystal of KCl appear sometimes violet? [*AI* 2006 (*C*)]

Ans. It is due to presence of F centre, the electrons present at the site of anion which absorb light from visible ragion and radiate complementary colour.

Q8. Which point defect in crystal does not alter the density of the relevant solid? [*CBSE* 2009]

Ans. Frenkel defect

Q9. Name the type of point defect that occurs in a crystal of zinc sulphide.

Ans. Frenkel defect

Q10. Name the non-stoichiometric point defect responsible for colour in alkali metal halides.

Ans. Metal excess defect or F-centres which is due to electrons entrapped in anionic vacancies.

Q11. How many octahedral voids are there in 1 mole of a compound having cubic close packed structure?

Ans. No. of octahedral voids = No. of atoms in the packing = 1 mole = 6.022×10^{23}.

Q12. What type of substances show antiferromagnetism? [*CBSE* 2008]

Ans. Substances which are expected to possess paramagnetism or ferromagnetism but actually possess zero magnetic moment show antiferromagnetism *e.g.,* MnO.

Q13. Name an element with which germanium can be doped to produce an *n*-type semiconductor. [*Foreign* 2005]

Ans. Arsenic

Q14. What happens when a ferromagnetic substance is subjected to high temperature?

Ans. At high temperature, the ferromagnetic substance becomes paramagnetic due to randomisation of spins.

Q15. Why is glass considered a super cooled liquid? [*AI* 2008]

Ans. Glass is an amorphous solid. It has a tendency to flow very slowly like liquids and make the bottom portion of glass panes in the windows slightly thicker. Therefore, glass is considered a super cooled liquid.

Q16. How do metallic and ionic substances different in conducting electricity? [*AI* 2009]

Ans. Conductivity of metals is due to the free electrons while the conductivity of ionic substance is due to ions present in the solution.

Q17. Which point defect of its crystals decreases the density of a solid? [*CBSE* 2009]

Ans. Schottky defect

Q18. Copper is conducting in solid state while copper sulphate is conducting only in molten state or in aqueous solution? [*AI* 2006 *C*]

Ans. Copper is conducting because it has free electrons whereas $CuSO_4$ conduct electricity in molten state because ions become free to move in molten state or in aqueous solution but not in solid state.

Q19. Name a substance which on addition to AgCl causes cation vacancy in it. [*CBSE* 2004]

Ans. Cadmium chloride or Strontium chloride

Q20. What is coordination number of metal atom in ccp structure? [*Foreign* 2004]

Ans. 12

Q21. What is photovoltaic cell?

Ans. The device used to convert sunlight into electricity is called photovoltaic cell.

Q22. Define super–conductivity of a substance.

Ans. The property of a substance to offer no resistance to the flow of electricity at a particular temperature is called super–conductivity.

Q23. In a crystal of zinc sulphide, zinc occupies tetrahedral voids. What is the co-ordination number of zinc?

Ans. 4

Q24. Define the term amorphous.

Ans. A solid is said to be amorphous if its constituent particles are not arranged in a regular fashion.

Q25. What type of crystal defect is produced when sodium chloride is doped with $MgCl_2$?

Ans. It is called impurity defect. A cation vacancy is produced.

Q26. Name one solid which has both schottky and Frenkel defects.

Ans. Silver bromide (AgBr)

Q27. Define void.

Ans. The empty spaces present between the metal atoms or the ions when they are packed within the crystal are called voids.

Q28. What are 'point defects' in crystals?

Ans. The defects which are caused by missing or misplaced atoms or ions in the crystal.

Q29. Why does ZnO appear yellow on heating?

Ans. ZnO loses oxygen on heating and vacant sites of anions are occupied by electrons which absorbs light from the visible region and radiate the complementary colour.

Q30. How can a material be made amorphous?

Ans. By melting the material and then cooling it rapidly.

Q31. What is the effect of pressure on NaCl type crystals?

Ans. On increasing pressure, the coordination number of NaCl type crystals increases from 6 to 8.

Q32. Why is Frenkel defect not found in metal halides?

Ans. Because metal (alkali) halides ions cannot get into interstitial sites due to their large sizes.

Q33. Mention one property which is caused due to the presence of F-centre in a solid.

Ans. F-centre is responsible for the colour and paramagnetic behaviour of the solid.

Q34. What is meant by coordination number in an ionic crystal?

Ans. Coordination number of an atom or in an ionic crystal is the number of nearest neighbours.

Q35. What is the maximum possible coordination number of an atom in a hcp crystal structure of an element?

Ans. 12.

Q36. In a crystal of zinc sulphide, zinc occupies tetrahedral voids. What is the coordination number of zinc?

Ans. Four

Q37. Name the non-stoichiometric point defect responsible for colour in alkali halides.

Ans. It is due to the electrons trapped in anionic vacancies or due to F-centres.

Q38. Explain the term dislocation in relation to crystals.

Ans. A dislocation extends along lines and results from the imperfect orientation of plane with respect to one another in the crystal.

Q39. What is the percentage of free space in body-centred cubic crystal?

Ans. In body-centred cubic crystal free space is 32%.

Q40. What is the formula of a compound in which the element Y forms ccp Lattice and atoms of X occupy 2/3rd of tetrahedral voids? [*CBSE* 2016]

Ans. Number of element Y = n

Number of element X = $2n \times \frac{2}{3}$

As number of tetrahedral void = $2n$

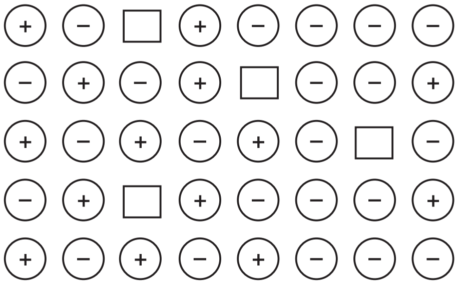
$$X : Y = \frac{4n}{3} : n$$

Formula = X_4Y_3

II. Short Answer Type Questions

(2 *or* 3 *Marks*)

Q1. Examine the illustration of a portion of the defective crystal given below and answer the following questions: [*CBSE* 2014]



(*i*) What is the type of vacancy defect called?

(*ii*) How is the density of a crystal affected by this defect?

(*iii*) Name one ionic compound which can show this type of defect in the crystalline state.

(*iv*) How is the stoichiometry defect of the compound affected?

Ans. (*i*) Schottky defects (*ii*) Decreases

(*iii*) Na^+Cl^- (*iv*) Not affected

Q2. Analysis shows that a metal oxide has the empirical formula $M_{0.96}O_{1.00}$. Calculate the percentage of M^{2+} and M^{3+} ions in the crystal?

Ans. Let the number of M^{2+} ion = x

then the number of M^{3+} ion will be

$= (0.96 - x)$

Total no. of cations

$= 2x + 3\ (0.96 - x)$

$= 2x + 2.88 - 3x = -x + 2.88$

No. of anions O^{2-}

$= -2 \times 1 = -2$

No. of cations

= No. of anions $-x + 2.88 = 2$

$-x = -2.88 + 2$

$-x = -0.88$

$x = 0.88$

$$\% \text{ of } M^{2+} \text{ ion} = \frac{0.88}{0.96} \times 100 = 91.67\%$$

$$\% \text{ of } M^{3+} = \frac{0.08}{0.96} \times 100 = 8.33\%$$

Q3. An element E crystallises in a body-centred cubic structure. If the edge centre of the cell is 1.469×10^{-10}m and the density is 19.3 g cm^{-3}. Calculate the atomic mass of this element. Also calculate the radius of an atom of this element.

Ans. $$d = \frac{zM}{a^3 N_A}$$

where d = density of the element

z = no. of atoms

$a = 1.469 \times 10^{-10}$ m

$= 146.9 \times 10^{-10}$ cm

$N_A = 6.022 \times 10^{23}$

$$M = \frac{da^3 N_A}{z}$$

$$= \frac{19.3 \times 146.9 \times 10^{-10} \times 6.02 \times 10^{23}}{2}$$

$= 183.5\ g$

$$r = \frac{\sqrt{3}}{4} a = \frac{\sqrt{3} \times 1.469 \times 10^{-8}}{4}$$

$r = 0.634 \times 10^{-8}$ cm

Q4. Assign reason for the following:

(*i*) phosphorous doped silicon is a semiconductor.

(*ii*) Schottky defect lowers the density of a solid. [*AI* 2007]

Ans.

(*i*) It is because its conductance is intermediate between conductor and insulator.

(*ii*) In Schottky defect, both cations and anions are missing which leads to lowering the density of a solid.

Q5. (*a*) With reference to crystal structure what is meant by coordination number?
(*b*) What is the coordination number of atoms:

(*i*) in a cubic close-packed structure

(*ii*) in a body-centred cubic structure? [*CBSE* 2006 *C*]

Ans. (*a*) It is number of atoms surrounding a given atoms in a crystal lattice.
(*b*) (*i*) 12 (*ii*) 8.

Q6. What is a semiconductor? Describe two main types of semiconductors, giving examples and their distinctive features. [*AI* 2006 *C*]

Ans. Semiconductor is a substance whose conductance is intermediate between conductor and insulator.

(*i*) *n*-type semiconductor: They have excess of electrons. For example, Ge doped with As.

(*ii*) *p*-type semiconductor: They have positive charge or hole *e.g.,* Si dopped with B.

Q7. Calculate the efficiency (percentage of volume occupied and unoccupied) of packing in case of metal crystal for simple cubic. [*AI* 2006 *C*]

Ans. $a = 2r$

Efficiency =

$$\frac{\text{Volume occupied by all spheres}}{\text{Total volume of cube}} \times 100$$

$$\text{Efficiency} = \frac{\frac{4}{3}\pi r^3}{(2r)^3} \times 100$$

$$= \frac{\pi}{6} \times 100 = 52.4\%$$

% of volume occupied = 52.4%
% of volume unoccupied = 47.6%

Q8. Explain each of the following with a suitable example. [*Foreign* 2012]

(*i*) Paramagnetism

(*ii*) Frenkel defect in crystals [*CBSE* 2007]

Ans.

(*i*) Those substances which are attracted by magnet and have unpaired electrons are called paramagnetic substances and the phenomenon is called paramagnetism. *e.g.*, Ni, Co, Cr are paramagnetic.

(*ii*) It is due to the missing of cations from the lattice sites and these occupy the interstitial sites.
e.g., in AgCl, Ag^+ occupies void, therefore causes Frenkel defect.

Q9. Iron has a body centred cubic (bcc) unit cell with a cell dimension of 286.65 pm. The density of iron is 7.874 g/cm^3. Use the information to calculate Avogadro's number. (Atomic mass of Fe = 55.845 u). [*Foreign* 2012], [*Delhi* 2012], [*AI* 2014]

Ans. $z = 2$

In b.c.c no. of atoms = 2

M = Atomic mass of Iron
= 55.845 u

$d = 7.874$ g/cm^3

a (edge length) = 286.65 pm

$$d = \frac{zM}{a^3 . N_A}$$

$$7.874 = \frac{2 \times 55.845}{(286.65 \times 10^{-10})^3 \times N_A}$$

$$N_A = \frac{2 \times 55.845}{7.874 \times (286.65 \times 10^{-10})^3}$$

$= 6.167 \times 10^{23}$

Q10. State the difference between Schottky and Frenkel defects. Which of these two changes density of the solid?

Ans. **Schottky Defect:** It is due to the equal number of cations and anions missing from the Lattice sites. It results in decrease the density of the crystal. It occurs in compounds with high coordination. Such as NaCl and CsCl.

Frenkel Defect: It is due to missing of ions from the Lattice sites and these occupy interstitial sites. It has no effect on density of crystal. It is found in crystal where the difference of size of cations and anions is very large. e.g., AgCl, AgBr.

Q11. An element (atomic mass = 60) having face-centred cubic unit cell has a density of 6.23 g cm^{-3}. What is edge length of unit cell?

Ans.

$$a^3 = \frac{z \times M}{N_A \times d} = \frac{4 \times 60}{6.022 \times 10^{23} \times 6.23}$$

$$a^3 = 64 \times 10^{-24}\ cm^3$$

$$a = (4 \times 10^{-8} \times 10^{10})pm$$

$$= 400\ pm$$

Q12. A metal (atomic mass = 50) has a body-centred cubic Lattice. The density of the metal is 5.91 g cm^{-3}. Find out the volume of the unit cell. [$N_A = 6.022 \times 10^{23}$]

Ans.

$M = 50\ g\ mol^{-1}$

$z = 2$

$d = 5.91\ g\ cm^{-3}$

$V = a^3$

$N_A = 6.022 \times 10^{23}$

$$d = \frac{z \times M}{N_A \times a^3}$$

$$V = a^3 = \frac{z \times M}{N_A \times d}$$

$$= \frac{2 \times 50}{5.91 \times 6.023 \times 10^{23}}$$

$$= 2.809 \times 10^{-23}\ cm^3$$

Q13. An element crystallizes in the simple cubic structure. Its density is 8 g cm^{-3} and its 200g contains 24×10^{23} atoms. Calculate the edge length.

Ans.

$z = 1$ for simple cubic

$M = 200\ g$

$N = 24 \times 10^{23}$ atoms

$a = ?$

$d = 8g\ cm^{-3}$

$$a^3 = \frac{z \times M}{d \times N} = \frac{1 \times 200}{8 \times 24 \times 10^{23}}$$

$$a^3 = 10.41 \times 10^{-24}\ cm^3$$

$$a = 2.18 \times 10^{-8} \times 10^{10}\ pm$$

$$= 218\ pm$$

[$\therefore$ 1 cm = 10^{10} pm]

Q14. Copper crystallises with face centred cubic unit cell. If the radius of copper atom is 127.8 pm, calculate the density of copper metal.

(Atomic mass of Cu = 63.55 u and Avogadro's Number $N_A = 6.02 \times 10^{23}\ mol^{-1}$) [*AI* 2014]

Ans. In f.c.c., z = 4

$r = 127.8$ pm

$d = ?$

$$d = \frac{zM}{a^3 \times N_A}$$

$$a = \frac{4r}{\sqrt{2}} \text{ (In f.c.c)}$$

$$a = \frac{4 \times 127.8}{\sqrt{2}} = \frac{4 \times \sqrt{2} \times 127.8}{\sqrt{2} \times \sqrt{2}}$$

$$= 2 \times \sqrt{2} \times 127.8 = 357.84\ pm$$

$$d = \frac{4 \times 63.55}{(357.84 \times 10^{-10})^3 \times 6.02 \times 10^{23}}$$

$$= 92.20\ gm/cm^3$$

Q15. How does amorphous silica differ from quartz?

Ans. Amorphous silica is obtained when molten silica is cooled rapidly because of the solid silica, so obtained lacks the internal order of repeating SiO_4 tetrahedra. Since the degree of internal order known as crystallising is a variable quantity. It is possible to increase the crystallinity of amorphous solids by employing special techniques. Quartz has greater degree of crystallinity in its structure.

Q16. What do you understand by imperfections in ionic crystals? Name the types of imperfections which generally occur in ionic crystal.

Ans. Any departure from perfectly ordered arrangement of constituents particles in crystal is called imperfection or defect. Ionic crystal generally shows two types of defect:

(*i*) Schottky Defect. (*ii*) Frenkel Defect.

Q17. The density of copper metal is 8.95 g cm^{-3}. If the radius of copper atom be 127.8 pm, is the copper unit cell simple cubic, body-centred cubic or face-centred cubic?

(Given atomic mass of Cu = 63.54 g mol^{-1} and $N_A = 6.02 \times 10^{23}$ mol^{-1}).

Ans.
$$d = \frac{z \times M}{a^3 \times N_A}$$

$$8.95 = \frac{z \times 63.54}{a^3 \times 6.022 \times 10^{23}}$$

$$a^3 = \frac{z \times 63.54}{8.95 \times 6.022 \times 10^{23}}$$

Let z = 4 (i.e., let copper has fcc)

$$a^3 = \frac{4 \times 63.54}{8.95 \times 6.022 \times 10^{23}}$$

$$= \frac{254.16}{53.91} \times 10^{-23}$$

$$= 4.7145 \times 10^{-23} \text{ cm}^3$$

$$a = 3\sqrt{47.145 \times 10^{-24}}$$

$$= 3.612 \times 10^{-8} \text{ cm}$$

$$= 361.2 \text{ pm.}$$

For fcc $4r = \sqrt{2}\,a$

$$r = \frac{\sqrt{2}\,a}{4} = \frac{a}{2\sqrt{2}}$$

$$= \frac{361.2}{2 \times 1.414} = 127.72 \text{ pm,}$$

which is in close agreement with the given value.

It shows Cu has fcc structure.

Q18. Non-stoichiometric cuprous oxide, Cu_2O can be prepared in laboratory. In this oxide, copper to oxygen ratio is slightly less than 2:1. Can you account for the fact that this substance is a *p*-type semiconductor?

Ans. Since Cu_2O is non-stoichiometric oxide, it contains Cu in two oxidation states, +1 and +2. Cu^{2+} provides an excess of positive charge. As a result an electron from a neighboring Cu^+ is transferred to Cu^{2+}. The transfer of electron leaves behind a hole, which carries an extra positive charge and a negative hole is created. It appears that the positive hole moves through the lattice, hence it appears as *p*-type semiconductor.

Q19. Examine the given defective crystal:

X^+	Y^-	X^+	Y^-	X^+
Y^-	○	Y^-	X^+	Y^-
X^+	Y^-	X^+	○	X^+
Y^-	X^+	Y^-	X^+	Y^-

Answer the following questions:

(*i*) Is the above defect stoichiometric or non-stoichiometric?

(*ii*) Write the term used for this type of defect. Give an example of the compound which stones this type of defect.

(*iii*) How does this defect affect the density of the crystal?

Ans.

(*i*) Stoichiometric

(*ii*) Schottky defect
CX : —NaCl

(*iii*) Density of the crystal decreases.

Q20. An element with density 10 g/cm^3 forms a cubic unit cell with edge length of 3×10^{-8} cm. What is the nature of the cubic unit cell if the atomic mass of the element is 81 g/mol? [*CBSE* 2015]

Ans.
$$d = \frac{Z \times M}{a^3 \times N_A}$$

$$10 = \frac{Z \times 81}{(3 \times 10^{-8})^3 \times 6.022 \times 10^{23}}$$

$$Z \times 81 = 10 \times 27 \times 10^{-24} \times 6.022 \times 10^{23}$$

$$Z = 2+$$

III. Long Answer Type Questions

(*Carrying* 5 *Marks*)

Q1. What are amorphous solids? Give their important properties and uses.

Ans. If there is no regular arrangement of its constituent particles or at the most, there is only a short range order of its constituent particles, the solids are called amorphous solids.

Properties of amorphous solids:

(*i*) The constituent particles are not arranged in any regular fashion, there may be at the most some short range order only.

(*ii*) They have irregular shape.

(*iii*) They melt over a range of temperature.

(*iv*) They are isotropic.

(*v*) They do not have definite heat of fusion.

(*vi*) They undergo an irregular cut.

(*vii*) They are pseudo solids or super cooled liquids.

Uses of amorphous solids:

Amorphous solids are very useful materials in our everyday life. A few applications are given below:

(*i*) The most widely used amorphous are inorganic glasses, which find application in construction, house-ware, laboratory ware etc.

(*ii*) Another well-known amorphous solid is rubber which is used in making tyres.

(*iii*) A large number of plastics which are amorphous solids are being used in articles of everyday Life.

(*iv*) Amorphous silica has been found to be the best material for converting sunlight into electricity (in photovoltaic cells).

Q2. What do you understand by point defects? Briefly explain the different types of point defects.

Ans. **Point defects:** When the deviations or irregularities exist from the ideal arrangement around a point or an atom in a crystalline substance, the defect is called point defect.

Types of point defect: Point defects in a crystal may be classified into the following three types:

(A) Stoichiometric defects.

(B) Non-stoichiometric defects

(C) Impurity defects.

(A) **Stoichiometric Defects:** When the stoichiometry of the solid is not disturbed the defect is called stoichiometric defects. These defects are of two types:

(*i*) Vacancy defects

(*ii*) Interstitials defects.

(*i*) **Vacancy defects:** In a crystalline substance some of the lattice sites are vacant, it results in the decreases in the density of the substance, generally shown by non-ionic solid.

(*ii*) **Interstitial defects:** When some constituent particles are present in the interstitial sites the crystal is said to have interstitial defect, results in the increase in the density of substance.

(B) **Non-stoichiometric defects:** These defects results in either excess of the metal atoms or non-metal atoms.

(C) **Impurity defects:** These defects arise when foreign atoms are present at the lattice size.

Q3. Derive the expressions for the following:

(*i*) Density of a cubic crystal of an element of edge 'a' and atomic mass M.

(*ii*) Packing efficiency of a body centred cubic structure.

Ans.

(*i*) $$d = \frac{z \times M}{a^3 \times N_A}$$

Where d = density of the substance

z = No. of atoms

M = atomic mass of the element

a^3 = Volume of the crystal

$N_A = 6.022 \times 10^{23}$

(*ii*) Packing efficiency of a body centred cubic structure.

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

Total no. of atoms = 2

$$\text{Volume of the sphere} = 2 \times \frac{4}{3}\pi r^3$$

$$\text{Volume of cube} = \left(\frac{4r}{\sqrt{3}}\right)^3$$

Packing efficiency

$$= \frac{\text{Volume occupied by the two sphere in unit cell}}{\text{Total volume of the unit cell}} \times 100$$

$$= \frac{2 \times \frac{4}{3}\pi r^3 \times 100}{\left(\frac{4r}{\sqrt{3}}\right)^3} = \frac{\frac{8}{3}\pi r^3 \times 100}{\frac{64}{3\sqrt{3}} r^3} \times 100$$

= 68%

Q4. Explain the difference between the following:

(*i*) Ferromagnetism and antiferromagnetism

(*ii*) *n* and *p*-type semiconductors.

Ans.

(*i*) **Ferromagnetic substances:** Substances which show permanent magnetism even in the absence of magnetic field are called ferromagnetic substances. *e.g*. Fe, Ni, Co, gadolinium (Gd) and CrO_2 show ferromagnetism. Such substances remain permanently magnetised once they have been magnetised.

Antiferromagnetic substances: Substances which are expected to possess paramagnetism or ferromagnetism on the basis of magnetic moments of the domains but actually they possess zero magnetic moment are called antiferromagnetic substances *e.g.,* MnO.

(*ii*) ***n*-type semiconductor:** When doping is done with electron rich impurities or we can say there is increase in conductivity due to negatively charged electrons for example, silicon or germanium doped with group 15 element like P or as the delocalized electrons increase the conductivity of silicon or germanium.

***p*-type semiconductor:** When doping is done with electron deficit impurities, then silicon or germanium is doped with group 13 element like B, Al, or Ga. Hence, electron deficit doped silicon and germanium are called *p*-type semiconductor.

Q5. An element crystallizes in a fcc lattice with cell edge of 400 pm. The density of the element is 7 g/cm^3. How many atoms one present in 280 g of the element? [*CBSE* 2016]

Ans. Volume of unit cell

$= a^3$ (a = edge length)

= 400 pm

$= (400 \times 10^{-12}\ \text{m})^3$

$= (400 \times 10^{-10}\ \text{cm})^3$

$= 64 \times 10^{-24}\ \text{cm}^3$

Volume of 208 g of the element

$$= \frac{208}{7\ \text{g/cm}^3} = 29.71\ \text{cm}^3$$

Number of unit cells in this volume

$$= \frac{\text{Vol. of given amount}}{\text{Vol. of one unit cell}}$$

$$= \frac{29.71}{64 \times 10^{-24}} = 0.46 \times 10^{24}$$

Since each f.c.c. unit cell contains 4 atoms therefore,

total number

$= 4 \times 0.46 \times 10^{24}$

$= 1.84 \times 10^{24}$ atoms.

IV. Value-Based Question

Q1. Sudanshu made a model of the unit cell of diamond. It resembled the unit cell of ZnS.

If the unit cell of ZnS has 4 units of ZnS per unit cell, it has the same packing efficiency as ZnS. But diamond is the hardest known substance.

(*a*) What is the number of atoms of carbon per unit cell of diamond?

(*b*) Diamond is stronger than ZnS. Why?

(*c*) What is the value that Sudanshu can derive from these facts?

Ans.

(*a*) The number of atoms of carbon per unit cell is 8 in diamond.

(*b*) The C—C bond is very strong in diamond (due to small size of carbon) unlike the Zn—S bond in ZnS.

(*c*) Though from the same background *i.e.*, with the same structure the property can be different. Thus, with a little effort, we can do same things differently and bring about major changes.

V. HOTS Questions

Q1. A compound forms hexagonal close packed structure. What is the total number of voids in 0.5 mol of it? How many of these are tetrahedral voids?

Ans. 1 mole of hexagonal packed structure contains 1 mole of octahedral voids and two moles of tetrahedral voids. Therefore, 0.5 moles of hexagonal packed structure contains 0.5 moles of octahedral voids and 1 mole of tetrahedral voids.

No. of tetrahedral voids

$= 6.022 \times 10^{23}$

No. of octahedral voids

$= \frac{1}{2} \times$ No. of tetrahedral voids

No. of octahedral voids

$= \frac{1}{2} \times 6.022 \times 10^{23} = 3.011 \times 10^{23}$

Total no. of voids

$= (6.022 + 3.011) \times 10^{23}$

$= 9.033 \times 10^{23}$.

Q2. Sodium crystalizes in a bcc unit cell. Calculate the approximate number of unit cells in 9.2 g of sodium. (Atomic Mass of Na = 23 *u*)

Ans. No. of atoms per unit cell for bcc(z) = 2

No. of atoms in 9.2 g of Na

$$= \frac{9.2\text{g}}{23\text{g mol}^{-1}} \times 6.022 \times 10^{23} \text{ atoms mol}^{-1}$$

No. of Na atoms $= 2.4088 \times 10^{23}$

No. of unit cells

$$= \frac{2.4088 \times 10^{23} \text{ atoms}}{2 \text{ atoms unit cell}^{-1}}$$

$= 1.2044 \times 10^{23}$

Q3. The energy required to vapourise one mole of copper is smaller than that of energy required to vapourise 1 mol of diamond. Why?

Ans. Copper is a metallic solid having metal-metal bonds while diamond is a covalent solid having covalent bonds. Metallic bonds are weaker than covalent bonds and thus less amount of energy is required to break metallic bonds than covalent bonds.