

# SOLID STATE

## CHAPTER 01

### INTRODUCTION:

Solids are one of the three states of matter, along with liquids and gases. They are characterized by their unique properties and behaviors. Here is a definition and some key characteristics of solids:

#### **Definition:**

Solids are substances that have a definite shape and volume. The constituent particles in solids are tightly packed together, forming a regular and ordered arrangement

Solids are substances that have a definite shape and volume. Their particles are tightly packed together in an ordered arrangement. They have high density, are incompressible, and exhibit a regular crystalline structure in many cases. Solids have a well-defined melting point, expand when heated, and possess mechanical strength. Understanding these characteristics is essential to —comprehend the behaviors and properties of solids and their applications in different fields.

| Characteristics          | Crystalline Solids                               | Amorphous Solids                          |
|--------------------------|--|---|
| Arrangement of particles | Regular and repeating arrangement                | Random arrangement                        |
| Long –Range Order        | Yes  | No  |
| Sharp Melting Point      | Yes  | No  |
| Shape Retention          | Retain shape when subjected to external forces   | Gradual change in properties upon heating |
| Particles Mobility       | Particles can move along specific crystal planes | Particles can move freely                 |
| Translation Symmetry     | Exhibits translational symmetry                  | Lacks translational symmetry              |
| Examples                 | Diamond, NaCl, Quartz                            | Glass, Rubber, Plastic                    |

## **TYPES OF SOLIDS**

| Crystal type | Constituent particles                                    | Main binding forces                       | Properties  | Examples   |
|--------------|--|---|---|--|
| Ionic        | Positive and negative ions arranged in a definite order  | Strong electrostatic forces of attraction | Brittle, high m.p., good conductors in the aqueous solution of fused state, high heats of fusion  | Salts like NaCl, AgCl, MgO, KNO <sub>3</sub> , LiF, BaSO <sub>4</sub> etc.                 |
| Molecular    | Small molecules  | Vander Waal's forces                      | Soft, low m.p., volatile, electrical insulators, poor thermal conductors, low heat of fusion  | Solid CO <sub>2</sub> (dry ice) H <sub>2</sub> , graphite sheets and CH <sub>4</sub> , wax |
| Covalent     | Atoms chemically bound together in the form of a network | Covalent bond forces                      | Very hard, high m.p., poor conductors of heat and electricity, high heat of fusion  | Diamond, silicon, quartz   |
| Metallic     | Positive ions and mobile electrons                       | Electrical attractions (metallic bond)    | Very soft to very hard, low to high m.p., good conductors of electricity and heat, metallic luster, malleable and ductile, moderate heats of fusion | All metals and some alloys   |

### **BRAGG'S LAW**

The Bragg's Law is a fundamental principle in X-ray diffraction that explains the relationship between the angle of incidence, the spacing of crystal lattice planes, and the resulting constructive interference of X-rays. It is named after Sir William Lawrence Bragg, who formulated this law in 1912.

Bragg's Law states that for a construction interference of X-rays to occur, the following condition must be satisfied:

$$n\lambda = 2d \sin\theta \text{ WHERE,}$$

- $n$  is the order of the diffraction peak.
- $\lambda$  is the wavelength of the incident X-ray.
- $d$  is the spacing between adjacent planes in the crystal lattice.
- $\theta$  is the angle between the incident X-ray and the crystal lattice planes.

## Crystal Lattice and Unit Cells

### Crystal Lattice:

- A crystal lattice refers to the three-dimensional arrangement of constituent particles (atoms, ions, or molecules) in a crystalline solid.
- It represents the repeating pattern of the crystal structure, extending indefinitely in all directions.
- The crystal lattice provides the basis for the macroscopic properties of the solid.

### Unit Cells:

- A unit cell is the smallest repeating unit within a crystal lattice.
- It is a parallelepiped (a three-dimensional shape with six faces) that represents the fundamental building block of the crystal structure.
- The entire crystal lattice can be constructed by replicating the unit cell in all directions.
- Each unit cell has its own set of dimensions, edges, angles, and symmetry elements.

### Types of Unit Cells:

5. **Simple Cubic (SC):** Contains particles only at the corners of the unit cell.
6. **Body-Centered Cubic (BCC):** Has particles at the corners and an additional particle at the center of the unit cell.
7. **Face-Centered Cubic (FCC):** Contains particles at the corners and on the faces of the unit cell.
8. **Hexagonal Close-Packed (HCP):** Consists of a hexagonal lattice with additional particles above and below the plane.

## CRYSTAL SYSTEM

| Crystal System           | Possible variations                                   | Axial distances or edge lengths | Axial angles                                       | Examples  |
|--------------------------|---|---------------------------------|--|---|
| Cubic                    | Primitive, Body-centered, Face-centered               | $a=b=c$                         | $\alpha=\beta=\gamma=90^\circ$                     | NaCl, Zinc blende   |
| Tetragonal               | Primitive, Body centered                              | $a=b \neq c$                    | $\alpha=\beta=\gamma=90^\circ$                     | White tin, $\text{SnO}_2$ , $\text{TiO}_2$ , $\text{CaSO}_4$  |
| Orthorhombic             | Primitive, Body centered, Face centered, End centered | $a \neq b \neq c$               | $\alpha=\beta=\gamma=90^\circ$                     | Rhombic Sulphur, $\text{KNO}_3$ , $\text{BaSO}_4$   |
| Hexagonal                | Primitive   | $a=b \neq c$                    | $\alpha=\beta=90^\circ$<br>$\gamma=120^\circ$      | Graphite, $\text{ZnO}$ - $\text{CdS}$   |
| Rhombohedral or Trigonal | Primitive   | $a=b=c$                         | $\alpha=\beta=\gamma \neq 90^\circ$                | Calcite ( $\text{CaCO}_3$ ), $\text{HgS}$ (cinnabar)  |
| Monoclinic               | Primitive, End centered                               | $a \neq b \neq c$               | $\alpha=\gamma=90^\circ$<br>$\beta \neq 120^\circ$ | Monoclinic Sulphur, $\text{Na}_2\text{SO}_4 \cdot \text{H}_2\text{O}$                                   |
| Triclinic                | Primitive   | $a \neq b \neq c$               | $\alpha \neq \beta \neq \gamma \neq 90^\circ$      | $\text{K}_2\text{Cr}_2\text{O}_7$ , $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , $\text{H}_3\text{BO}_3$ |

8. Contribution of each atom present on the corner  $= \frac{1}{8}$

9. Contribution of each atom present on the face  $= \frac{1}{2}$

10. Contribution of an atom present on the edge  $= \frac{1}{4}$

11. Contribution of each atom within the body  $= 1$

12. Number of atoms present in the simple unit cell  $= \frac{1}{8} \times 8 = 1$

13. Number of atoms present in the face- centre unit cell  $= \frac{1}{8} \times 8 + \frac{1}{2} \times 6 = 4$

14. Number of atoms present in the body-centre unit cell  $= \frac{1}{8} \times 8 + 1 = 2$



## PACKING AND STRUCTURE OF CRYSTALS

| <u>Aspect</u>       | <u>Description</u>   |
|---------------------|--|
| Packing of crystals | <ul style="list-style-type: none"> <li>➤ Close Packing: Maximizes efficient use of space. Types include hexagonal close packing (hcp) and cubic close packing (ccp).</li> <li>➤ Body-Centred Packing: Additional atom or ion at the centre of the unit cell.</li> <li>➤ Simple Packing: Basic arrangements without additional atoms or ions in the unit cell.</li> </ul> |
| Crystal Structures  | <ul style="list-style-type: none"> <li>➤ Determined by bonding type and arrangement of constituent particles.</li> <li>➤ Crystal lattice is built by repeating a basic building block called the unit cell.</li> <li>➤ Different crystal systems have specific unit cell types: cubic, tetragonal, orthorhombic, etc.</li> </ul>   |

$$\text{Packing density} = \frac{vZ}{V} = \frac{\frac{4}{3}\pi r^3 Z}{a^3}$$

| Structure          | r related to a            | v  | Packing density                |
|--------------------|---------------------------|--|--------------------------------|
| Simple cubic       | $r = \frac{a}{2}$         | $\frac{4}{3}\pi\left(\frac{a}{2}\right)^3$         | $\frac{\pi}{6} = 0.52$         |
| Face-centred cubic | $r = \frac{a}{2\sqrt{2}}$ | $\frac{4}{3}\pi\left(\frac{a}{2\sqrt{2}}\right)^3$ | $\frac{\sqrt{2}\pi}{6} = 0.74$ |
| Body-centre cubic  | $r = \frac{\sqrt{3}a}{4}$ | $\frac{4}{3}\pi\left(\frac{\sqrt{3}a}{4}\right)^3$ | $\frac{\sqrt{3}\pi}{8} = 0.68$ |

## TYPES OF CLOSED PACKED STRUCTURES

| Close-packed Structures       | Description   |
|-------------------------------|---|
| Hexagonal Close Packing (HCP) | <ul style="list-style-type: none"> <li>➤ In HCP, the spheres (atoms, ions, or molecules) are arranged in a close-packed manner forming hexagonal layers.</li> </ul> |
|                               | <ul style="list-style-type: none"> <li>➤ Each subsequent layer is placed directly above the previous one, resulting in an ABAB... stacking pattern.</li> </ul>      |
|                               | <ul style="list-style-type: none"> <li>➤ The coordination number of each sphere is 12.</li> </ul>   |
| Cubic Close Packing (CCP)     | <ul style="list-style-type: none"> <li>➤ In CCP, the spheres are arranged in a close-packed manner forming stacked layers.</li> </ul>                               |
|                               | <ul style="list-style-type: none"> <li>➤ Each subsequent layer is placed directly above the previous one, resulting in an ABCABC... stacking pattern.</li> </ul>    |
|                               | <ul style="list-style-type: none"> <li>➤ The coordination number of each sphere is 12.</li> </ul>   |

Radius ( $r$ ) of the tetrahedral void =  $0.225 R$

Radius ( $r$ ) of the octahedral void =  $0.414 R$

No. of octahedral voids = Number of atoms in the close packed arrangement.

No. of tetrahedral voids =  $2 \times$  Number of atoms or octahedral voids.

## RADIUS RATIO

| Radius ratio range | Coordination Number (Cation) | Coordination Number (Anion) | Geometry        |
|--------------------|------------------------------|-----------------------------|-----------------|
| $<0.155$           | Varies                       | Varies                      | Not Stable      |
| $0.155-0.225$      | 2                            | 2                           | Linear          |
| $0.225-0.414$      | 3                            | 6                           | Trigonal Planar |
| $0.414-0.732$      | 4                            | 4                           | Tetrahedral     |
| $0.732-1.0$        | 6                            | 6                           | Octahedral      |
| $>1.0$             | 8+                           | 6                           | Cubic or BCC    |

Relationship between the nearest neighbor's distance (d) and the edge (a) of the unit cell and radius of the atom (r) for pure elements

| <u>Simple</u>     | <u>Body-center</u>                  | <u>Face-center</u>                   |
|-------------------|-------------------------------------|--------------------------------------|
| $d = a$           | $d = \frac{\sqrt{3}}{2} a = 0.866a$ | $d = \frac{1}{\sqrt{2}} a = 0.707a$  |
| $r = \frac{a}{2}$ | $r = \frac{\sqrt{3}}{4} a = 0.433a$ | $r = \frac{a}{2\sqrt{2}} = 0.3535 a$ |

### DENSITY OF CUBIC CRYSTAL

The density of a cubic crystal in the solid state can be calculated using the formula:

Density = (Molar mass of the substance) / (Volume of the unit cell)

For a simple cubic crystal structure, the unit cell contains only one lattice point at each corner of the cube. The volume of a simple cubic unit cell can be determined using the formula:

Volume of a Simple Cubic Unit Cell = (Edge length) <sup>3</sup>

The edge length of a simple cubic unit cell is equal to the lattice parameter (a).

Therefore, the density (ρ) of a simple cubic crystal can be calculated as:

Density = (Molar mass of the substance) / [(Edge length) <sup>3</sup>]

It is important to note that the actual density may vary depending on the isotopic composition and packing efficiency of the crystal lattice. Additionally, different crystal structures have different unit cell configurations and formulas for calculating density.

$$\rho = \frac{Z \times M}{a^3 \times N_0 \times 10^{-30}} \text{ g/cm}^3$$

Where Z = Number of atoms present per unit cell

M = Atomic mass of the element

a = Edge of the cubic crystal in pm.,

N<sub>0</sub> = Avogadro's number

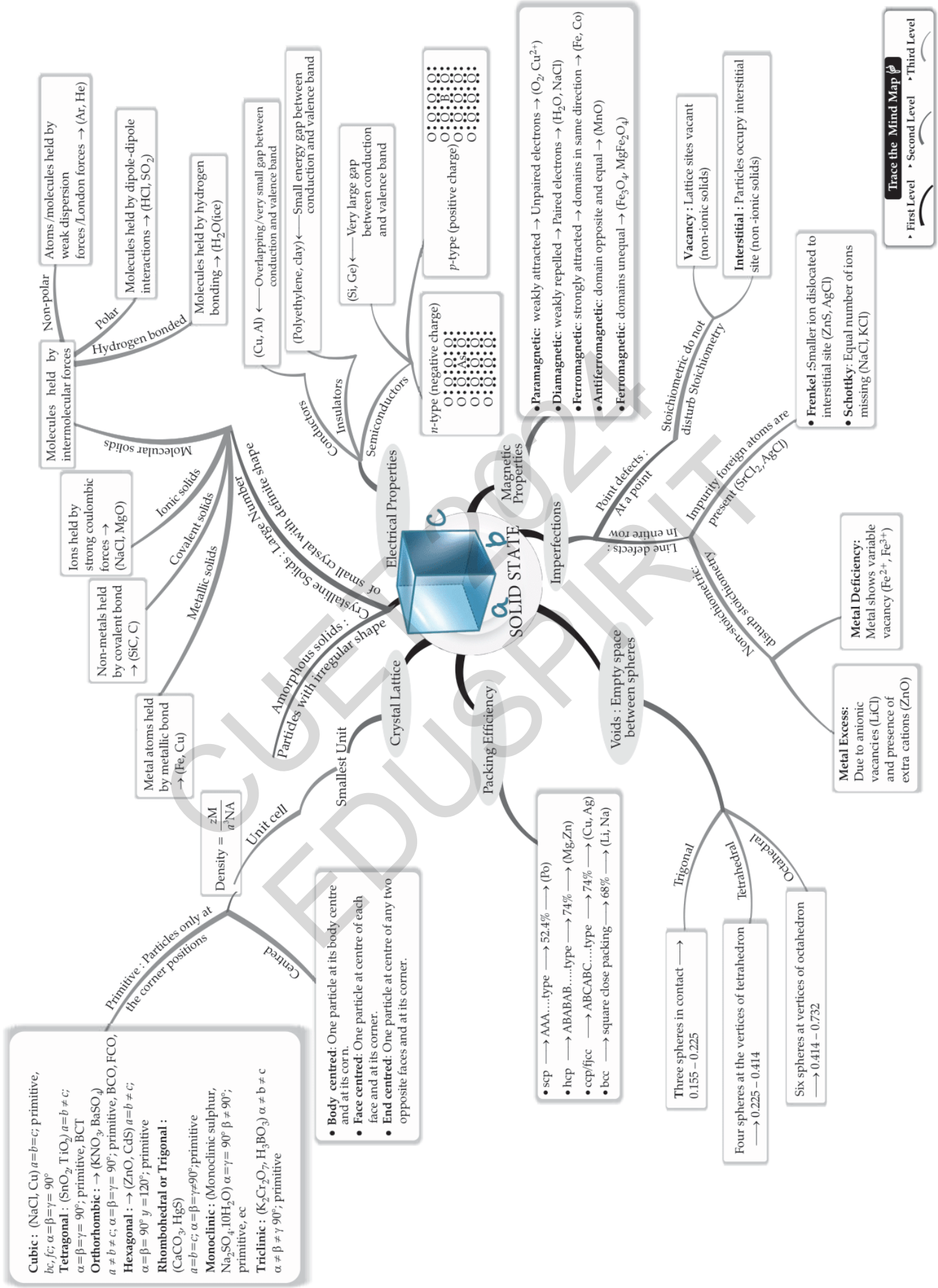
## DEFECTS OF CRYSTALLINE SOLIDS

| Defect Type                 | Description   | Examples   |
|-----------------------------|---|--|
| <b>Vacancy Defects</b>      | Occur when lattice sites are unoccupied by atoms or ions.   | Metals, ceramics, semiconductors                               |
| <b>Interstitial Defects</b> | Result from atoms or ions occupying positions between the lattice sites.  | Carbon interstitials in steel, boron in silicon                |
| <b>Impurity Defects</b>     | Arise when foreign atoms or ions are present in the crystal lattice.  | Doping in semiconductors, color centers in gemstones           |
| <b>Dislocations</b>         | Linear defects caused by the misalignment of crystal planes.  | Edge dislocations, screw dislocation                           |
| <b>Surface Roughness</b>    | Irregularities on the surface due to imperfect lattice termination.   | Surface of crystals, thin films                                |
| <b>Steps Edges</b>          | Discontinuities in the crystals lattice at the surface.   | Terraces and steps on crystal surfaces                         |
| <b>Grain Boundaries</b>     | Interfaces between adjacent crystalline grains with different orientations.   | Polycrystalline materials, boundaries in metals and ceramics   |
| <b>Twin Boundaries</b>      | Planar defects where two regions of the crystal have a mirror image relationship.   | Twins in metals, minerals and alloys                           |
| <b>F-Centers</b>            | An anion vacancy occupied by an electron, creating an electron color center.  | Crystals exhibiting coloration and absorption of light         |
| <b>Schottky Defects</b>     | Equal number of cations and anions missing from their lattice sites. Results in vacancies in both cation and anion positions. | Ionic compounds with high coordination numbers and low charges |
| <b>Frenkel Defects</b>      | Displacement of an ion from its lattice site to an interstitial position. Involves the creation of a cation in vacancy        | Ionic compounds with low coordination numbers and high charges |



## **PROPERTIES OF SOLIDS**

1. **Thermal Conductivity:** Solids can conduct heat to varying extents. Metals are generally good conductors of heat due to the movement of free electrons, while non-metals exhibit lower thermal conductivity.
2. **Electrical Conductivity:** Solids can be classified into conductors, semiconductors, and insulators based on their ability to conduct electricity. Conductors allow the flow of electric charges, semiconductors have intermediate conductivity, and insulators restrict the flow of electric current.
3. **Optical Properties:** Solids can exhibit diverse optical properties, including transparency, opacity, and reflectivity. These properties depend on the interactions of light with the solid's atomic or molecular structure.
4. **Elasticity:** Solids can deform under the influence of an external force but can regain their original shape when the force is removed. This ability is known as elasticity and is related to the arrangement and flexibility of the solid's constituent particles.
5. **Magnetic Properties:** Some solids exhibit magnetic behaviour, such as ferromagnetism, para -magnetism, or diamagnetism, based on the alignment and interaction of their magnetic moments.



### PRACTICE QUESTIONS

- Which of the following is a characteristic of crystalline solids?
  - Random arrangement of particles
  - Lack of long-range order
  - Definite shape and volume
  - Low melting point
- Which type of solid has a three-dimensional network of covalent bonds?
  - Ionic solid
  - Molecular solid
  - Metallic solid
  - Covalent network solid
- Which of the following is not a type of crystal lattice structure?
  - Simple cubic
  - Body-centred cubic
  - Face-centred cubic
  - Tetrahedral cubic
- Which of the following is an example of an amorphous solid?
  - Sodium chloride
  - Quartz
  - Glass
  - Diamond
- Which of the following is an example of a molecular solid?
  - Sodium chloride
  - Graphite
  - Diamond
  - Iodine
- The coordination number of a particle in a face-centred cubic (FCC) lattice is:
  - 4
  - 6
  - 8
  - 12
- Which type of solid has a high electrical conductivity?
  - Ionic solid
  - Covalent solid
  - Metallic solid
  - Molecular solid
- Which of the following defects occurs when a cation occupies an interstitial site in a crystal lattice?
  - Frenkel defect
  - Schottky defect
  - Substitutional defect
  - Interstitial defect
- The packing efficiency of a face-centred cubic (FCC) lattice is approximately:
  - 26%
  - 52%
  - 68%
  - 74%
- Which type of defect does not affect the density of a crystal lattice?
  - Frenkel defect
  - Schottky defect
  - Vacancy defect
  - Interstitial defect

11. Which of the following is an example of a metalloid?

- a) Sodium (Na)      b) Silicon (Si)      c) Copper (Cu)      d) Iron (Fe)

12. Which type of solid has a disordered arrangement of particles?

- a) Crystalline solid      b) Amorphous solid  
c) Metallic solid      d) Molecular solid

13. Which of the following is not a type of point defect?

- a) Dislocation      b) Vacancy  
c) Frenkel defect      d) Interstitial defect

14. Which type of solid has a high melting point and is an excellent conductor of electricity?

- a) Ionic solid      b) Covalent solid  
c) Metallic solid      d) Molecular solid

15. Which of the following is an example of a covalent network solid?

- a) Sodium chloride      b) Diamond      c) Copper      d) Oxygen

16. Which type of solid has a low melting point and is usually a poor conductor of electricity?

- a) Ionic solid      b) Covalent solid  
c) Metallic solid      d) Molecular solid

17. The unit cell of a simple cubic lattice consists of how many atoms or ions?

- a) 1      b) 2      c) 4      d) 8

18. Which type of solid has strong electrostatic forces between positively and negatively charged ions?

- a) Ionic solid      b) Covalent solid  
c) Metallic solid      d) Molecular solid

19. Which of the following defects occurs when an atom or ion is missing from its lattice site?

- a) Frenkel defect      b) Schottky defect  
c) Substitutional defect      d) Vacancy defect

20. Which type of solid has a delocalized sea of electrons?

- a) Ionic solid      b) Covalent solid  
c) Metallic solid      d) Molecular solid



21. Which of the following statements is true about amorphous solids?
- They have a regular, repeating pattern.
  - They have a well-defined melting point.
  - They are usually good conductors of electricity.
  - They have long-range order.
22. The coordination number of a particle in a body-centred cubic (BCC) lattice is:
- 4
  - 6
  - 8
  - 12
23. Which type of solid has a variable composition and lacks a sharp melting point?
- Ionic solid
  - Covalent solid
  - Metallic solid
  - Amorphous solid
24. Which of the following defects is caused by the displacement of atoms or ions in a crystal lattice?
- Dislocation
  - Grain boundary
  - Frenkel defect
  - Interstitial defect
25. The packing efficiency of a hexagonal close-packed (HCP) lattice is approximately:
- 26%
  - 52%
  - 68%
  - 74%
26. Which of the following solids is a conductor of electricity in the molten state but not in the solid state?
- Covalent solid
  - Ionic solid
  - Molecular solid
  - Metallic solid
27. Which of the following defects does not lead to an increase in the density of a crystal lattice?
- Frenkel defect
  - Schottky defect
  - Vacancy defect
  - Interstitial defect
28. The unit cell of a face-centred cubic (FCC) lattice consists of how many atoms or ions?
- 1
  - 2
  - 4
  - 8
29. Which type of solid has a random arrangement of particles with short-range order?
- Crystalline solid
  - Amorphous solid
  - Metallic solid
  - Molecular solid
30. The packing efficiency of a simple cubic lattice is approximately:
- 26%
  - 52%
  - 68%
  - 74%

31. Which of the following substances is a molecular solid?

- a) Sodium chloride      b) Graphite      c) Copper      d) Aluminium oxide

32. Which of the following is an example of a substitutional defect?

- a) Frenkel defect      b) Schottky defect  
c) Vacancy defect      d) Interstitial defect

33. Which type of solid has a low melting point and is a poor conductor of electricity?

- a) Ionic solid      b) Covalent solid  
c) Metallic solid      d) Molecular solid

34. The unit cell of a hexagonal close-packed (HCP) lattice consists of how many atoms or ions?

- a) 1      b) 2      c) 4      d) 8

35. Which type of solid has a definite melting point and is hard and brittle?

- a) Ionic solid      b) Covalent solid  
c) Metallic solid      d) Molecular solid

36. Which of the following defects involves a pair of vacancy and interstitial sites?

- a) Frenkel defect      b) Schottky defect  
c) Substitutional defect      d) Interstitial defect

37. Which type of solid has a highly regular arrangement of particles with long-range order?

- a) Crystalline solid      b) Amorphous solid  
c) Metallic solid      d) Molecular solid

38. Which of the following is an example of a covalent solid?

- a) Sodium chloride      b) Diamond      c) Copper      d) Oxygen

39. The coordination number of a particle in a cubic close-packed (CCP) lattice is:

- a) 4      b) 6      c) 8      d) 12

40. Which type of solid has weak van der Waals forces between particles?

- a) Ionic solid      b) Covalent solid  
c) Metallic solid      d) Molecular solid

41. The unit cell with dimensions  $\alpha=\beta=\gamma=90^\circ$ ,  $a=b\neq c$  is:

- a) Cubic                      b) Monoclinic                      c) Tetragonal                      d) Rhombohedral

42. An fcc element (atomic mass = 80) has a cell edge of 500 pm. Its density is:

- a)  $7.233 \text{ gcm}^{-3}$                       b)  $7.43 \text{ gcm}^{-3}$   
c)  $7.63 \text{ gcm}^{-3}$                       d)  $7.83 \text{ gcm}^{-3}$

43. For a crystal system where  $a=b=c$  and  $\alpha=\beta=\gamma=120^\circ$

- a) Cubic                      b) Hexagonal                      c) Rhombohedral                      d) Monoclinic

44. The number of atoms (n) contained within a cubic cell is:

- a) 1                      b) 2                      c) 3                      d) 6

45. All the substances become diamagnetic at:

- a) 1 K                      b) 5 K                      c) 15 K                      d) 30 K

46. Ferrimagnetic is converted into paramagnetic at:

- a) 200 K                      b) 350 K                      c) 500 K                      d) 700 K

47. A mineral exhibits:

- a) Cubic symmetry                      b) Monoclinic symmetry  
c) Orthorhombic symmetry                      d) Trigonal symmetry

48. The oxide that possesses electrical insulating property:

- a)  $\text{V}_2\text{O}_5$                       b)  $\text{CrO}_2$                       c)  $\text{NiO}$                       d)  $\text{MnO}_2$

49. The arrangement ABAB... is referred to as:

- a) Octahedral close packing                      b) Simple cubic packing  
c) Tetragonal close packing                      d) Hexagonal close packing

50. The lattice points of a crystal of sodium chloride ( $\text{NaCl}$ ) are occupied by:

- a)  $\text{Na}^+$  cations and  $\text{Cl}^-$  anions                      b) Na atoms and Cl atoms  
c)  $\text{NaCl}$  molecules                      d)  $\text{Na}_2\text{Cl}_2$  molecules

51. An element has bcc structure having unit cells  $8.95 \times 10^{23}$ . The number of atoms in these cells is:

- a)  $8.95 \times 10^{23}$       b)  $17.9 \times 10^{23}$       c)  $26.85 \times 10^{23}$       d)  $35.8 \times 10^{23}$

52. A metal has bcc structure and the edge length of its unit cell is 2.48 Å. The volume of the unit cell in  $\text{cm}^3$  will be:

- a)  $1.2 \times 10^{-21} \text{ cm}^3$       b)  $3.52 \times 10^{-23} \text{ cm}^3$       c)  $5.67 \times 10^{-23} \text{ cm}^3$       d)  $7.1 \times 10^{-24} \text{ cm}^3$

53. The edge length of a face-centered cubic cell of an ionic substance is 460 pm. If the radius of the cation is 95 pm, the radius of the anions is:

- a) 215 pm      b) 285 pm      c) 370 pm      d) 120 pm

54. An ionic compound is expected to have a tetrahedral structure if  $r_+/r_-$  lies in the range of:

- a) 0.452 to 0.823      b) 0.331 to 0.452      c) 0.158 to 0.331      d) 0.823 to 1

55. A compound CuCl has a face-centered cubic structure. Its density is  $5 \text{ g cm}^{-3}$ . The length of the unit cell is:

- a) 4.0 Å      b) 4.5 Å      c) 5.0 Å      d) 5.5 Å

56. In an orthorhombic unit cell, the values of a, b, and c are respectively 4 Å, 5 Å, and 6 Å. Given the molecular mass of the solute is  $150 \text{ g mol}^{-1}$ , and the density is  $3 \text{ g/cc}$ , the number of formula units per unit cell is:

- a) 2      b) 3      c) 4      d) 5

57. A metallic element has a cubic lattice. Each edge of the unit cell is 2 Å. The density of the metal is  $4 \text{ g cm}^{-3}$ . The unit cells in 200 g of metal are:

- a)  $1 \times 10^{24}$       b)  $2 \times 10^{24}$       c)  $3 \times 10^{24}$       d)  $4 \times 10^{24}$

58. Potassium has a bcc structure with a nearest neighbor distance of 3 Å. Its atomic weight is 40. Its density will be:

- a)  $750 \text{ kg m}^{-3}$       b)  $800 \text{ kg m}^{-3}$       c)  $850 \text{ kg m}^{-3}$       d)  $900 \text{ kg m}^{-3}$

59. Lithium forms a body-centered cubic structure. The length of the side of its unit cell is 3 Å. Atomic radius of lithium will be:

- a) 1.5 Å      b) 1.8 Å      c) 2.0 Å      d) 2.2 Å

60. An fcc element (atomic mass = 70) has a cell edge of 4 Å. Its density is:

- a)  $7.5 \text{ g cm}^{-3}$       b)  $8.0 \text{ g cm}^{-3}$       c)  $8.5 \text{ g cm}^{-3}$       d)  $9.0 \text{ g cm}^{-3}$



## ANSWERS

1. **Answer:** c) Definite shape and volume

Explanation: Crystalline solids have a definite shape and volume due to the highly ordered arrangement of their constituent particles.

2. **Answer:** d) Covalent network solid

Explanation: Covalent network solids are formed by an extended three-dimensional network of covalent bonds, resulting in a high melting point and hardness.

3. **Answer:** d) Tetrahedral cubic

Explanation: The tetrahedral cubic structure is not a recognized crystal lattice structure. It is an incorrect option among the given choices.

4. **Answer:** c) Glass

Explanation: Glass is an example of an amorphous solid that lacks long-range order and has a disordered arrangement of particles.

5. **Answer:** d) Iodine

Explanation: Iodine is an example of a molecular solid where discrete molecules are held together by weak intermolecular forces.

6. **Answer:** c) 8

Explanation: In a face-centred cubic (FCC) lattice, each particle has 8 nearest neighbouring particles or a coordination number of 8.

7. **Answer:** c) Metallic solid

Explanation: Metallic solids have a high electrical conductivity due to the presence of a delocalized sea of electrons that can move freely within the lattice.

8. **Answer:** a) Frenkel defect

Explanation: Frenkel defect occurs when a cation occupies an interstitial site in the crystal lattice, leading to a vacancy and an interstitial pair.

9. **Answer:** d) 74%

Explanation: The packing efficiency of a face-centred cubic (FCC) lattice is approximately 74%, maximizing the efficient packing of spheres.

10. **Answer:** d) Interstitial defect

Explanation: Interstitial defect occurs when foreign atoms or ions occupy the interstitial sites in the crystal lattice, without causing a disruption in the lattice structure.

11. **Answer:** b) Silicon (Si)

Explanation: Silicon is an example of a metalloid, which exhibits properties of both metals and non-metals.

12. **Answer:** b) Amorphous solid

Explanation: Amorphous solids have a disordered arrangement of particles, lacking long-range order or a well-defined crystalline structure.

13. **Answer:** a) Dislocation

Explanation: Dislocation is a line defect caused by the displacement of atoms or ions along crystal planes, resulting in localized strain.

14. **Answer:** c) Metallic solid

Explanation: Metallic solids have a high melting point and are excellent conductors of electricity due to the presence of delocalized electrons.

15. **Answer:** b) Diamond

Explanation: Diamond is an example of a covalent network solid where carbon atoms are bonded in a three-dimensional network through strong covalent bonds.

16. **Answer:** a) Ionic solid

Explanation: Ionic solids have a low melting point and are usually poor conductors of electricity in the solid state, but they can conduct when molten or dissolved in water.

17. **Answer:** a) 1

Explanation: The unit cell of a simple cubic lattice consists of only one atom or ion.

18. **Answer:** a) Ionic solid

Explanation: Ionic solids are held together by strong electrostatic forces between positively and negatively charged ions.

19. **Answer:** d) Vacancy defect

Explanation: Vacancy defect occurs when an atom or ion is missing from its lattice site, leaving behind a vacant site.

20. **Answer:** c) Metallic solid

Explanation: Metallic solids have a delocalized sea of electrons that can move freely throughout the lattice, allowing them to conduct electricity.

21. **Answer:** d) They have long-range order.

Explanation: Amorphous solids lack long-range order and have a disordered arrangement of particles.

22. **Answer:** c) 8

Explanation: In a body-centred cubic (BCC) lattice, each particle has 8 nearest neighbouring particles or a coordination number of 8.

23. **Answer:** d) Amorphous solid

Explanation: Amorphous solids have a variable composition and lack a sharp melting point, as their particles are arranged randomly.

24. **Answer:** a) Dislocation

Explanation: Dislocation is caused by the displacement of atoms or ions in a crystal lattice along specific planes, resulting in localized strain.

25. **Answer:** c) 68%

Explanation: The packing efficiency of a hexagonal close-packed (HCP) lattice is approximately 68%, maximizing the efficient packing of spheres.

26. **Answer:** b) Ionic solid

Explanation: Ionic solids conduct electricity when molten or dissolved in water due to the mobility of ions, but they are insulators in the solid state.

27. **Answer:** a) Frenkel defect

Explanation: Frenkel defect does not lead to an increase in the density of a crystal lattice since it involves the creation of a vacancy and an interstitial pair.

28. **Answer:** c) 4

Explanation: The unit cell of a face-centred cubic (FCC) lattice consists of 4 atoms or ions, one at each corner and one in the centre of each face.

29. **Answer:** b) Amorphous solid

Explanation: Amorphous solids have a random arrangement of particles with short-range order, lacking the long-range order characteristic of crystalline solids.

30. **Answer:** a) 26%

Explanation: The packing efficiency of a simple cubic lattice is approximately 26%, as only 26% of the total volume is occupied by particles.

31. **Answer:** b) Graphite

Explanation: Graphite is a covalent network solid composed of layered carbon atoms held together by weak van der Waals forces.

32. **Answer:** c) Vacancy defect

Explanation: Vacancy defect occurs when an atom or ion is missing from its lattice site, resulting in a vacant site within the crystal lattice.

33. **Answer:** d) Molecular solid

Explanation: Molecular solids have weak van der Waals forces between particles, resulting in low melting points and poor electrical conductivity.

34. **Answer:** b) 2

Explanation: The unit cell of a hexagonal close-packed (HCP) lattice consists of 2 atoms or ions, one at each base of the hexagonal prism.

35. **Answer:** a) Ionic solid

Explanation: Ionic solids have a definite melting point and are hard and brittle due to the strong electrostatic forces between ions.

36. **Answer:** a) Frenkel defect

Explanation: Frenkel defect involves the simultaneous occurrence of a cation vacancy and an interstitial cation within the crystal lattice.

37. **Answer:** a) Crystalline solid

Explanation: Crystalline solids have a highly regular arrangement of particles with long-range order, resulting in well-defined crystal structures.

38. **Answer:** b) Diamond

Explanation: Diamond is a covalent solid where carbon atoms are covalently bonded in a tetrahedral network, giving it exceptional hardness and thermal conductivity.

39. **Answer:** d) 12

Explanation: In a cubic close-packed (CCP) lattice, each particle has 12 nearest neighbouring particles or a coordination number of 12.

40. **Answer:** d) Molecular solid

Explanation: Molecular solids consist of discrete molecules held together by weak intermolecular forces, resulting in low melting points and poor electrical conductivity.



41. **Answer:** b) Monoclinic

Explanation: The given unit cell has all angles ( $\alpha$ ,  $\beta$ ,  $\gamma$ ) equal to  $90^\circ$ , which suggests it could be either cubic or monoclinic. However, the condition  $a=b \neq c$  indicates that two edges are equal while the third one is different, which is a characteristic of a monoclinic unit cell.

42. **Answer:** b)  $7.43 \text{ gcm}^{-3}$

Explanation: For a face-centred cubic (fcc) unit cell, there are 4 atoms per unit cell. The volume of the unit cell can be calculated as  $(\text{edge length})^3$ . Then, the density can be calculated using the formula:  $\text{Density} = \frac{(\text{Atomic mass} \times \text{Number of atoms})}{\text{Volume}}$ . Plugging in the values, we get:

$$\begin{aligned}\text{Density} &= \frac{(80 \times 4)}{(500 \text{ pm})^3} \\ &= 7.43 \text{ gcm}^{-3}.\end{aligned}$$

43. **Answer:** b) Hexagonal

Explanation: The given values of  $a=b=c$  and  $\alpha=\beta=\gamma=120^\circ$  describe a crystal system with hexagonal symmetry.

44. **Answer:** d) 6

Explanation: A cubic cell can have atoms only at its corners. Each corner atom is shared among eight neighbouring unit cells. Hence, the effective contribution of each corner atom to a unit cell is  $1/8$ . Since there is only one corner atom in a cubic cell, the total number of atoms ( $n$ ) within the cell is  $1 \times \frac{1}{8} = \frac{1}{8}$ . However, since atoms are present at both ends of the unit cell in each dimension ( $x$ ,  $y$ , and  $z$ ), the total number of atoms in the cubic cell is  $\frac{1}{8} \times 8 = 1$ .

45. **Answer:** a) 1 K

Explanation: Diamagnetism is a property exhibited by all substances, where they generate a weak magnetic field in the opposite direction to an applied magnetic field. This weak repulsion is due to the orbital motion of electrons in atoms. At low temperatures, typically below 1 Kelvin (1 K), the thermal energy is low, and the diamagnetic effect becomes more pronounced. Therefore, all substances become diamagnetic at temperatures close to absolute zero, around 1 Kelvin.

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46. **Answer:** b) 350 K

Explanation: Ferrimagnetic materials exhibit spontaneous magnetization and have a non-zero net magnetic moment due to unequal alignment of magnetic moments in the material. As the temperature increases, thermal energy disrupts the magnetic order, and the material transitions to a paramagnetic state. Paramagnetic materials have individual atomic magnetic moments that align with an applied magnetic field but do not exhibit a net magnetic moment when the field is removed. The transition temperature for ferrimagnetic to paramagnetic behaviour typically occurs around 350 K.

47. **Answer:** c) Orthorhombic symmetry

Explanation: Minerals can exhibit different crystal symmetries based on their atomic arrangement. Orthorhombic symmetry is characterized by three mutually perpendicular axes of different lengths. The angles between these axes are 90 degrees. This type of symmetry is commonly observed in various minerals.

48. **Answer:** a)  $V_2O_5$

Explanation: Among the given options,  $V_2O_5$  is known to be an electrical insulator. Electrical insulators are materials that do not conduct electricity well.  $V_2O_5$  is a vanadium oxide and is used in various applications, including as an insulating material in electronic devices.

49. **Answer:** d) Hexagonal close packing

Explanation: The arrangement ABAB... is known as the hexagonal close packing (HCP) structure. In this packing arrangement, each sphere is surrounded by six other spheres, forming a hexagonal pattern in one layer, and the next layer is placed in an ABAB... sequence. HCP is one of the most efficient ways to pack spheres together with maximum density.

50. **Answer:** c) NaCl molecules

Explanation: Sodium chloride, commonly known as table salt, is an ionic compound composed of  $Na^+$  cations and  $Cl^-$  anions. In the crystal lattice of NaCl, the sodium cations and chloride anions are arranged in a three-dimensional alternating pattern, forming a repeating unit of NaCl. Therefore, the lattice points of the NaCl crystal are occupied by  $Na^+$  cations and  $Cl^-$  anions.

51. **Answer:** c)  $26.85 \times 10^{23}$

Explanation: In a body-centered cubic (bcc) structure, there are 2 atoms per unit cell.

So, the total number of atoms in the given unit cells is  $8.95 \times 10^{23} \times 2 = 17.9 \times 10^{23}$ .

52. **Answer:** b)  $3.52 \times 10^{-23} \text{ cm}^3$

Explanation: The volume of a bcc unit cell can be calculated using the formula  $V = a^3$ , where 'a' is the edge length.

Converting  $2.48 \text{ \AA}$  to cm ( $1 \text{ \AA} = 1 \times 10^{-8} \text{ cm}$ ), we get 'a' as  $2.48 \times 10^{-8} \text{ cm}$ .

Now,  $V = (2.48 \times 10^{-8} \text{ cm})^3 \approx 3.52 \times 10^{-23} \text{ cm}^3$

53. **Answer:** b) 285 pm

Explanation: In a face-centered cubic (fcc) structure, the edge length is related to the atomic radii. For an fcc structure with cations and anions, the edge length 'a' is given by

$$a = 2 (\text{radius of cation} + \text{radius of anion}).$$

Rearranging the formula,

$$\begin{aligned} \text{The radius of the anion} &= \left(\frac{a}{2}\right) - \text{radius of cation} = \left(\frac{460 \text{ pm}}{2}\right) - 95 \text{ pm} \\ &= 230 \text{ pm} - 95 \text{ pm} = 135 \text{ pm}. \end{aligned}$$

Since the radius of the anion is half of the distance between the centers of two adjacent anions, the diameter of the anion is  $2 \times 135 \text{ pm} = 270 \text{ pm}$ .

Therefore, the radius of the anion is  $\frac{270 \text{ pm}}{2} = 285 \text{ pm}$ .

54. **Answer:** b) 0.331 to 0.452

Explanation: In an ionic compound with a tetrahedral structure, the ratio of cation radius ( $r_+$ ) to anion radius ( $r_-$ ) typically lies in the range of 0.331 to 0.452.

55. **Answer:** c)  $5.0 \text{ \AA}$

Explanation: In a face-centered cubic (fcc) structure, the edge length of the unit cell 'a' is related to the density ( $\rho$ ) using the formula:  $\rho = \frac{4 \text{ mass of one atom}}{a^3}$ .

Solving for 'a', we get  $a = \left(\frac{4 \text{ mass of one atom}}{\rho}\right)^{1/3}$ .

Given that the density is  $5 \text{ g cm}^{-3}$  and the mass of a copper atom is approximately  $63.5 \text{ g/mol}$ , the mass of one atom is approximately  $1.06 \times 10^{-22} \text{ g}$ . Substituting these values into the formula, we get  $a \approx 5.0 \text{ \AA}$ .



56. **Answer:** b) 3

Explanation: For an orthorhombic unit cell, the number of formula units per unit cell is determined by the ratio of the unit cell volume to the volume occupied by one formula unit. The unit cell volume is given by  $V = a \times b \times c$ , where a, b, and c are the lengths of the unit cell edges. The volume occupied by one formula unit is equal to the molecular mass divided by the density. Given the values of a, b, c, molecular mass, and density, we can calculate the unit cell volume and the volume occupied by one formula unit. Then, we can find the ratio and round it to the nearest whole number to determine the number of formula units per unit cell.

57. **Answer:** c)  $3 \times 10^{24}$

Explanation: The number of unit cells in 200 g of metal can be calculated using the formula:  $\text{Number of unit cells} = \frac{\text{mass of metal}}{\text{mass of one unit cell}}$

The mass of one unit cell can be obtained by calculating the volume of the unit cell ( $V = a^3$ ) and then multiplying it by the density. Since we have the edge length 'a' and density, we can find the number of unit cells.

58. **Answer:** b)  $800 \text{ kg m}^3$

Explanation: The density of a bcc structure can be calculated using the formula:

$$\text{Density} = \frac{\text{mass of one atom}}{\text{volume of one atom}}$$

Since the atomic weight of potassium is 40 g/mol, the mass of one atom is  $40 \text{ g} / \text{Avogadro's number}$ . The volume of one atom can be approximated as  $\frac{4}{3}\pi(\text{radius of atom})^3$ . Given the nearest neighbor distance (edge length of the unit cell 'a'), we can calculate the radius of the potassium atom and then find its volume.

59. **Answer:** c)  $2.0 \text{ \AA}$

Explanation: In a body-centered cubic (bcc) structure, the edge length 'a' is related to the atomic radius 'r' using the formula:  $a = \frac{4r}{\sqrt{3}}$ . Rearranging the formula, we get the atomic radius ' $r$ ' =  $\frac{a\sqrt{3}}{4}$ . Given the edge length 'a' as  $3 \text{ \AA}$ , we can calculate the atomic radius of lithium.

60. **Answer:** b)  $8.0 \text{ g cm}^{-30}$

Explanation: The density of an fcc structure can be calculated using the formula:

$$\text{Density} = \frac{\text{mass of one atom}}{\text{volume of one atom}}$$

Since we have the edge length 'a', we can calculate the volume of one atom ( $V = a^3$ ) and then find its mass based on the atomic mass of the element.