The Solid State

Chapter at a Glance

Solid: In a solid atoms/molecules are strongly bound. Solids are held together by strong cohesive forces and cannot move randomly, thus a well ordered molecular arrangement is found.

Characteristics of Solids:

(a) Definite shape and are rigid.
(b) High density and low compressibility.
(c) Definite volume and diffusion is very slow.

There are two types of solids: Crystalline and Amorphous solids.

Distinction between Crystalline and Amorphous Solids

Crystalline Solids	Amorphous Solids
Geometry: The atoms or molecules are arranged in an orderly three dimensional network so as to give it a definite geometrical shape.	An amorphous solid lacks an orderly or regular arrangement of atoms or molecules. This is due to the nature of short-range binding force of the crystals.
Bond Strength: Bond existing between atoms or molecules have the same strength.	Bonds existing in amorphous solids are not equally strong.
Anisotropy and Isotropy: Crystalline solids are anisotropic, *i.e.*, their physical properties like electrical conductivity, thermal conductivity, refractive index, etc. are different along different directions.	Amorphous solids are isotropic, *i.e.*, their physical properties are same in all directions.
Symmetry: Crystalline solids have crystal symmetry, *i.e.*, when a crystalline solid is rotate about an axis, its appearance does not change.	Amorphous solids do not possess symmetry.

1. The classification of crystalline solids is based on their property. The crystalline property depends on the nature of interactions between the constituent particles and therefore these solids are divided into four different categories:
   (a) Ionic solids
   (b) Covalent or Network solids
   (c) Molecular solids
   (d) Metallic solids
2. **Crystal lattice:** The symmetrical three dimensional arrangements of atoms in a crystal.
3. **Unit cell:** The smallest three dimensional unit of crystal lattice.
4. A lattice can be generated by repeating a small portion called the unit cell. Below are some of the different varieties of the unit cell:
   (a) Primitive Cubic Unit Cell: Atoms touch each other along edges, $r = \frac{a}{2}$.
   (b) Body-centred Cubic Unit Cell: 4 cell atoms touch each other along the body diagonal, $r = \frac{\sqrt{3}a}{4}$.
   (c) Face centred cubic unit cell: Atoms touch each other along the face diagonal, $r = \frac{\sqrt{2}a}{4}$.

5. **Number of atoms in unit cell:**
   (a) Simple cubic – Z = 1
   (b) BCC – Z = 2
   (c) FCC – Z = 4
6. **Coordination number:** The number of spheres which are touching a particular sphere is called its coordination number. For CCP, it is 12 and for BCC, it is 8.
7. Density of unit cell = $\dfrac{\text{mass of unit cell}}{\text{volume of the unit cell}} = \dfrac{\text{m}}{\text{V}} = \dfrac{z \times ma}{a^3} = \dfrac{z \times \text{M}}{a^3 \times \text{N}_\text{A}}$.
8. Packing Efficiency (PE) is the percentage of total space filled by the particles.
   (a) For Simple cubic – (PE) = 52.4%
   (b) For BCC – (PE) = 68%
      (c) For FCC – (PE) = 74%
9. Empty or vacant space present between spheres of a unit cell, is called void or space or hole or interstitial void. When particles are closed packed resulting in either CPP or HCP structure, two types of voids are generated.
10. Tetrahedral voids are holes or voids surrounded by four spheres Present at the corner of a tetrahedron. Coordination number of a tetrahedral void is 4.
11. **Point defects:** Point defects are the irregularities or deviations from ideal arrangement around a point or an atom in a crystalline substance.
12. Point defects can be classified into three types:
   (a) Stoichiometric defect: In this kind of point defect, the ratio of positive and negative ions (Stoichiometric) and electrical neutrality of a solid is not disturbed. Sometimes it is also known as intrinsic or thermodynamic defects. Fundamentally, they are of two types: Vacancy defect and Interstitial defect.
      (i) Frenkel defect: In ionic solids generally, the smaller ion (cation) moves out of its place and occupies an intermolecular space. In this case, a vacancy defect is created on its original position and the interstitial defect is experienced at its new position.
      (ii) Schottky defect: This kind of vacancy defects is found in ionic Solids. But in ionic compounds, we need to balance the electrical neutrality of the compound so an equal number of anions and cations will be missing from the compound. It reduces the density of the substances. In this, the size of cations and anions are of almost the same.
   (b) Non-stoichiometric crystals are those which do not obey the law of constant proportions. The numbers of positive and negative ions present in such compounds are different from those expected from their ideal chemical formulae. However, the crystal as a whole in neutral.
13. When there is an excess of metal ions in non-stiochiometric compounds, the crystal lattice has vacant anion sites. These sites are occupied by electrons. Such sites are called **F-centres**.
14. Based on their electrical conductivity, solids are classified as:
   (a) Conductors
   (b) Insulators
(c) Semi-conductors
15. Pure substances that show conducting behaviour like that of silicon and germanium are called intrinsic semiconductors.
16. When solid substances are placed in a magnetic field, they do not show the same behaviour. Depending on their response to magnetic field, the substances are classified as:
   (a) Diamagnetic substances:
      (i) These substances are weakly repelled by a magnetic field.
      (ii) The electrons are paired.
   (b) Paramagnetic substances:
      (i) These substances are weakly attracted by the magnetic field.
      (ii) These substances have permanent magnetic dipoles due to die presence of atoms, molecules or ions containing unpaired electrons.

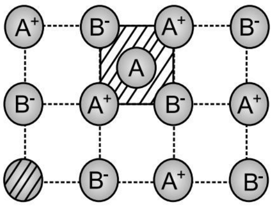
- **(c) Ferromagnetic Substances:** These are attracted by the magnetic field and show permanent magnetism even in the absence of magnetic field *e.g.*, Fe, Co and Ni.
- **(d) Anti-ferromagnetic Substances:** These substances have net magnetic moment zero due to compensatory alignment of magnetic moments, *e.g.*, MnO, MnO_2, FeO, etc.
- **(e) Ferrimagnetic Substances:** These substances have a net dipole moment due to unequal parallel and anti-parallel alignment of magnetic moments, *e.g.*, Fe_3O_4, ferrites, etc.

Multiple choice questions

1. In a crystal, the atoms are located at the position of:

(a) Maximum potential energy
(b) Minimum potential energy
(c) Zero Potential energy
(d) Infinite potential energy

2. The crystal showing Frenkel defect is:

(a)


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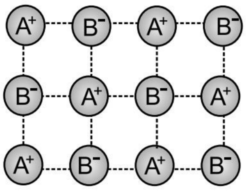

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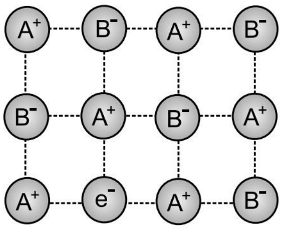

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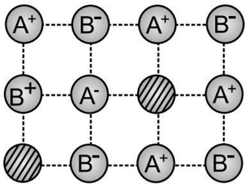


3. In a face centered cubic lattice, atom (A) occupies the corner positions and atom (B) occupies the face centre positions. If one atom of (B) is missing from one of the face centered points, the formula of the compound is :

(a) A_2B_5 (b) A_2B_3
(c) AB_2 (d) A_2B

4. Copper has the face centred cubic structure. The coordination number of each ion is:

(a) 4 (b) 12
(c) 14 (d) 8

5. Schottky defect in crystal is observed when :

(a) An ion leaves its normal site and occupies the interstitial site.
(b) Equal number of cations and anions are missing from the lattice.
(c) Unequal number of cations and anions are missing from the lattice.
(d) Density of the crystal is increased.

6. Crystalline solids are anisotropic in nature. What is the meaning of anisotropic in the given statement?

(a) A regular pattern of arrangement of particles which repeats itself periodically over the entire crystal.
(b) Different values of some of physical properties are shown when measured along different directions in the same crystals.
(c) An irregular arrangement of particles over the entire crystal.
(d) Same values of some of physical properties are shown when measured along different directions in the same crystals.

7. Piezoelectric crystals are used in :

(a) Radio (b) T.V.
(c) Record player (d) Refrigerator

8. Cubic close packing arrangement is also known as :

(a) Hexagonal close packing
(b) Face centered cubic
(c) Body centered cubic
(d) None of these

9. Which of the following is an example of paramagnetic solid?

(a) NaCl (b) KF
(c) TiO2 (d) CuO

10. Crystals show colour due to the presence of:

(a) F-centres (b) Y-centres
(c) Defects (d) None of these

11. Which one of the following is non-crystalline or amorphous?

(a) Diamond (b) Graphite
(c) Glass (d) Common Salt

12. In NaCl structure, Na^+ ions occupies:

(a) All octahedral and tetrahedral sites are occupied
(b) Only octahedral sites are occupied
(c) Only tetrahedral sites are occupied
(d) Neither octahedral nor tetrahedral sites are occupied

13. Edge length of unit cell of chromium metal is 287 pm with bcc arrangement. The atomic radius is of the order:

(a) 287 pm (b) 574 pm
(c) 124.27 pm (d) 143.5 pm

14. The density of a metal which crystallises in bcc lattice with unit cell edge length 300 pm and molar mass 50 g mol^{-1} will be:

(a) 10 g cm^{-3} (b) 14.2 g cm^{-3}
(c) 6.15 g cm^{-3} (d) 9.3 2 g cm^{-3}

15. What is the effect of Frenkel defect on the density of ionic solids?

(a) The density of the crystal increases
(b) The density of the crystal decreases
(c) The density of the crystal remains unchanged
(d) There is no relationship between density of a crystal and defect present in it

16. To get n-type of semiconductor, germanium should be doped with:

(a) Gallium (b) Arsenic
(c) Aluminium (d) Boron

17. *p*-type semi-conductors are formed when Si or Ge are doped with:

(a) Group 14 elements (b) Group 15 elements
(c) Group 13 elements (d) Group 18 elements

18. Which of the following statement is not true about amorphous solids ?

(a) On heating they may become crystalline at certain temperature.
(b) They may become crystalline on keeping for long time.
(c) Amorphous solids can be moulded by heating.
(d) They are anisotropic in nature.

19. Which of the following arrangements shows schematic alignment of magnetic moments of anti-ferromagnetic substances?

(a) ↑↑↑↑↑↑
(b) ↓↓↓↓↓↓
(c) ↑↑↓↑↑↓
(d) ↑↓↑↓↑↓

20. The relationship between atomic radius (*r*) and the edge length '*a*' of a body centred cubic unit cell is:

(a) $r = \frac{a}{2}$ (b) $r = \sqrt{\frac{a}{2}}$
(c) $r = \frac{\sqrt{3}}{4}a$ (d) $r = \frac{3a}{2}$

21. Na and Mg crystallise in bcc and fcc structures respectively. The value of Z (number of atoms) for their crystals is:

(a) 8 and 14 (b) 2 and 4
(c) 14 and 8 (d) 6 and 4

22. Which type of defect has the presence of cations in the interstitial sites?

(a) Schottky defect
(b) Vacancy defect
(c) Frenkel defect
(d) Metal deficiency defect

23. The vacant space in body centred cubic lattice unit cell is:

(a) 32% (b) 26%
(c) 48% (d) 68%

Formula based questions

24. A compound formed by elements A and B has a cubic structure in which A atoms are at the corners of cube and B atoms are at the face centres. The formula of the compound will be:

(a) A_2B_4 (b) AB_3
(c) AB_5 (d) A_2B_6

25. A solid is made up of two elements X and Y. Atoms of Y are in ccp arrangement while atoms of X occupy all the tetrahedral sites. The formula of the compound will be:

(a) X_2Y_4 (b) XY_3
(c) X_3Y (d) X_2Y

26. An ionic compound is made up of A cations and B anions. If A cations are present at the alternate corners and B anion is present at the diagonal, the formula of the ionic compound will be:

(a) A_2B_4 (b) AB_3
(c) AB_2 (d) A_2B

27. An alloy of gold (Au) and cadmium (Cd) crystallises with a cubic structure in which gold atoms occupy the corners and cadmium atoms fit into the face centres. What is the formula of this alloy?

28. A solid with cubic crystal is made of two elements P and Q. Atoms of Q are at the corners of the cube and P at the body-centre. The formula of the compound will be:

(a) PQ_4 (b) PQ

(c) PQ_2 (d) PQ_3

Fill in the blanks

29. Glass is an example of .... solid. The coordination number of atoms in a body-centred cubic structure is ....

(a) Amorphous, 8 (b) Crystalline, 4

(c) Stoichiometric, 8 (d) Amorphous, 4

30. Of the three cubic lattices the one that has the largest amount of empty space is the .... Crystals of .... and .... have face centered cubic lattices

(a) Body centered cubic, CsCl, NaCl,

(b) Closed cubic, KCl, NaCl

(c) Simple cubic, CsCl, NaCl

(d) Face centered cubic, KBr, NaCl

31. In rock-salt structure .... percent of the octahedral voids are occupied by cations. In bcc arrangement of atoms .... percent of the available space is occupied by atoms.

(a) 68, 72 (b) 100, 68

(c) 100, 78 (d) 100, 89

32. An atom at the corner of a unit cell makes .... contribution to a particular unit cell. If the radius ratio r^+/r^- is 0·325, the cation would most probably be present in a/an .... void.

(a) 1/4, Octahedral (b) 2/8, Square Planar

(c) 1/6 , Tetrahedral (d) 1/8, Tetrahedral

33. When the anionic sites of a crystal are occupied by unpaired electrons, the ionic sites are called………… In diamond inter-particle forces are ....

(a) F-centres, covalent bonds

(b) F-centres, ionic bonds

(c) Cationic, ionic bonds

(d) Anionic , covalent bonds

34. ………… is obtained when silicon is doped with boron. …………..is produced when AgCl is doped with $CdCl_2$.

(a) *n*-type semiconductor, frenkel defect

(b) *p*-type semiconductor, schottky defect

(c) *p*-type semiconductor, impurity defect

(d) *n*-type semiconductor, schottky defect

35. ……………….. observed in ionic crystals which large difference in the size of ions. The substances that are strongly attracted by a magnetic field are called …………… .

(a) Frenkel defect, ferromagnetic substances

(b) Impurity defect, anti-ferromagnetic substances

(c) Frenkel defect, paramagnetic substances

(d) Schottky defect, paramagnetic substances

36. The ability of certain materials to generate an electrical potential when they are heated or cooled is called as ……………… The materials or substances which resist or don't allow the current to flow through them are called as ………………

(a) Piezolectricity, conductors

(b) Pyroelectricity, conductors

(c) Piezolectricity, semi-conductors

(d) Pyroelectricity, insulators

37. A form of magnetism in which the magnetic moments of neighbouring atoms are arranged anti-parallel is called as …………………. In anti-fluoride structure, cations are present in .... voids

(a) Dimagnetism, octahedral

(b) Anti-ferromagnetism, tetrahedral

(c) Paramagnetism, octahedral

(d) Paramagnetism, tetrahedral

38. In ccp arrangement of atoms .... percent of the available space remains vacant. In hcp arrangement of spheres, the coordination number is ....

(a) 26, 8 (b) 26, 10

(c) 26, 12 (d) 36, 8

Match the following

39. Match the items of column A to those given in column B.

Column A	Column B
1. Colour in crystals	(p) Tetrahedral arrangement of atoms
2. Diamond	(q) centre
3. Hexagonal close packing	(r) Coordination number of 8
4. CsCl crystal	(s) bcc
5. 68% occupancy of space	(t) ABAB type of close packing
6. Metallic crystal	(u) Diamond
7. Covalent crystal	(v) Malleable and ductile

(a) 1-(q), 2-(p), 3-(t), 4-(r), 5-(s), 6-(v), 7-(u)

(b) 1-(p), 2-(q), 3-(s), 4-(r), 5-(t), 6-(u), 7-(v)
(c) 1-(v), 2-(s), 3-(u), 4-(p), 5-(r), 6-(q), 7-(t)
(d) 1-(r), 2-(u), 3-(t), 4-(q), 5-(v), 6-(s), 7-(p)

Numerical based questions

40. A compound AB has a simple cubic structure and has molecular mass 99. Its density is 3.4 g cm^{-3}. What will be the edge of the unit cell ?

(a) 3.6×10^{-8} cm (b) 4.2×10^{-6} cm
(c) 3.8×10^{-8} cm (d) 4.6×10^{-6} cm

41. An element has atomic weight 93 g mol^{-1} and density 11.5 g cm^{-3}. It the edge length of its unit cell is 300 pm, identify the type of unit cell.
(NA = 6.023×10^{23} mol^{-1})

(a) 4 (b) 1
(c) 2 (d) 5

42. An element with density 2.8 g cm^{-3} forms a fee unit cell with edge length 4×10^{-8} cm. Calculate the molar mass of the element.
(**Given:** $N_A = 6.022 \times 10^{23}$ mol^{-1}).

(a) 42 g mol^{-1} (b) 27 g mol^{-1}
(c) 36 g mol^{-1} (d) 28 g mol^{-1}

43. An element occurs in bcc structure. It has a cell edge length of 250 pm. Calculate the molar mass if its density is 8.0 g cm^{-3}. Also calculate the radius of an atom of this element.

(a) 109.25pm (b) 108. 27 pm
(c) 208.24pm (d) 108.25 pm

44. A bcc element (atomic mass 65) has a cell edge of 420 pm. Calculate its density in g/cm^3.

(a) 2.25 g cm^{-3} (b) 2.97 g cm^{-3}
(c) 2.84 g cm^{-3} (d) 2.91 g cm^{-3}

45. Aluminium crystallises in a cubic close-packed structure. Radius of the atom in the metal is 125 pm.

(i) What is the length of the side of the unit cell?
(ii) How many unit cells are there in 1 cm^3 of aluminium?

(a) 354 pm, 2.254×10^{22} unit cells
(b) 254 pm, 3.254×10^{22} unit cells
(c) 454 pm, 4.254×10^{22} unit cells
(d) 654 pm, 5.254×10^{22} unit cells

46. An element A crystallizes in fcc structure, 208 g of it has 4.2832×10^{24} atoms. Calculate the edge length of the unit cell if density of A is 7.2 g cm^{-3}.

(a) 2×10^{-8} cm (b) 4.3×10^{-8} cm
(c) 5.2×10^{-8} cm (d) 3×10^{-8} cm

47. Calculate the efficiency of packing in case of metal crystal for simple cubic (with the assumption that atoms are touching each other.

(a) 52.4% (b) 62.4%
(c) 54.4% (d) 72.4%

48. An element crystallizes in a structure having fee unit cell of an edge 200 pm. Calculate the density if 200 g of this element contains 24×10^{23} atoms.

(a) 42.66 g/cm^3 (b) 41.66 g/cm^3
(c) 43.66 g/cm^3 (d) 44.66 g/cm^3

49. Calculate the packing efficiency of bcc structure.

(a) 88% (b) 78%
(c) 68% (d) 58 %

50. Gold has cubic crystal whose unit cell has an edge length of 407.9 pm. Density of gold is 19.3 g cm^{-3}. Atomic weight of gold is 197 g mol^{-1}. ($N_A = 6.02 \times 10^{23}$ mol^{-1})

(i) The number of atoms (Z) in a unit cell of gold is :

(a) 1 (b) 2
(c) 3 (d) 4

(ii) The type of crystal structure of gold is :

(a) Simple cubic unit cell
(b) Body centred cubic unit cell
(c) Face centred cubic unit cell
(d) Side centred cubic unit cell

51. A metal has face centred cubic lattice. The edge length of the unit cell is 404 pm. The density of the metal is 2.72 g/cm^3. ($N_A = 6.023 \times 10^{23}$ mol^{-3})

(i) The molar mass of the metal is :

(a) 20 g mol^{-1} (b) 27 g mol^{-1}
(c) 30 g mol^{-1} (d) 40 g mol^{-1}

Structure based questions

52. Examine the given defected crystal

A^+ B^- A^+ B^- A^+
B^- O B^- A^+ B^-
A^+ B^- A^+ O A^+
B^- A^+ B^- A^+ B^-

Answer the following questions :

(i) What type of stoichiometric defect is shown in the crystal ?

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

(iii) What type of ionic substance show such defect ?

(a) Schottky defect, decreases, NaCl and KCl etc

(b) Frenkel defect, increases, As and Si etc

(c) Schottky defect, increases, As and Bi etc

(d) Frenkel defect, decreases, NaCl, KCl etc

53. Examine the given defective crystal :

$X^+ \quad Y^- \quad X^+ \quad Y^- \quad X^+$
$Y^- \quad X^+ \quad Y^- \quad X^+ \quad Y^-$
$X^+ \quad Y^- \quad X^+ \quad e^- \quad X^+$
$Y^- \quad X^+ \quad Y^- \quad X^+ \quad Y^-$

Answer the following questions :

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

(ii) Write the term used for the electron occupied site.

(iii) Give an example of the compound which shows this type of defect.

(a) Stoichiometric, F-centre, KBr

(b) Non-stoichiometric, holes, NaCl

(c) Non-stoichiometric, F-centre, LiCl

(d) Stoichiometric, holes, KCl

Assertion-Reason based questions

Directions: In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as:

(a) If both assertion and reason are true and reason is the correct explanation of assertion.

(b) If both assertion and reason are true, but reason is not the correct explanation of assertion.

(c) If assertion is true, but reason is false.

(d) If both assertion and reason are false

54. Assertion: Quartz glass is crystalline solid and quartz is an amorphous solid.

Reason: Quartz glass has long range order.

55. Assertion: Graphite is a good conductor of electricity however diamond belongs to the category of insulators.

Reason: Graphite is soft in nature on the other hand diamond is very hard and brittle.

56. Assertion: In crystalline solids, the value of resistance is diffierent in different directions.

Reason: Crystalline solids are isotropic in nature.

57. Assertion: Glass panes fixed to windows or panes of old buildings are found to be slightly thicker at the bottom.

Reason: Amorphous solids have a tendency to flow.

58. Assertion: Face-centred cubic cell has four atoms per unit cell.

Reason: In *fcc* unit, there are eight atoms at the corner and six atoms at face centers.

59. Assertion: CsCl has body centred cubic arrangement.

Reason: CsCl has one Cs^+ ion and eight Cl^- ions in its unit cell.

60. Assertion: In crystal lattice, the size of the tetrahedral hole is large than an octahedral hole.

Reason: The cations occupy more space than anions in crystal packing.

61. Assertion: On heating ferromagnetic or ferrimagnetic substances, they become paramagnetic.

Reason: The electrons change their spin on heating.

62. Assertion: The total number of atoms present in a simple cubic unit cell is one.

Reason: Simple cubic unit cell has atoms at its corners, each of which is shared between eight adjacent unit cells.

63. Assertion: The packing efficiency is maximum for the fcc structure.

Reason: The coordination number is 12 in *fcc* structures.

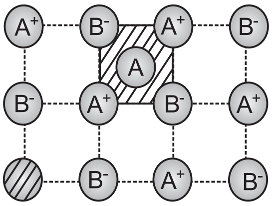
Answers

Multiple choice questions

1. (b) Minimum potential energy

Explanation: In a crystal, the atoms are located at the position of minimum potential energy in order to attain greater stability. An equilibrium exist between attractive and repulsive forces between the atoms for greater stability. When two atoms approach each other in a crystal, the potential energy decreases gradually in order to attain higher stability.

2. (a)



Explanation: A Frenkel defect is a point defect which is created when an atom or cation leaves its original place in the lattice structure to create a vacancy while occupying another interstitial position within the solid crystal. Hence, out of the given four lattice structure, (a) is showing the Frenkel defect.

3. (a) A_2B_5

Explanation:

Number of atoms of 'A' = $8 \times \frac{1}{8} = 1$

Number of atoms of 'B' = $5 \times \frac{1}{2} = \frac{5}{2}$

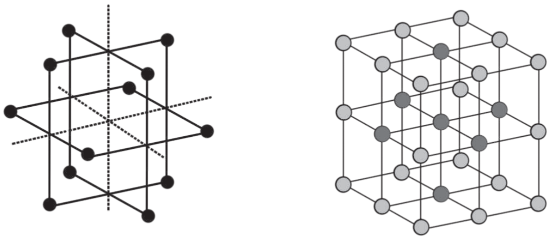
$A + B = 1 \times \frac{5}{2} = 2:5$

formula of the solid = A_2B_5

4. (b) 12

Explanation: The copper ion shows the structural arrangement of a face-centered cubic structure and any atom present in *fcc* lattice touches 12 other atoms. Therefore, the coordination number of each ion in *fcc* structure of copper is 12.

FCC : Coordination number



FCC

Coordination number = 12

3 mutually perpendicular planes.

4 nearest neighbours on each of the three planes.

5. (b) Equal number of cations and anions are missing from the lattice.

Explanation: In Schottky defect, equal number of cations and anions are missing from the lattice and due to this defect, density of crystal decreases.

6. (b) Different values of some of physical properties are shown when measured along different directions in the same crystals.

Explanation: Crystalline solids are anisotropic in nature *i.e.,* some of their physical properties like electrical resistance or refractive index show different values when measured along different directions in the same crystals.

7. (c) Record player

Explanation: Piezoelectric crystals are used in record player. They are used as pickups in record players where they produce electrical signals due to application of the pressure.

8. (b) Face centered cubic

Explanation: Cubic close packing arrangement or ccp is also known as Face centred cubic. In the face-centred cubic (fcc), or cubic-closest-packed lattice, there are points at all the corners as well as at the centre of each of the six faces.

9. (d) CuO

Explanation: NaCl cannot be paramagnetic as in Na^+ & Cl^- all the electrons are paired. TiO_2 cannot be paramagnetic because in TiO_2, Ti^{+4} is in d° configuration. KF cannot be paramagnetic as in K^+ & F^- all the electrons are paired.

On the other hand, in CuO, Cu^{+2} is in d^9 electronic configuration and hence CuO has unpaired electron and it is paramagnetic in nature.

10. (a) F-centres

Explanation: F-centres are the anionic sites occupied by unpaired electrons. Such defects also imparts colour to the crystal. When light from the visible region falls on the crystal with F-centres, the unpaired electrons gets excited and the crystals appear coloured. Some of the examples of crystals with F-centres are:

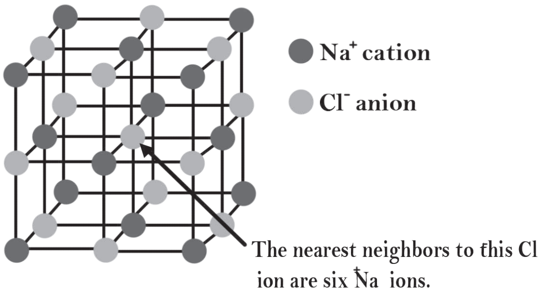
1. KCl impart violet colour
2. NaCl impart yellow colour
3. HCl impart pink colour

11. (c) Glass

Explanation: Amorphous solids display isotropism which is a property whereby a substance exhibits an equal or uniform interaction in all directions. Out of the given options, glass is an amorphous solid (also known as a pseudo solid) whereas diamond, graphite and common salt are crystalline solids.

12. (b) Only octahedral sites are occupied

Explanation: NaCl has fcc structure with Cl^- occupies all corner and face-centered **sites** and Na^+ occupies all **octahedral sites**



13. (c) 124.27 pm

Explanation:

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

$$r = \frac{\sqrt{3}}{4} \times 287$$

$$r = 124.27 \text{ pm.}$$

Hence, the atomic radius is of the order 124.27 pm

14. (c) 6.15 g cm^{-3}

Explanation: Given for bcc in $n = 2$; $a = 300 \times 10^{-10}$ cm, M = 50 g

$$\therefore \quad \rho = \frac{2 \times 50}{6.022 \times 10^{23} \times (300)^3 \times (10^{-10})^3}$$

$$= 6.15 \text{ g/cm}^3$$

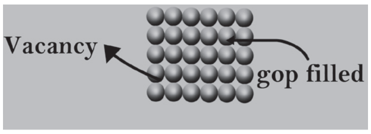
Hence, the density of metal will be 6.15 g cm^{-3}

15. (c) The density of the crystal remains unchanged

Explanation: In Frenkel defect, ions get displaced from their original position and move to interstitial sites. Hence, there is no change in the density of the crystal.

Frenkel defect

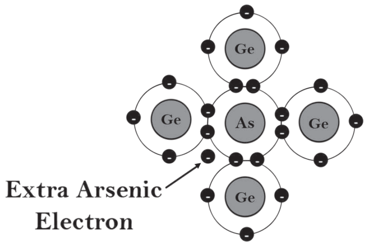
The density of the crystal does not change



16. (b) Arsenic

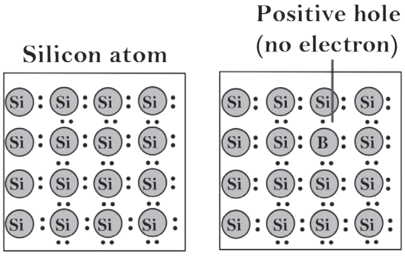
Explanation: In n-type semiconductors, the extra band named as the donor band (will lead to excess of electrons available for excitation) is added in the between the conduction and valence band. This makes it easy for the excitation of an electron from the donor band to the conduction band. To create a donor band, germanium should be doped with group 15 elements as it will lead to excess of electrons. Thus, arsenic is the only element that belongs to group 15. Hence, germanium should be doped with arsenic to get n-type semiconductor.

Germanium with Arsenic Doping



17. (c) Group 13 elements

Explanation: The extrinsic p-Types semiconductor is formed when a trivalent impurity is added to a pure semiconductor in a small amount, and as a result, a large number of holes are created in it. This hole is the carrier of a p-type semiconductor. A p - type of semiconductor is generated when a crystal of group 14 elements such as Si or Ge is doped with a group 13 element such as B, Al, or Ga which contains only three valence electrons.



18. (d) They are anisotropic in nature.

Explanation: Amorphous solids are isotropic in nature because they show thermal and optical properties same in all directions. Hence, the statement which is not true about amorphous solids is that they are anisotropic in nature.

19. (d) (↑)(↓)(↑)(↓)(↑)(↓)

Explanation: In anti-ferromagnetic substances, their domains are oppositely oriented and cancel out each other's magnetic moment.

20. (c) $r = \frac{\sqrt{3}}{4}a$

Explanation: In bcc : The atoms at the body diagonal touch each other.

So, $\sqrt{3a} = 4r$

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

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

21. (b) 2 and 4

Explanation: The bcc cell consists of 8 atoms at the corners and one atom at center.

Number of atoms (n) = $\left(8 \times \frac{1}{8}\right) + 1 = 2.$

The fcc cell consists of 8 atoms at the eight corners and one atom at each of the six faces. This atom at the face is shared by two unit cells.

$\therefore$ Number of atoms (n) = $8 \times \frac{1}{8} + \left(6 \times \frac{1}{2}\right) = 4$

22. (c) Frenkel defect

Explanation: A frenkel defect arises when an ion of an ionic compound is missing from its regular lattice site and occupies an interstitial position between the lattice points . This defect is found in ionic crystals like ZnS, AgCl, AgBr and AgI.

23. (a) 32%

Explanation: Packing fraction of bcc unit cell is 68%. Therefore, the vacant space in bcc unit cell is 32%.

Formula based questions

24. (b) AB_3

Explanation: No. of A atoms per unit cell = 8 (at corner) × 18 = 1

Number of B atoms per unit cell = 6 (at the face centre) × 12 = 3

A : B = 1 : 3

The formula of compound is AB_3.

25. (d) X_2Y

Explanation: Let the number of atoms of Y in ccp arrangement = N

So, number of tetrahedral sites = 2N

Therefore, number of X atoms = 2N

X : Y = 2N : N

Hence, the formula of compound is = X_2Y

26. (c) AB_2

Explanation: No. of A cations at alternate corners = 4 (at alternate corner) × 18 = 12

No. of B atoms at the diagonal = 1

A : B = 12 : 1

The formula of the compound is AB_2

27. Gold atoms occupy all the corners of a unit cell, So, the number of gold atoms per unit cell = 8 × 18 = 1 atom.

And cadmium atoms fit into the face centres, therefore, the number of cadmium atoms per unit cell = 6 × 12 = 3 atoms

Ratio of gold (Au) and cadmium (Cd) = 1:3

Hence, formula for the given alloy is $AuCd_3$.

28. (b) PQ

Explanation: As atoms of Q are present at the 8 centres of the cube, therefore, number of atoms of Q in the unit cell = 18 × 8 = 1 The atom P is at the body centre. Therefore, number of atoms = 1 Ratio of atoms P : Q = 1 : 1

Hence, the formula of the compound is PQ.

Fill in the blanks

29. (a) Amorphous, 8

Explanation: Glass is an example of amorphous solid. The coordination number of atoms in a body-centred cubic structure is 8.

30. (c) Simple cubic, CsCl, NaCl

Explanation: Of the three cubic lattices the one that has the largest amount of empty space is the simple cubic. Crystals of CsCl and NaCl have face centered cubic lattices

31. (b) 100, 68

Explanation: In rock-salt structure 100 percent of the octahedral voids are occupied by cations. In bcc arrangement of atoms 68 percent of the available space is occupied by atoms.

32. (d) 1/8, Tetrahedral

Explanation: An atom at the corner of a unit cell makes 1/8 contribution to a particular unit cell. If the radius ratio r^+/r^- is 0·325, the cation would most probably be present in a/an tetrahedral void.

33. (a) F-centres, covalent bonds

Explanation: When the anionic sites of a crystal are occupied by unpaired electrons, the ionic sites are called F-centres. In diamond inter-particle forces are covalent bonds

34. (c) *p*-type semiconductor, impurity defects

Explanation: *p*-type semiconductor is obtained when silicon is doped with boron. Impurity defects is produced when AgCl is doped with $CdCl_2$.

35. (a) Frenkel defect, Ferromagnetic substances

Explanation: Frenkel defect is observed in ionic crystals which large difference in the size of ions. The substances that are strongly attracted by a magnetic field are called ferromagnetic substances.

36. (d) Pyroelectricity, insulators

Explanation: The ability of certain materials to generate an electrical potential when they are heated or cooled is called as pyroelectricity. The materials or substances which resist or don't allow the current to flow through them are called as insulators.

37. (b) Anti-ferromagnetism, tetrahedral

Explanation: A form of magnetism in which the magnetic moments of neighbouring atoms are arranged anti-parallel is called as anti-ferromagnetism In anti-fluoride structure, cations are present in tetrahedral voids.

38. (c) 26, 12

Explanation: In ccp arrangement of atoms 26 percent of the available space remains vacant. In hcp arrangement of spheres, the coordination number is 12.

Match the following

39. (a) 1-(q), 2-(p), 3-(t), 4-(r), 5-(s), 6-(v), 7-(u)

Explanation: F-centres leads to colour in a crystal. Diamond has tetrahedral arrangement of atoms. Hexagonal close packing is ABAB type of close packing, CsCl has coordination number of 8. Bcc has 68% occupancy of space. Metallic crystals are malleable and ductile. Diamond is a covalent crystal.

Numerical based questions

40. (a) 3.6×10^{-8} cm

Explanation:

Simple cubic structure molecular mass = 99

$$\rho = 3{\cdot}4 \text{ g/ cm}^3$$

Edge length = ?

$$\rho = \frac{Z \times M}{a^3 \times N_A} g/cm^3$$

$$3{\cdot}4 = \frac{1 \times 99}{a^3 \times 6{\cdot}023 \times 10^{23}}$$

$$a^3 = \frac{99}{3{\cdot}4 \times 6{\cdot}023 \times 10^{23}}$$

$$a = 3{\cdot}6 \times 10^{-8} \text{ cm.}$$

41. (c) 2

Explanation:

Given, Atomic weight (M) = 93 g mol^{-1}

Density = 11.5 g cm^{-3}

Edge length (a) = 300 pm = 3×10^{-8} cm

We know that—

$$\text{Density, } d = \frac{(Z \times M)}{N_A \times a^3}$$

Substituting the values –

$$11.5 \text{ g cm}^{-3} = \frac{(93 \text{ g mol}^{-1} \times Z)}{6.023 \times 10^{23} \times (3 \times 10^{-8} \text{ cm})^3}$$

$$\text{Or, } Z = \frac{[11.5 \text{ g cm}^{-3} \times 6.023 \times 10^{23} \times (3 \times 10^{-8} \text{cm})^3]}{93 \text{ g mol}^{-1}}$$

$$Z = 2.01 \approx 2$$

Hence, the number of atoms present in one unit cell is 2 which indicates a body centered cubic system.

42. (c) 27 g mol^{-1}

Explanation: $d = 2.8$ g cm^{-3}, Z = 4 for *fcc*, $a = 4 \times 10^{-8}$ cm, M = ?, $N_A = 6.022 \times 10^{23}$ mol^{-1}

$$\therefore \quad d = \frac{Z \times M}{a^3 \times N_A}$$

$$\Rightarrow M = \frac{d \times a^3 \times N_A}{Z} = \frac{2.8 \times (4 \times 10^{-8})^3 \times 6.022 \times 10^{23}}{4}$$

$$\Rightarrow = 2.8 \times 16 \times 10^{-1} \times 6.022$$

$$\Rightarrow M = \frac{269.78}{10} = 26.978 = 27 \text{ g mol}^{-1}$$

43. (d) 108.25 pm

Explanation:

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

$$\Rightarrow M = \frac{d \times a^3 \times N_A}{Z} = \frac{8.0 \text{ g cm}^{-3} \times (250)^3 \times 10^{-30} \text{ cm}^3 \times 6.023 \times 10^{23}}{2}$$

[In *bcc*, Z = 2]

$$\Rightarrow M = \frac{8 \times 15.625 \times 6.023}{20} = \frac{752.875}{20}$$

$$M = 37.64 \text{ g mol}^{-1}$$

For *bcc*, $4r = \sqrt{3}a$

$$\Rightarrow r = \frac{\sqrt{3}a}{4} = \frac{1.732 \times 250}{4} = 108.25 \text{ pm}$$

44. (d) 2.91 g cm^{-3}

Explanation:

$$\text{Density,} \quad \rho = \frac{Z \times M}{a^3 \times N_A}$$

Given : Z = 2(for bcc arrangement),

M = 65, $a = 420$ pm = 420×10^{-10} cm

$N_A = 6{\cdot}023 \times 10^{23}$

$$\therefore \qquad \rho = \frac{2\times65}{(420\times10^{-10})^3\times6{\cdot}023\times10^{23}}$$

$$= \frac{2\times65\times10^4}{(42)^3\times6{\cdot}023}$$

$$= 2{\cdot}91\ \text{g cm}^{-3}$$

Density of given element is $2{\cdot}91\ \text{g cm}^{-3}$.

45. (a) 354 pm, 2.254×10^{22} unit cells

Explanation:

(i) $r = 125 \times 10^{-12}$ m,

$4r = \sqrt{2}a$

$$\Rightarrow a = \frac{4r}{\sqrt{2}} = r \times 2\sqrt{2} = 125 \times 10^{-12} \times 2\sqrt{2} = 354 \text{ pm}$$

(ii) $a^3 = (354)^3 \times (10^{-12})^3 \text{ m}^3 = 44.36 \times 10^{-30} \text{ m}^3$

Number of unit cells in 1 cm^3.

$$= \frac{\text{Total volume}}{\text{Volume of one unit cell}}$$

$$= \frac{10^{-6}\ \text{m}^3}{44.36\times10^{-30}\ \text{m}^3} = 2.254\times10^{22} \text{ unit cells.}$$

46. (d) 3×10^{-8} cm

Explanation:

Let the edge length of the unit cell = a

$\therefore$ Volume of the unit cell = a^3

$$\text{Mass of an atom of A} = \frac{208}{4{\cdot}2832\times10^{24}}$$

$$= 4{\cdot}856 \times 10 \text{ g}$$

Since in fcc structure, there are 4 atoms per unit cell

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

$$= \frac{4\times\text{Mass of an atom of A}}{a^3}$$

$$7{\cdot}2\ \text{g cm}^{-3} = \frac{4\times(4{\cdot}856\times10^{-23}\ \text{g})}{7{\cdot}2\text{gcm}^{-3}}$$

$$a^3 = \frac{4\times(4{\cdot}856\times10^{-23}\ \text{g})}{7{\cdot}2\text{gcm}^{-3}}$$

$$= 2{\cdot}7 \times 10^{-23}\ \text{cm}^3$$

$$= 27 \times 10^{-24}\ \text{cm}^3$$

$$\therefore \qquad a = 3 \times 10^{-8} \text{ cm.}$$

The edge length of the unit cell = 3×10^{-8} cm.

47. (a) 52.4%

Explanation:

$$\text{Packing efficiency} = \frac{\text{Z}\times\text{Volume of one atom}}{\text{Volume of cubic unit cell}}\times100$$

$$= \frac{2\times\frac{4}{3}\pi r^3}{a^3}\times100$$

For simple cubic lattice,

$$a = 2r \text{ and Z} = 1$$

$$\therefore \text{Packing efficiency} = \frac{1\times\frac{4}{3}\pi r^3}{(2r)^3}\times100$$

$$= \frac{\pi}{6}\times100$$

$$= 52{\cdot}36\% = 52{\cdot}4\%$$

48. (b) $41.66\ \text{g/cm}^3$

Explanation:

24×10^{23} atoms of an element have mass = 200 g

$\therefore$ 6.022×10^{23} atoms of an element have mass

$$= \frac{200}{24\times10^{23}} = 6.022 \times 10^{23} = 50.18 \text{ g}$$

Given $a = 200 \text{ pm} = 200 \times 10^{-12}$ cm.

Z = 4 (For fee), M = 50.18 g

$$\text{Using the formula : } \rho = \frac{\text{Z}\times\text{M}}{a^3\times\text{N}_\text{A}}$$

$$\Rightarrow \rho = \frac{4\times50.18}{(200\times10^{-10})^3\times6.022\times10^{23}}$$

$$\therefore \quad \rho = \frac{200.72}{8\times6.022\times10^{-1}} = \frac{2007.2}{48.176} = 41.66\ \text{g/cm}^3$$

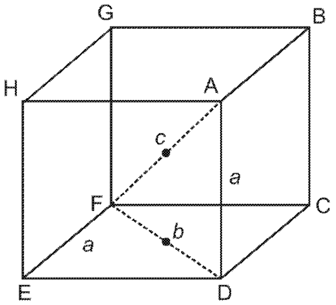
49. (c) 68%

Explanation:

Efficiency of packing in bcc structure : In this case the atom at the centre is in touch with other two atoms which are diagonally arranged. The sphere along the body diagonal are shown with solid boundaries.

In Δ EFD, $\qquad b^2 = a^2 + a^2 = 2a^2$

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



In Δ AFD,

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

$$= 3a^2$$

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

The length of the body diagonal *a* is equal to 4*r*. *r* being the radius of the sphere (atom). As all the three spheres along the diagonal touch each other.

$$a = 4r$$

$$\therefore \quad a = 4r = \sqrt{3a}$$

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

As already calculated the total number of atoms associated with a bcc unit cell is 2, the volume (v) is therefore

$$2 \times \frac{4}{3}\pi r^3 = \frac{8}{3}\pi r^3$$

Volume of the unit cell (V) = a^3

$$= \left(\frac{4r}{\sqrt{3}}\right)^3 = \frac{64r^3}{3\sqrt{3}}$$

Packing efficiency = $\frac{v}{V} \times 100$

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

$$\pi \times 100 = 68\%$$

Therefore, 68% of unit cell is occupied by atoms and the rest 32% is empty space in bcc structure.

50. (i) (d) 4

(ii) (c) Face centred cubic unit cell.

Explanation: Density (ρ) = $\frac{z \times M}{a^3 \times N_0 \times 10^{-30}}$

or $z = \frac{r \times a^3 \times N_0 \times 10^{-30}}{M}$

Density of unit cell (ρ) = 19.3 g cm^{-3}.

Atomic mass of gold (M) = 197 amu = 197 g mol^{-1}

Avogadro's no. (N_0) = 6.022 × 10^{23} mol^{-1}.

Edge length of unit cell (*a*) = 407.9 pm

$$z = \frac{(19.3g\ \text{cm}^{-3}) \times (407.9)^3 \times (6.022 \times 10^{23}\ \text{mol}^{-1}) \times (10^{-30}\ \text{cm}^3)}{(197\ g\ \text{mol}^{-1})}$$

= 4 (*fcc* structure)

51. (i) (b) 27 g mol^{-1}

Explanation: The density of the unit cell is given as

$$d = \frac{\text{mass of unit cell}}{\text{volume of unit cell}} = \frac{ZM}{a^3 N_A}$$

$$\text{or } M = \frac{da^3\ N_A}{Z}$$

$$= \frac{(2.72)\,(4.4 \times 10^{-10})^3\ (6.02 \times 10^{23})}{4}$$

= 26.9 mol^{-1}

Structure based questions

52. (a) Schottky defect, decreases, NaCl and KCl etc

Explanation: (i)Schottky defect

(ii) Decreases

(iii) This type of defect is shown by ionic compounds which have high coordination number and small difference in size of cations and anions *e.g.*, NaCl, KCl etc.

53. (c) Non-stoichiometric, F-centre, LiCl

Explanation: (i) Non-stoichiometric

(ii) F-centre

(iii) When LiCl is heated with lithium vapours, it shows this type of defect.

Assertion-Reason based questions

54. (d) Quartz glass is an amorphous solid because it is formed by fusing the crystal which is then cooled rapidly. Whereas, quartz, like all other minerals, is a crystalline solid with the molecular formula SiO_2. Quartz glass has no long range order because the components in its structure are not arranged in regular arrays whereas crystalline solids have regular long range order because the components in its structure are held together by uniform inter-molecular forces and they have a certain pattern of atoms that is repeated over and over in three dimension. Thus, both assertion and reason are false.

55. (b) Diamond is bad conductor of electricity because valence electrons of carbon are involved in bonding. In graphite, however, three out of four valence electrons are involved in bonding and the fourth electron remain free between adjacent layers which makes it a good conductor. Graphite is soft because parallel layers are held together by weak Van der Waal's force. However, diamond is hard due to compact three dimensional network of bonding. Thus, both assertion and reason are true, but reason is not the correct explanation of assertion.

56. (c) Crystalline solids are anisotropic in nature *i.e.,* some of their physical properties such as electrical resistance or refractive index show different values along different directions due to different arrangement of particles in different directions. Thus, assertion is correct but reason is not correct.

57. (a) Amorphous Solids have a tendency to flow, though very slowly. Glass is sometimes called a supercooled liquid because it does not form a crystalline structure, but instead forms an amorphous solid that allows molecules in the material to continue to move. This is the reason that the glass panes fixed to windows or panes of old buildings are found to be slightly thicker at the bottom than at the top because glass is pseudo solid or supercooled liquid. Thus, both assertion and reason are true and reason is the correct explanation of assertion.

58. (a) The face-centred cubic structure has atoms located at each of the corners and the centres of all the cubic faces. Each of the corner atoms is the corner of another cube so the corner atoms are shared among eight-unit cells. Thus, both assertion and reason are true and reason is the correct explanation of assertion.

59. (c) CsCl has body centred cubic arrangement but it has one Cs^+ ion and one Cl^- ion in its unit cell. Thus, assertion is true but reason is false.

60. (d) In a crystal lattice, Tetrahedral holes are smaller in size than an octahedral holes. Cations usually occupy less space than anions. Thus, both assertion and reason are false.

61. (a) All magnetically ordered solids (ferromagnetic, ferrimagnetic and anti frerromagnetic solids) transform to the paramagnetic state at high temperature due to the randomisation of spins *i.e.,* electrons change their spin on heating. Thus, both assertion and reason are true and reason is the correct explanation of assertion.

62. (a) In a simple cubic unit cell, atoms are present at each corners and each of it is shared between eight adjacent unit cells. Therefore, the total number of atoms present in a simple unit cell is $8 \times \frac{1}{8} = 1$. Thus, both assertion and reason are true and reason is the correct explanation of assertion.

63. (b) The coordination number is 12 in fcc structures and In fcc unit cell, CCP arrangement is present with packing efficiency of 74.01% which is maximum. Thus, both assertion and reason are true, but reason is not the correct explanation of assertion.

Word of Advice

1. Most of the students calculated the value of Z *i.e.,* number of atoms correctly, but they did not write the type of unit cell.
2. Majority of the students calculated edge length of the cell correctly but determination of radius from edge length was either missing or incorrect.
3. Some of the students wrote only the formula of the given alloy given in the particular question without showing the calculation for the number of atoms at the corners and at the center.
4. Some of the students either did not convert the edge length into 'cm' from 'pm' or took the value of Z (number of atoms) for body centered cubic unit cell as four instead of two.

5. Some of the students wrote the given defect as 'non- stoichiometric' instead of 'stoichiometric defect.' They wrote that there would be no change in density whereas stoichiometric defect decreases the density of crystal.
6. Some of the students wrote that coordination number of Na^+ and Cl^- ions will be 4 : 4 instead of 6 : 6.
7. Most of the students did not explain that in frenkel defect generally cations are missing from the crystal lattice site whereas, in case of Schottky defect, instead of writing an equal number of positive and negative ions are missing from the crystal lattice, they wrote atoms are missing.
8. Most of the students wrote the number of atoms present in body centred and face centred arrangement of atoms directly without showing the calculation as asked in the question.
9. Some of the students substituted the value of $z = 4$ instead of $z = 1$ due to which the value of edge length was not calculated correctly.
10. Most of the students calculated the radius of bcc unit cell incorrectly because they used the wrong formula.
11. In a face centered cubic lattice, atom (A) occupies the corner positions and atom (B) occupies the face centred positions. If one atom of (B) is missing from one of the face centered points, than the formula of the compound is A_2B_5 but some of the students wrote A_2B_3 or AB_2 which was incorrect.
12. Most of the students wrote that the percentage of unoccupied spaces in bcc and fcc arrangements are '68%' and '74%' instead of 32% and '26%' respectively.
13. The packing efficiency of simple cubic structure, body centered cubic structure and face centered cubic structure is 52.4%, 68% and 74 % respectively but some of the students wrote 68%, 74% and 52.4% which was incorrect.