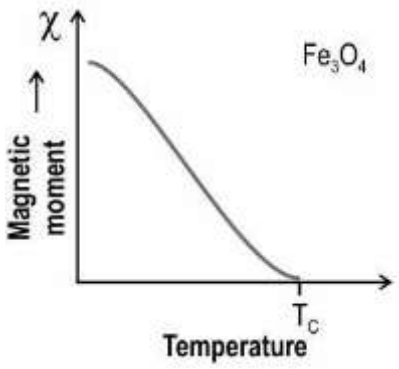
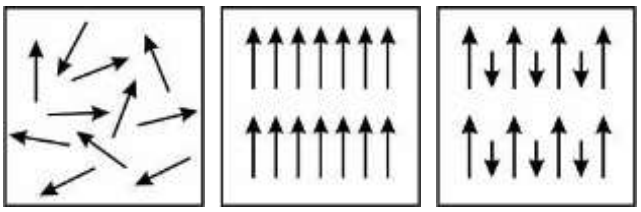
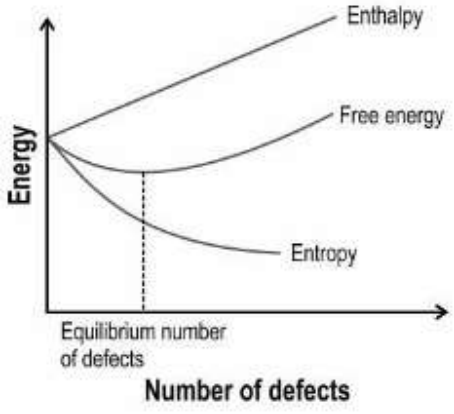
1. THE SOLID STATE

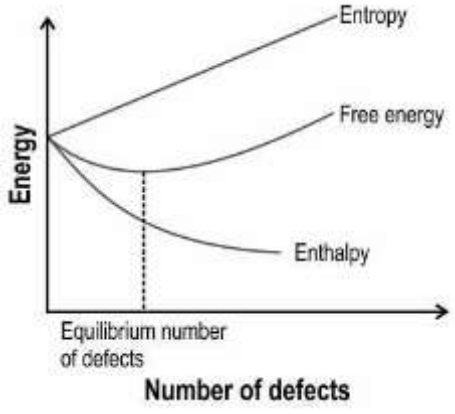
Q.No.	Question	Marks
	Multiple Choice Question	
Q.1	The below graph shows the variation of the magnetic property of magnetite (Fe_3O_4) with respect to temperature.  Based on this graph, which of the following represents the alignment of the magnetic moment of Fe_3O_4 at T >Tc?  none of the above A B C D	1
Q.2	Given below are two statements labeled as Assertion (A) and Reason (R). Assertion (A): Frenkel defect is shown by compounds having a low r+/r- ratio and low dielectric constant. Reason (R): Frenkel defect maintains the neutrality of a crystal. Select the most appropriate answer from the options given below: A. Both A and R are true and R is the correct explanation of A. B. Both A and R are true but R is not the correct explanation of A. C. A is true but R is false.	1

	D. A is false but R is true.	
Q.3	Which combination of the characteristics of element X, a metal, and Y, a non-metal, is most likely to lead to ionic bonding? **Element X** / **Element Y** A: Low ionization energy / High electronegativity value B: Low ionization energy / Low electronegativity value C: High ionization energy / High electronegativity value D: High ionization energy / Low electronegativity value	1
Q.4	Which of the following combinations is INCORRECT? A: GeP / n-type B: SbSi4 / n-type C: GeAs / p-type D: AlSi4 / p-type	1
Q.5	Which of the following statements is/are true? (i) A non-stoichiometric compound $Fe_{0.94}O$ is formed when 18% of Fe^{2+} ions are replaced by Fe^{3+} ions. (ii) The conductivity of both intrinsic and extrinsic semiconductors is directly proportional to temperature. (iii) The BCC structure is the densest crystal structure. A. i and iii	1

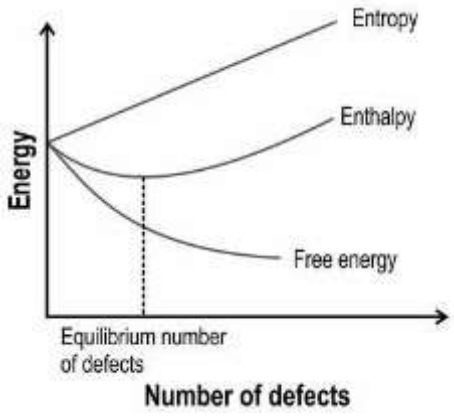
	B. ii and iii C. only i D. i and ii	
Q.6	Which of the following graphs correctly represents the enthalpy, free energy, and entropy during the formation of Schottky defects in solids? (Hint: The overall change in free energy is given by ΔG = ΔH - TΔS)	1



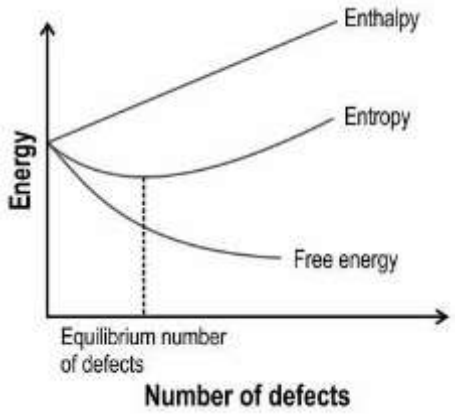
A.



B.

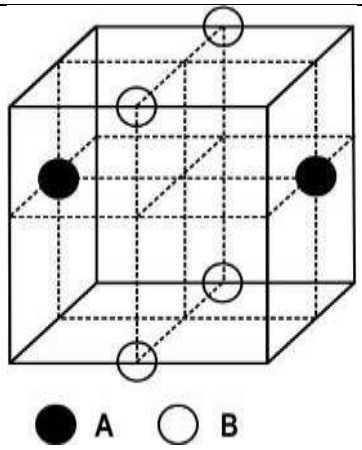


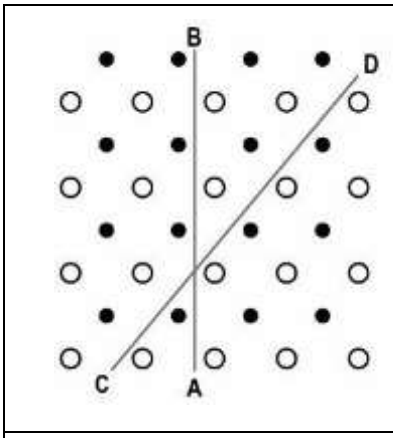
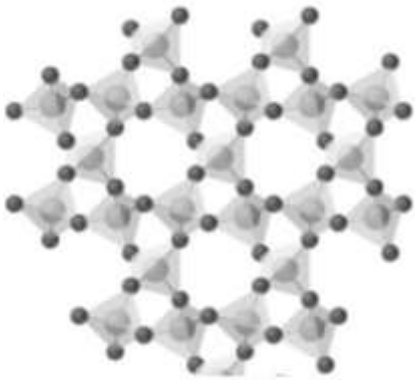
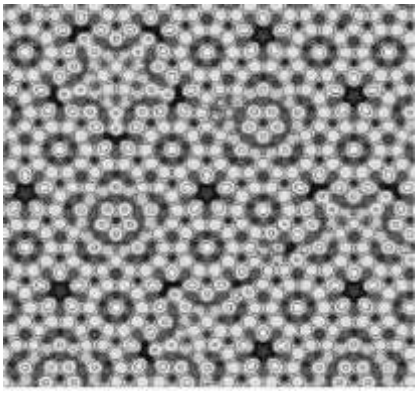
C.

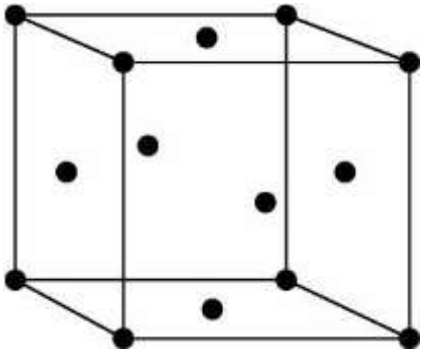
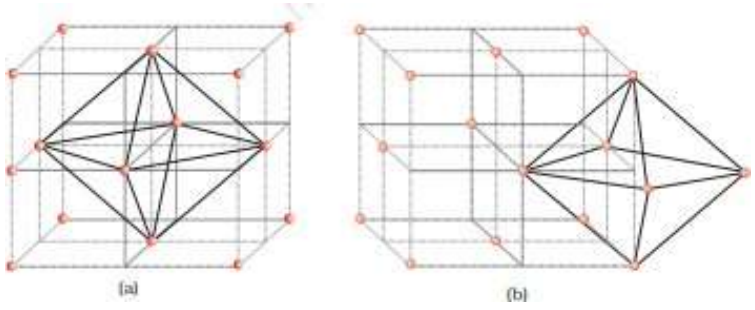


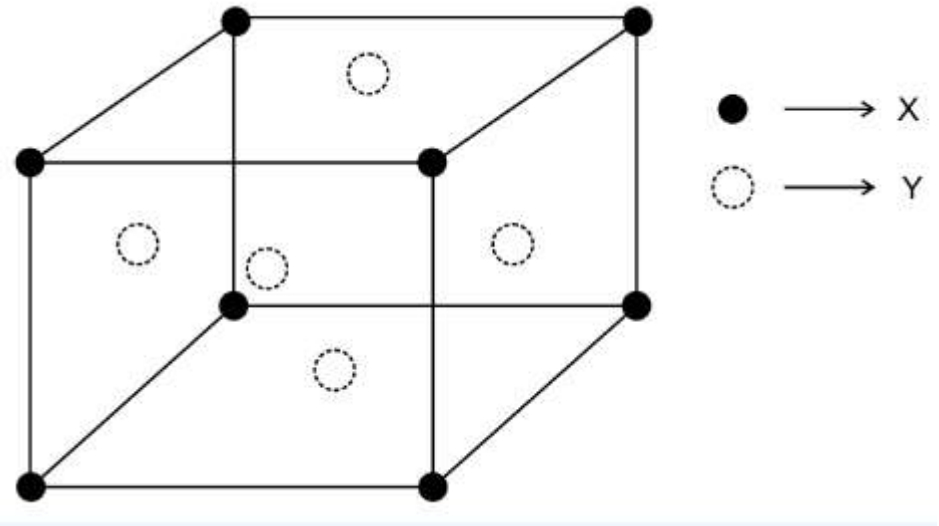
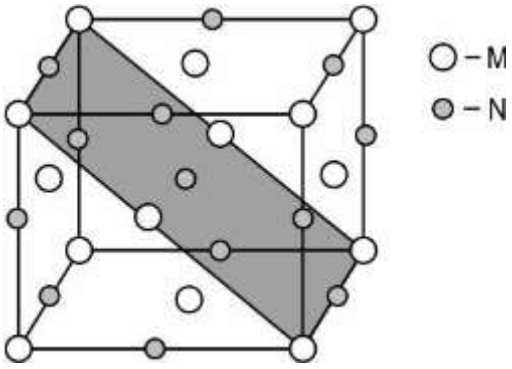
D.

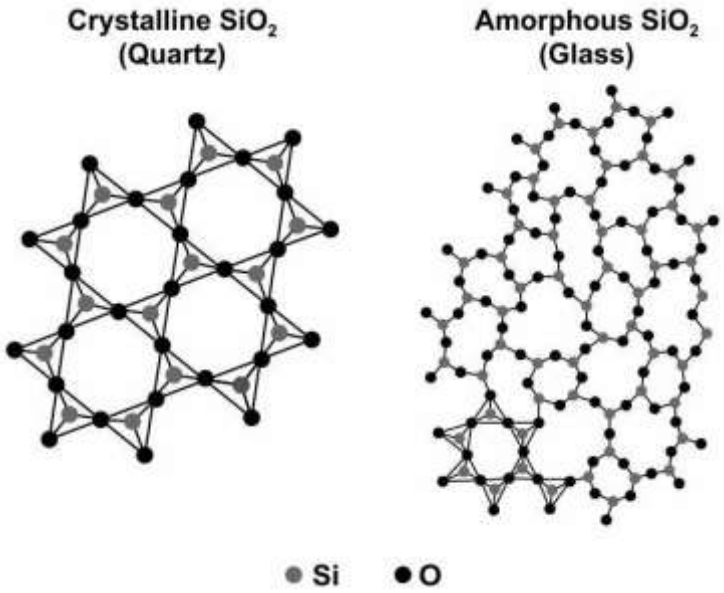
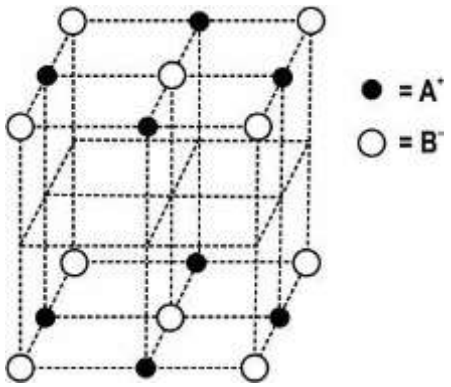
Q.7	A compound is formed by two ions A and B in a cubic unit cell. The radius of A+ is smaller than that of B-. (as shown below)	1

	 Which of the following statement is/are correct? (i) The radius ratio, r+/r- is 0.414. (ii) The cations and anions have different coordination geometry. (iii) The ratio of A-B bond length to unit cell edge length is 0.866. (iv) The formula of the compound is AB. A. i and iii B. iii and iv C. ii and iv D. All of them	
Q.8	On the morning of 8 April 1982, an image counter to the laws of nature appeared in Dan Shechtman's electron microscope. In all solid matter, atoms were believed to be packed inside crystals in symmetrical patterns that were repeated periodically over and over again. For scientists, this repetition was required in order to obtain a crystal. Shechtman's image, however, showed that the atoms in his crystal were packed in a pattern that could not be repeated. Such a pattern was considered just as impossible as creating a football using only six-cornered polygons when a sphere needs both five- and six-cornered polygons. His discovery was extremely controversial. In the course of defending his findings, he was asked to leave his research group. (Source:https://www.nobelprize.org/prizes/chemistry/2011/press-release/) Which of the following patterns could illustrate the finding of Shechtman's crystal?	1

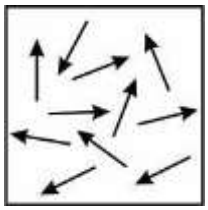
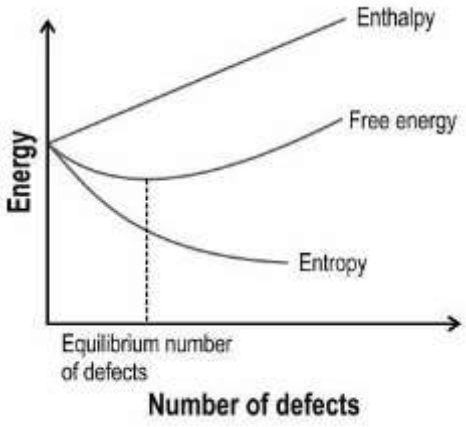
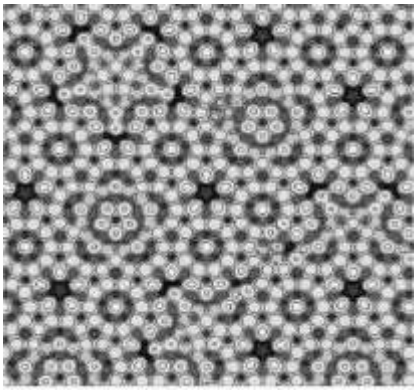
<table>
<tr><td></td><td>
<table>
<tr><td> 
</td><td>  </td></tr>
<tr><td>A.</td><td>B.</td></tr>
<tr><td>  </td><td>  </td></tr>
<tr><td>C.</td><td>D.</td></tr>
</table>
</td><td></td></tr>
<tr><td colspan="3">Free Response Question/ Subjective Question</td></tr>
<tr><td>Q.9</td><td>Read the statements below and answer the question based on them:
- Graphite conducts electricity and is used as a lubricant.
- Diamond is hard and does not conduct electricity.
Explain these statements on the basis of the structure and bonding present in these two solids.</td><td>4</td></tr>
<tr><td>Q.10</td><td>If the unit cell length of NaCl is a=563.1 pm and the density of NaCl is measured to be 2.17×10^{3} kg m^{-3}. Calculate Z, the number of formula units in the unit cell.
(The atomic masses of sodium and chlorine are 22.99 and 35.45, respectively.)</td><td>3</td></tr>
<tr><td>Q.11</td><td>The figure shown below represents a unit cell of a face-centered cubic structure.</td><td>3</td></tr>
</table>

	 How many atoms are in a FCC cell? (i) Draw diagrams to represent 100, 110, and 111 planes. (ii) Calculate the relative density per unit area for the above three planes. (Hint: Calculate the area of each plane assuming a cell length a. Decide the fractional contribution made by each atom to the plane.)	
Q.12	KCl crystallizes in the same type of lattice as NaCl. If rNa+/rCl- = 0.5 and rNa+/rK+ = 0.7. What is the ratio of the side of the NaCl unit cell to that of the KCl unit cell?	2
Q.13	Explain why crystalline solids are generally MORE DEFECTIVE at high temperatures. (Hint: Use the Gibbs energy equation)	2
Q.14	The diagram below shows the location of octahedral void per unit cell at the body center and at the center of one edge of the unit.  (a) (b) If the distance between the two nearest octahedral voids is 'ν2p' cm, where p is any positive number. (i) What is the minimum distance between the two tetrahedral voids in the same unit cell? (ii) What is the maximum distance between the two tetrahedral voids in the same unit cell?	3

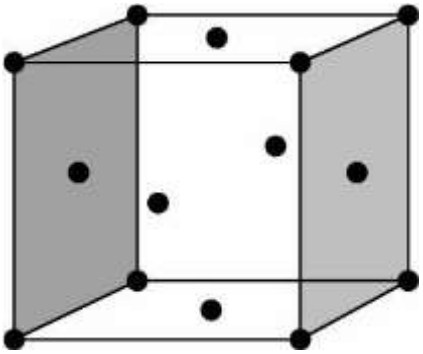
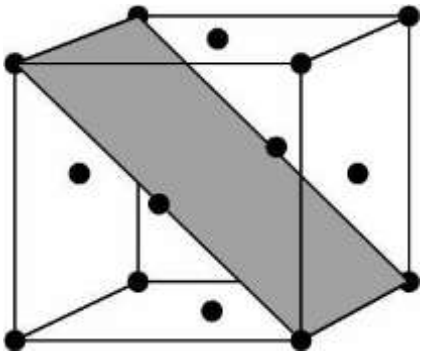
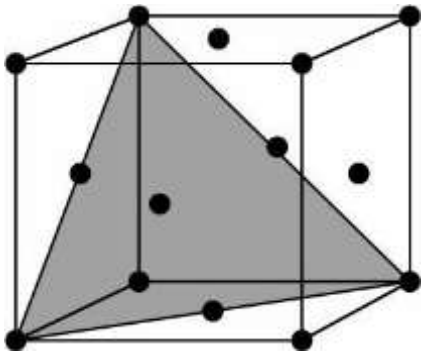
Q.15	In a face-centered cubic lattice, atom X is at the corners of the cube, and atom Y is at the face center position. If one atom of Y is missing from the face-centered positions as shown below, then what is the formula of the solid? 	2
Q.16	In an FCC lattice, with the help of a diagram, show that the minimum distance between an octahedral void and a tetrahedral void is (√3/4)a. (Note: a is the side length of the unit cell)	4
Q.17	In a crystal, there are N possible cation and anion sites. If there are nc cation vacancies and na anion vacancies in the same crystal, then what is the number of ways in which one can distribute: (i) Cation vacancies (ii) Anion vacancies (iii) Total number of ways of distributing these defects	2
Q.18	A compound is formed by two elements M and N. The element M forms fcc lattice and N occupies all the octahedral voids. If all the atoms along the 011 plane (as shown below in grey) are missing, then derive the formula of the compound? 	3

Q.19	In a chemistry laboratory, a quartz crystal is taken and heated above its melting point. Post that the solid was allowed to cool down rapidly. After cooling the solid, SiO2 loses its crystalline structure and became quartz glass (amorphous solid) as shown below:  (i) Explain why do quartz crystals, on heating and then rapid cooling, lose their crystalline property and become amorphous? (ii) Draw the temperature-time graph to illustrate the melting point of amorphous and crystalline solids.	5
Q.20	The diagram below shows a part of the structure of a crystal with some ions missing.  (i) Complete the diagram by placing cation A and anion B at appropriate sites. (ii) Identify the formula of this crystal.	3

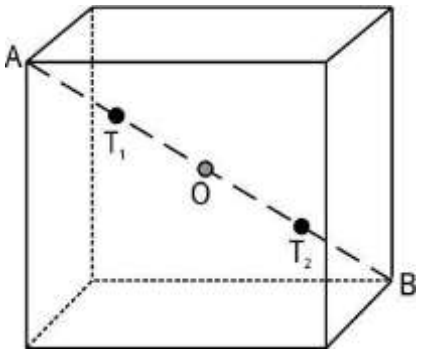
Answer Key & Marking Scheme

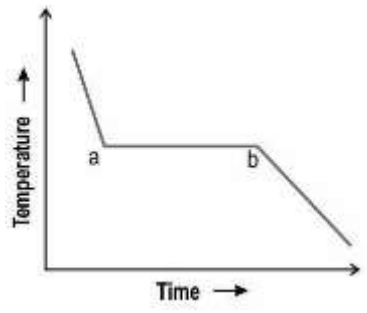
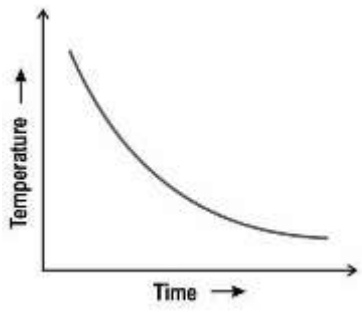
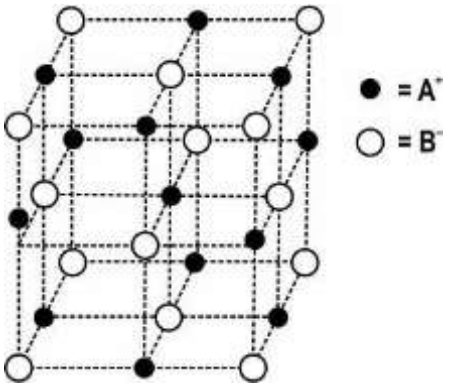
Q.No	Answers	Marks
Q.1	A. 	1
Q.2	D. A is false but R is true.	1
Q.3	A. A	1
Q.4	C. C	1
Q.5	C. only i	1
Q.6	A. 	1
Q.7	B. iii and iv	1
Q.8	D. 	1
Q.9	Graphite:	4

	- Each carbon atom is covalently bonded to three other carbon atoms forming flat, hexagonal rings which are arranged in layers [0.5] - C has sp^2 hybridization. Due to this the fourth valence electron is delocalized and is free to move. Free moving electrons make it a good conductor. [0.5] - Graphite is used as a lubricant because the layers of graphite are held together by weak intermolecular/ 'Van der Waals' forces and hence these layers can slide over each other [1 mark] Diamond: - Each carbon atom is covalently bonded to 4 other carbon atoms, forming a tetrahedral structure around C. C has sp^3 hybridization [1 mark] - The strong covalent bonds and tetrahedral structure and absence of delocalized electrons make diamond hard and an electrical insulator. [1 mark]	
Q.10	Step 1: Noting down what's given and what needs to be calculated. If the mass of the unit cell contents is M and the unit cell volume is V then the density, ρ is given by $\rho = M/V = 2.17 \times 10^3$ kg m^{-3} but $V=(563.1\times10^{-12})^3$ m^3 Step 2: - The mass of one mole of NaCl=$(22.99+35.45)\times10^{-3}$ kg - Dividing the mass by the Avogadro constant we get that the mass of one formula unit of NaCl= $(22.99+35.45)\times10^{-3})/(6.022 \times 10^{23})$ kg [0.5 marks] - and if there are Z formula units in one unit cell, then the mass of the unit cell contents is M= z x $(22.99+35.45)\times10^{-3})/(6.022 \times 10^{23})$ kg [0.5 marks] Step 3: Substituting the value of M and V in density formula and solving to get z=3.99, or z=4 (rounding to the nearest whole number)	3
Q.11	(i) Draw diagrams to represent 100, 110, and 111 planes:	3

	<table><tr><td>100 plane</td><td>110 plane</td></tr><tr><td>  </td><td>  </td></tr><tr><td colspan="2">111 plane</td></tr><tr><td colspan="2">  </td></tr></table> (ii) Calculate the density of atoms per unit area for each type of plane: - The area of the 100 plane shown, is a^2 and contains (1+4×¼)=2 atoms.[0.5] - The 110 plane contributes an area of $a^2\sqrt{2}$ and contains (2×½+4×¼)=2 atoms.[0.5] - The 111 plane contributes an area of ($a^2\sqrt{3}$)/2) and contains (3×1/2+3×1/6)=2 atoms.[0.5] - The relative densities per unit area for these three planes are thus: 100:110:111=2:1.414:2.31.[0.5]	
Q.12	Calculating ratio of the side of NaCl to that of KCl: - NaCl crystallizes in fcc unit such that $r_{Na+} + r_{Cl-} = a/2$ (assuming a is side length of an unit cell for NaCl)[0.5 marks] - Given that $r_{Na+} / r_{Cl-} = 0.5$ and $r_{Na+}/r_{K+} = 0.7$, thus $(r_{Na+} + r_{Cl-})/r_{Cl^-} = 1.5$ and $r_{K+}/r_{Cl-} = 0.5/0.7$ [0.5 marks] - Using the above equations:	2

	$(r_{K+} + r_{Cl-})/(r_{Na+} + r_{Cl-}) = (1.2/0.7) \times (1/1.5)$ $\therefore a_{NaCl} : a_{KCl} = 1:1.143$ [1 mark]	
Q.13	- As per the Gibbs-Helmholtz equation: $\Delta G = \Delta H - T\Delta S$; To create defects, the enthalpy of formation must be provided. [1 mark] - A large positive increase in entropy will be associated with the defect. - At high temperatures, it is more likely that the term $T\Delta S > \Delta H$, and thus $\Delta G < 0$ and defects may form at thermodynamic equilibrium. [1 mark]	2
Q.14	(i) minimum distance between the two tetrahedral voids - minimum distance between the two octahedral voids = $a/\sqrt{2}$; where a is the side of the unit cell. - $a/\sqrt{2} = \sqrt{2}p$; p is a positive number $\therefore a = 2p$ [1 Mark] So, the minimum distance between the two tetrahedral voids = $a/2 = p$ [1 mark] (ii) the maximum distance between the two tetrahedral voids - the maximum distance between the two tetrahedral voids = $\sqrt{3}a/2$; where a is the side length of unit cell - so maximum distance = $\sqrt{3}p$ [1 mark]	3
Q.15	**Calculating the formula of the solid**: - No. of atoms (X) in the corner of the solid = $8 \times 1/8 = 1$ [0.5 mark] - No of atoms (Y) at the face centers of the solid = $(6-1) \times 1/2 = 2.5$ [0.5 mark] $\therefore$ The formula of the solid = $XY_{2.5}$ that is X_2Y_5 [1 mark for correct formula]	2
Q.16	**Calculating the shortest distance between an octahedral void and a tetrahedral void in FCC solid**: - Draw the diagram of one-unit cell showing the position of the octahedral void, and tetrahedral void as below: [1 mark]	4

	 - In the above figure, AB is the diagonal of the cube, T1 and T2 are tetrahedral voids, and O is the octahedral void at the centre of the cube. [0.5 mark] - In FCC, tetrahedral voids are located at 1/4th distance from the corner along the diagonal. So, $AT_1 = AB/4$ - Since $AB = \sqrt{3}a$; $AT_1 = \sqrt{3}a/4$ [1 mark] - Since the octahedral void is at the centre of the cube/diagonal. So, AO = AB/2 ∴ $AO = \sqrt{3}a/2$ [0.5 mark] - Now the distance between an octahedral void and a tetrahedral void = $AO - AT_1$ $= \sqrt{3}a/2 - \sqrt{3}a/4 = \sqrt{3}a/4$ [1 mark]	
Q.17	(i) No. of ways one can distribute cation vacancies: - Probability theory shows that the no. of ways of distributing n defects over N sites = N!/(N-n)!n! ∴ No. of ways one can distribute cation vacancies = $N!/(N-n_c)!n_c!$ [0.5 mark] (ii) Similarly, No. of ways one can distribute anion vacancies = $N!/(N-n_a)!n_a!$ [0.5 mark] (iii) Total number of ways of distributing these defects = $N!/(N-n_c)!n_c!$ x $N!/(N-n_a)!n_a!$ [1 mark]	2
Q.18	**Finding the formula of the compound**: - In the new arrangement the no of atoms of M = (1/8 x 8 + 1/2 x 6) - (1/8 x 4 + 1/2 x 2) = 5/2 [1 mark] - the no. of atoms of N = (1/4 x 12 +1) - (1/4 x 2 +1) = 5/2 [1 mark] - So the new formula = MN [1 mark for correct answer]	3
Q.19	**(i) Conversion of the quartz crystal to quartz glass**: - Upon heating the quartz crystal, the *Bravais lattice structure of the crystal breaks*, and atoms that are arranged at a fixed position start to move randomly. [1 mark]	5

	- For molten material to solidify as a crystalline solid the atoms have to *come together during cooling and need to arrange themselves in a periodic fashion that occurs by diffusion*. [1 mark] - If the cooling rate is very high it will not allow the diffusion to occur; not allow the atoms to move, come together and form a cluster that solidifies as crystalline solids. [1 mark] *(Note: Keywords are: breakdown of Bravais lattice, diffusion, rate of cooling/solidification vs diffusion or long-range order)* **(ii) Temperature-time curve for solids:** **Crystalline solid [1 mark]** / **Amorphous solid [1 mark]**  	
Q.20	(i) Diagram  (ii) Formula: -No. of atoms A = (1/4 x 12 + 1) = 4 [0.5 mark] - No. of atoms B = 1/8 x 8 + 1/2 x 6 = 4 [0.5 mark] - Formula = AB [1 mark]	3