I.3 Solid State

Civil Services 2016–2026: **26** parts, **245** marks · IFoS 2016–2025: **21** parts, **195** marks

Syllabus. Crystal systems; designation of crystal faces, lattice structures and unit cell; Bragg's law; X-ray diffraction by crystals; close packing, radius ratio rules, calculation of some limiting radius ratio values; structures of NaCl, ZnS, CsCl and CaF_2; stoichiometric and nonstoichiometric defects, impurity defects, semi-conductors.

Marks	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
CSE	20	15	25	10	20	20	30	20	25	30	30
IFoS	10	25	0	10	23	23	23	28	30	23	

How to use this chapter. Read every question once and mark the ones that repeat. Pick three, write them by hand against the clock (about 7 minutes for 10 marks), then compare with the model answers on vkcscience.com.

2026

CSE 2026 · Q5(d) Spacing of the (111) planes of a simple cubic lattice [5 marks]

What is the shortest distance between two successive 111 planes of simple cubic lattice of edge length 200 pm? Explain.

CSE 2026 · Q7(c) Packing fractions of SC, BCC and FCC; Bragg condition for constructive interference [25 marks]

(i) Out of three lattice structures SC, BCC and FCC, which one is most economically packed and which one least? Give your answer, calculating packing fraction of each lattice structure.

(ii) For Bragg X-ray diffraction studies of crystalline solid, what is the Bragg condition for constructive interference? Explain.

2025

CSE 2025 · Q1(c) Raising the conductivity of Ge and Si by trace elements [5 marks]

Germanium and Silicon elements have very low electrical conductivity. How can the electrical conductivity be enhanced by adding other elements in trace amount? Explain by examples.

CSE 2025 · Q2(c) Radius ratio and the structure of ZnS [15 marks]

The radii of Zn^{2+} and S^{2-} ions are 0.74 Å and 1.84 Å respectively. Determine the most stable form of arrangement of ions in ZnS crystal lattice. Draw the CCP (Cubic Close Packing) structure of ZnS.

CSE 2025 · Q2(d) Stoichiometry of NaCl doped with Ca^{2+} [5 marks]

In a sample of NaCl, one of every 10,000 sites, normally occupied by Na^+, is occupied instead by Ca^{2+}. Assuming that all of the Cl^- sites are fully occupied, what is the stoichiometry of the sample?

CSE 2025 · Q3(e) Why crystals have more defects at higher temperature [5 marks]

Explain why crystalline solids are generally more defective as a result of increasing temperature.

IFoS 2025 · Q1(b) Formula from occupied crystal voids [8 marks]

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

IFoS 2025 · Q3(a) BCC edge length from diffraction; NaCl unit cell and Avogadro constant [15 marks]

(i) A certain solid crystallizes in the body-centered cubic lattice. The first-order X-ray (λ = 0.154 nm) reflection maximum from a set of (2 0 0) planes was observed at 16.1°. Calculate the edge length of the unit cell. [Given: $\sin 16.1^\circ = 0.2773$] 5

(ii) Describe the unit cell structure of NaCl. Calculate the value of the Avogadro's constant from the following data:
Density of NaCl = 2.165 gm cm^{-3}; Distance between Na^+ and Cl^- ions in NaCl = 281 picometre (pm); Molar mass of NaCl = 58.5 gm mol^{-1} 10

2024

CSE 2024 · Q1(b)(ii) Unit cell and the cubic Bravais lattices [5 marks]

(ii) Define 'unit cell'. Draw all the Bravais lattices for a cubic system. *5*

CSE 2024 · Q2(c) Limiting radius ratio for coordination numbers 3 and 6; Stoichiometric defects [20 marks]

(i) Calculate the limiting radius ratio for the crystals with coordination number 3 and 6. *10*

(ii) Explain stoichiometric defects with an example. *10*

IFoS 2024 · Q2(b) Equilibrium vacancy concentration [15 marks]

Derive an expression to calculate the number of vacancies per mole of metal atoms at a given temperature. Assume the following:
(i) Contribution to entropy by vibration of atoms is small and can be neglected.
(ii) Use E_v as the energy required to create one mole of vacancy.

IFoS 2024 · Q3(d) Cubic diffraction selection rules [5 marks]

Consider 'A' and 'B' are two metals with cubic unit cell. The powder XRD pattern of 'A' gives XRD lines corresponding to (110), (200), (220), (311), (400) and (331) planes, while the powder XRD pattern of 'B' gives XRD lines corresponding to the planes of (110), (200), (211), (220), (301) and (222). Comment on the type of space lattice in 'A' and 'B', and justify. What fraction of space in the unit cell of 'A' is available for tightest possible packing of its atoms?

IFoS 2024 · Q8(d) Colour centres in sodium chloride [10 marks]

Why is yellow colour observed, when sodium chloride is heated in sodium vapour?

2023

CSE 2023 · Q1(c) Bragg equation and the layer spacing [10 marks]

(i) Derive an expression that relates the wavelength of the X-rays with the distance between the layers of atoms in a crystal.
(ii) The X-rays of wavelength 220 pm are diffracted from an ionic crystal at an angle of 23°. What is the distance between the layers that are responsible for this diffraction?

CSE 2023 · Q2(c) Primitive cubic lattice: points, voids and the sphere at the centre [10 marks]

Consider a primitive cubic lattice structure of an element.
(i) How many lattice points are present in this unit cell?
(ii) What is the coordination number of the atom present in this structure?
(iii) What is the percentage void volume of this structure?
(iv) If the radius of the atom present in this lattice is 178.1 pm, then find the radius of the sphere that can fit in the centre of this cubic unit cell.
(v) What is the coordination number of this sphere?

IFoS 2023 · Q1(c) Ions per unit cell of FeO [8 marks]

Iron(II) oxide, FeO, crystal has a cubic structure and each edge of the unit cell is 5.0 Å. Taking density of oxide as 4.0 g cm^{-3}, calculate the number of Fe^{2+} and O^{2-} ions present in each unit cell.

IFoS 2023 · Q3(a) Ionic distances and radius-ratio predictions [10 marks]

(i) The density of NaCl is 2.17 g cm^{-3}. Calculate the interionic distance. (F. wt. of NaCl = 58.45)
(ii) The ionic radii of Rb^+, Br^- and I^- ions are 1.47 Å, 1.95 Å and 2.16 Å respectively. Predict the most probable type of geometry exhibited by RbBr and RbI on the basis of radius ratio rule.

IFoS 2023 · Q3(b) Avogadro constant from diffraction [10 marks]

The density of LiF is 2.601 g cm^{-3}. The (111) first-order reflection in the X-ray diffraction from LiF occurs at 8°44′ when X-rays of wavelength 70.8 pm are used. If there are four LiF molecules per unit cell, calculate Avogadro's number. LiF crystallizes in the cubic system. Li = 6.939, F = 18.998.

2022

CSE 2022 · Q1(c) F-centres: one colour by every route; effect on density [10 marks]

(i) *F*-centre defect can be introduced in several ways. Regardless of the method used, the colour produced in any particular crystal is always same. Explain the reasons.
(ii) How would the formation of *F*-centre affect the density of the crystal?

CSE 2022 · Q2(c) Simple cubic cell from the (100) reflection; room for an interstitial atom [20 marks]

In a certain material of simple cubic structure, (100) diffraction is obtained at $\theta = 14.88°$ with radiation of $\lambda = 1.541$ Å. Can this material accommodate an atom of 1.08 Å radius interstitially in void space without lattice distortion?
[Sin 14.88 = 0.257]

IFoS 2022 · Q1(c) MgO impurity in alumina [8 marks]

Mention point defects which can arise for MgO as an impurity in Al_2O_3. How many Mg^{2+} ions must be added to form each of these defects?

IFoS 2022 · Q2(c) Limiting radius ratio for trigonal coordination; Why zinc blende is face-centred cubic [15 marks]

(i) Prove that the minimum value of $R_A/R_X = 0.155$ will provide a 3 : 3 coordination for A and X ions in AX compound (A is the cation, X is the anion, R_A is the radius of cation, R_X is the radius of anion). 10
(ii) Zinc blende lattice is face-centered cubic. However, each atom is tetrahedrally bonded to four nearest neighbours. Explain how a Zinc blende lattice can be a face-centered cubic lattice. 5

2021

CSE 2021 · Q2(c) Iron: atomic radius from the b.c.c. cell; volume change on going to f.c.c [20 marks]

Iron crystallizes in a b.c.c. unit cell at room temperature (ρ = 7.86 g/cm^3). Calculate the radius of an iron atom in this crystal. At temperatures more than 910 °C, iron prefers to be in f.c.c. If we neglect the temperature dependence of radius of iron on the grounds that it is negligible, use this information to determine whether iron expands or contracts when it undergoes transformation from b.c.c. to f.c.c. structure. The atomic mass of iron is 55.845 u.

IFoS 2021 · Q1(a) Frenkel disorder in silver bromide [8 marks]

(i) Does the Frenkel disorder in AgBr create vacancies of Ag^+, vacancies of Br^- or both? Explain. The ionic radii are 1.15 Å for Ag^+ and 1.96 Å for Br^-.

(ii) Calculate the temperature at which the fraction of Frenkel defects in a crystal of AgBr exceeds 1 part per billion. The enthalpy of Frenkel defect formation, ΔH_f, has the value of 1.16 eV/defect, and the entropic prefactor, A, has a value of 3.091.

IFoS 2021 · Q2(c) Void fraction with one octahedral occupant [15 marks]

In a face-centred unit cell with all the positions occupied by A atoms, the body centred octahedral hole in it is occupied by an atom B of an appropriate size. Calculate the void space per unit volume of unit cell for such a crystal.

2020

CSE 2020 · Q1(b) Spacing of the (123) planes of an orthorhombic cell [10 marks]

An orthorhombic unit cell has the following parameters : a = 0.5 Å, b = 1.0 Å, c = 1.5 Å. What will be the smallest spacing between two successive 123-planes?

CSE 2020 · Q6(b) Coordination number of the cations in NaBr and KBr from radius ratios [10 marks]

The ionic radii of Na^+, K^+ and Br^- are 137, 148 and 195 pm, respectively. Determine the coordination number and geometry of cations in NaBr and KBr.

IFoS 2020 · Q1(c) Lattice parameter of CsCl from ionic radii [8 marks]

Cesium chloride (CsCl) crystal has a cubic structure in which Cs^+ ions occupy the centre position of a unit cell and its corner positions are occupied by all Cl^- ions. If the ionic radii of Cs^+ ion and Cl^- ion are 0·169 nm and 0·181 nm, respectively, compute the lattice parameter, a.

IFoS 2020 · Q3(c) Cubic lattice type and lattice constant from diffraction angles [15 marks]

For an unknown cubic metal, the diffracting angles (θ), obtained with Cu K_α radiation (λ = 1·541 Å) are 20·1°, 29·2°, 36·6°, 43·5°, 50·2°, 57·4°, 65·5°. Identify whether the metal is simple cubic, body centred or face centred. Determine the lattice constant a for this metal. Given—

sin (20·1°) = 0·344
sin (29·2°) = 0·488
sin (36·6°) = 0·596
sin (43·5°) = 0·688
sin (50·2°) = 0·768
sin (57·4°) = 0·842
sin (65·5°) = 0·910

2019

CSE 2019 · Q3(a) Conductivity of ZnO heated in vacuum and in oxygen [10 marks]

Zinc oxide is a semiconductor that loses oxygen atoms in a vacuum but gains additional oxygen atoms when heated in oxygen. Its conductivity increases when it is heated in a vacuum but decreases when it is heated in oxygen. Account for these observations.

IFoS 2019 · Q3(b) hcp and ccp packing; octahedral and tetrahedral voids [10 marks]

(i) Draw hexagonal and cubic close packed systems (assuming that the atoms/ions are spherical in nature). Calculate the packing efficiency and void volume in each case.
(ii) How many kinds of voids are generated in a hexagonal close packed system? Calculate the maximum size of an atom/ion that can occupy the octahedral and tetrahedral voids in hexagonal close packed system of O^{-2} ions. (Radius of O^{-2} = R)
Explain through diagram. 5+5=10

2018

CSE 2018 · Q2(d)(i) Derivation of Bragg's equation [5 marks]

Derive Bragg's equation.

CSE 2018 · Q2(d)(ii) Number of K^+ and Cl^- ions in 1.00 g of KCl [5 marks]

The potassium chloride crystal structure is like that of sodium chloride. The unit cell contains four potassium ions and four chloride ions. Given that the size of unit cell as 6.29 Å and the density of potassium chloride as 1.99 g/c.c. Calculate the number of potassium ions and chloride ions in 1.00 g of the salt.

CSE 2018 · Q4(a)(i) Crystal defects; stoichiometric defects [10 marks]

What are crystal defects? Give a brief account on stoichiometric defects.

CSE 2018 · Q4(a)(ii) Conduction in semiconductors [5 marks]

Explain the conduction mechanism in semiconductors.

2017

CSE 2017 · Q3(c) Polonium: cubic class and cell edge from three Bragg reflections [15 marks]

Polonium crystallizes in the cubic system. Using X-ray of wavelength 0.154 nm, first order Bragg reflections occur at $\sin\theta$ values 0.225, 0.316 and 0.388 from (100), (110) and (111) planes respectively. Determine the class (SC or BCC or FCC) of the cubic crystal and edge length (a) of unit cell.

IFoS 2017 · Q1(a) NaCl unit cell: ions per cell, cell volume and X-ray wavelength [20 marks]

NaCl (molecular weight : 58·5) consists of a face-centred cubic lattice of Na^+ ions interlocked with a similar lattice of Cl^- ions and has a density of 2·17 g/cm^3.
(i) Draw the unit cell structure of NaCl.
(ii) Calculate the number of Na^+ and Cl^- ions that are present in a unit cell.
(iii) Calculate the volume of the unit cell.
(iv) The first-order reflection from the d_{100} planes of NaCl occurs at 5·9°. Calculate the wavelength of X-ray.
5+5+5+5=20

IFoS 2017 · Q2(d) n-type and p-type semiconductors [5 marks]

Write brief notes on n-type and p-type semiconductors.

2016

CSE 2016 · Q1(c)(i) Derivation of the Bragg equation [5 marks]

Derive the relation $n\lambda = 2d \sin\theta$ in crystallography.

CSE 2016 · Q1(c)(ii) Spacing of the (110) planes of a cubic cell [5 marks]

What is the perpendicular distance between (110) planes of a cubic unit cell?

CSE 2016 · Q3(a)(ii) Semiconductors: n-type, p-type and the effect of temperature [10 marks]

What are semiconductors? Explain *n*-type and *p*-type semiconductors. Discuss the effect of temperature on semiconductors.

IFoS 2016 · Q1(d)(i) Crystal systems with mutually perpendicular axes [5 marks]

How many crystal systems are there? Name the crystal systems wherein the unit cell axes are mutually perpendicular. Give one example in each case.

IFoS 2016 · Q1(d)(ii) Spacing of the (110) planes, axes mutually perpendicular [5 marks]

What is the equation for the distance between the planes (110) for a crystal with mutually perpendicular axes?