2025

PHYSICS — HONOURS

Paper : CC-14

(Solid State Physics)

Full Marks : 50

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Answer ***question no.* 1** and ***any four*** questions from the rest.

1. Answer ***any five*** questions : 2×5

(a) Show that nearly 74% of the volume of the unit cell in FCC structure is occupied by the atoms.

(b) Obtain the Miller indices of a plane with intercepts a, $b/2$, c on the crystallographic axes, where a, b and c are the lattice parameters.

(c) State Bloch's theorem in periodic crystals.

(d) Which ion, Na^+ or K^+, has the higher absolute magnitude of diamagnetic susceptibility? Justify your answer.

(e) Why Na^+ is expected to have smaller electronic polarizability than Ne, even though both contain the same number of electrons?

(f) The relative permittivity of argon at 0°C and one atmospheric pressure is 1.000435. Calculate the polarizability of the argon atom.

(g) Sketch the specific heat of a material in its superconducting as well as normal state in the same graph. (Indicate the critical transition temperature in the graph.)

2. (a) Write down the primitive basis vectors of a BCC lattice and find out the angle between the axes.

(b) Write down Bragg's law of X-ray diffraction in real space and reciprocal space. How is this law modified due to refraction at crystal surface?

(c) Determine the wavelength of the X-ray diffracted by the (111) planes of Ni crystals at an angle 28°. Given, Ni has FCC structure with lattice parameter of 3.52 Å. (1½+1½)+(2+3)+2

3. (a) Obtain the dispersion relation for an infinite one-dimensional array of identical atoms. What is the minimum wavelength of the wave that can be propagated through such array of interatomic separation 1.8 Å in equilibrium?

(b) Following the Debye approximation on vibrational modes in crystal, the molar energy is given by

$$U = 9RT\left(\frac{T}{\Theta_D}\right)^3 \int_0^{\Theta_D/T} \frac{x^3 dx}{e^x - 1},$$

where $x = h\nu/kT$, Θ_D is the Debye temperature and other symbols have usual meanings. Use this expression of energy to determine the molar specific heat of the crystal at (i) high temperature and (ii) low temperature.

(c) Explain why the Debye theory is superior to the Einstein theory on specific heat of solids. (3+1)+(2+2)+2

4. (a) What is the basic assumption of the quantum theory of paramagnetism? For strong magnetic field and at low temperature find out the expression for magnetisation.

(b) Show the magnetisation curve for a ferromagnetic specimen clearly marking the regions of magnetisation produced by the displacement of domain boundaries and rotation of the domains.

(c) The saturation magnetisation of iron is 1.75×10^6 ampere/meter. Assuming that iron has a BCC structure with an edge-length of 2.87 Å, find the average number of Bohr magnetons contributing to the saturation magnetisation per atom. (2+4)+2+2

5. (a) Consider an electron of charge e, mass m bound harmonically to an atom, which exhibits a resonant absorption at a frequency ω_0. Show that the electronic polarizability of the atom at a frequency ω is given by

$$\alpha_e = \frac{e^2}{m\left(\omega_0^2 - \omega^2\right)}.$$

(b) The refractive index and the dielectric constant of water are 1.33 and 81 respectively. Determine the percentage of ionic polarizability in water molecules.

(c) Using the free electron gas model, derive an expression for the electrical conductivity in metals. Hence, explain that resistivity of metals increases with increase in temperature. 3+3+(3+1)

6. (a) What do you mean by 'effective mass' of an electron in a solid?

(b) The energy wave vector dispersion relation for a one-dimensional crystal of lattice constant 'a' is given by

$$E(k) = E_0 - \alpha - 4\beta \cos ka, \quad \text{where } E_0,\ \alpha,\ \beta \text{ are constants.}$$

(i) Find the value of k at which the velocity of an electron is maximum.

(ii) Find the difference between the top and the bottom of the energy band.

(iii) Obtain the effective mass m^* of the electron at the bottom and at the top of the band.

(c) Taking the origin at the bottom of the conduction band, calculate the crystal momentum for a free electron of energy 0.015 eV. Given, effective mass of electron = 0.25 m_0. 2+(2+2+2)+2

7. (a) What is Hall effect in semiconductors? Derive the expression for the Hall coefficient (R_H) in semiconductors. What is the sign of R_H for intrinsic semiconductors? Justify your answer.

   (b) The critical temperature for mercury with isotope mass 199.5 amu is 4.185 K. Calculate its critical temperature when its mass changes to 203.4 amu.

   (c) Write down the London equation mentioning the symbols used. What do you mean by the penetration depth? How does the penetration depth vary as the temperature of the superconductor approaches the critical temperature? (1+3+1)+2+(1+1+1)
