2026

PHYSICS — HONOURS

Paper : DSCC-14

(Solid State Physics)

Full Marks : 75

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 five*** questions from the rest.

1. Answer ***any five*** questions :

(a) Distinguish between crystalline and amorphous solids with suitable examples. 2+1

(b) Obtain the Miller indices of a plane with intercepts $3a$, $-2b$, $3c/2$ on the crystallographic axes, where a, b and c are the lattice parameters. 3

(c) What is a phonon? Mention an evidence supporting the existence of phonons. 3

(d) State and explain Bloch's theorem in periodic crystals. 3

(e) Write down the different components contributing to the local electric field acting on an atom in a dielectric crystal and explain the physical origin of each component. 3

(f) A rectangular semiconductor chip of thickness 0.50 mm carries a current of 20 mA along its length. When placed in a perpendicular magnetic field of magnitude 0.80 T, a Hall voltage of 3.2 mV is developed across the specimen. Calculate the Hall coefficient of the semiconductor. 3

(g) Plot the spontaneous magnetization for a ferromagnetic substance as function of temperature for $J = 1/2$ and $J = 1$. The curve for $J = 1/2$ fits the data best. What does that imply? 3

(h) Why is perfect diamagnetism considered a more fundamental characteristic of superconductors than zero electrical resistance? 3

2. (a) Write down Laue condition for constructive interference in a crystal and derive the Bragg's Law for X-ray diffraction for a simple cubic lattice.

(b) Prove that the reciprocal lattice to a BCC lattice is FCC lattice.

(c) X-rays of wavelength 0.71 Å are reflected from the (110) plane of rock salt crystal having a simple cubic structure of lattice constant a = 2.82 Å. Calculate the corresponding glancing angle for 2nd order reflection.

(d) Draw the crystal planes (002) and (012) in an FCC lattice. (1+3)+3+3+2

3. (a) Define mobility of free electorns in a metal. What is its relation with conductivity?

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

   (c) Derive the expression for the specific heat of a solid according to Einstein's theory of specific heat. Show that, at high temperatures, the expression reduces to the Dulong-Petit law.

   (2+1)+(3+1)+(4+1)

4. (a) Show that the phonon dispersion relation for a vibrating diatomic chain in which alternate atoms are of mass m and $M(M > m)$ is given by

$$\omega^2(k) = \beta\left(\frac{1}{M}+\frac{1}{m}\right) \pm \beta\left[\left(\frac{1}{M}+\frac{1}{m}\right)^2 - \frac{4}{Mm}\sin^2 ka\right]^{1/2},$$

   where β is the force constant and a is the lattice spacing.

   (b) Using the above expression, determine the angular frequencies of the acoustical and optical branches near the center $(k \to 0)$ and boundaries $(k = \pm \pi/2a)$ of the first Brillouin zone.

   (c) Sketch the acoustical and optical phonon dispersion branches over the first Brillouin zone clearly marking the forbidden frequency band in this case. 4+(1½×4)+2

5. (a) Show that the relative permittivity (ϵ_r) of a solid dielectric material is related with the electronic polarizability (α_e) of its constituent atoms by the following equation :

$$\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N\alpha_e}{3\epsilon_0},$$

   where N is the atomic density of the material. What is the importance of this relation?

   (b) Plot the variation of refractive index of a gas with the wavelength of incident electromagnetic radiation, clearly indicating the regions of normal dispersion and anomalous dispersion.

   (c) Explain why the refractive index of a dielectric medium is determined primarily by electronic polarizability, and not by ionic or dipolar polarizability. According to the classical theory of electronic polarization, the refractive index n of a gas is given by :

$$n^2(\lambda) = 1 + \sum_k \frac{A_k \lambda^2}{\lambda^2 - \lambda_k^2},$$

   where A_k and λ_k are constants. Using this relation, explain the phenomenon of normal dispersion. What is the origin of anomalous dispersion? (3+1)+2+(2+2+2)

6. (a) What is the Kronig-Penney model? Draw the periodic potential used in this model.

   (b) Following the Kronig-Penny model, the energy spectra of the electron in a one-dimensional lattice are obtained from the equation :

$$\frac{P}{\alpha a}\sin \alpha a + \cos \alpha a = \cos ka, \text{ where } P = \frac{mV_0 ab}{\hbar^2} \text{ and } \alpha^2 = \frac{2mE}{\hbar^2}.$$

   Other symbols have their usual meanings.

(i) Explain the idea of allowed and forbidden energy bands by plotting the above mentioned equation as a function of αa.

(ii) Show that for $P << 1$, the bottom level of the lowest band is given by

$$E = \frac{\hbar^2 P}{ma^2}$$

(c) The dispersion relation in a 3D lattice is given by

$$E(k_x, k_y, k_z) = \alpha \cos k_x a + \beta \cos k_y b + \gamma \cos k_z c,$$

where α, β, γ are constants and a, b, c are the lattice parameters. Find the effective mass tensor at the corner of the first Brillouin zone $\left(\frac{\pi}{a}, \frac{\pi}{b}, \frac{\pi}{c}\right)$. (1+1)+(3+3)+4

7. (a) What is Hall effect? Define Hall coefficient. Show that Hall coefficient in semiconductors is given by

$$R_H = \frac{\mu_h^2 p - \mu_e^2 n}{e(\mu_h p + \mu_e n)^2},$$

where μ_h, and μ_e are the mobilities of holes and electrons respectively, p and n are the corresponding carrier concentrations, and e is the electronic charge.

(b) Using the above expression, justify that the Hall coefficient is positive for p-type semiconductors. What is the sign of the Hall coefficient for intrinsic semiconductors? Explain.

(c) Using Drude's free electron theory, show that the ratio of thermal conductivity to electrical conductivity of a metal is directly proportional to its absolute temperature. (1+1+4)+(1+1)+4

8. (a) From the Weiss field theory, find out the expression of magnetic susceptibility for a ferromagnetic material and show how does it vary above and below the Curie temperature.

(b) Explain the B-H loop with the help of domain theory.

(c) Assuming iron has a body-centered cubic structure with an edge length of 2.87 Å, calculate average number of Bohr magnetons which contributes to saturation magnetization per atom.

Given, saturation magnetization of iron = 1.75×10^6 A/m

1 Bohr magneton $\mu_B = 9.27 \times 10^{-24}$ Am^2. (3+1½+1½)+3+3

9. (a) Draw the variation in electrical resistivity with the absolute temperature for an impure metal and a superconductor at very low temperature.

(b) For lead, the critical field at 0 K is 6.39×10^4 A/m and the critical temperature for zero magnetic field is 7.18 K. Find the critical field for lead at 4 K.

(c) Derive the London equation and hence, explain the Meissner effect in superconductors.

(d) How does the superconducting transition temperature (T_C) vary with isotopic mass? Write down the relation between T_C and the Debye temperature. 2+3+(3+2)+(1+1)
