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CMDE/M-24 **4700**

SOLID STATE PHYSICS

Paper–PHY–203

Time Allowed : 3 Hours] [Maximum Marks : 60

Note : Attempt **five** questions in all, selecting **one** question from each Unit. Question No. **1** is compulsory. All questions carry equal marks.

Compulsory Question

1. Explain the following questions :

(a) For an X-ray of wave length 0.1 nm. the scattered intensity show first-order maxima at a scattering angle 60º. Calculate the sapcing *d* between the associated lattice planes and the magnitude of the RLV satisfying the Laue condition. 3

(b) Consider two lattice waves with wave vectors k and k′ = k + G, where G is a reciprocal lattice vector. Deduce relation between the lattice wave frequencies ω_k and $\omega_{k'}$. 3

(c) Justify that $\hbar k$ does not represent the linear momentum of the electron described by the Bloch function $\psi_k(r) = e^{ik.r} u_k(r)$. 3

(d) What do you understand by Energy gap in a Superconductor? How does the gap manifest in the interaction of Superconductor with an Electromagnetic radiation. 3

UNIT–I

2. (a) Introduce the concept of reciprocal lattice. Prove the statement: "*The diffraction pattern of a crystal is a map of its reciprocal lattice*". 6

(b) The structure of diamond may be described by an *fcc* lattice and a diatomic basis of Carbon atoms, with the two atoms positioned at 000 and $\frac{1}{4}\frac{1}{4}\frac{1}{4}$. Taking a cubic unit cell, find the structure factor S_G and the corresponding scattered X-ray intensity. What are the condition(s) for a non-zero S_G ? 6

3. (a) Describe the rotating crystal method for determining the structure of a crystal. Illustrate its principle using the picture of Ewald sphere. Explain whether the diffraction pattern for a single crystal consists of concentric rings? 5

(b) How diffraction from an amorphous solid is different from a crystalline solid? Starting directly with the Debye formula of scattered intensity, show how structure of an amorphous solid can be described by the radial distribution function *g(r)*. 7

UNIT–II

4. (a) Explain how the Pauli exclusion principle gives rise to a repulsive interaction at small spacing between inert gas atoms. 4

(b) Taking a cubic crystal with a monatomic basis, obtain and plot the dispersion relation for elastic waves along a symmetry direction. Illustrate the atomic displacements for the mode $k = \pm\frac{\pi}{a}$ (a is the lattice parameter). 8

5. (a) Define the term "density of lattice vibration modes" $D(\omega)$. Derive $D(\omega)$ in three dimensions, and then use it to calculate $D(\omega)$ in the Debye model, along with the calculation of Debye cutoff frequency. 6

(b) Take a one-dimensional crystal with inter-atomic potential energy $U(x) = cx^2 - gx^3 - fx^4$. Use the Boltzmann distribution function to calculate the average displacement of an atom. Comment whether thermal expansion can be understood by taking $g = f = 0$? 6

UNIT–III

6. (a) For a linear crystal, solve the central equation at and near the zone boundary using the two-component approximation. Plot the calculated energy bands along with a comparison with the free electron result. 8

(b) What do you understand by cohesive energy? Estimate it for sodium within the framework of Wigner-Seitz method. 4

7. (a) The tight binding method applied to a non-degenerate level yields the electronic energy as : 8

$$\varepsilon_k = -\alpha - \gamma \sum_m \exp\left(-ik.\rho_m\right).$$

(i) Use this result to calculate ε_k for a square lattice.

(ii) Show that ε_k is more at the corner of the zone than that at the midpoint of a side of the zone.

(iii) Calculate the number of Bloch orbitals in the calculated energy band. Under what conditions the bond can be fully filled.

(b) For a Bloch orbital $\psi_k(r) = e^{ik.r}u_k(r)$, show that $\psi_k(r) = \psi_{k+G}(r)$ and $\varepsilon_{k+G} = \varepsilon_k$. 4

UNIT–IV

8. (a) What is persistent current? Can you suggest a way to set up and measure the presence of such a current. 4

(b) Describe the main qualitative features of the BCS theory of superconductivity. Treating the superconducting state as a charged Bose gas, derive the London equation. 8

9. (a) Show that the magnetic flux associated with a superconducting ring is quantized. 6

(b) Describe the ac Josephson Effect and give a plausible theoretical explanation of the same. Discuss how this effect can be used to measure the precise value of $e/\hbar$. 6