No. of Printed Pages : 7 **MPH–012**

M. SC. (PHYSICS)
(MSCPH)
Term-End Examination
June, 2025

MPH-012 : CONDENSED MATTER PHYSICS

Time : 2 Hours *Maximum Marks : 50*

Note : *Attempt any* ***five*** *questions. You may use a calculator. Symbols have their usual meanings. Marks are indicated against each question.*

1. (a) What is a Bravais lattice ? List the different Bravais lattices for a cubic crystal system. What are the characteristics of its unit cell ? Draw the plane (110) for a cubic unit cell. 5

(b) Explain why X-rays are appropriate for probing crystal structure. Derive Bragg's condition for X-ray diffraction. At what angle will a diffracted beam emerge from the (110) planes of a cubic crystal with a unit cell length of 0.6 nm ? Assume that diffraction occurs in the first order and the wavelength of the X-rays is 0·150 nm. 5

2. Derive the dispersion relation for vibration of a chain of two different types of atoms, of masses m and M respectively. Hence explain the difference between the optical and acoustic branch of frequencies. 8+2

3. (a) What is the cohesive energy of a solid ? Derive the expression for equilibrium lattice energy for an ionic crystal. 5

(b) What are the free electron approximation and the independent electron approximation in the free electron theory of metals ? Starting from the equation of motion of the electron in the Drude model, derive the expression for the electrical conductivity of a metal. 5

4. (a) State Bloch's theorem for a system of electrons moving under the influence of a static periodic potential :

$$U(\vec{r} + \vec{R}) = U(\vec{r})$$

where $\vec{R}$ are the Bravais lattice vectors. 2

(b) Show that, for an electron moving through a one-dimensional periodic lattice of periodicity A, the following

wave function does not satisfy Bloch's theorem :

$$\psi = (x) = \mathrm{N} \exp\left[i\left(\frac{\pi x}{\mathrm{A}} + \cos \frac{\pi x}{2\mathrm{A}} \right) \right]$$

N is the normalization constant. 4

(c) What is the tight binding approximation for the one-electron wave function in the crystal ? How is the tight binding approximation different from the nearly free electron approximation ? 4

5. (a) Starting from the expression for the density of states $g(\varepsilon)$ per unit volume in a crystal :

$$g(\varepsilon) = \frac{4\pi(2m)^{3/2}}{h^3}(\varepsilon^{1/2})$$

derive an expression for the concentration of electrons in an intrinsic semiconductor at a temperature T. 5

(b) Explain the importance of determining the Fermi surface in metals. What is the de-Haas-Van Alphen effect ? How is it used to map the Fermi surface of metals ? 5

6. (a) Explain the different mechanisms of polarisation in materials. What are the polarisation mechanisms in NaCl ? 5

(b) The correction in the nth energy level (E_n) of an atomic electron in the presence of a magnetic field $\vec{B}$ upto first order in perturbation theory is given by :

$$\Delta E_n = \frac{e}{2m_e} < \phi_n \mid (\vec{L} + g\vec{S}) \mid \phi_n > . \vec{B}$$

$$+ \frac{e^2 B^2}{8m_e} < \phi_n \mid \sum_i (x_i^2 + y_i^2) \mid \phi_n >$$

Use this relation to derive the expression for the Larmor diamagnetic susceptibility of a solid. 5

7. (a) Describe using the help of diagrams, any *two* different types of exchange interactions that can give rise to spontaneous magnetic order. 5

(b) Starting from the following relation between entropy of a superconducting material in its normal and superconducting states (S_n, S_s) and the critical magnetic field (H_c) :

$$S_n - S_s = -\mu_o H_c \frac{dH_c}{dT}$$

derive the expression relating the specific heat of the superconductor in its normal and superconducting states. 5

8. (a) (i) Explain Meissner effect. Derive the value of the magnetic susceptibility of an ideal superconducting state. 3

(ii) What is persistent current ? 2

(b) Describe the structural and electrical properties of cuprate superconductors. Explain any *two* strategies that have been used to increase the critical temperature of cuprate semi-conductors. 5

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