No. of Printed Pages : 9 **MPH–012**

M. SC. (PHYSICS)

(MSCPH)

Term-End Examination

December, 2025

MPH–012 : CONDENSED MATTER PHYSICS

Time : 2 Hours *Maximum Marks : 50*

Note : *(i) Attempt any **five** questions.*

(ii) Symbols have their usual meanings.

(iii) You may use a calculator.

(iv) Marks for each question are indicated against it.

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1. (a) Explain all the different symmetries observed in a cubic crystal. 5

(b) The direct lattice vectors of a crystal lattice are $\vec{a}_1, \vec{a}_2, \vec{a}_3$. Write the expressions for the reciprocal lattice vectors. Show that the volume of the primitive cell in the reciprocal lattice space is inversely proportional to the volume of the primitive cell in the direct lattice. 5

2. (a) Explain the rotating crystal method of X-ray diffraction. State *one* advantage and *one* drawback of the neutron diffraction method as compared to the X-ray diffraction method. 5

(b) The potential energy function for a system of two atoms is expressed as $u(r) = -\frac{\alpha}{r} + \frac{\beta}{r^8}$, where r is the interatomic distance, α and β are constants. Calculate the interatomic distance at which the potential energy is a minimum. Show that in the stable configuration the energy of attraction is eight times the energy of repulsion. 5

3. (a) What are phonons ? Derive the expression for the phonon density of states in a one-dimensional chain of length L with N atoms, and interatomic separation a. 5

(b) Metallic sodium is monovalent and crystallizes in a bcc structure with a lattice constant of 4.25 Å. Calculate the number density of electrons and the Fermi energy at 0 K. Use $\hbar = 1.054 \times 10^{-34}$ Js and $m_e = 9.1 \times 10^{-31}$ kg. 5

4. (a) Write the wave function for the electron in a periodic potential in the Tight Binding Approximation. Show that this wave function satisfies the Bloch Theorem. 5

(b) Starting from the energy dispersion relation $E_{\vec{k}} = E_i - \alpha - \beta \sum_p e^{i\vec{k}.\left(\vec{R}_q - \vec{R}_p\right)}$ for the s-band, where α and β are constants and the summation is overall $\vec{R}_p$ for nearest neighbour sites of the atom located at $\vec{R}_q$, derive the band energy dispersion for the s-band in the primitive cubic cell. 5

5. (a) What is the semi-classical model for studying the motion of electrons in bands ? Show that the velocity of the electron in the nth band can be written as : 5

$$\vec{v}_n(\vec{k}) = \frac{1}{\hbar}\vec{\nabla}\left[\varepsilon_n\left(\vec{k}\right)\right]$$

(b) Derive the expression for the variation of the Fermi energy with temperature in an intrinsic semiconductor. 5

Use the following expressions for the electron and hole concentrations :

$$n_h = \mathrm{N}_v \exp\left[\frac{-\left(\varepsilon_\mathrm{F} - \varepsilon_\mathrm{V}\right)}{k_\mathrm{B}\mathrm{T}}\right],$$

$$n_e = \mathrm{N}_c \exp\left[\frac{-\left(\varepsilon_c - \varepsilon_\mathrm{F}\right)}{k_\mathrm{B}\mathrm{T}}\right]$$

where N_c and N_v are the effective density of states in the conduction and valence band respectively. Where is the Fermi level located at $T = 0$?

6. (a) Starting from the Lorentz relation between the molecular field $\vec{E}_m$ and the total macroscopic field in a dielectric $\vec{E}$:

$$\vec{E}_m = \vec{E} + \frac{\vec{P}}{3\varepsilon_0},$$

Show that the polarization $\vec{P}$ can be written as :

$$\vec{P} = \frac{N\alpha\vec{E}}{1 - \dfrac{N\alpha}{3\varepsilon_0}}$$

where N is the number of molecules/volume. Hence show that the polarisability α and the dielectric constant K are related as : 5

$$K = \frac{1 + \dfrac{2N\alpha}{3\varepsilon_0}}{1 - \dfrac{N_\alpha}{3\varepsilon_0}}.$$

(b) Explain the origin of Van Vleck paramagnetism and Curie paramagnetism in solids. How does the Curie paramagnetic susceptibility vary with temperature ? 5

Using Hund's rules, calculate L, S and J for M_n given the electronic configuration :

$$M_n : 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4d^5 .$$

7. (a) Define the molecular field in a ferromagnet. Write the Heisenberg-Hamiltonian for a ferromagnet in the presence of a magnetic field in terms of the molecular field. Explain on the basis of the hysteresis curve, what are hard and soft magnetic materials. 5

(b) Define the critical magnetic field for a superconductor. The critical field for superconducting Niobium is 10^5 Am^{-1} at 8 K and 2×10^5 Am^{-1} at 0 K. Calculate the transition temperature. 5

8. (a) What are the assumptions of the Ginzburg-Landau's theory ? How does

the Ginzburg-Landau's theory describe the phase transition from the superconducting to the normal phase of a superconductor ? 5

(b) Describe any *two* applications of high T_c superconductors. 5

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