2022

PHYSICS

Paper : PHY-512

(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.

Symbols have their usual meaning.

Answer ***any five*** questions.

1. (a) Determine the $\left(\frac{c}{a}\right)$ ratio of HCP structure. Calculate the bond angle between carbon atoms in a diamond lattice. Determine the number and positions of tetrahedral sites in an FCC crystal.

   (b) Show that $\sum_m e^{-i\Delta\vec{k}.\vec{r}_m}$ will exist only if $\Delta\vec{k}$ is equal to the reciprocal lattice vector.

   (c) Write down the expression of geometric scattering factor for diamond lattice. Hence determine the *hkl* combination for which diffraction lines will be present. (2+2+1)+2+3

2. (a) Show that in dipolar dispersion, polarizability satisfies the relation

$$\sigma_d(\omega) = \frac{\sigma_d(0)}{1 - i\omega\tau},$$

   where symbols have their usual meanings. Plot the real part of dielectric function with imaginary part for Debye-type dipolar excitation. Hence establish a relation between the real and imaginary parts.

   (b) Derive Lyddane-Sachs-Teller (LST) relation. Hence discuss its application in the context of ferroelectric transition. Draw the temperature variation of spontaneous polarization with temperature for first-order ferroelectric transition. (3+2)+(2+2+1)

3. (a) Derive Bloch's equations in context with the nuclear magnetic resonance. Hence interpret the relevant relaxation time(s).

   (b) Explain the effect of 90° pulse in the Fourier Transform spectroscopy of NMR.

   (c) Write down the spin Hamiltonian corresponding to the magnetic resonance. Explain each term contained in the spin Hamiltonian. 5+2+3

4. (a) Prove that the total magnetic flux that passes through a superconducting ring may assume only quantized values.

(b) Show that in a superconducting state, there exists a two-electron bound state, whose energy is lower than that of the fully occupied Fermi sea ($T = 0$).

(c) A superconducting lead has a critical temperature of 7.26K at zero magnetic field and a critical field of 8×10^5 A/m at 0K. Find the ciritical field at 5K. 3+5

5. (a) Explain why transparent KCl crystals, on heating in an atmosphere of potassium vapour, acquire a violet tinge.

(b) Derive an expression for the Pauli paramagnetic susceptibility.

(c) Briefly discuss (no derivation required) the role of anisotropy energy in a ferromagnetic sample in deciding the width of a domain wall.

(d) MnS is an antiferromagnetic crystal. Its susceptibility at temperature 240K is double of its susceptibility at 640 K. Assuming that the mean-field treatment of antiferromagnetism gives exact results, calculate the Néel temperature of MnS. 2+4+2+2

6. (a) Consider an alloy Cu_3Au that forms an FCC lattice, consisting of $4N$ sites and 4 interpenetrating sublattices : α, β, γ and δ. There are N number of Au atoms and $3N$ number of Cu atoms. In the ordered phase, all the gold atoms occupy α sublattice, and copper atoms occupy the other three sublattices. The sublattices β, γ and δ are always equivalent in the system, i.e., the ratio of the number of copper and gold atoms are same in all three of them.

(i) Construct a parameter P that measures the long-range-order in the system.

(ii) Calculate the entropy of the system in terms of P and N.

(b) Using Boltzmann transport equation, find an expression for the electrical conductivity of a metal. (2+3)+5

7. (a) Consider a system of nearly free electrons in 1-dimension in a weak periodic potential $V(x) = V_0 \cos(2\pi x/a)$. Applying degenerate perturbation theory, calculate the eigenstates $|\Psi_+\rangle$ and $|\Psi_-\rangle$ at $k = \pm\pi/a$. Hence argue that it would lead to the opening of an energy gap at the zone boundary.

(b) In the light of band theory, explain why a monovalent alkali metal like Sodium has a high electrical conductivity.

(c) The normal mode ω of a one-dimensional monoatomic chain is given by

$$\omega = \sqrt{\frac{4C}{M}}\left|\sin\left(\frac{ka}{2}\right)\right|.$$

Calculate the group velocity. Show that at the zone-boundary, it represents a standing wave. (4+2)+2+2