

Roll No.

Total Pages : 5

CMDQ/D-23

5120

CONDENSED MATTER PHYSICS

Paper-PHY-303-A

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. Answer the following questions :

- (a) If an electron is excited from an orbital k_e of valence band into the conduction band, show that wave vector and energy of hole are, respectively : $k_h = -k_e$, $\varepsilon_h(k_h) = -\varepsilon_e(k_e)$. Using this information, draw the valence and hole bands. 3
- (b) Dispersion relation for electromagnetic waves in a medium is : $\varepsilon(\omega, k)\omega^2 = c^2 K^2$. Deduce conditions for propagation and damping of *em* waves through the medium. 3
- (c) Distinguish between displacive and order-disorder class of ferroelectrics. Give at least one example for each class. 3

- (d) Consider a 1D ferromagnetic solid within the framework of Heisenberg model $\hat{H} = -2\sum_{i,j} J_{ij}\hat{S}_i\cdot\hat{S}_j$. Treating spins as classical vectors and including only the nearest neighbor interaction calculate energies of the ground state and the state with two consecutive spins reversed. 3

UNIT-I

2. (a) Draw suitable ε vs. k diagrams for a direct and an indirect band gap semiconductor. Why a direct photon absorption at the energy of minimum gap is not possible in an indirect band gap semiconductor? 4
- (b) Develop equation of motion for an electron in an energy band, and use it to obtain the trajectory of electron in k -space in the presence of an external static homogeneous magnetic field B . Under what condition the trajectory can be a circle? 6
- (c) An electron may have a negative value of effective mass near the top of energy band. What is the physical interpretation of negative effective mass? 2
3. (a) Consider that a two-dimensional electron gas is subjected to a strong (static and homogeneous) magnetic field B at $T = 0K$. Taking $N = 50$ and $\rho = 0.5$, show graphically the number of electrons in completely and partially occupied Landau levels, electronic energy, and magnetic moment as a function of $100/B$. What is the practical utility of these plots? 8

- (b) State the Integral Quantized Hall Effect (IQHE), along with the illustrative plots of the potential drop (in the direction of current flow) and the Hall voltage as a function of gate voltage at a fixed transverse magnetic field and low temperature. 4

UNIT-II

4. (a) What are longitudinal plasma oscillations and plasmons? Determine the plasma oscillation frequency in the long wavelength limit. Outline the principle involved in experimental measurement of plasmons. 6
- (b) Let us consider that a (point) positive charge q is held fixed in a sea of conduction electrons. Show that the screened coulomb potential in the Thomas-Fermi approach is given by : $\phi(r) = \frac{q}{r} \exp(-k_s r)$, where k_s is the Thomas-Fermi screening length. 6
5. (a) Define the terms reflectivity coefficient $r(\omega)$ and optical reflectance $R(\omega)$. Develop the Kramers-Kronig relations to show how $r(\omega)$ can be completely specified from the experimental knowledge of $R(\omega)$. 6
- (b) What are excitons? Differentiate between Frenkel and Mott-Wannier excitons. Calculate the ionization energy of Mott-Wannier exciton by treating it like an atom of hydrogen. 6

UNIT-III

6. (a) How macroscopic electric field is different from local electric field at the site of an atom in a dielectric substance. Work out various contributions to the local electric field at a general lattice site. 8
- (b) Find the frequency dependence of the electronic polarizability of an electron having the resonance frequency ω_0 , treating the system as a simple harmonic oscillator. 4
7. (a) Explain the origin of spontaneous electric polarization (P_s) in BaTiO_3 by drawing its crystal structure below and above the Curie temperature. Given that the volume of unit cell is $64 \times 10^{-24} \text{ cm}^3$ and P_s at room temperature is $8 \times 10^4 \text{ esu cm}^{-2}$, estimate the order of displacement of positive ions with respect to negative ions in BaTiO_3 . 8
- (b) What are ferroelectric domains? Explain in brief their microscopic origin? 4

UNIT-IV

8. (a) Develop a quantum-mechanical formulation using the perturbation method to calculate the atomic magnetic susceptibilities, and apply it to estimate the magnetic susceptibility of a solid composed of N ions with all electronic shells filled. 8

- (b) Illustrate energy-level splitting for an electron in a magnetic field B directed along positive z axis, and use it to deduce and plot the fractional populations N_1/N and N_2/N as a function of $\mu_B B/k_B T$ for a (two-level paramagnetic solid). 4
9. (a) Explain what are spin waves and magnons? How can these be created and detected? Calculate the average number of magnons in a ferromagnetic substance in thermal equilibrium and use it to obtain the fractional change in magnetization with rising temperature. 8
- (b) What are ferromagnetic domains? Explain the mechanism that leads to the formation of domains. How do they reflect in the technical magnetization curve? 4