B Sc Physics 3rd Year 1st Semester Special Supplementary Examination 2024

Paper: DSE 01 A2

(Condensed Matter Physics)

Time: Two hours — Full marks: 40

(20 marks for each group)

Use separate answerscripts for each group.

Group A

Answer any TWO questions.

$2 \times 10 = 20$

1. What do you mean by lattice? How it is different from a crystal? Define a primitive unit cell. What is Wigner Seitz cell? Describe with proper diagram the tetragonal crystal structure. How many rotational symmetry axis and mirror symmetry planes are possible in a cube? Draw all the possible 3-fold rotational axis. [CO1] [1+1+1+1+2+1+3=10]

2. If the position coordinate of an element is (x, y, z) then what will be its position coordinate after mirror operation where mirror plane is perpendicular to x-axis, explain with proper drawing. Differentiate between point group and space group. Draw and explain Screw symmetry. Explain with proper diagram and calculations why 5-fold symmetry is not permissible in symmetry of lattice system? [CO1] [2+2+2+4=10]

3. Starting from Bragg's equation explain in details with proper drawings how to construct an Ewald sphere? What are the classifications of nanomaterials based on their dimension? What are the unique characteristics of nanomaterials.. Explain why nanoparticles are more reactive compared to their bulk counterpart? [CO2] [5+1+2+2=10]

Group B

Answer any TWO questions.

$2 \times 10 = 20$

1. Consider a one dimensional Bravais lattice with diatomic basis in which the masses of two atoms are the same, M and where the nearest neighbours interact alternately through the spring constants $\mathcal{K}$ and $\mathcal{G}$ such that the total potential of the system is

$$V_{\text{Harm}} = \frac{\mathcal{K}}{2}\sum_n \left(\mathrm{u}_n^{\mathrm{A}} - \mathrm{u}_n^{\mathrm{B}}\right)^2 + \frac{\mathcal{G}}{2}\sum_n \left(\mathrm{u}_n^{\mathrm{B}} - \mathrm{u}_{n+1}^{\mathrm{A}}\right)^2.$$

Symbols have their usual meaning.

(a) Solving the corresponding equation of motion, show that the dispersion relations are

$$\omega_\pm^2 = \frac{\mathcal{K}+\mathcal{G}}{M} \pm \frac{1}{M}\sqrt{\mathcal{K}^2 + \mathcal{G}^2 + 2\,\mathcal{K}\mathcal{G}\cos(\mathrm{k}a)}.$$

(b) Draw the dispersion curves.

(c) Find the expression of band gap (value of minimum separation between the two curves).

(d) When $\mathcal{K} = \mathcal{G}$, compare the dispersion relations with that of the one dimensional Bravais lattice with mono atomic basis. Discuss how two branches (acoustic and optical) in the first Brillouin zone of the diatomic basis do collapse into a single (acoustic) branch in the first Brillouin zone of the mono atomic basis.

[CO3] [5+1+1+3=10]

2. (a) Prove the Sommerfeld expansion,

$$\int_0^\infty f(E)\,\frac{\partial F}{\partial E}\,dE = F(E_F) + \frac{\pi^2}{6}\,(k_B T)^2 \left(\frac{\partial^2 F}{\partial E^2}\right)_{E_F},$$

where $f(E)$ is the Fermi-Dirac distribution function and $F(E)$ is a regular function and such that $F(0) = 0$.

(b) By using the density of states, $g(E) = \frac{3}{2} n(E_F(0))^{-\frac{3}{2}}\sqrt{E}$, and Fermi level

$$E_F(T) \approx E_F(0)\left[1 - \frac{\pi^2}{12}\left(\frac{T}{T_F}\right)^2\right],$$

for the three-dimensional free electron systems, derive the expression of Pauli paramagnetic susceptibility at finite temperature, $\chi_P(T)$. Symbols have their usual meanings. [CO4] [4+6=10]

3. (a) State the assumptions in the formulation of Drude model.

(b) Consider the heat conduction through an insulated solid rod of uniform cross section. Now finding the net energy flux from hot to cold end obtain the expression of thermal conductivity for a three-dimensional body;

$$\kappa = \frac{1}{3} v_{\text{rms}}^2 \tau \, C_{\text{V}},$$

where the symbols have their usual meaning.

(c) Using the expression of dc electrical conductivity,

$$\sigma_0 = \frac{ne^2\tau}{m},$$

describe the Wiedemann-Franz law. [CO4] [3+5+2=10]