Five Year Integrated M.Sc. Examination, 2019

Semester - VIII

Course: PH-4-8-1

(Physics: Material Science)

Time: Four Hours **Full Marks: 80**

Questions are of value as indicated in the margin.
Answer ***Question No.1*** and ***any four*** from the rest.

1. Answer **any five** questions: $4 \times 5 = 20$
   (a) How does the defects in crystal affect the conductivity of a perfect ionic solid. Explain with diagram.
   (b) Briefly explain the basic ideas of Born-Oppenheimer approximation.
   (c) Define density of states. Calculate density of states for free electron gas confined in two dimensions.
   (d) Physically explain the phenomenon of electronic heat transport from high temperature region to low temperature region.
   (e) Using equipartition theorem prove Dulong-Petit Law.
   (f) Physically explain the idea of Born-Oppenheimer approximation.
   (g) Explain the origin of color center in a crystal with diagram. Why does it called color center?

2. (a) What are point defects in solids? Define different kinds of point defects with appropriate diagrams.
   (b) Suppose there are n number of vacancies at temperature T within a crystal containing N number of ions. Calculate the the number of possible ways of arranging the vacancies within the crystal.
   (c) Hence minimizing the Gibbs free energy of the crystal, calculate the thermal average of the number of vacancies $(\bar{n})$ within the crystal at temperature T. (2+4)+4+5=15

3. (a) Consider a uniform monatomic one dimensional crystal lattice with lattice spacing a. Obtain the equations of motion of an ion in the lattice. Show that the trial solution used for solving these equations of motion, satisfies Bloch theorem.
   (b) Assuming periodic boundary condition find out the first Brillouin zone for the aforesaid lattice system.
   (c) Hence calculate the dispersion relation and plot the dispersion curve. (3+2)+3+7=15

4. (a) Consider a classical diatomic lattice consists of two types of ions (A and B types) with masses M_A and M_B respectively. Write the equations of motion for both types of ions assuming uniform force constant k and inter-ionic spacing a.
   (b) Choosing appropriate trial solutions, show that non-trivial solutions for the equations of motion exist provided normal mode's frequencies are given by

   $$\omega^4 - 2\omega^2(k_1 + k_2) + 4k_1k_2\sin^2(qa) = 0,$$

   where $k_1 = k/M_A$, $k_2 = k/M_B$ and q is wave vector.
   (c) Draw the dispersion relations for acoustic mode and optical mode. 3+9+3=15

5. (a) Calculate specific heat of a solid according to the Einstein's theory.
   (b) Show that at high temperature limit, Einstein's theory of specific heat reproduces classical Dulong Petit law. 10+5=15

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6. (a) What are the limitations of Einstein's theory.

   (b) Briefly explain the modification in Einstein's theory adopted by Debye.

   (c) Calculate the density of states of phonon in three dimension according to the Debye theory and show that it can be written as

$$g^D(\omega) = A\omega^2\Theta(\omega_D - \omega),$$

   where A is a constant for a particular solid and ω_D is Debye cut-off frequency.

   (d) Calculate ω_D in terms of number of atoms (N) in a lattice.

   (e) Hence show that the specific energy i.e. energy per unit volume varies as $\sim T^4$ with temperature (T). 2+2+3+3+5=15

7. (a) Consider a one-dimensional conductor extended along x-direction. Electrons inside it allowed to move along the x-axis only. Hence prove that in steady state the thermal current flowing towards x-direction has a magnitude

$$j^q = -\kappa\frac{dT}{dx},$$

   where dT/dx is the temperature gradient along x-axis and thermal conductivity, $\kappa = \frac{1}{3}v^2\tau c_v$, where v^2 is mean square electronic speed, τ mean free time and c_v is the electronic specific heat.

   (b) Clearly state the assumptions one need to adopt to derive the aforesaid expression.

   (c) Calculate dc electrical conductivity (σ) of electron gas using Drude model.

   (d) Show that the ratio of thermal conductivity and electrical conductivity varies linearly with temperature. 6+2+5+2=15