M. Sc (Physics) (Under CBCS), Third semester Examination, 2021
PHY 512: Solid State Physics

Full marks: 50 Time 2.5 hrs

(2 hours for answering and 30 minutes for downloading, scanning, and mailing back)

Important instructions. Please read carefully.

(i) For the theory papers, the students will receive the papers (pdf file) by e-mail. The students should send back a single scanned pdf file of the answer script to the e-mail from which they received the paper. The return mail should preferably be sent from the e-mail, in reply mode, to which the question paper was delivered.

(ii) Please write your complete Examination Roll Number (with college code and subject category) and Registration Number (from an earlier admit card)at the top of your answer script. They should be clearly legible. Do not write your name or class roll number anywhere.

(iii) The answer script file for the paper PHYAAA(where AAA is the paper code like 511, 522, and so on)must be named as instructed: Note that your Examination Roll Number is of the form ZZZ/PHY/XXXXXX, where ZZZ is the college identifier (like C91, 031, etc.), and XXXXXX is a 6-digit number like 201099.

— For CU students, the filename for the paper PHYAAA must be CUXXXXXXPHYAAA.pdf. For example, the script of PHY511 coming from C91/PHS/201099 must be namedCU201099PHY511.pdf.

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Answer any **five** questions.

1. (a) What is the essential difference between the nearly free electron model and tight binding approximation for an electron in a periodic potential? Both are extremely simplified models, so how do you justify the existence of bands from these theories?

   (b) If you regard the periodic potential as a perturbation for an otherwise free electron, what is the effect of first order perturbation on the energy?

   If you apply second order perturbation theory, what happens at the Bragg plane?

   (c) Show that for a partially filled band, the total current density can be attributed to holes.

   (2+2)+3+3

2. (a) How do the Debye theory and Einstein theory, in the context of heat capacity of phonons, differ in terms of assumptions and results? (No derivation required)

   (b) Find the density of states for phonons in two dimensions. Hence, using the Debye theory, show that the phonon heat capacity of a two dimensional crystal is proportional to T^2.

   4+(2+4)

3. (a) Consider the BCC lattice as two interpenetrating simple cubic lattices C_1 and C_2 which are occupied by two types of molecules A and B. Number of molecules for both A and B is N. The number of A type molecules on C_1 is given by $\frac{1}{2}(1+P)N$.

   Calculate the free energy of the system in terms of P, N and the interaction strengths between the different components.

   (b) The Hamiltonian for N electrons in presence of a magnetic field $\vec{B}$ can be written as

$$H = \frac{1}{2m}\sum_i^N p_i^2 + \mu_B(\vec{L} + g_0\vec{S}).\vec{B} + \frac{e^2}{8mc^2}\sum_i^N (x_i^2 + y_i^2)B^2$$

   (All other symbols carrying usual significance)

   What kind of susceptibility is dominating in the following three cases?

   (i) $L = 1, \quad S = 1/2$
   (ii) $L = 1, \quad S = 1$
   (ii) $L = 0, \quad S = 0$

   4+6

4. (a) Find an expression for the temperature dependence of magnetic susceptibility for a ferrimagnetic sample in the mean field approximation. Does the antiferromagnetic susceptibility show a divergence?

(b) State and explain the line broadening mechanism in NMR. What do you mean by motional narrowing?

(3+2)+5

5. (a) What are the differences between the Laue and Bragg diffraction theories of X ray diffraction by a crystal?

(b) Calculate structure factor S_G for a BCC lattice. Identify the planes from which diffraction peaks can be observed for the following examples
(i) (100) (ii) (200) (iii) (111) (iv) (211).

(c) Explain with diagram the characteristics of the radial distribution function for an amorphous material.

(d) Draw the first and second Brillouin zones of a square lattice.

2+4+2+2

6. (a) What do you mean by the flux quantization in a superconducting ring? Show that the quantum of flux ϕ_0 is inversely proportional to the charge of a Cooper pair.

(b) Establish the phenomenon of interference of currents through a pair of Josephson junctions connected in parallel.

(c) Calculate the frequency of the AC field produced when a DC voltage of $5\mu V$ is applied across a Josephson junction.

(1+3)+3+3

7. (a) Write down the Landau free energy expansion for the second order ferroelectric transition. Determine and plot the temperature dependence of the inverse susceptibility above and below the critical temperature.

(b) What is molecular polarizability? Show that the polarizability due to permanent dipole moment of a molecule is $(\mu^2/3kT)E$. The symbols have their usual meanings.

(c) State and explain the Lyddane-Sachs-Teller relation for the polarization in a dielectric.

4+4+2