SPH 401: SOLID STATE PHYSICS

INSTRUCTIONS:

1. Question one is compulsory
2. Attempt **Question one** and **any two** questions. Question 1 carries 30 marks, the rest carry 20 marks each. Marks will be awarded for clearly worked out solutions.

1. a) i) State the **statistics** used to describe the following in a system:
- distinguishable particles
- indistinguishable particles with half integral spins
- indistinguishable particles with zero/ integral spins (3 marks)

ii) What are the limitations of the free electron model? (3 marks)

b) i) The **energy of crystals is quantized**, Explain? (3 marks)

ii) If the energy of an electron in a box is assumed to be entirely kinetic, show that this implies that momentum is quantized. (3 marks)

c) i) Why is the Debye model for specific heat capacity of solids preferred over Einstein's model? (4 marks)

ii) What is meant by Larmor frequency? (2 marks)

d) i) Differentiate between an n-type and p-type semiconductor. (4 marks)

ii) What is Fermi-energy of a metal? (2 marks)

e) i) Which law is represented by the expression: $\chi_m = \frac{C}{T}$? Explain the meaning of the symbols in the law. (4 marks)

ii) Explain superconductivity occurs with direct rather than alternating current. (2 marks)

Q2. a) i) Assuming a free electron model, write down the Schrodinger equation for this problem and obtain the general solution to the problem by setting the correct boundary conditions, given that the distance between the walls is L. (6 marks)

ii) Obtain the expression for the energy eigen values. (6 marks)

b) The energy of N oscillators in the Einstein's model of specific heat capacity of a solid is given by $E = N\langle n\rangle\hbar\mu$ where $\langle n\rangle$ is the Bose-einstein distribution function, show that the heat capacity at constant

volume is given by

$$C_v = 3Nk_B(\ \hbar\mu)^2 \frac{e^{\ \hbar\mu}}{(e^{\ \hbar\mu}-1)^2} \qquad \text{(8 marks)}$$

(Assume each of the atoms N has 3N degrees of freedom)

Q3. a) i) Derive the density of states in the form

$$°(E) = \frac{V}{2®^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2} E^{1/2} \qquad \text{(6 marks)}$$

ii) Using the density of states equation above show that the kinetic energy of a three dimensional gas containing N free electrons at 0 K is given by

$$U_o = \frac{3}{5}NE_F \qquad \text{(6 marks)}$$

b) Briefly describe the following techniques of growing crystals:

i) liquid phase epitaxy
ii) vapor phase epitaxy
iii) molecular beam epitaxy
iv) chemical beam epitaxy (8 marks)

Q4. a) i) Obtain an expression for the electrical conductivity of a free electron gas placed in an alternating electric field given by $Ee^{-i\mu t}$ (4 marks)

ii) What is the value of the Hall constant for a sample of p-type germanium of conductivity $100\Omega^{-1}m^{-1}$ (Take $«_e = 0.39m^2V^{-1}s^{-1}$ and $«_h = 0.19m^2V^{-1}s^{-1}$ for germanium) (3 marks)

iii) Explain how magnetism is caused in a material? (4 marks)

b) Distinguish between the following magnetic properties

i) diamagnetism
ii) paramagnetism
iii) ferromagnetism (9 marks)

Q5. a) i)What is superconductivity? (2 marks)

ii) Distinguish between type **I** and type **II** superconductors. (2 marks)

b) i) Show that the total magnetic moment of an atom/ ion is given by

$$« = g«\ J$$

where g is the splitting factor, « is Bohr magneton and J is the

total angular momentum of the electronic system (4 marks)

ii) Show that $B = «_o «_r H$ where $«_r = 1 + ¡_m$ where the symbols have their usual meanings. (6 marks)

c) Outline the conditions under which magnetic resonance occurs and hence explain what happens in solids with weak phonon interactions. (6 marks)