NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHYSICS DEPARTMENT

SOLID STATE PHYSICS - SPH 2202

EXAMINATION

BSc HONOURS PART II : DECEMBER 2004 *DURATION : 3 HOURS*

ANSWER ALL QUESTIONS IN SECTION A AND ANY THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS

SECTION A

1. (a) Explain the differences, if any, between the following:

(i) a polycrystalline material and an amorphous material;
(ii) a Bravais lattice and a real crystal lattice [5]

(b) Distinguish between (i) Schottky and Frenkel defects; and (ii) edge dislocation and screw dislocation.

State which physical properties will be affected by each type of defect. [6]

(c) Compare the *direct* and the *reciprocal lattice* of a crystalline substance and show how their vectors are related. What is the purpose of the reciprocal lattice? [6]

(d) Name and briefly describe the two branches of the dispersion relation $\omega(k)$ for a diatomic linear chain. How can such vibrational modes be excited in an actual crystal structure? [5]

(e) Explain the concept of *a phonon*. Give its characteristic properties as compared to those of *a photon*. [6]

(f) List three electron emission phenomena in metals and briefly discuss one of them. [5]

(g) Distinguish between *intrinsic* and *extrinsic* semiconductors and discuss the phenomenon of electric conductivity in anyone of the two types of semiconductors. [7]

SECTION B

2. (a) Write down the following for the $NaCl$ structure:
   (i) the Bravais lattice;
   (ii) the coordination number of the Na^+ and Cl^- ions;
   (iii) the fractional coordinates of the Na^+ and the Cl^- ions in a unit cell of the structure. [6]

   (b) Draw the following planes and directions each in a cubic crystallographic system: **(1 0 1)** **(2 2 1)** **[0 1 1]** **[2 0 1]** [6]

   (c) The packing ratio is defined as the total volume of the unit cell that is filled by atoms. Determine the maximum value of this ratio for equal spheres located at the lattice points of simple cubic; bcc and fcc crystals. [8]

3. (a) In a structure determination experiment neutrons of kinetic energy 10^{-1} eV are incident on a magnetic crystal. Explain briefly whether or not the experiment would be able to resolve all details of the crystal structure. [5]

   If instead of neutrons in the above experiment X-rays of energy 10^4 eV were used, would the experiment prove equally successful? [3]

   (b) Write down an expression for 'Bragg's equation' and define all terms in it. Explain why Bragg's diffraction condition for X-ray diffraction is in itself not completely satisfactory for the determination of crystal structures. [6]

   (c) Describe in detail any method you know for determining the structure of crystalline materials. [6]

4 (a) Define the following terms used in the theory of lattice dynamics, giving an expression where appropriate:

   (i) normal lattice mode, [3]
   (ii) phonon density of states, [3]
   (iii) Debye temperature. [3]

   (b) Derive an expression for the phonon contribution to the specific heat of a solid $\mathbf{c}_v^P$, according to Debye's theory, and show schematically how $\mathbf{c}_v^P$ varies with temperature. [11]

5. (a) Define the term *Fermi surface* of a solid. Why is the study of *Fermi surface* so important in the theory of solids? [6]

(b) Sketch the Fermi surface of the free electron gas in a metal according to quantum theory. [4]

(c) Given that the electrons in a metal satisfy Fermi - Dirac distribution law, write down the expression for the occupational probability f(E) and sketch the function for temperatures T = 0K and T > 0K. [4]

(c) The electron gas in a metal at 0K is characterized by a density of states function

$$g(E) = 4\pi \left(2m_e / h^2 \right)^{3/2} E^{1/2}$$

Use the above expression to calculate the value for the Fermi energy E_f, if the total number of electrons per cubic meter is 10^{28}. [6]

6. (a) On the basis of the free electron theory of solids, derive an expression for the electrical conductivity of a metal in terms of the electron concentration N and the electron mobility μ of electrons having a charge e. [8]

(b) Draw labeled diagrams showing the first three bands of the E versus k curve for a linear lattice, according to the band theory of solids in the following schemes of representations :

(i) the extended zone scheme ;

(ii) the reduced zone scheme;

(iii) the periodic zone scheme. [6]

(c) What is the energy span of the first three allowed bands in the extended zone scheme? [6]