NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHYSICS DEPARTMENT

SPH 2208 SOLID STATE PHYSICS I

SUPPLEMENTARY EXAMINATION

BSC HONOURS PART II : JULY 2001 DURATION : 3HOURS

ANSWER ALL PARTS OF QUESTIONS 1 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 terms:

(i) a polycrystalline material and an amorphous material; [3]

(ii) a Bravais lattice and a real crystal lattice. [3]

(b) The *packing ratio* is defined as the total volume of the cell that is filled by atoms. Determine the maximum value of this ratio for equal spheres located at the points of simple cubic; *bcc*, and *fcc* crystals. [6]

(c) List three types of defects observed in real crystals and illustrate them with appropriate sketches. [6]

(d) Explain briefly why Bragg's diffraction condition for X-ray diffraction is in itself not completely satisfactory for the determination of crystal structures. [6]

(e) Discuss the fundamental differences between the election gas of quantum theory and the ideal gas of kinetic theory in respect of quantization and distribution. [6]

(f) Show that the electron contribution to the specific heat of a metallic solid at temperature T is given by $c_v^{el} = \frac{3}{2}(Rz)$, where R is the universal gas constant and z is the total number of free electrons. [5]

(g) Explain the concept of a *phonon*. Give its characteristic properties as compared to *photon*. [5]

SECTION B

2 (a) Name and write the expressions of the two types of interactions in ionic crystals. Write down the total potential energy function, U_t and sketch the graph of $U(r)$ *vs* r, the separation of the ions. [6]

(b) The potential energy of an ionic crystal containing N ions of each type can be given by the Born-Meyer quantitative theory as:

$$U(r) = N(z\lambda e^{-\frac{r}{\rho}} - \frac{\alpha q^2}{4\pi\varepsilon_0 r})$$

(i) Define all terms in the above equation; [3]

(ii) Determine the equilibrium inter-ionic distance, r_o for that crystal. [6]

(c) Define the *Madelung constant*, give a general expression for it and explain its physical meaning. [5]

3 (a) Discuss the vibrational motion of the atoms in a monoatomic linear chain when an elastic wave of wavevector k is propagating in the crystal. Write down the equation of motion of the atoms. [6]

(b) Obtain the dispersion relation $\omega(k)$ between the lattice vibrations frequency ω and the wave vector k. Illustrate this relation graphically and comment briefly. [10]

(c) On the same graph indicate the boundaries of the first Brillouin zone and explain its physical meaning. [4]

4 (a) Compare the approximatious made in the Einstein model and the Debye model for determination of the phonon heat capacity of a solid. [6]

(b) Given the expression for the total thermal energy in a solid, according to Debye's model

$$U = 9Nk_BT\left(T/\theta_D\right)^3 \int_0^{x_D} \left[\frac{x^3}{e^x - 1}\right] dx$$

where $X_D = \frac{h\omega_D}{kT}$

(i) Explain the meaning of the term "Debye temperature". [4]

(ii) Discuss the high and low temperature limits of the thermal energy U above, deriving the expression for the specific heat, C_v in each case.

(Hint: $\int_0^\infty \left[\frac{x^3}{e^x - 1}\right] dx = \frac{\pi^4}{15}$) [10]

5 (a) Write down the basic assumption of the free electron theory. [6]

(b) A metal crystalline specimen is maintained at OK. Use the electron density of states

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

to deduce expressions for:

(i) the number of electrons $N(E)$ lying in the range E and $E + dE$; and [4]

(ii) the Fermi energy level E_F [4]

(c) Given that the electrons satisfy the Fermi – Dirac distribution statistics, Write down the expression for the occupation probability $f(E)$ and sketch the function for $T = 0K$ and $T > 0$. [6]

6 (a) Discuss the phenomenon of conduction of electricity in:

(i) conductors; (ii) insulators; and (iii) semiconductors,

using the Band theory of solids. [15]

(b) The inter-atomic distance in most metals is of the order of 4Å. Calculate the width of the conduction band, of a typical metal. [5]

END OF EXAM PAPER