NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHYSICS DEPARTMENT

SPH 2202 – SOLID STATE PHYSICS

EXAMINATION

BSC HONOURS PART II: MAY 2003 DURATION: 3 HOURS

ANSWER ALL PARTS OF QUESTION 1 IN SECTION A AND ANY THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.

Planck's Constant	$h = 6.63 \times 10^{-34}$ Js
Boltzmann's Constant	$k = 1.38 \times 10^{-23}$ JK^{-1}
Speed of light	$c = 3.00 \times 10^{8}$ ms^{-1}
Charge on an electron	$e = 1.60 \times 10^{-19}$ C
Mass of an electron	$m_e = 9.10 \times 10^{-31}$ kg
Electron Volt	$1\ eV = 1.60 \times 10^{-19}$ C
Atomic mass unit	$1u = 1.66 \times 10^{-27}$ kg
Atomic weight for	Na = 23.9 a. m. u.
	Cl = 35.5 a. m. u.

SECTION A

1. (a) A plane in a cubic crystal cuts the principal axis at points $\frac{a}{2}$, b and 3c.

Determine the Miller indices of the plane, showing the steps in their deduction. Construct it graphically. [5]

(b) List three types of crystal deffects in real crystals and comment briefly on how they affect the physical properties of a solid. [6]

(c) Explain what is *reciprocal lattice* of a crystaline substance and show how the reciprocal and the crystal lattice vectors are related. [6]

(d) Distinguish between *crystalline* and *amorphous* solids, giving three examples of each. [5]

(e) Explain the formation of a covalent bond. Comment on the nature of the forces that keep the atoms bound together at low temperatures in covalent crystals. [6]

(f) From 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 of electrons having a charge e. [6]

(g) Define *magnetic susceptibility* X_m and classify magnetic materials on the basis of this quantity. [6]

SECTION B

2 (a) (i) Write down an expression for the "Bragg equation". On the observation of what phenomenon in crystals is it considered to be a sufficient condition? [2]

(ii) X-rays of wavelength 0.0705nm are incident on a cubic crystal of lattice constant $a = 0.282\ nm$. Find the angle for the second order Bragg reflection from the (111) set of planes. [4]

(b) Comment briefly advantages and disadvantages of the electron and the neutron diffraction methods used in crystal structure analysis as compared to the X-ray diffraction methods. [8]

(c) Define the term *Geometric scattering factor*. Explain why certain planes are missing from the difraction pattern of a *bcc* crystal despite the fact that the Bragg's condition is satisfied. [6]

3. (a) Derive an expression for the dispersion relation $\omega(k)$ for a linear diatomic lattice in which the unit cell is composed of two atoms of masses m and M, and the neighbouring atoms are separated by a distance a. [8]

(b) Plot ω versus k and explain the physical meaning of the two branches of the dispersion curve. [6]

(c) The frequency of maximum absorption of electromagnetic radiation by NaCl crystal is $5.01 x10^{13} rad\ s^{-1}$ (Infrared region). Calculate:

(i) the interatomic force constant;
(ii) Young's modulus; and
(iii) the velocity of sound in the NaCl crystal. [6]

NOTE: Density of NaCl = 2.18 x 10^3 kg/m^3, interatomic separation a = 5.63 Å.

4. (a) Explain the concept of *a phonon*. Give its characteristic properties and compare them with *a photon*. [6]

(b) Derive an expression for the phonon contribution to the specific heat (c_v) of a solid based on the Debye model. Illustrate graphically how specific heat varies with temperature and comment briefly. [10]

(c) Compare the Debye model with the Einstein model. [4]

5. (a) Describe in brief, the fundamental differences between the electron gas of the quantum theory and an ideal gas of the kinetic theory. [5]

(b) For a metal specimen maintained at 0K, the density of state function is given by;

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

Deduce an expression for:

(i) the number of electrons that can be accomodated up to energy level E_F, the Fermi energy and [3]

(ii) the magnitude of the fermi energy E_F. [5]

(c) Explain the significance of the *Fermi energy* for the properties of the metal? [2]

(d) What is the probability for an electron to occupy an energy level above the Fermi-level if the temperature of the solid is:

(i) Near 0K, and

(ii) room temperature (300K)? [5]

6. (a) (i) Draw well-labeled energy band diagrams for conductors, semi-conductors and insulators. [5]

(ii) The interatomic distance in most metals is of the order of 4 Å. Calculate the width of the conduction band (in eV) for a typical metal. [3]

(b) Distinguish between *intrinsic* and *extrinsic* semiconductors and discuss the phenomenon of electric conductivity in any one of the two types of semiconductors. [6]

(c) In semiconductors, electrons may be moved from the valence band to the conduction band by several methods. Name **three** such excitation mechanisms and briefly describe one of them. [6]

- END OF EXAMINATION -