MASENO UNIVERSITY

UNIVERSITY EXAMINATIONS 2015/2016

FIRST YEAR FIRST SEMESTER EXAMINATIONS FOR THE DEGREE OF MASTER OF SCIENCE IN PHYSICS

MAIN CAMPUS

SPH 804: SOLID STATE PHYSICS I

Date: 14^{th} December, 2015 Time: 9.00 - 12.00pm

INSTRUCTIONS:

- Answer any THREE Questions.

Qn 1 (a). Define a reciprocal lattice vectors b_1, b_2 and b_3 in terms of the normal lattice vectors a_1, a_2 and a_3. (4mks)

(b). If the particles of a crystal lattice plane, s, are thermally excited to vibrate with displacement u_s so that displacement to the left is u_{s-1} and to the right is u_{s+1}, use Newton's law of motion as applied to a harmonic oscillator to derive the dispersion relation for this system.

(8mks)

(c). Metallic crystal can be described as composed of ions in a 'sea' of electrons. Show that for electrostatic screening, the potential energy component at k = 0 gives the screened ion limit for metals as:

$$U = -\frac{2}{3}E$$ (8mks)

Qn 2. (a). Show that at long wave lengths when ka << 1, the wave group velocity v_g is equal to the speed of sound v_o for mono-atomic crystal lattice where

$$v_o = a\left(\frac{c}{m}\right)^{\frac{1}{2}}$$ (10mks)

(b). Using appropriate dispersion relation for mono-atomic linear lattice of 1000 atoms with nearest neighbor interactions, determine the density of modes if the normal angular frequency is 150 s^{-1} but which can reach a maximum of 200 s^{-1}. (5mks)

(c). Define phonon with reference to crystal lattice vibrations. Give its energy.

(5mks)

Qn 3. (a). Particles in solids are subjected to two forces: repulsion and attraction. Show that for equilibrium to exist,

$r_o = (4\pi\varepsilon_0 C)^{\frac{1}{n-2}}$ and that the bonding energy of the particles is given by:

$$U_B = \frac{e^2}{4\pi\varepsilon_0 r_0}\left(1 - \frac{1}{n-1}\right)$$ (7mks)

(b). Briefly explain the following as applied to crystal lattice:

(i). Bloch functions (3mks)

(ii). Warnier functions. (3mks)

(c). Using Bloch function for a single energy band, deduce an expression for determining the energy eigenvalue for a specified perturbation U_o when additional field U(r) changes rapidly and is non-zero only within the bounds of a single crystal cell. (7mks)

Qn 4. (a). Explain Bragg diffraction condition in terms of the wave vector **k** and reciprocal lattice vector **G**. (6mks)

(b). Give an expression for structure factor for fcc lattice and explain why no reflections occur for partly even and partly odd indices. (6mks)

(d). Given that for a simple cubic lattice Eo – C = 0, determine electron energy at the centre of the Brillouin zone. (8mks)

Qn.5. (a). Explain what is meant by "lattice sums" (4mks)

(b). Fermi-Dirac distribution function gives the probability that an electron has energy E at temperature T. It is given that this probability is equal to one for electron energies less than Fermi Energy and to zero for electron energies greater than Fermi Energy at 0K. Use this information to determine mean electron energy in the solid. (8mks) (c). The expansion of solids when heated is due to the existence of anharmonicity, γ, and at the same time the elastic force constant, β, also affects thermal expansion. Given that:

$\gamma = \frac{52e^2}{a^4}$ and $\beta = \frac{8e^2}{a^4}$ where a is the lattice constant, determine the coefficient of linear expansion of this material. Leave your answer in terms of a, k and e.

(8mks)