UNIVERSITY OF EMBU

2017/2018 ACADEMIC YEAR

SECOND SEMESTER EXAMINATIONS

FOURTH YEAR MAIN EXAMINATION FOR THE DEGREE OF BACHELOR OF SCIENCE AND BACHELOR OF EDUCATION SCIENCE.

SPH 403: SOLID STATE PHYSICS II

DATE: APRIL 11, 2018 **TIME: 8:30-10:30AM**

INSTRUCTIONS:

Answer Question ONE and ANY Other TWO Questions.

Constants: Unless otherwise specified, take;

- Gravitational acceleration, g = 9.8 $m.s^{-2}$
- Speed of light, c = 3.0 x 10^8 $m.s^{-1}$
- Gravitational constant, G = 6.67 X 10^{-11} m^3/s^2. kg.
- Earth's mass, M=5.98 X 10^{24} kg.
- Earth's radius, R_E = 6.37 X 10^6 m.

Mass of the electron m = 9.11×10^{-31} kg
Planck's constant h = $2\pi \times 1.05 \times 10^{-34}$ Js
elementary charge e = 1.60×10^{-19} C
one electron volt = 1.60×10^{-19} J
Boltzmann's constant k_B = 1.38×10^{-23} JK^{-1}
permittivity of vacuum ϵ_0 = 8.85×10^{-12} Fm^{-1}
Avogadro's number = 6.02×10^{23}

QUESTION ONE (30 MARKS)

a) An x-ray beam of wavelength 0.16 nm is incident on a set of planes of a certain crystal. The first Bragg reflection is observed for an incidence angle of 36°. What is the plane of separation? Will there be any higher order reflections? (3 marks)

b) Calculate the minimum wavelength of the radiation emitted by an X-ray tube operated at 30 kV. (3 marks)

c) If the minimum wavelength recorded in the continuous X-ray spectrum from a 50 kV tube is 0.247°A, calculate the value of Plank's constant. (3 marks)

d) The Debye temperature θ for iron is known to be 360 K. Calculate ν_m, the maximum frequency. (3 marks)

e) An atomic plane in a crystal lattice makes intercept of 3a, 4b and 6c with the crystallographic axes where a, b and c are the dimensions of the unit cell. Calculate the Miller indices of the atomic plane. (3 marks)

f) Identify any three symmetries the crystal shown in Figure 1.1 has. (3 marks)

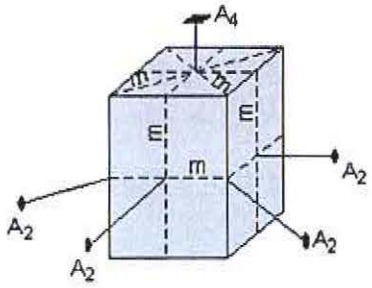

Figure 1.1

g) Explain what you understand by superconductivity of metals. (2 marks)

h) Briefly explain what is Meissner Effect. (2 marks)

i) State the Wiedemann-Franz law and give the related equation. (2 marks)

j) Distinguish between Type I and Type II superconductors. (2 marks)

k) What is a superfluid? And superfluidity? (2 marks)

l) Distinguish between a reciprocal lattice and a reciprocal lattice vector. (2 marks)

QUESTION TWO (20 MARKS)

a) Einstein's model of solids gives the expression for the specific heat as

$$C_v = 3N_0k\left(\frac{\theta_E}{T}\right)^2 \frac{e^{\theta_E/T}}{(e^{\theta_E/T}-1)^2} \qquad \text{where } \theta_E = h\nu_E/k.$$

The factor θ_E is called the characteristic temperature. Show that

(i) At high temperatures Dulong Petit law is reproduced.

(ii) But at very low temperatures the T^3 law is not given (5 marks)

b) The density of states function for electrons in a metal is given by: $Z(E)dE = 13.6 \times 10^{27}E^{1/2}dE$. Calculate the Fermi level at a temperature few degrees above absolute zero for copper which has 8.5×10^{28} electrons per cubic metre and hence find the velocity of electrons at the Fermi level in copper. (5 marks)

c) For a free electron gas in a metal, the number of states per unit volume with energies from E to $E + dE$ is given by

$$n(E)dE = \frac{2\pi}{h^3}(2m)^{3/2}E^{1/2}dE$$

Show that the total energy is, $3NE_{max}/5$. (10 marks)

QUESTION THREE (20 MARKS)

a) Consider the spring model of a one-dimensional monatomic lattice consisting of N atoms which are equally spaced with separation distance a, and each of mass m. If the force constant holding each atom with its nearest neighbours is **K**,

i) Show that the dispersion relation is given by the equation; (5 marks)

$$\omega^2 = \frac{2}{m}\sum \mathbf{K}(1 - \cos(ka)).$$

ii) Derive an equation for the group velocity V_g as a function of k. (5 marks)

iii) Find the value of V_g at very small values of k; $(k \rightarrow 0)$. What is the significance of these very low values of k? *(Support your answer with a graph).* (5 marks)

iv) Find the value of V_g at Brillouin Zone boundary, $(k = \frac{\pi}{a})$. What is the significance of these boundary values of k? (5 marks)

QUESTION FOUR (20 MARKS)

a) With the aid of a diagram, determine the reciprocal lattice vectors for the primitive unit cells of the FCC lattice. (10 marks)

b) Calculate the length of the [211] vector for the FCC primitive reciprocal lattice. Hence find the separation of the (211) planes of the primitive lattice. (10 marks)

QUESTION FIVE (20 MARKS)

a) Discuss the characteristic properties of superconductors. (10 marks)

b) With the aid of a well labeled diagram of an x-ray tube, give a detailed explanation of the production of X-rays. (10 marks)

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