JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY
SCHOOL OF BIOLOGICAL AND PHYSICAL SCIENCES
UNIVERSITY EXAMINATION FOR THE DEGREE OF BACHELOR OF EDUCATION (SCIENCE)
4^{TH} YEAR 1^{ST} SEMESTER 2018/2019 ACADEMIC YEAR
MAIN
REGULAR

COURSE CODE: SPH 401

COURSE TITLE: SOLID STATE PHYSICS

EXAM VENUE: **STREAM: EDUCATION**

DATE: **EXAM SESSION:**

TIME: 2:00 HRS

Instructions:

1. **Answer question 1 (Compulsory) and ANY other 2 questions.**
2. **Candidates are advised not to write on the question paper.**
3. **Candidates must hand in their answer booklets to the invigilator while in the examination room.**

Useful constants
Mass of an electron $m_e = 9.11 \times 10^{-31}\ kg$
Planck's constant $h = 6.63 \times 10^{-34}\ Js$
$1eV = 1.6 \times 10^{-19}\ J$

SECTION A

QUESTION 1 (30 MARKS)

a) Define the following terms as used in Solid state Physics.

(i) Degeneracy **(1 mark)**

(ii) Crystal **(1 mark)**

(iii) Phonons **(1 mark)**

(iv) Lattice **(1 mark)**

b) Explain the formation of a crystal **(2 marks)**

c) Starting with the time-dependent Schroedinger equation, obtain the time evolution operator. **(3 marks)**

d) The plane intercepts in a crystal occur $3\vec{a}, 2\vec{b}, 2\vec{c}$. Determine the Miller indices of the plane, hence obtain the interplanar distance given that the lattice parameter is a. **(3 marks)**

e) Given that Iron has a Fermi energy of $11.1\, eV$, calculate the radius k_F of the Fermisphere by assuming that electrons in Iron have an effective mass equal to the free electron mass. **(3 marks)**

f) By defining $x = \left(\dfrac{\varepsilon_i - \mu}{k_B T}\right)$ in the Fermi-Dirac distribution function, show that the average population of an eigenstate for fermions cannot exceed 1. **(2 marks)**

g) Outline **any TWO** characteristics of Bose-Einstein distribution. **(2 marks)**

h) State the paradox in the Drude's free electron model hence explain how this paradox was removed by Sommerfeld. **(2 marks)**

i) Assuming that the transverse and longitudinal waves have a common velocity, show that the limiting frequency in the Debye theory of specific heat is given by $\upsilon_m = \left(\dfrac{3N}{4\pi V}\right)^{\frac{1}{3}} c$

where the symbols have their usual meanings. **(2 marks)**

j) A crystal lattice has a lattice constant a. By modeling a section of the lattice between two lattice points separated by a distance a as a string of mass m and length a fixed on both ends and vibrating freely, show that the equation for the energy spectrum of the atoms is $E_n = n^2 \dfrac{\hbar^2 \pi^2}{2ma^2}; n = 1,2,....$ **(3 marks)**

k) Distinguish between diamagnetic and paramagnetic substances. **(1 mark)**

l) Derive an equation for the fundamental condition for nuclear magnetic resonance absorption.

(2 marks)

m) Explain the difference between Type I and Type II superconductors. **(1 mark)**

SECTION B

Attempt any TWO questions in this section

QUESTION 2 (20 MARKS)

a) State the **THREE** basic assumptions of the Drude model of free electron theory. **(3 marks)**

b) Show that the magnetization of a two-level paramagnetic system in the limiting case for which $\frac{\mu B}{k_B T} << 1$ is given by $M = N\frac{\mu^2 B}{k_B T}$ **(7 marks)**

c) Derive the general expression for the molar heat capacity according to Einstein's theory of specific heat. **(10 marks)**

QUESTION 3 (20 MARKS)

(a) Using the classical free electron theory of solids, derive the equation for the conductivity of a metal in the form $\sigma = \frac{ne^2\tau}{m}$ where each symbol has its usual meaning. **(5 marks)**

b) The element sodium has a density $0.97\times10^{-3}\ kgm^{-3}$, relative atomic mass 23 and electrical conductivity $2.1\times10^{7}\ \Omega^{-1}m^{-1}$. Determine the mobility of electrons in sodium. **(5 marks)**

c) Show that the Fermi-Dirac distribution function is given by $\frac{n_i}{g_i} = \left(e^{\left(\frac{\varepsilon_i-\mu}{k_B T}\right)}+1\right)^{-1}$ where the symbols have their usual meanings **(10 marks)**

QUESTION 4 (20 MARKS)

a) Obtain the dispersion relation governing the propagation of a longitudinal on a vibrating linear monatomic lattice in the form $\omega = 2\sqrt{\frac{K}{M}}\left|\sin\frac{1}{2}ka\right|$ where the symbols have their usual meanings. **(15 marks)**

b) Provide a graphical representation of the dispersion relation in 4(a). **(2 marks)**

c) Determine the maximum value of phase velocity of the waves in 4(a). **(3 marks)**

QUESTION 5 (20 MARKS)

a) Outline **any FIVE** lattice types in three-dimensions. **(5 marks)**

b) Present a derivation of equation for density of states in the compact form $\rho(\varepsilon)=\frac{3N}{2\varepsilon}$, hence state the physical interpretation of this compact form. **(15 marks)**