JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY
SCHOOL OF BIOLOGICAL AND PHYSICAL SCIENCES
UNIVERSITY EXAMINATION FOR THE DEGREE OF BACHELOR OF EDUCATION (SCIENCE)
4TH YEAR 1ST SEMESTER 2022/2023ACADEMIC YEAR
MAIN
REGULAR

COURSE CODE: SPB 9425

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 ONE (30 MARKS)

a) Distinguish between optical mode and acoustic modes of lattice vibrations. (3 marks)

b) What are phonons. (2 marks)

c) Derive the time independent Schrödinger equation from initial time-dependent equation,

. (3 marks)

d) Copper has fcc lattice of 3.61Å. The first order Bragg's reflection from (111) appears at an angle of 21.7°. determine the wavelength os the x-rays. (3 marks)

e) Write the mathematical formulae describing the following statistics: Fermi-Dirac, Bose-Einstein and Maxwell-Boltzmann (3 marks)

f) Outline **any TWO** characteristics of Maxwell-Boltzmann distribution. (2 marks)

g) Restate the paradox in the Drude's free electron model hence explain how this paradox was resolved by Sommerfeld. (2 marks)

h) 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

$E_n = n^2 \frac{\hbar^2 \pi^2}{2ma^2}; n = 1,2,....$ (3 marks)

j) Distinguish between diamagnetic and paramagnetic substances. (2 marks)

j) State the conditions necessary for magnetic resonance to occur in a material. (2 marks)

k) What is Superconductivity? Differentiate between the types I and II superconductors. (3 marks)

l) Sketch the dispersion relations for diatomic lattice showing acoustic and optical modes (3 marks)

QUESTION TWO (20 MARKS)

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

b) What are salient features of Einstein's theory of lattice heat capacity (2 marks)

c) Derive the general expression for the molar heat capacity according to Debye's approximation theory of lattice heat capacity. (10 marks)

d) Discuss the finding in (c) at high and low temperature regimes (5 marks)

QUESTION THREE (20 MARKS)

a) Obtain the dispersion relation governing the propagation of a longitudinal vibration on a vibrating linear diatomic lattice. (10 marks)

b) What is thermal conductivity? (2 marks)

c) What is meant by the Fermi level and Fermi energy? (2 marks)

d) The Fermi level for a particular material at $T = 300\,\mathrm{K}$ is 6.25 eV. The electrons in this material follow Fermi-Dirac distribution function.

i) Find the probability of an energy level at 6.50 eV being occupied by an electron. (3 marks)

ii) Find the probability of an energy level being occupied if the temperature is increased to T= 950 K. (3 marks)

QUESTION FOUR (20 MARKS)

a) Define the term density of states (2 marks)

b) Sketch the electron density of states for free electron system at a temperature above 0 K. (2 marks)

c) Derive the density of states function in the form $\rho(\epsilon) = \frac{V}{2\pi^2}.\left(\frac{2m}{\hbar^2}\right)^{\frac{3}{2}}\epsilon^{\frac{1}{2}}$ (8 marks)

d) Assuming that the energy of the atoms in a crystal is governed by the Maxwell-Boltzmann statistics, show that the mean energy is given by $E \approx k_B T$ (8 marks)

QUESTION FIVE (20 MARKS)

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

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