JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY SCHOOL OF BIOLOGICAL AND PHYSICAL SCIENCES UNIVERSITY EXAMINATION FOR THEDEGREE OF BACHELOR OF EDUCATION (SCIENCE)

MAIN

REGULAR RESIT

COURSE CODE: SPH 401

COURSE TITLE: SOLID STATE PHYSICS

EXAM VENUE: LAB 1 **STREAM: (BED SCI)**

DATE: 4/5/2016 **EXAM SESSION:9:00-11:00AM**

TIME: 2:00HRS

<u>Instructions:</u>

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.**

Apply where necessary

$R = 8.31 J/K$

$\gamma = C_p / C_V = 1.4$

SECTION A: - COMPULSARY (30 MARKS)

1. (a) Thermal vibration of crystal particles can affect the properties of solids. Discuss the nature of these vibrations and how they lead to Debye temperature. (3 marks)

(b) Explain the difference between diamagnetism, paramagnetism and ferromagnetism. (4 marks)

(c) Describe how electric resistivity occurs in a conducting solid and give two main courses. (3 marks)

(d) The total number electrons of mass m enclosed in orbital's of volume V and energy E is $N = \frac{V}{3\pi^2}\left(\frac{2mE}{\hbar^2}\right)^{3/2}$. Show that within a factor of unity, the number of electrons per unit energy range at Fermi energy is the total number of conduction electrons divided by the Fermi energy (3 marks)

(e) The Fermi energy of a certain element is $7.0\,eV$ at $0\,K$. Calculate the mean energy and the root mean square velocity of free electron of this element. (4 marks)

(f) Orbital and spin angular momentum can be coupled to determine the magnetic susceptibility of a solid crystalline material. Explain the difference between L-S and j-j coupling. (3 marks)

(g) Define distinguishable and indistinguishable particles and identify appropriate statistical distribution functions for describing them. (4 marks)

(h) Based on the band theory of solids, explain the nature of conductors, semiconductors and insulators. (3 marks)

(i) Describe the dependence of electrical resistivity on temperature for perfectly pure metal and impure metal and use it to explain the important property changes that occur in materials when they change from normal to superconducting state. (3 marks)

SECTION B: - ANSWER ANY TWO QUESTIONS FROM THIS SECTION

2. (a) In 1907, Einstein constructed a model that assumed that every atom is in an identical harmonic well and has a frequency ω (Einstein frequency). The energy eigenvalue of a quantum mechanical harmonic oscillator in one dimension $E_n = \hbar\omega\left(n + \frac{1}{2}\right)$ are determined by a quantum number n which assume all numbers $0, 1, 2\ldots$.

(i) Show that internal energy of one oscillator is $E_n = \hbar\omega\left(n_B + \frac{1}{2}\right)$, where $n_B = \frac{1}{\exp\left(\hbar\omega/\kappa T\right) - 1}$ is the Bose occupation factor. (8 marks)

(ii) Generalizing the results in question 2 a (i) for a three dimensional case, evaluate the heat capacity per atom for the limiting case of high temperature $T \to \infty$. Which law is recovered? (7 marks)

(b) A particle of mass m is confined in a field free region between impenetrable walls at $x = 0$ and $x = a$. Show that the stationary energy levels of the particle are given by $E_n = \frac{n^2 h}{8ma^2}$. Explain the important conclusions from this equation. (5 marks)

3. (a) Debye in 1913 improved the Einstein theory by taking in to account a more realistic model for the frequency spectrum of the solid. Debye wrote the expression of total internal energy analogous to the Einstein expression as

$$E = \int_0^{\omega_d} d\omega\, g(\omega)\hbar\omega\, n_B$$

where $n_B = \frac{1}{\exp\left(\hbar\omega/\kappa T\right) - 1}$ is the Bose occupation factor and $g(\omega) = \frac{9N\omega^2}{\omega_d^3}$ is the density of state and $\omega_d = \left(6\pi n v^3\right)^{1/3}$ is the Debye frequency. The other symbols have usual meaning.

(i) Show that at low temperature the molar specific heat of the solid is given by

$$C = \frac{12\pi^4 N\kappa}{5}\left(\frac{T}{T_D}\right)^3$$

where T_D is the Debye temperature. To what extent does this model agree with experiment? (8 marks)

(ii) Obtain the expression for the molar specific heat of the solid at high temperature. Comment on your answer. (4 marks)

(b) The Fermi energy for a system of free electrons of mass m is $E_F = \left(\frac{h^2}{2m}\right)\left(\frac{3n}{8\pi}\right)^{2/3}$, where n is the density of electrons.

(i) Show that the wavelength associated with an electron having energy equal to Fermi energy is given by $\lambda_F = 2\left(\frac{\pi}{3n}\right)^{1/3}$. (4 marks)

(ii) The following table gives the Fermi temperatures T_F of selected metals

Metal	Lithium	Aluminum	Sodium	Copper
$T_F\left(K\right)$	5.84×10^4	13.52×10^4	3.75×10^4	8.81×10^4

Use the table to identify the metal whose wavelength is $0.68\,nm$.

Take $\left(\frac{h^2}{2m}\right)\left(\frac{3}{8\pi}\right)^{2/3} = 5.84\times10^{-38}\,Jm^{-1}$ (4 marks)

4. (a) What are superconductors? Mention the important property change that occurs in materials when they change from normal superconducting state. Give three examples of practical uses that exploit the above property changes. (7 marks)

(b) Show that the entropy of a superconducting state is less than that of the normal sate. The difference in free energy between the normal and superconducting state in applied field strength H_a is given as

$$g_n - g_s\left(H_a\right) = -\frac{1}{2}\mu_0\left(H_c^2 - H_a^2\right),$$

where H_c is the critical field strength. (8 marks)

(c) What are Brillouin zones? How are they related to the energy levels of electrons in metals? (5 marks)

1. (a) (i) Show that the resultant magnetization of N atoms per unit volume having energy $E = \pm\mu H$; $\mu = \mu_0\mu_B$ in a magnetic field is given by $M = N\mu_B \tanh x$; $x = \mu H / \kappa T$. (7 marks)

(ii) Obtain the expression for the resultant magnetization for (I) normal temperature and (II) low field and low temperature and strong fields. (4 marks)

(b) Consider a circular orbit of radius r in which an electron revolves with an angular velocity ω_0 around the nucleus of charge. If a magnetic field B is applied o the electron, show that the angular velocity becomes

$$\omega = \pm\omega_0 - \frac{eB}{2m}$$

What is the significance of this equation? (9 marks)