MASENO UNIVERSITY

UNIVERSITY EXAMINATIONS 2016/2017

FOURTH YEAR FIRST SEMESTER EXAMINATION FOR DEGREE OF BACHELOR OF SCIENCE IN PHYSICS AND MATERIALS SCIENCE WITH INFORMATION TECHNOLOGY

MAIN CAMPUS

SPH 401: SOLID STATE PHYSICS

Date: 6th December, 2016 Time: 12.00 - 3.00pm

INSTRUCTIONS:

- Answer Question ONE and any other TWO

Useful Constants

Permeability of vacuum	$\mu = 4\pi \times 10^{-7} Hm^{-1}$
Electron charge	$e = 1.6 \times 10^{-19} C$
Electron mass	$m_e = 9.11 \times 10^{-31} kg$
Permittivity of vacuum	$\varepsilon_o = 8.85 \times 10^{-12} Fm^{-1}$
Boltzman constant	$K = 1.38 \times 10^{-23} JK^{-1}$

QUESTION ONE (30 marks)

a)i. In terms of the vibrational frequency of the oscillators, state the main drawbacks of Einstein theory of specific heat. (2 marks)

ii. Differentiate between Fermions and Bosons (2 marks)

b) i. Find the root mean square speed of oxygen (atomic mass 16 u) at 0 °C (2 marks)

ii. Define a black body (2 marks)

c) i. What is meant by the term Fermi-energy of a metal? (2 marks)

ii. Find the Fermi-energy for copper of density $8.94 \times 10^3 kg/m^3$ and atomic mass 63.5 u (3 marks)

d) i. Explain the mechanism of heat flow in solids (2 marks)

ii. Differentiate between crystalline and amorphous solids (2 marks)

e) Name three classes of magnetic materials (3 marks)

f) What is meant by zero point energy crystal (2 marks)

g) i. Define superconductivity (2 marks)

ii. Differentiate between type I and Type II superconductors (2 marks)

h) What causes magnetic property in materials? (2 marks)

28 mks

Question Two (20 marks)

a) I. Write the Schrodinger equation for the electron in a box model (2 marks)

ii. By applying the appropriate boundary conditions to the problem obtain the general solution

(4 marks)

iii. Obtain the expression for the energy eigen values (6 marks)

b) Assuming that the energy of the atoms in a crystal is governed by the Maxwell- Boltzmann statistics. Show that the mean energy at high temperature is given by

$$E \approx kT$$ (8 marks)

QUESTION THREE (20 marks)

a) The energy of N oscillators in the Einstein's model of a solid is given by $E = N\langle n\rangle \hbar\omega$

where $\langle n\rangle$ is the Bose-Einstein distribution function. Show that the molar specific capacity at constant volume is given by $C_v = 3Nk(\beta\hbar\omega)^2 \frac{e^{\beta\hbar\omega}}{\left(e^{\beta\hbar\omega}-1\right)^2}$ (8 marks)

(Assume each of the n atoms has 3N degrees of freedom)

b) i. State the conditions required for magnetic resonance to occur in a material (3marks)

ii. Write the expression for the change in orbital frequency of electrons in a material when a magnetic field B is applied across it and hence show that it leads to a circulating current given by

$I = \frac{Ze^2B}{4\pi m}$ where Z is the number of electrons. (4 marks)

c) The Fermi –energy of copper at 0 K is 7 eV. Calculate the mean energy of conduction electrons and their root- mean- square velocity (5 marks)

QUESTION FOUR (20 marks)

a) Briefly describe the following magnetic properties

- Diamagnetism
- Ferromagnetism

- Paramagnetism (6 marks)

ii. Derive the density of states function in the form of

$$\rho(E) = \frac{V}{2\pi}\left(\frac{2m_e}{\hbar_2}\right)^{3/2} E^{1/2}$$ (6 marks)

iii. Hence show that the kinetic energy of a 3-D gas with N free electrons at 0 K is given by

$U_o = \frac{3}{5}NE_F$ (6 marks)

iv. In terms of electrons pairing differentiate between magnetic and non-magnetic materials

(2 marks)

QUESTION FIVE (20 marks)

a) i. Show that the magnetic field inside a solenoid with a soft iron core is given by $B = \mu_o \mu_r H$

where μ_o is permeability of free space, μ_r is relative permeability (5 marks)

ii. State Curie's law (2 marks)

b) i. Derive an expression for the Hall constant R_H (4 marks)

ii. Determine the value of Hall constant for a sample of P-type germanium of conductivity $100\Omega^{-1}m^{-1}$

(take $\mu_e = 0.39m^2V^{-1}s^{-1}$ and $\mu_h = 0.19m^2V^{-1}s^{-1}$) (3 marks)

c) State the properties of particles described by each of the following statistics:

- Maxwell-Boltzmann
- Fermi-Dirac
- Bose-Einstein (6 marks)