MAASAI MARA UNIVERSITY

REGULAR UNIVERSITY EXAMINATIONS

2023/2024 ACADEMIC YEAR

FOURTH YEAR *SECOND* SEMESTER

SCHOOL OF PURE, APPLIED AND HEALTH SCIENCES

BACHELOR OF SCIENCE (PHYSICS)

COURSE CODE: PHY 4248-1

COURSE TITLE: SOLID STATE PHYSICS II

DATE: **TIME:**

INSTRUCTIONS TO CANDIDATES

1. Answer Question **ONE** and any other **TWO** questions
2. Use of sketch diagrams where necessary and brief illustrations are encouraged.
3. Read the instructions on the answer booklet keenly and adhere to them.

This paper consists of ***three*** *printed pages. Please turn over.*

You may use the following constants in your calculations

Electronic rest mass m_e	=	9.10 x 10^{-31} kg
Electron effective mass	=	$0.26m_o$
Hole effective mass	=	$0.39m_o$
Electronic charge e	=	1.60 x 10^{-19} C
Boltzmann constant k_B	=	1.381 x 10^{-23} JK^{-1}
Planck constant h	=	6.60 x 10^{-34}JS
Electron concentration N_c	=	2.8×10^{19} cm^{-3}
Hole concentration N_V	=	1.04×10^{19} cm^{-3}
Speed of light in vacuum c	=	3.0 x $10^{8}ms^{-1}$
Permittivity constant μ_o	=	4π x 10^{-7}
Permeability constant ε_o	=	8.850 x 10^{-12}
1 eV	=	1.60 x 10^{-19}J
Bohr Magneton μ_B	=	9.27 x $10^{-24}Am^2$

QUESTION ONE: [20 marks]

a) State any three concepts that summarizes the band theory of solids (3mks)

b) State three factors that affect a material's ability to superconduct (3mks)

c) Diagrammatically differentiate between ferromagnetism, ferrimagnetism and antiferromagnetism (3mks)

d) The free electron wavefunction are plane waves of the form $\psi_k = e^{i\mathrm{k.r}}$. Show that a combination of wavefunctions of electrons in a periodic potential are standing waves (3mks)

e) Define Hall effect and state two parameters that it can determine (3mks)

f) What are the possible polarization types in dielectrics (2mks)

g) Describe Meissner effect (3mks)

QUESTION TWO: [15 marks]

a) Discuss the difference between Schottky and Frenkel defects (5mks)

b) Find $E_C - E_F$ if $N_D = 1.0\times10^{22}/\mathrm{m}^3$ for Si at 300 K. (3mks)

c) At 300 K, $\mu_n = 0.15\text{m}^2/\text{V.s}$. Determine its value at 200 K if lattice scattering dominates (2mks)

d) From the postulate of the existence of an internal field, the Weiss field, H_E. show that the molecular field parameter, λ is given by $\lambda^{-1} = \frac{Ng_L^2\mu_B J(J-1)}{3k_B T_c}$ (5mks)

QUESTION THREE: [15 marks]

a) Define the following terms as used in superconductivity
   i. Zero resistivity (1mk)
   ii. 2nd order transition temperature (1mk)
   iii. Critical magnetic field (1mk)

b) It can be assumed that a surface current acts to shield the inner superconductor from the external magnetic field resulting in a perfectly diamagnetic medium. From London's second equation $\nabla \times J = -\frac{n_s e^2 \text{B}}{m}$, and the fact that in superconducting state, the magnetic field decreases exponentially as one proceeds from the surface into the superconductor $B_y(x) = B_y(0)e^{\frac{-x}{\lambda_L}}$, proof Meissner effect (7mks)

c) Derive the Rutgers formula which represents a discontinuity in the specific heat at the transition temperature T_c (5mks)

QUESTION FOUR: [15 marks]

a) Starting with the local field of the induced dipole moment, $\text{p} = \alpha E_{\text{LF}}$, show the Claussius-Mosotti relation for a cubic crystal. (6mks)

b) Given the Claussius-Mosoti relation $\frac{\varepsilon - 1}{\varepsilon + 2} = \frac{1}{3\varepsilon_o} N_i \alpha_i$ (the symbols used have their usual meaning). Rearrange the equation giving the condition under which polarization catastrophe will be experienced (3mks)

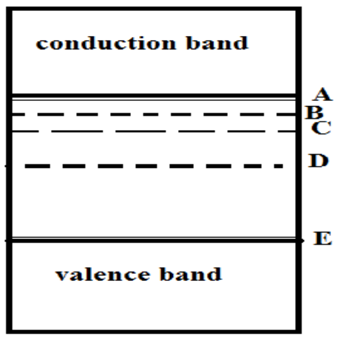
c) Discuss the difference between Schottky and Frenkel defects (4mks)

d) Define
   i. Neel temperature (1mk)
   ii. Curie temperature (1mk)

QUESTION TWO (20 MARKS)

a. i. Impurities improve the conductivity of semiconductors, with the aid of a bond diagram describe the doping process. **4 mks**

ii. The figure below shows the schematic energy bands for an n-type extrinsic semiconductor, name A, B, C, D and E **5 mks**



b. Show on a sketch diagram the location of E_F in the energy band of silicon, at 300K with **5 mks**

$n = 10^{17}\text{cm}^{-3}$? And for $p = 10^{14}\text{cm}^{-3}$?

c. Find the conductivity and resistivity of a pure silicon crystal at temperature 300°K. The density of electron hole pair per cc at 300°K for a pure silicon crystal is 1.072×10^{10} and the mobility of electron μ_n= 1350 cm^2/volt-sec and hole mobility μ_h= 480 cm^2/volt-sec. **6 mks**

QUESTION THREE (20 MARKS)

a. Using the mass action law, find the electron concentration when the Hall coefficient is zero for a semiconductor. Using $n_i = 1.5\times10^{10}\ \text{cm}^{-3}$, and electron and hole drift mobilities, respectively $\mu_n = 1350\ \text{cm}^2\text{V}^{-1}\text{s}^{-1}$, and $\mu_p = 450\ \text{cm}^2\text{V}^{-1}\text{s}^{-1}$, what are n and p in Si for R_H=0 **4 mks**

b. Define Hall effect and state two effects Hall effect can determine **3 mks**

c. State three important conditions that relate the probes and sample that make Hall effect measurements valid. **3 mks**

d i. Find E_C - E_F if N_D = 1 x 10^{22} /m^3 for Si at 300 K. **3 mks**

ii. At 300 K, μ_n = 0.15 m^2/V.s. Determine its value at 200 K if lattice scattering dominates **2 mks**

e Show that the molecular field parameter, λ is given by

$$\lambda^{-1} = \frac{Ng_L^2\mu_B J(J-1)}{3k_B T_c},$$

from the postulate of the existence of an internal field, the Weiss field, H_E. **5 mks**

QUESTION FOUR (20 MARKS)

a. Differentiate between Type I and II superconductors giving examples in each case **4 mks**

b. Explain what you understand by Meissner effect **3 mks**

c. It can be assumed that a surface current acts to shield the inner superconductor from the external magnetic field resulting in a perfectly diamagnetic medium. From London's second equation $\nabla \times J = -\frac{n_s e^2 \text{B}}{m}$, and the fact that in superconducting state, the magnetic field decreases exponentially as one proceeds from the surface into the superconductor $B_y(x) = B_y(0)e^{\frac{-x}{\lambda_L}}$, proof Meissner effect **7 mks**

d. Derive the Rutgers formula which represents a discontinuity in the specific heat at the transition temperature T_c **6 mks**

QUESTION FIVE (20 MARKS)

a.
i. Starting with the local field of the induced dipole moment, $\text{p} = \alpha E_{\text{LF}}$, show the Claussius-Mosotti relation for a cubic crystal. **6 mks**

ii. Given the Claussius-Mosoti relation (the symbols used have their usual meaning)

$$\frac{\varepsilon - 1}{\varepsilon + 2} = \frac{1}{3\varepsilon_o} N_i \alpha_i$$

Rearrange the equation giving the condition under which polarization catastrophe will be experienced **4 mks**

b. Briefly describe the following types of magnetism giving clear differences between them

i. Diamagnetism

ii. Paramagnetism **6 mks**

c. Define:

(i) Neel temperature **2 mks**

(ii) Curie temperature **2 mks**