ALUPE UNIVERSITY

OFFICE OF THE DEPUTY VICE CHANCELLOR

ACADEMICS, RESEARCH AND STUDENTS AFFAIRS

UNIVERSITY EXAMINATIONS

2024/2025 ACADEMIC YEAR

FOURTH YEAR FIRST SEMESTER REGULAR MAIN EXAMINATION

FOR THE DEGREE OF BACHELOR OF EDUCATION SCIENCE

COURSE CODE: **PHY 414**

COURSE TITLE: **SOLID STATE PHYSICS II**

DATE: 7th January 2025 **TIME:** 1400 – 1700 HRS

INSTRUCTION TO CANDIDATES

- **SEE INSIDE**

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REGULAR – MAIN EXAMINATION

PHY 414: SOLID STATE PHYSICS II

STREAM: BED (SCIENCE) **DURATION: 3 Hours**

INSTRUCTIONS TO CANDIDATES

i. *Answer the **TWO** question in **SECTION A** and any other **THREE** questions in **SECTION B.***

ii. *The following constants maybe useful*

Boltzmann's constant	K $=1.38\times10^{-23}$ J/K or 8.62×10^{-5} eV/K
Electronic charge	$e=1.60\times10^{-19}C$
Free electron rest mass	$m_o=9.11\times10^{-31}$ Kg
Permeability of free space	$\mu_o=4\pi\times10^{-7}$ H/m
Permittivity of free space	$\epsilon_0=8.85\times10^{-12}$ F/m
Planck's constant	$h=6.625\times10^{-34}J/s$
	$\hbar=\dfrac{h}{2\pi}=1.054\times10^{-34}$ J/s
Proton rest mass	$M=1.67\times10^{-27}$ Kg
Density of states in silicon (T=300K),	$\left(N_C=2.8\times10^{19}cm^{-3}\right)$
Density of states in silicon (T=300K)	$\left(N_V=1.04\times10^{19}cm^{-3}\right)$
Intrinsic carrier concentration in Silicon (300 K)	$n_i=1.5\times10^{10}cm^{-3}$

SECTION A (28 MARKS)

Question One (14 Marks)

a) Briefly describe the motion of an electron in a crystal according to the band theory? (2 Marks)

b) State Bloch theorem (1 Mark)

c) Highlight the differences between electrons and holes in terms of their motion in a semiconductor. (2 Marks)

d) In intrinsic semiconductor, conductivity σ and temperature T is given by the equation:
$\ln\sigma = -\left(\frac{E_g}{2k}\right)\frac{1}{T} + \frac{3}{2}\ln T + \frac{3}{2}\ln T + constant$. Plot the graph of $\ln\sigma$ versus $1/T$. (2 Marks)

e) Distinguish between soft superconductor and hard superconductors (4 Marks).

f) Using well labelled diagram, explain how electron-phonon interaction helps to produce Cooper pairs. (3 Marks)

Question Two (14 Marks)

a) State Larmor theorem (1 Mark)

b) Give three contributions that are responsible for permanent magnetic moments. (3 Marks)

c) Plot variation of magnetic susceptibility, χ with temperature, T for paramagnetism, ferromagnetism and antiferromagnetism. (6 Marks)

d) What is the difference between Polarization, P and polarizability, α. (2 Marks)

e) With the help of $BaTiO_3$ crystal, explain ferroelectricity in the region $T < T_C$. (2 Marks)

SECTION B (42 MARKS)

Question Three (14 Marks)

a) Draw a well labelled band model of a n-type semiconductor and explain what happens to Fermi level as temperature increases. (4 Marks)

b) Silicon at $T = 300\,K$ is doped with arsenic atoms such that the concentration of electrons is $n_o = 7\times10^{15}\,cm^{-3}$.

i) Find $E_C - E_F$ (2 Marks)

ii) Calculate p_o (1 Mark)

iii) Find $E_F - Ei$ (2 Marks)

c) At $T = 300\,\text{K}$, the intrinsic silicon has $n_i = 1.5 \times 10^{16}\ m^{-3}$. The electron and hole mobilities are $\mu_n = 0.13\text{m}^2\text{V}^{-1}\text{s}^{-1}$ and $\mu_p = 0.05\text{m}^2\text{V}^{-1}\text{s}^{-1}$. Calculate the conductivity σ of silicon. (2 Marks)

d) Given that $p = N_V \exp\left[-\left(\frac{E_F - E_V}{kT}\right)\right]$ and $p_i = N_V \exp\left[-\left(\frac{E_i - E_V}{kT}\right)\right]$, where the symbols have their usual meanings. Obtain an equation describing p and the position of E_F relative to E_i . (3 Marks)

Question Four (14 Marks)

a) The magnetic moment of current loop containing single electron is given by the product of the current and the area of the loop: $\mu_e = -\frac{e^2B}{4m}\rho^2$. If an atom contains Z electrons and $\langle\rho^2\rangle = \frac{2}{3}\langle r^2\rangle$. Derive expression of diamagnetic susceptibity, χ_{dia} of a solid consisting of N atoms per unit volume. What is the effect of T on χ_{dia} . (4 Marks)

b) Sketch the variation of Langevin function, L(x) with $x = \frac{\mu B}{kT}$ and deduce the expression for paramagnetic susceptibility, χ_{para} in the region $x << 1$, given that $M = N\mu L(x)$. (6 Marks)

c) When an external magnetic is applied to antiferromagnetic material, briefly describe what happens in the region $T < T_N$ with respect to $\chi_\perp$ and $\chi_\parallel$. (4 Marks)

Question Five (14 Marks)

a) Write the expression of Curie-Weiss law in the paramagnetic region $T > T_C$. (1 Mark)

b) What is the difference between antiferromagnetims and ferrimagnetism (2 Marks)

c) State two important hypothesis that constitute Weiss theory of ferromagnetism. (2 Marks)

d) Briefly explain the origin of exchange field responsible for the alignment of dipoles in the domains. (2 Marks)

e) Draw a well labelled diagram of a typical M-H hysteresis loop and define remanent magnetization (M_r) and coercive field (H_C). (4 Marks)

f) Highlight three similarities between ferrimagnetic and ferromagnetic solids. (3 Marks)

Question Six (14 Marks)

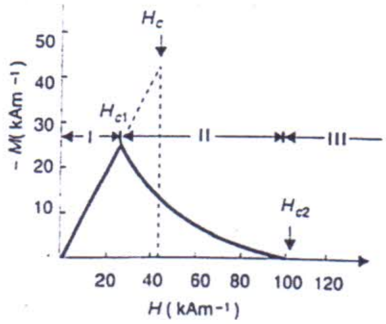
a) With aid of well labelled figures, briefly describe Meissner effect. (2 Marks)

b)

i) Sketch a plot of critical magnetic field, H_c versus temperature, T for lead. (2 Marks)

ii) Lead in the superconducting state has critical temperature of 6.2 K at zero magnetic field and critical field of 0.064 $\mathrm{Mam^{-1}}$ at 0 K. Determine the critical field at 4 K. (2 Marks)

c) The magnetization curve of lead-bismuth alloy at 4.2 K is shown below



Highlight the magnetic behaviour in the following regions

i) $H<H_{C1}$ (1 Mark)

ii) $H_{C1}<H<H_{C2}$ (2 Marks)

iii) $H>H_{C2}$ (1 Mark)

d) Sketch electronic specific heat, $C_{es}/\gamma T_c$ versus temperature T_c/T for superconducting gallium. What does the plot suggest? (2 Marks)

e) What is the effect of temperature on the band gap of a superconductor at T=0 K and $T = T_C$. (2 Marks)

Question Seven (14 Marks)

a) Define the following terms applicable to dielectric properties of solids
   i) Electric susceptibility, χ_e (1 Mark)
   ii) The local field, E_{local} (1 Mark)
   iii) Dielectric constant, ε_r (1 Mark)
   iv) Polarization catastrophe (1 Mark)

b) Using the Langevin function and $x = \frac{pE}{kT}$, deduce the expression of dipolar polarizability per molecule. (3 Marks)

c) Using well labelled diagram, illustrate that crystals possessing centre of inversion have no piezoelectricity. (2 Marks)

d) State any two applications of Piezoelectric crystals (2 Marks)

e) Consider a pure Si crystal that has $\varepsilon_r = 11.9$ and N= 5×10^{28} atoms per unit volume. Apply the Clausius–Mossotti equation to find α_e (3 Marks)

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