UNIVERSITY OF ESWATINI

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2020/2021

TITLE OF PAPER	:	ADVANCED CONDENSED MATTER PHYSICS
COURSE CODE	:	PHY631
TIME ALLOWED	:	THREE HOURS
INSTRUCTIONS	:	ANSWER ANY **FOUR** OUT OF **FIVE** QUESTIONS.
		EACH QUESTION CARRIES **25** MARKS.
		MARKS FOR DIFFERENT SECTIONS ARE SHOWN IN FAR RIGHT MARGIN

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THIS EXAMINATION PAPER HAS **FIVE (5)** PRINTED PAGES INCLUDING THE COVER PAGE

Question 1

(a) Crystalline solids are often considered in terms of the four idealised bonding categories: ionic bonding, covalent bonding, metallic bonding and Van der Waals interaction. For each of these bonding categories, it is the electrostatic Coulomb interaction that provides the attractive force.

(i) Discuss the physical mechanisms that are primarily responsible for the bonding energy in each of the above bonding categories. [8]

(ii) In addition to the electrostatic Coulomb force, there exist between the atoms in a solid, a short range repulsive force. Briefly discuss the physical reasons such a repulsive force must exist and the physical origins of this force. [4]

(b) A quantitative model of bonding in ionic crystals was developed in the 1930s by Born and Mayer. In this model the total potential energy of the system is assumed to be of the form:

$$U_{\text{tot}} = N\left(z\lambda e^{-R/\rho} - \frac{\alpha q^2}{4\pi\varepsilon_0 R}\right),$$

where symbols have their usual meaning.

(i) Discuss the first and second terms and their origins. [4]

(ii) Sketch U_{tot} as a function of R. [4]

(iii) At equilibrium separation show that: [5]

$$U_{\text{tot}} = -\frac{N\alpha q^2}{4\pi\varepsilon_0 R_0}\left(1 - \frac{\rho}{R_0}\right),$$

Question 3

(a) (i) Briefly discuss the physics underlying Bragg's law of diffraction. [3]

(ii) Explain the reason that Bragg's law is equivalent to Laue condition (or Laue equations). [3]

(b) Historically two early models of the phonon density of states used to try and explain the observed low temperature behaviour of the lattice heat capacity $C_v(T)$ were the Einstein model and the Debye model.

(i) Briefly discuss the physics underlying the Einstein model. What is the primary assumption that this model makes about the behaviour of the phonon frequencies as a function of wave vector? [4]

(ii) Briefly discuss the physics underlying the Debye model. What is the primary assumption that this model makes about the behaviour of the phonon frequencies as a function of wave vector? Contrast this with the assumption made in the Einstein model. [5]

(c) In the study of phonon collisions, collision processes can be characterised by two different ways: normal process and Umklapp process.

(i) Give the definition of the two processes. [6]

(ii) What is the importance of the Umklapp process in thermal transport phenomena? [4]

Question 3

(a) (i) Explain the term Fermi energy. [3]

(ii) Find the expression $g(\varepsilon)$ for the number of orbitals per unit energy range, so called density of states, for a free electron gas under periodic boundary condition. [4]

(b) The probability that an orbital at energy ε is occupied in an ideal Fermi gas in thermal equilibrium at temperature T is given by the Fermi-Dirac distribution:

$$f(\varepsilon) = \frac{1}{e^{[(\varepsilon-\mu)/k_B T]} + 1},$$

where symbols have their usual meaning, μ depends on T and is often called the Fermi level.

(i) Explain that at $T = 0$ K the Fermi level is equal to the Fermi energy. [4]

(ii) Draw a plot of $g(\varepsilon)f(\varepsilon)$ versus ε for the case $T = 0$ K and $T \neq 0$ K. Shade the filled electron orbitals under the curves of the plots for the two cases. [4]

(iii) When the system is heated from absolute zero to T (where $0 < k_B T \ll \mu$), which part of electrons in orbitals can be excited thermally? [3]

(c) Explain why the electrical resistance of a non-superconducting metal will never decrease to 0 Ω as $T \to 0\ K$. [2]

(d) With aid of a well labeled diagram and relevant equations discuss how the Hall coefficient can be determined in a rectangular metal bar? [5]

Question 4

(a) (i) What is the origin of the energy gap in metals? [3]

(ii) The Kronig – Penney model equation is given by:

$$\frac{P}{\alpha a}\sin\alpha a + \cos\alpha a = \cos ka, \quad \text{where } P = \frac{mV_o ba}{\hbar^2}.$$

Discus what happens when $V_o b \to \infty$ and $V_o b \to 0$. [5]

(b) With the aid of equations and relevant diagrams discuss the mapping that takes place from an extended zone scheme to a reduced zone scheme. [3]

(c) Draw and explain the $\epsilon(k)$ energy level diagram for:

(i) Group I metal [3]

(ii) Group II metal [3]

(d) List four assumptions made in constructing Fermi surface in the nearly free electron model. [4]

(e) A two-dimensional metal in the form of a square lattice has two conduction electrons per atom. In the almost free electron approximation, sketch carefully the electron and hole energy surfaces. For the electron choose a zone scheme such that the Fermi surface is shown as closed. [4]

Question 5

(a) What is superconductivity? [1]

(b) Draw the following physical properties as a function of temperature for the given metals, in the superconducting and normal states. Use same axis for each metal.

(i) Thermal conductivity of lead. [2]

(ii) Heat capacity of gallium. [2]

(c) With the aid of diagrams and relevant equations distinguish between paramagnetism and antiferromagnetism. [5]

(d) Including relevant equations and diagrams where possible, write explanatory notes on the following:

(i) Liquid crystals. [5]

(ii) Polymers. [5]

(iii) Colloids. [5]

END OF QUESTION PAPER

DATA SHEET

Planck's constant	$h = 6.63 \times 10^{-34}$ J s
Speed of light	$c = 3.00 \times 10^{8}$ m/s
Mass of electron	$m_e = 9.11 \times 10^{-31}$ kg
Mass of proton	$m_p = 1.672 \times 10^{-27}$ kg
Mass of neutron	$m_n = 1.675 \times 10^{-27}$ kg
Electronic charge	$e = 1.60 \times 10^{-19}$ C
Angstrom unit	1 Å $= 10^{-10}$ m
Electron volt unit	1eV $= 1.60 \times 10^{-19}$ J