

UNIVERSITY EXAMINATIONS

1ST SEMESTER 2022/2023 ACADEMIC YEAR

FOURTH YEAR EXAMINATION FOR THE DEGREE OF
BACHELOR OF EDUCATION (SCIENCE)

PHYS 412: SOLID STATE PHYSICS

STREAM: R

TIME: 2 HRS

DAY: TUESDAY [11.30AM – 13.30] DATE: 13/12/2022

THIS QUESTION PAPER CONSISTS OF FOUR (4) PAGES

PLEASE DO NOT OPEN UNTIL THE INVIGILATOR SAYS SO.

INSTRUCTIONS

- i. Read the question paper carefully
- ii. DO NOT carry a mobile phone or any electronic transmission device into examination room
- iii. Answer question ONE and any other TWO
- iv. Question one carries 40 marks and the rest carry 15 marks each
- v. You may need the following;
 - a) Resistivity of copper = $1.76 \times 10^{-6} \Omega \cdot m$
 - b) Atomic density of copper = 8.5×10^{22} atoms/cm³
 - c) Avogadro's number = 6.025×10^{23}
 - d) Electronic charge = 1.6×10^{-19} C
 - e) E_f for copper = 7.00 eV

QUESTION ONE

- (a) Briefly distinguish between ionic and covalent bonds. Give two properties of each bond. (4 marks)
- (b) State three types of cubical crystal lattice. (3 marks)
- (c) For a pair of atoms, sketch a graph showing how the potential energy per atom pair varies with the distance between the atoms. Show on your graph the equilibrium separation r_0 . (4 marks)
- (d) State any two physical situations that defined one-dimensional monatomic lattice. (2 marks)
- (e) Outline briefly the shortcomings of free electron model. (4 marks)
- (f) Identify the excitations which carry the heat currents (2 marks)
- (g) Give at least four salient features of phonons. (4 marks)
- (h) Distinguish between Einstein and Debye models for lattice specific heats and hence define the Debye's temperature (4 marks)
- (i) What is the specific heat per mole of a monatomic gas at constant volume. (2 marks)
- (j) What are the seven crystalline systems? (7 marks)
- (i) On the basis of the free electron theory account for the following
 - (i) Ohm's law (3 marks)
 - (ii) Electrical conductivity in solids (2 marks)

QUESTION TWO

- (a) Define “the reciprocal lattice” and explain its relation to Bragg reflection. (4 marks)
- (b) A beam of electrons with kinetic energy 1KeV is diffracted as it passes through a polycrystalline metal foil. The metal has a cubic crystal structure with a spacing of $1\text{\AA}$.
- (i) Calculate the wavelength of the electrons. (4 marks)
- (ii) Calculate the Bragg angle for the first order diffraction maximum (4 marks)
- (c) State three symmetry operations that can be applied on the crystal structure. (3 marks)

QUESTION THREE

- (a) Diffraction studies involving X-rays, electron or neutrons gives information about the crystallographic properties of solids. Compare these three techniques with reference to particles energies and types of information that can be obtained. (6 marks)
- (b) Write down definitions and formulae which describe thermal conductivity of a solid (2 marks)
- (c) Sketch a graph of the thermal conductivity of a metal as a function of temperature. (3 marks)
- (d) Briefly describe the mechanism for thermal conductivity of crystalline insulating solids. (4 marks)

QUESTION FOUR

- (a) The free electron model for a metal assumes that the conduction electrons can be approximated by a gas of free electrons where electrons where the only important parameters for the gas are n , the number density of electrons and τ the time between collisions. Show that in this model the electrical conductivity of a metal can be expressed as $\sigma = \frac{ne^2\tau}{m}$ (6 marks)
- (b) Estimate the collision time τ for an electron in copper. (5 marks)
- (c) What is the specific heat per mole at constant volume for a diatomic gas? Explain. (4 marks)

QUESTION FIVE

- (a) Consider a one-monatomic lattice with one atom of mass m per lattice point interacting with only nearest neighbors with force constant K . Derive an expression for the net force on the n th atom. **(5 marks)**
- (b) The conduction of heat by a non-metallic crystalline solid requires a mechanism by which the phonon distribution may be brought in to thermal equilibrium.
- (i) Show that a three-phonon collision process of the type $\mathbf{q}_1 + \mathbf{q}_2 = \mathbf{q}_3$ will not establish equilibrium. **(6 marks)**
- (ii) Describe the form of the process which establishes equilibrium. **(4 marks)**

