KISII UNIVERSITY

UNIVERSITY EXAMINATIONS
FOURTH YEAR EXAMINATION FOR THE AWARD OF THE DEGREE OF BACHELOR OF EDUCATION SCIENCE AND BACHELOR OF SCIENCE

SECOND SEMESTER 2021/2022
(FEBRUARY – JUNE, 2022)

PHYS 421: SOLID STATE PHYSICS

STREAM: Y4 S2 **TIME: 2 HOURS**

DAY: THURSDAY, 9:00 AM – 11:00 AM **DATE: 12/05/2022**

INSTRUCTIONS

1. ***Do not write anything on this question paper.***
2. ***Answer Question ONE (Compulsory) and any other TWO Questions.***
3. ***The following constants may be useful:***

Mass of proton $m_p = 1.007276u$
Mass of an electron $m_e = 9.11 * 10^{-31} kg$
Speed of light, $C = 2.9979\ m/s^2$
Electron charge $e = 1.6021773 \times 10^{-19} C$
Avogadro's number $N_A = 6.02 \times 10^{23}$ *atoms/molecules*
Boltzmann $K_B = 1.38 \times 10^{-23} J/K = 8.62 \times 10^{-5}\ eV/K$
Coulomb constant, $\boldsymbol{K} = 8.99 \times 10^9 NM^2/C^2$

QUESTION ONE

a) Explain briefly what is meant by the terms "Crystal Planes" and "Miller Indices" for the case where the axes of a lattice are all mutually orthogonal/perpendicular to each other (4 marks)

b) **i)** Find the intercepts, corresponding the plane which has the following miller indices [4 2 1]. (4 marks)

ii) Sketch the lattice planes given by the following miller indices

(013); (112); (101) (6 marks)

c) A primitive cell of a Bravais lattice is defined by the primitive vectors; $\overrightarrow{a_1}=(a,0,0)$ and $\overrightarrow{a_2}=(0,b,0)$. A matrix transformation operates on this cell so as to yield a cell of vectors, $\overrightarrow{a_1'}$ = $(2a,-b,0)$ and $\overrightarrow{a_2'}=(-a,b,0)$. Show that the new conventional cell is identical in size as the primitive cell (5 marks)

d) Explain any two properties of metals that could not be explained using the classical free electron theory. (6 marks)

e) Explain the features of atomic structure that determine whether an element is diamagnetic or paramagnetic material. (5 marks)

QUESTION TWO

a) Consider the body-centered cubic crystal lattice (bcc) to be simple cubic crystal;

i) Write down the primitive translation vectors for this type lattice (3 marks)

ii) workout the ratio of the volume of the conventional unit cell to the primitive unit cell (4 marks)

iii) calculate also the corresponding translational vectors in its reciprocal space (4 marks)

iv) For this type of crystal, proof the relation;

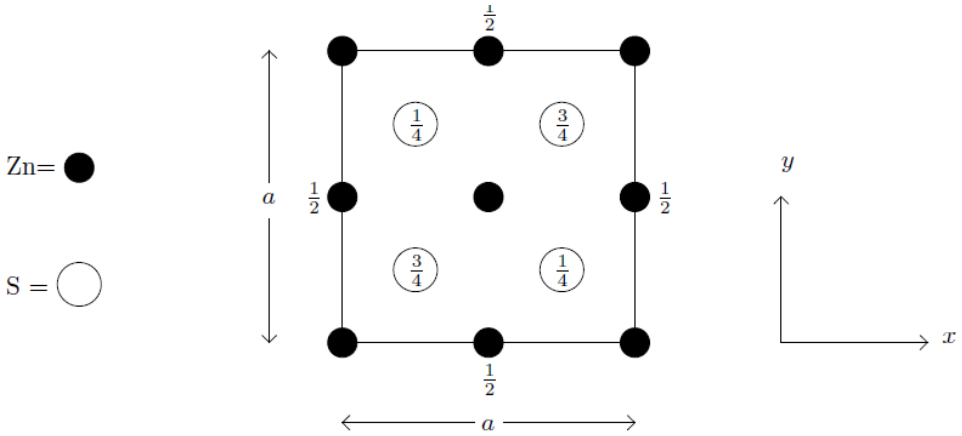
$$V_k = \frac{(2\pi)^3}{V}$$

(The symbols in this equation assume their usual meaning)(5 marks)

b) Verify that in the ideal **hcp** lattice structure, **c/a** = $\sqrt{\frac{8}{3}}$ (4 marks

QUESTION THREE

a) Figure 1 below shows a plan view of a structure of cubic ZnS (zinc blende) looking down the ***z*** axis. The numbers attached to some atoms represent the heights of the atoms above the z = 0 plane expressed as a fraction of the cube edge ***a***. Unlabeled atoms are at z = 0 and z = a.



i) list the primitive translation vectors **(**3 marks)

ii) Given that **a** = 0.541 nm, calculate the nearest-neighbor Zn-Zn, Zn-S, and S-S distances. (8 marks)

b) **i)** Show that in cubic crystal systems, the spacing between the planes, $d_{(hkl)}$ is related to the lattice constant **a** using the relation,

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

(5 marks)

ii) Using the relation in (i), calculate the distance d_{hkl} for a simple cubic cell for (002) and (003) planes (4 marks)

QUESTION FOUR

a) Assuming that the classical free electron theory;

i) Using the $J = nev_d$ and Ohm's law, show that the mean drift speed $\boldsymbol{v_d}$ of an electron in an applied electric field,**E** is;

$$v_d = \frac{\sigma E}{ne};$$

Where σ is the electrical conductivity and $\boldsymbol{n}$ is the density of electrons (4 marks)

ii) Given that $\sigma = \frac{ne^2\tau}{m_e}$, write an expression for σ that involves $\boldsymbol{L}$, the mean free path of the electrons by (4 marks)

b) Applying the electron theory to a silver (A = 108) wire whose density is $10.5*10^3 kg/m^3$ and given that for this metal, the free mean path, L is equal to 100 times the atomic spacing, $\boldsymbol{d}$ and that $\boldsymbol{v_d}$, is equal to the velocity corresponding to the fermi energy, $\boldsymbol{E_f}$ = 5.5eV; calculate;

i) the velocity corresponding to the fermi energy, (fermi velocity), v_f (3 marks)

ii) the density of the electrons, $\boldsymbol{n}$ in this wire (3 marks)

iii) the free mean path, L (3 marks)

iv) the conductivity of the wire (3 marks)

QUESTION FIVE

a) What is superconductivity? Name two types of superconductors (4 marks)

b) **i)** Briefly explain thefollowing terms in relation to superconductivity
Critical temperatureEnergy gap, $\mathbf{E_g}$ (5 marks)

ii) Calculate the E_g for Sn (Tin) whose critical temperature is 3.72k (5 marks)

c) Given that for mercury (Hg), the critical temperature at which superconductivity ensues with zero applied magnetic field is 4.15k, and the critical applied magnetic field at which superconductivity will not take place at any temperature is 0.041T, Calculate the applied magnetic field that will stop superconductivity of the wire at 2.2k (6 marks)