JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY

UNIVERSITY EXAMINATION FOR THE DEGREE OF BARCHELOR IN EDUCATION SCIENCE WITH IT

MAIN

REGULAR

COURSE CODE:

COURSE TITLE: SOLID STATE PHYSICS

EXAM VENUE: **STREAM: BACHELOR OF EDUCATION**

DATE: **EXAM SESSION:**

TIME: 2:00HRS

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1. **<u>Instructions:</u> Answer question 1 (Compulsory) in Section A and ANY other 2 questions in Section B.**
2. **Answer Question 1 (compulsory) and ANY other 2 questions**
3. **Candidates are advised not to write on the question paper.**
4. **Candidates must hand in their answer booklets to the invigilator while in the examination room.**

<u>QUESTION 1 (30 MARKS)</u>

a. State the **Dulong-Petit Law** for crystalline matter [2mks]

b. What is the probability at 400K that a state at the bottom of the conduction band is occupied in silicon. Given that $E_g = 1.1$ eV [4mks]

c. Derive the expression for the **Wannier Theorem** [5mks]

d. Consider a monoatom of mass M in a basis. Show that in the long wavelength limit i.e. **K**a<<1, the dispersion relation becomes $\omega^2 = (C/M)K^2a^2$ where C and a are spring and lattice constants respectively [4mks]

e. Give a brief overview of the **tight binding model** and state how it deviates from **the free electron gas model** [5mks]

f. Define the Debye frequency ω_D D in terms of the ebye Temperature T_D [3mks]

g. The Debye temperature θ for iron is known to be 360 K. Calculate ν_m, the maximum frequency [4mks]

h. State the Dulong-Petit Law for crystalline matter [3mks]

QUESTION 2 (20MARKS)

a. Consider a two dimensional square lattice of lattice parameter a. Each site provides two conducting electrons.

I. Determine k_F in terms of a. [4mks]

II. Under free electron model, at what value of k_y [4mks]

III. Will the Fermi sphere cross the boundary at x=π/a? [4mks]

IV. The electrons are actually only nearly free and a gap of $2U=0.1E_F$ opens up at the Brillouin zone boundary. At what value of k_y will the Fermi surface in the first Brillouin zone cross the boundary at x=π/a? [4mks]

V. How about the second Brillouin zone? (You can express your answers in unit of π/a.) [4mks]

QUESTION 3 (20MARKS)

a) The energy of interaction of two atoms a distance r apart can be written as:

$$E(r) = -\frac{p}{r} + \frac{q}{r^7}$$ where p and q are constants.

i. Show that for the particles to be in equilibrium, $r = r_o = (7\,q/p)^{1/6}$ [4mks]

ii. In stable equilibrium, show that the energy of attraction is seven times that of the repulsion [4mks]

iii. The energy of attraction and repulsion at a stable equilibrium are equal. Show [3mks] b)

i) Define mobility of a carrier of current and show how it is related to the **Hall Coefficient** [3mks]

ii) Compare the mobility of an electron in the conduction band of a semiconductor and the mobility of an electron (or hole) in the valence band. Give reason for your answer [3mks]

iii) Derive an expression for the electrical conductivity of a metal on the basis of free electron [3mks]

QUESTION 4 (20 MARKS)

a. Define **Madelung Energy** and explain why care must be taken when calculating this cohesive energy in order to avoid getting divergent results [5mks]

b. Use the **Drude Model** to derive the expressions for the net drift current in a metal and state the assumptions made [5mks]

c. Define the **Debye-Waller factor** and explain its significance in scattering experiments

[10mks]

QUESTION 5 (20 MARKS)

a. Compare the specific heat per mole of a monoatomic and a diatomic gas at constant volume. Use appropriate equations to explain your answer. [5mks]

b. Calculate the specific heat capacity of a monoatomic crystalline solid [6mks]

c. Debye's model of solids gives the expression for specific heat $C_v = 9N_0k\frac{1}{x^3}\int_0^x \frac{\sigma^4 e^\sigma}{\left(e^\sigma - 1\right)^2}dE$

where $\sigma = \frac{h\upsilon}{kT}$, $x = \frac{h\upsilon_m}{kT}$ and $\theta_D = \frac{h\upsilon_m}{k}$ is the Debye's characteristic temperature. Show that;

i. At high temperatures, Debye's model gives Dulong Petit law [6mks]

ii. At low temperatures it gives $C_V \propto T^3$ in agreement with the experiment [3mks]