University of Nottingham

FACULTY OF PURE SCIENCE

SCHOOL OF PHYSICS

PART II EXAMINATION, 1968

PHYSICS (ii)

TUESDAY *June 4th* 2.30 - 5.30

Answer FOUR *questions*

1. Discuss carefully the difference between the macroscopic electric field **E** of Maxwell's equations, and the local field $\mathbf{E}_{loc}$ in a solid, indicating how they can be related in the general case. Explain how $\mathbf{E}_{loc}$ causes the frequencies of transverse optical phonons to be lower than those of the longitudinal optical phonons.

Find the local field acting in a parallel sided slab of a cubic material 1 mm thick which has a dielectric constant of 13, if it is thinly metal plated on opposite faces and has a potential difference of 10 kY applied between these electrodes.

2. Explain the paramagnetism of rare earth ions in solids by considering how the magnetic moments of the 4*f* electrons are added together and indicate qualitatively how the temperature dependence of the susceptibility can be calculated. Under what conditions would you expect the simple theory to break down?

3. Outline the assumptions made in the free electron theory of metals and state how this theory describes the distribution of electrons in energy and momentum. How is this theory modified to account for real metals? Illustrate your answer by showing which momentum states are occupied for (*a*) monovalent metals (*b*) divalent metals and (*c*) semiconductors. Describe how you would experimentally verify these predictions.

4. Explain the difference in behaviour of majority and minority carriers when their equilibrium concentration is disturbed. Modify the diffusion equation to account for the finite lifetime of minority carriers and so obtain an equation for their concentration. Hence by applying it to a *p-n* junction derive an expression for the current as a function of voltage. Clearly state the approximations that you have to make and indicate the requirements that these make on the physical parameters involved.

5. Derive an expression for the dispersion relationship, $\omega(q)$, for longitudinal vibrations of a linear chain of point masses coupled by elastic springs which obey Hooke's law. Sketch the dispersion curve given by this relation. Describe qualitatively any changes in this relationship that occur if the masses are alternately of different magnitudes, m and M.

If the longitudinal vibrations in an ionic diatomic lattice could be represented by curves of this sort, state giving reason whicb parts of the curves would contribute to (*a*) the thermal conductivity and (*b*) the infra-red absorption of the solid.

Indicate briefly how information on the dispersion curve of a solid can be obtained.

[Turn over

6. Describe the experimental apparatus used in a method to determine the structure of a solid by means of an X-ray beam.

The structure of sodium chloride is face-centred cubic with sodium ions at

(0, 0, 0), (½,½, 0), (½, 0, ½), (0, ½, ½),

and chlorine ions at

(½,½,½), (0,0, ½), (0, ½, 0), (½, 0,0).

Explain, in principle, how you could verify that the structure was not that of caesiuin chloride which is simple cubic with caesium ions at the corners of the cube and a chlorine ion in the body centre position.

Calculate the electrostatic energy of the chlorine ion due to the first three sets of nearest ncighbours in ONE of these structures.

7. The specific heat of liquid ^{4}He at very low ternperatures has a cubic temperature dependence. Show that this is consistent with the excitations believed to be present at these temperatures and explain the change in this dependence that occurs at about 0.6 °K.

A closed, thermally insulated vessel is partially immersed in a bath of liquid ^{4}He at 0.3 ^{0}K and connected to it by a superleak. The temperature inside the vessel is raised to 0.5 ^{0}K by an electrical heater. If the resulting difference in level between the inside and outside of the vessel is 0.9 cm, calculate the specific heat of liquid ^{4}He at 0.1 °K. Derive any expressions you use.

[Take g = 1000 cm sec^{-2}.]

8. Derive expressions for the Gibbs free energy of a long thin cylinder of metal in an axial magnetic field H in (*a*) its normal state and (*b*) its superconducting state. In each case the energy is measured from its value in zero field. You may assume that the work done in magnetizing a material is given by $dW = VHdI$, where V is the volume and I the intensity of magnetization in the material.

Hence

(i) derive an expression for the difference between the specific heats of a metal at the transition temperature between its normal and superconducting states,

(ii) explain the difference in behaviour of type I and type II superconductors in a magnetic field,

(iii) explain the change and sign of the change in the temperature of a metal sample when its superconductivity is destroyed adiabatically by a magnetic field.

9. Write an essay on ONE of the following:

(*a*) the physical basis of the B.C.S. theory of superconductivity,

(*b*) the properties of liquid ^{3}He compared with those of an ideal Fermi -Dirac gas,

(*c*) ferroelectricity,

(*d*) ferromagnetism.