SECOND OPPORTUNITY EXAMINATION QUESTION PAPER

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This question paper consists of 3 pages
(including this front page)

INSTRUCTIONS

- Answer any FOUR questions. Each question carries 25 marks.
- Show all your calculations or steps.
- The following constants may be used:
  
  Avogadro’s No. $= 6.02 \times 10^{23}$ mol$^{-1}$
  Charge on electron $= 1.60 \times 10^{-19}$ C
  Mass of electron $= 9.11 \times 10^{-31}$ kg
  Mass of neutron $= 1.68 \times 10^{-27}$ kg
  1 eV $= 1.60 \times 10^{-19}$ J
  Planck’s constant, $h = 6.63 \times 10^{-34}$ J s
  Speed of light, $c = 3 \times 10^8$ m/s

UNIVERSITY OF NAMIBIA EXAMINATIONS
1(a) Differentiate between the fcc lattice and the bcc lattice. Draw suitable diagrams and give an example of each lattice. [6]
(b) Sketch the (i) (200) plane and (ii) (111) plane of a cubic crystal. [4]
(c) Give an account of the powder method of observing X-ray diffraction. [3]
(d) The edge of a unit cell in a simple cubic crystal is $a = 2.62 \times 10^{-10}$ m. If an X-ray beam having a wavelength $\lambda = 1.54 \times 10^{-10}$ m is incident on the crystal, find
(i) the energy (in eV) of the X-ray beam and the angles at which you will observe reflections from the (110) and (202) planes, and
(ii) the energy (in eV) of neutrons having the same wavelength as the X-rays and the angle at which you will observe second order reflections from the (110) planes. [12]

2(a) Discuss (in detail) the ionic bond. [4]
(b) The resultant force between atoms in a covalent solid can be written as
$$ F = \frac{B}{x^n} - \frac{A}{x^m} $$
where $A$ and $B$ are constants and $x$ is the distance between atoms.
(i) Find an expression for the force in terms of the equilibrium separation of atoms. [5]
(ii) Obtain an expression for the potential energy of the system in terms of $A$. [5]
(iii) Find an expression for the minimum potential energy. If the equilibrium separation of atoms is $1 \text{Å}$ (or $10^{-10}$ m) and the minimum potential energy is $5 \times 10^{-19}$ J, find $A$. Assume that $n = 10$ and $m = 2$. [5]
(c)(i) What is meant by doping? [2]
(ii) Write briefly on donors. (Draw a suitable diagram and give an example.) [4]

3(a)(i) Of what importance is the structure factor? [1]
(ii) Write an expression for the structure factor in terms of the Miller indices. [2]
(iii) Evaluate the expression (structure factor) for a bcc lattice and deduce the conditions under which the structure factor will not vanish for the bcc lattice. [10]
(iv) Which of the following reflections would be missing in the diffraction pattern of a bcc lattice? (100), (110), (111), (102), (200), (210), (220) and (211). [2]
(b) Write expressions for the primitive vectors $\vec{b}_1$, $\vec{b}_2$ and $\vec{b}_3$ of the reciprocal lattice in terms of the primitive vectors $\vec{a}_1$, $\vec{a}_2$ and $\vec{a}_3$ of the crystal lattice. [6]
(c) Show that the reciprocal lattice to the simple cubic lattice is itself a simple cubic lattice. [4]
4(a)(i) How does the electrical resistivity of metals vary with temperature at high temperatures? 

(ii) Sketch the variation of electrical resistivity with temperature for sodium.

(b) The element sodium has density $9.7 \times 10^3$ kg m$^{-3}$, atomic mass 23, electrical conductivity of $2.1 \times 10^7$ S m$^{-1}$, and one conduction electron per atom. Determine the mobility of electrons in sodium.

(c) The concentration of electrons in the conduction band of an intrinsic semiconductor is given by

$$n = 2 \left( \frac{m_e k_B T}{2 \pi h^2} \right)^{3/2} \exp \left( \frac{\mu - E_e}{k_B T} \right)$$

where the symbols have their usual meanings. Similarly, the concentration of holes in the valence band of an intrinsic semiconductor is

$$p = 2 \left( \frac{m_h k_B T}{2 \pi h^2} \right)^{3/2} \exp \left( \frac{E_v - \mu}{k_B T} \right).$$

(i) Find a relationship between the product $np$ and the energy gap $E_g$.

(ii) Estimate the ratio of the electron densities in the conduction bands of the insulator carbon and the semiconductor silicon at room temperature (300 K). Use $E_g = 5.33$ eV for carbon and $E_g = 1.14$ eV for silicon at room temperature. (Boltzmann’s constant $= 1.38 \times 10^{-23}$ J/K.)

5(a)(i) KBr has two atoms in the primitive cell. How many acoustical branches will be in its dispersion relation?

(ii) The energy of a lattice vibration is quantized. Draw the symbol for the quantum of energy.

(iii) Sketch (and label) the dispersion relation for a linear lattice with one atom in the primitive cell. Is there a frequency gap in the dispersion relation? Give a reason for your answer.

(b) Write down the Bloch theorem and explain the theorem.

(c) Show that for a simple square lattice (two dimensions) that the kinetic energy of a free electron at a corner of the first zone is higher than that of an electron at midpoint of a side face of the zone by a factor of 2.

END