KENYATTA UNIVERSITY

UNIVERSITY EXAMINATIONS 2011/2012

INSTITUTIONAL BASED PROGRAMME (AUGUST SESSION)

EXAMINATION FOR THE DEGREE OF BACHELOR OF EDUCATION AND BACHELOR OF SCIENCE

SPH 420: CONDENSED MATTER PHYSICS I

DATE: TUESDAY 3RD JANUARY 2012 TIME: 8.00 A.M – 10.00 A.M

INSTRUCTIONS

Answer question **one** and any other **two**. Question one carries 30 marks while each of the others carries 20 marks. Credit will be awarded for clear explanations and illustrations.

Question One

(a) i) Briefly cite the main differences between ionic, covalent, and metallic bonding.
ii) Offer an explanation as to why covalently bonded materials are generally less dense than ionically or metallically bonded ones. [6]

The variation of the potential energies as a function of interatomic separation for the atoms in solids is characterized by a bonding energy (E_0) at the equilibrium inter-atomic spacing. Discuss, giving examples, the significance of this bonding energy. [6]

(b) The conductivity in a metal may be expressed as

$$\sigma = N\frac{e^2\tau}{m^*}.$$

Discuss the dependence and veracity of the conductivity σ, on each of the parameters on the right hand side of the above expression. [6]

(c) There are different types of polarization processes, depending on the structure of the molecule, which constitute the solid. In discussing how a solid can have a dielectric response, which differs from that of empty space we must consider three forms of polarization on an atomic scale. Discuss these three polarization processes. [3,2,3]

(d) The polarization equation,

$$\vec{P} = (\varepsilon_r - 1)\varepsilon_0\vec{E}$$

can be used to work out the dipole moment $\vec{P}$ of an individual molecule, where the dimensionless constant of proportionality, $\chi_E = \varepsilon_r - 1$, is called the electric susceptibility of the material. Consider carbon tetrachloride (CCl_4), which at 20^0C has relative permittivity 2.24 and density 1.60 gm/cm^3. Given that the molecular weight of CCl_4 is 156 and that there are 74 electrons in each CCl_4 molecule, determine,

(i) the dipole moment of a single CCl_4 molecule,

(ii) the average electron displacement in a field of 10^7 volts/metre. [3,3]

(e) A magnetic material has a magnetization of 2300 Am^{-1} and produces a flux density of 0.00314 Wbm^{-2}. Calculate the magnetizing force and the relative permeability of the material. [6]

Question Two

(a) The net potential energy between two adjacent ions, E_N, may be represented by the following equation,

$$E_N = -\frac{A}{r} + \frac{B}{r^n}$$

Deduce an expression for the bonding energy E_0 in terms of the parameters A, B, and n. [7]

(b) For a K^+–Cl^- ion pair, attractive and repulsive energies E_A and E_R, respectively, depend on the distance between the ions r, according to

$$E_A = \frac{1.436}{r} \quad \text{and} \quad E_R = \frac{5.86 \times 10^{-6}}{r^9}.$$

For these expressions, energies are expressed in electron volts per K^+–Cl^- pair, and r is the distance in nanometers. The net energy E_N is just the sum of the two expressions above.

i. Superimpose on a single plot E_N, E_R, and E_A versus r up to 1.0 nm. [10]

ii. On the basis of this plot, determine

a) the equilibrium spacing r_0 between the K^+ and Cl^- ions, and

b) the magnitude of the bonding energy E_0 between the two ions. [2,1]

Question Three

(a) To explain the variation of molar heat capacity with temperature four assumptions were made in the Einstein model. State these assumptions. [5]

(b) On the basis of the four assumptions, deduce the Plank formula, i.e.

$$E_{AV} = \frac{E_t}{N} = \frac{h\nu}{e^{h\nu/kT} - 1},$$

where terms have their usual meaning. [5]

(c) Einstein's theory yields an expression for the molar heat capacity of a solid at constant volume (C_v) given by:

$$C_V = 3R\left(\frac{\theta_E}{T}\right)^2 \frac{e^{\theta_E/T}}{\left(e^{\theta_E/T} - 1\right)^2}.$$

where terms have their usual meaning. On the basis of this equation, summarize the results of the Einstein model after showing that it tends to 3R at elevated temperatures and to zero at low temperatures. 10]

Question Four

(a) Discuss the distinction between dielectric and insulating materials. [5]

(b) What is the significance of the relative permittivity (dielectric constant) ε_r, of a material? [3]

(c) Describe a simple procedure, which can be used for measuring the dielectric constant of a material. The following equation may be useful in your discussion:

$$\vec{D} = \varepsilon_0(1 + \chi_e)\vec{E} = \varepsilon_0\vec{E}\varepsilon = \varepsilon\vec{E},$$

where $\vec{D}$ is the electric induction or displacement vector and $\vec{E}$ is the electric field in the medium. [12]

Question Five

a) The data in the Table shown are for a transformer steel:

(i) Construct a graph of B versus H.
(ii) What are the values of the initial permeability and initial relative permeability?
(iii) What is the value of the maximum permeability?
(iv) At about what H field does this maximum permeability occur?
(v) To what magnetic susceptibility does this maximum permeability correspond?

H(A/m)	B (teslas)	H(A/m)	B (teslas)
0	0	200	1.04
10	0.03	400	1.28
20	0.07	600	1.36
50	0.23	800	1.39
100	0.70	1000	1.41
150	0.92		

[10]

b) A paramagnetic material has a bcc structure with a cube edge of 2.5 Å. If the saturation value of magnetization is 1.8×10^6 Am^{-1}, calculate the average magnetization contributed per atom in Bohr magnetons. [5]

c) Sodium metal with a bcc structure has two atoms per unit cell. The radius of sodium atom is 1.85 Å. Calculate its electrical resistivity at 0 °C, if the classical value of mean free time at this temperature is 3×10^{-14} s. [5]