UNIVERSITY OF FORT HARE

University of Fort Hare
Together in Excellence

INTRODUCTION TO SOLID STATE PHYSICS (PHY 512)

HONOURS EXAMINATIONS

DATE: June 2023

DURATION: 3 HOURS

MARKS: 100

INTERNAL EXAMINER

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EXTERNAL EXAMINER

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THIS PAPER CONSISTS OF ...7...PAGES INCLUDING COVER PAGE

INSTRUCTIONS:

1. Answer all the questions.
2. Write neatly and legibly.
3. Unless otherwise stated, all symbols retain their usual meanings.
4. Values of constants and formula sheet appear at end of the question paper.

QUESTION 1 [25 Marks]

1.1. Define the following:

1.1.1. Space Lattice (2)

1.1.2. Polycrystal (2)

1.2. Figure 1 below shows three mutually perpendicular coordinate axes, ox, oy and oz. A plane (hkl) parallel to the plane passing through the origin makes intercepts a/h, b/k and c/l on the three axes at A, B and C, respectively.

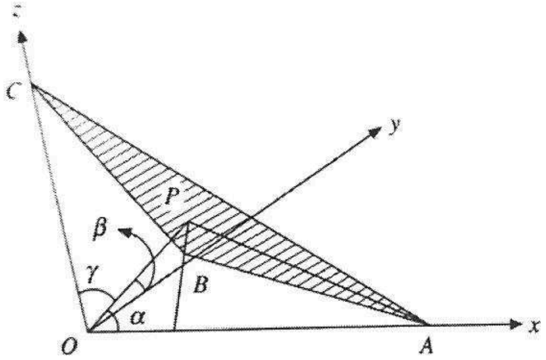

Figure 1.

Show that the interplanar spacing of the primitive tetragonal system is given by

$$d = \frac{1}{\sqrt{\frac{h^2 + k^2}{a^2} + \frac{l^2}{c^2}}}.$$

(7)

1.3. A cubic system is divided into three Bravais latices.

1.3.1. Draw the primitive unit cell of an FCC system and indicate the three low index planes. (4)

1.3.2. Determine the interplanar spacing for each low index plane. (6)

1.4. Differentiate between orthorhombic and hexagonal space lattice by making use of restrictions on conventional cell parameters. (4)

[25]

QUESTION 2 [25 Marks]

2.1. Define the following:

2.1.1. Permanent dipole bonding (2)

2.1.2. Cohesive energy (2)

2.2. Given that the total cohesive energy per kmol of a univalent NaCl crystal is given as

$$U = N\left[-\frac{Ae^2}{4\pi\varepsilon_0 R} + Be^{\left(-R/\rho\right)}\right]$$

and the volume of its unit cell is

$$V/mol = \frac{a^3}{4},$$

show that

$$\frac{R_e}{\rho} = \frac{18R_e^4\beta}{Ae^2} + 2$$ (10)

2.3. Calculate

2.3.1. the compressibility of NaCl crystal assuming the repulsive potential of the type B/R^9, the equilibrium separation $R_e = 2.81$ Å, the Madelung constant $A = 1.7496$. (4)

2.3.2. also calculate the cohesive energy per atom (ion) if the ionisation potential of Na is 5.14 eV and electron affinity of Cl is 3.61 eV. (6)

[25]

QUESTION 3 [25 Marks]

3.1. Briefly describe metallic bonding. (4)

3.2. Figure 2 shows a schematical representation of a tetrahedral void surrounded by four spheres in three dimensions.

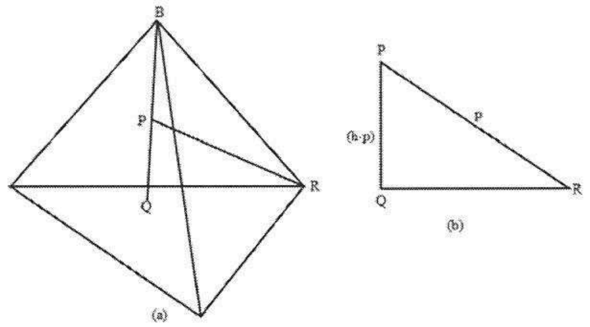

Figure 2

The centres of these spheres lie at the corners of a regular tetrahedron of side $a = 2R$. Show that the radius of the sphere representing the tetrahedral void is given by (7)

$$r = 0.225R$$

3.3. Determine the radius of the sphere that will just fit into the void produced by the packing of spheres of radius R on a square lattice of side "a". Also determine the free area per unit cell. (6)

3.4. Figure 3 shows a three-dimensional BCC lattice.

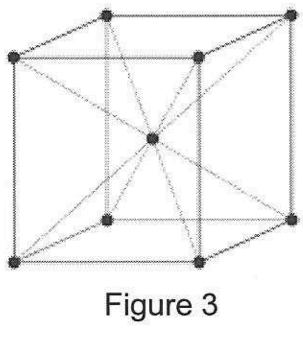

Figure 3

Show that the packing efficiency is 68 %. (5)

3.5. Consider Figure 4 below and show that the radius of the small that can fit into the void of the three large spheres is given as

$$r = 0.155R$$

where r is the radius of the small sphere and R is the radius of the large sphere.

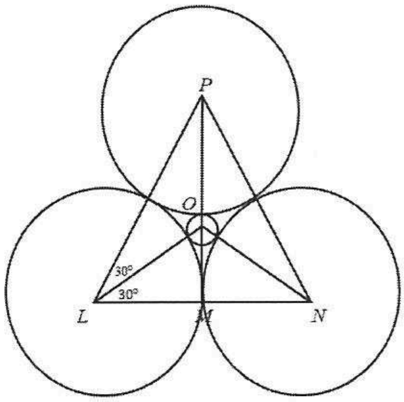

Figure 4

(3)

[25]

QUESTION 4 [25 Marks]

4.1. Define the following:

4.1.1. Interstitial impurity atom (2)

4.1.2. Schottky imperfection (2)

4.2. Figure 5 shows the hydrogen atom, where a single electron revolves in a circular orbit of radius r.

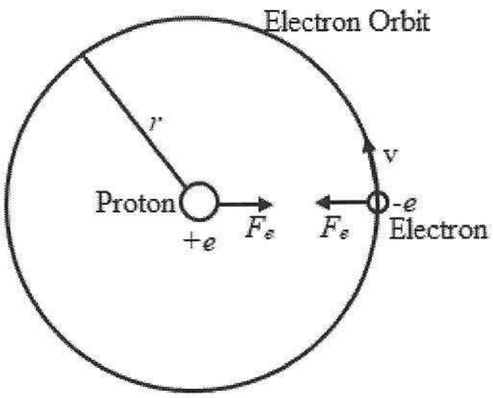

Figure 5.

Show that the corresponding energy (hv) of an orbit is give as; (10)

$$hv = \frac{mZ^2e^4}{8\varepsilon_0^2h^2}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

4.3. Determine the fraction of atoms in a given solid with the energy equal to or greater than 1.5 eV at 300 K and at 1500 K. (5)

4.4. An imperfect crystal contains $6nx$ linear oscillators with frequency ν' and $(6N - 6nx)$ oscillators with frequency ν, where x is the number of nearest neighbours surrounding a vacancy. Show that that the thermal entropy due to Schottky defects is given as

$$\Delta S_{th} = 6nxk \ln\left(\frac{\nu}{\nu'}\right)$$ (6)

[25]

Useful formulae

$$A\delta N = \frac{AdN}{V}.n; \quad \Delta E = I.P. - E.A; \quad U_e = -\frac{e^2}{4\pi\varepsilon_0 R_e}; \quad D.E. = U_e + I.P. - E.A;$$

$$U = -\frac{AZ_1Z_2e^2}{4\pi\varepsilon_0 R} + B\exp^{\left(-R/\rho\right)}; \quad \beta = -V\left(\frac{dP}{dV}\right); \quad f_i = 1 - \exp\left[\frac{(X_A - X_B)^2}{4}\right];$$

$$f_i^c = \frac{\mathrm{E}_\mathrm{i}^2}{\mathrm{E}_\mathrm{g}^2}; \quad \frac{(Ze)(e)}{4\pi\varepsilon_0 r^2} = \frac{mv^2}{r}; \quad mr_n v_n = n\left(\frac{h}{2\pi}\right); \quad \Delta E.\Delta t \geq \frac{h}{2\pi};$$

$$S_P = 3Nk\left[1 + \ln\left(\frac{kT}{hv}\right)\right]; \quad W_{\mathrm{cf}} = \frac{N!}{(N-n)!\,n!}; \quad S_{\mathrm{cf}} = k \ln W_{\mathrm{cf}} = k \ln\left[\frac{N!}{(N-n)!\,n!}\right];$$

Physical Constants	
Planck's constant	6.626 x 10^{-34} kg m^2/s
Boltzmann Constant	1.38 x 10^{-23} kg m^2 /Ks
Avogadro's constant	6.022 x 10^{23} mol^{-1}
Electronic Charge	1.6 x 10^{-19} C
Electron rest mass	9.11 x 10^{-31} kg
Proton rest mass	1.673 x 10^{-27} kg
Neutron rest mass	1.675 x 10^{-27} kg
Permittivity of free space	8.854 x 10^{-12} Am^2
Coulomb force constant	9 x 10^{-9} Nm^2C^{-2}
Faraday's constant	96.49 $kCmol^{-1}$
Atomic mass unit (amu)	1.660 x 10^{-27} kg

Group → / Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La *	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac **	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
			*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
			**	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	