UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION

21 APRIL 2011

First Year

APS 104S

INTRODUCTION TO MATERIALS AND CHEMISTRY

Q1	/10
Q2	/15
Q3	/10
Q4	/10
Q5	/15
Q6	/15
Q7	/15
Q8	/10
Total	/100

Exam Type B

Examiners: N. P. Kherani and K. Lian

NAME: ____
Last   First

STUDENT NO:____

INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- Answer <u>all</u> 8 questions.
- All work is to be done on the pages of this booklet.
- When answering the questions include all the steps of your work on these pages and then fill the answer in the respective boxes. For additional space, you may use the back of the preceding page.
- <u>Do not</u> unstaple this exam booklet.
- A Formula Sheet is attached to the end of this exam booklet; if you wish, you may tear-off this sheet *only*.

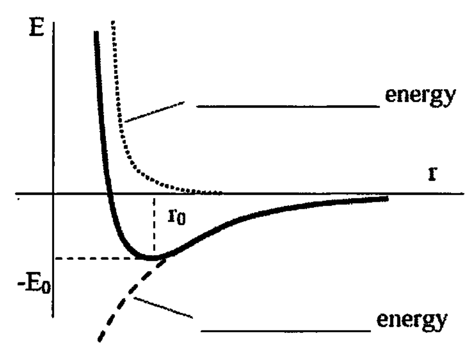
Name: ______________________________ *Student No:* ______________________________

QUESTION 1: ***Atomic and Molecular Bonding (10 pts)***

1.1 State the type of bonding (ionic, covalent, metallic, van der Waals, hydrogen-bonding) for each of the materials listed in the table below. **(3 marks)**

Substance	**Bond Energy (eV/(atom,ion,molecule)**	**Bonding Type**
H_2O	0.52	
NaCl	3.3	
Si	4.7	
Ar	0.08	
Fe	4.2	
NH_3	0.36	

1.2 The figure on the right shows the total potential energy curve (in bold line) which represents the interaction between two atoms as a function of the inter-atomic separation. The total potential energy curve is a sum of two different two types of potential energy interactions shown as dashed and dotted curves. **(2 marks)**



(a) Label the two types of potential energy on the figure;

(b) State the equilibrium interatomic distance: ______;

(c) State the binding energy between the atoms: _____.

1.3 The potential energy between Na^+ and Cl^- ions in a NaCl crystal can be written as:

$$E(r) = \frac{A}{r} + \frac{B}{r^8}$$

where $A = 4.03 \times 10^{-28}$ J.m and $B = 6.97\times10^{-96}$ J.m^8. The energy is given in Joules per ion pair. Calculate the equilibrium interatomic separation between the ions. **(5 marks)**

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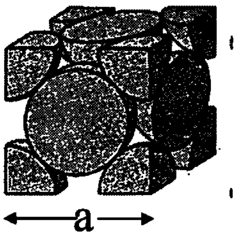
QUESTION 2: ***Crystal Structures and Density (15 pts)***

2.1 A unit cell is shown on the right. Given the atomic radius r = 0.1243 nm, and an atomic weight of 58.69 g/mol.

(a) Calculate the lattice constant "**a**". **(2 marks)**



The "a" value is:

(b) Calculate the density of the metal above. **(3 marks)**

The density is:

(c) What is the atomic packing factor of this unit cell? **(1 mark)**

The packing factor is:

2.2 Identify the respecitve family of planes and the family of directions that possess the highest planar and liner densities for the unit cell shown above. **(2 marks)**

The highest planar density family is:

The highest linear density direction is:

2.3 Derive a planar density expression for (100) plane in terms of the atomic radius "r" for the unit cell shown above **(3 marks)** .

2.4 Answer the following questions

(a) How many nearest neighbors does an atom possess in FCC crystal structure **(1 mark)** ?

(b) How many second nearest neighbor atoms are there for an atom in an FCC crystal structure **(1 mark)** ?

(c) Silicon has a similar crystal structure as diamond. How may atoms are there in a unit cell? Draw the unit cell and accordingly illustrate the justification for your answer. **(2 marks)**

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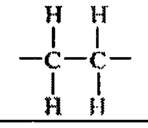
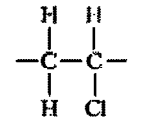
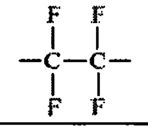
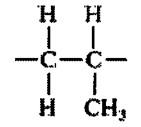
QUESTION 3: ***Polymers (10 pts)***

3.1 Are the following statements "true (T)" or "false (F)"? Circle the correct answer. (**1 mark**)

(a) Naturally occuring polymers include: silk, wood, rubber, plastics, cotton, leather. **T** **F**

(b) Synthetic polymers include: polyethylene, PTFE, PVC, wool, nylon, polypropylene: **T** **F**

3.2 For each of the given repeat units, state the corresponding name of the polymer. (**4 marks**)

POLYMER NAME	REPEAT UNIT
	
	
	
	

3.3 Molecular weights of polymers generally indicate the physical form of the polymer (that is, whether it is a solid, liquid, or waxy). State the physical form for the following molecular weights (**1 mark**):

M ~ 100 g/mol ____________

M ~ 1000 g/mol ____________

M ~ 10,000 g/mol ____________

3.4 Molecular weight data for a particular polymer are given below. (a) Calculate the number average molecular weight. (**2 marks**) (b) Determine the molecular weight of the repeat unit given DP = 406. (**1 mark**) (c) What is the most likely polymer given the MW of the repeat units. (**1 mark**) (Polypropylene: 42 g/mol; PTFE: 100g/mol; Polystyrene: 104 g/mol; Polycarbonte: 254.27 g/mol)?

Molecular Weight Range (g/mol)	x_i
10,000 – 20,000	0.02
20,000 – 30,000	0.15
30,000 – 40,000	0.30
40,000 – 50,000	0.35
60,000 – 70,000	0.15
70,000 – 80,000	0.03

M_n =	***MW Repeat Unit*** =	***Polymer:***

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QUESTION 4: ***Defects (10 points)***

4.1 Mark X for statements that are "True (T)" or "False (F)" **(3 marks):**

	T	F
- Frenkle defect for anions can exist in ceramic in large quantity	[ ]	[ ]
- Twin boundary is a type of linear defects	[ ]	[ ]
- Schottky defect is a type of point defect	[ ]	[ ]

4.2 Cite the relationship between the direction of the applied shear stress and the direction of dislocation line motion. **(2 marks)**

The direction of edge dislocation line motion is _______________ to the shear stress

The direction of screw dislocation line motion is _______________ to the shear stress

4.3 Consider that a certain species of solute atoms are added to a pure metal. State three governing criteria that favor the possibility of forming a solid solution. **(3 marks)**

1:

2:

3:

4.4 To dissolve LiF into MgF_2, what type of vacancy (anionic or cationic) should be introduced and why (explain briefly)? **(2 marks)**

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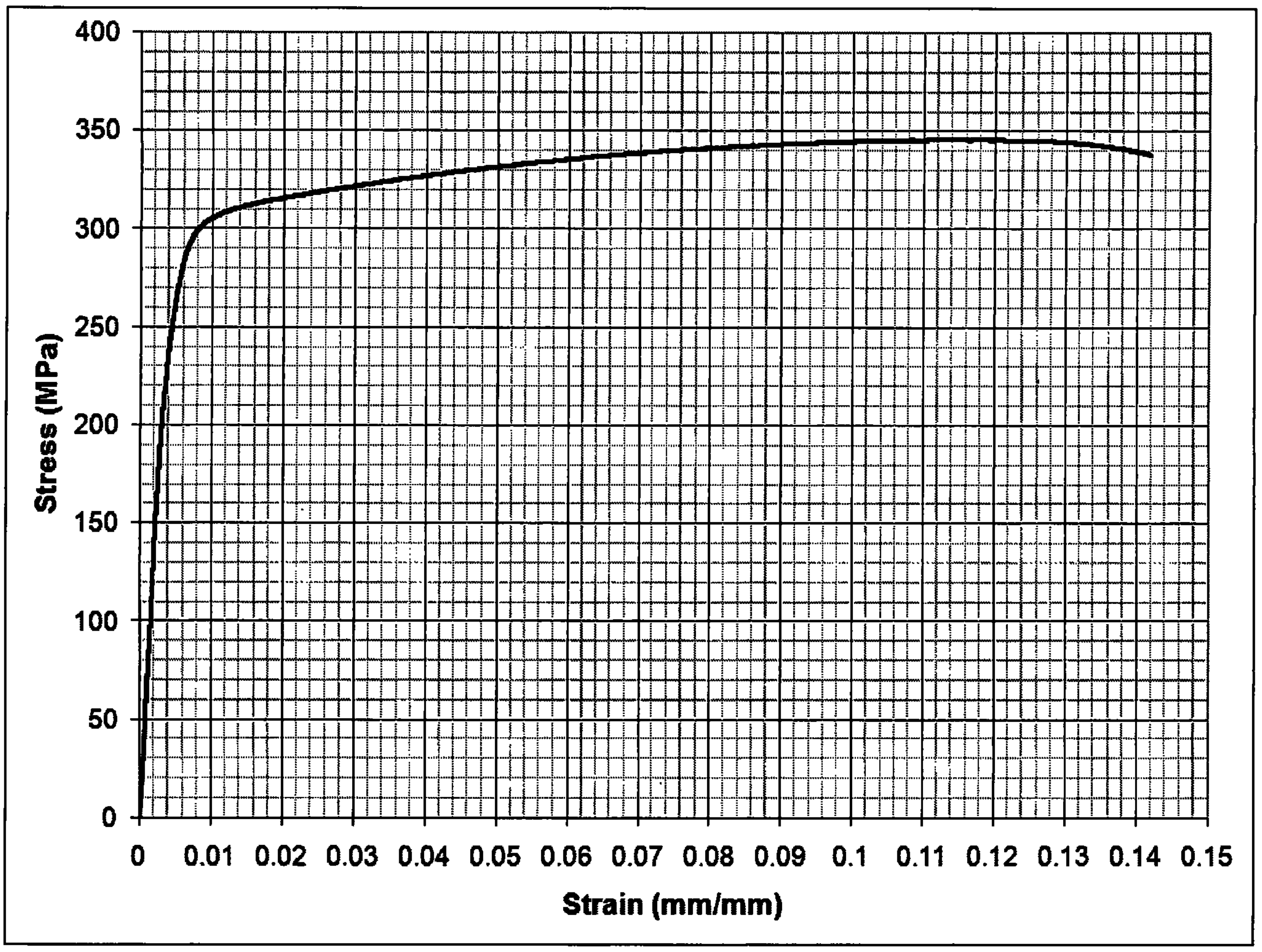
QUESTION 5: ***Mechanical Properties (15 pts)***

5.1 Consider the stress-strain curve for aluminum shown below.



(a) Using the above stree-strain curve, find:numerical values for: **(6 marks)**

Young's Modulus	
Proportional Limit	
0.2% Yield Strength	
Tensile Strength	
Ductility	
Toughness	

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(b) Consider an aluminum bar with an initial diameter of 10 mm and an initial length of 100 mm which is progressively subjected to different load conditions. Determine numerical values of the length of the aluminum bar corresponding to the load conditions given below:

(i) Length when the tensile load is increased from 0 MPa to 150 MPa; **(1 mark)**

(ii) Length when the tensile load is further increased to 330 MPa; **(1 mark)**

(iii)Length when the tensile load is reduced to 0 MPa (from 330 MPa). **(2 marks)**

5.2 Consider an aluminum nitride crystal, a piezoelectric material, which has a modulus of elasticity of 331 GPa.

Note: A piezoelectric material is one which upon application of a compressive mechnical strain exhibits an electrical effect owing to the fact that the specific piezoelectric material does not have an inversion symmetry; accordingly, there is an accumulation of charge which upon release of the mechanical strain leads to a release of the electrical charge and hence the production of electrical energy.

(a) The crystal is subjected to a compressive stress resulting in an elastic compressive strain of $1\text{x}10^{-5}$. Calculate the energy stored in the crystal per unit volume. **(3 marks)**

(b) Upon releasing the compressive stress, the crystal produces electrical energy. Assuming 100% energy conversion efficiency and a crystal volume of 1 mm^3, calculate the electrical energy produced. **(2 marks)**

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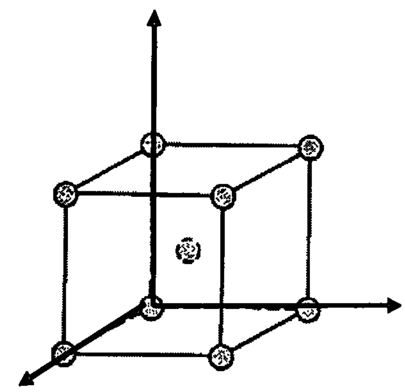
QUESTION 6: ***Deformation Mechanisms in Metals (15 pts)***

(a) A stress is applied in the [001] direction of a BCC single crystal. Calculate θ and λ for the $(1\bar{1}0)$ [111] slip system. **(4 marks)**



(b) If slip occurs on a (110) plane and in [111] direction with $\theta = 45°$ and $\lambda = 54.7°$, calculate the resolved stress (τ_R) when a tensile stress of 145 MPa is applied in [010] direction. If the yield strength σ_y is 70 MPa, will the sample yield? **(4 marks)**

(c) A metal rod with a diameter of 14 mm was deformed by drawing and resulted in a reduced diameter of 12.7 mm.

i) Calculate the percentage of cold work **(2 marks)**

ii) Commnent on the effect of drawing on the following properties (increase, decrease or unchanged) **(3 marks)**:

(1) Ductility –

(2) Tensile strength –

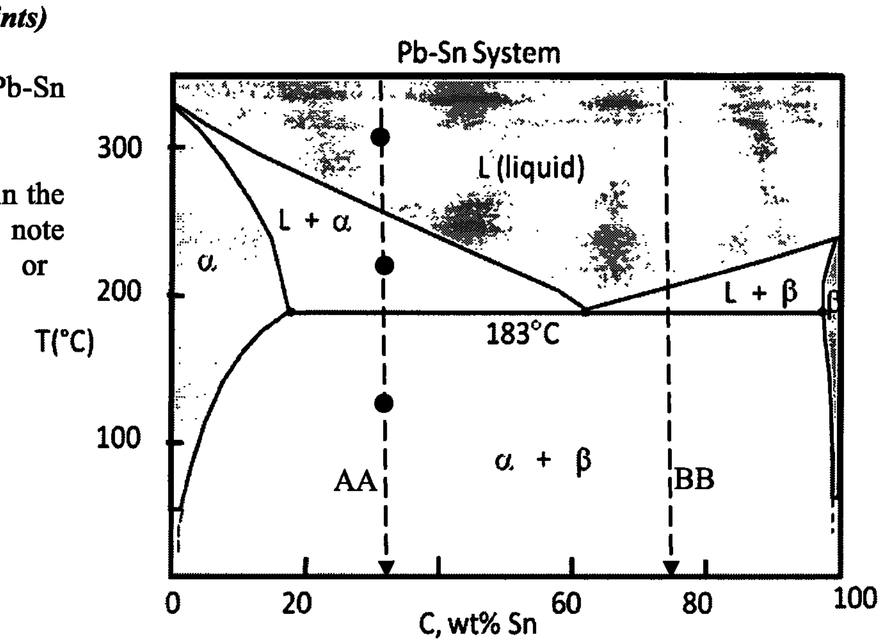
(3) Stiffness –

iii) Propose 2 other general methods that can increase the yield strength of metals **(2 marks)**.

Name: ____________________ Student No: ____________________

QUESTION 7: ***Phase Diagrams (15 points)***

7.1 Consider the phase diagram for the Pb-Sn system shown on the right.



(a) How many solid solutions are there in the phase diagram? State these and note whether these are solid solutions or intermediate solutions. **(2 marks)**

(b) What is the eutectic temperature and composition? **(1 mark)**

(c) The Pb-Sn system is gradually cooled along the line AA. Show the microstructure in the three regions denoted L, L + α, and α + β (corresponding to the three black dots). **(3 marks)**

L　　　　L + α　　　　α + β

(d) The microstructure in the two-phase region, depending on its composition, is given two different names. **(2 marks)**

Below the eutectic composition, it is referred to as ____________________.

Above the eutectic composition it is referred to as ____________________.

(e) Upon cooling the alloy starting from the liquid state at the eutectic composition, what is the resulting microstructure when below the eutectic temperature? **(1 mark)**

(f) Write out the eutectic reaction. **(1 mark)**

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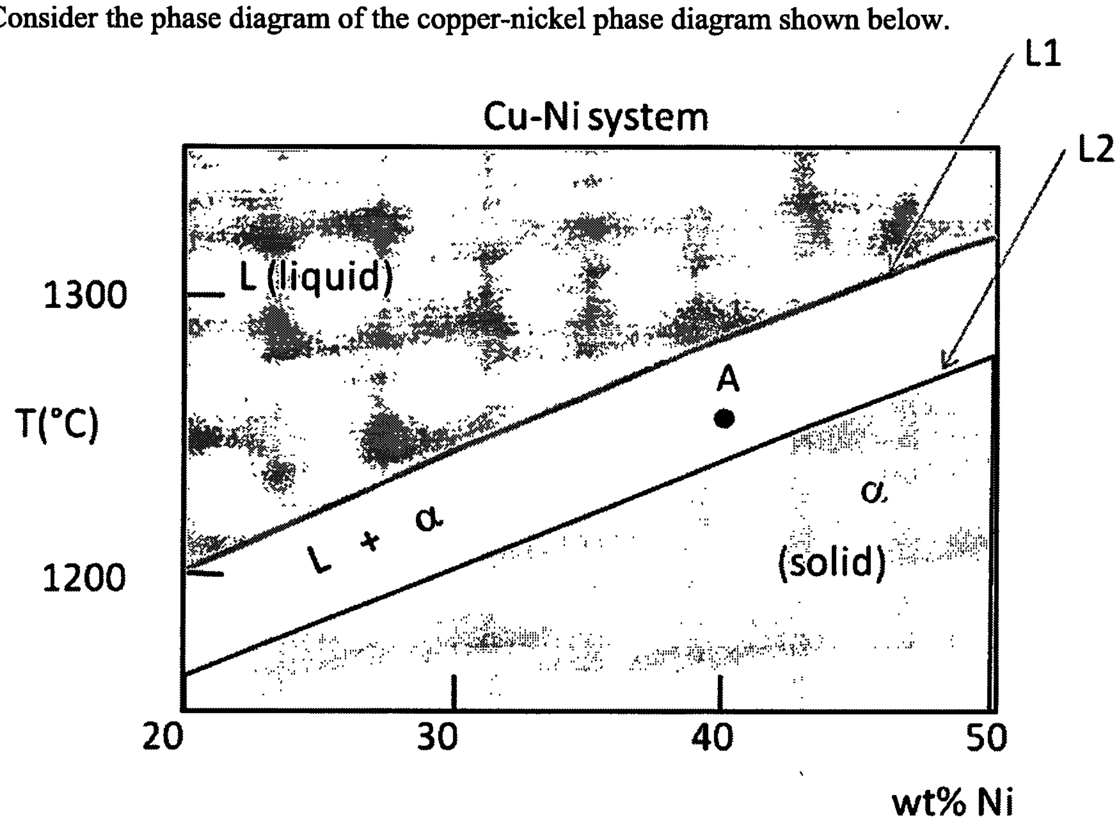
7.2 Consider the phase diagram of the copper-nickel phase diagram shown below.



(a) State the names given to the phase boundary lines denoted L1 and L2. (**1 mark**)

L1 : ______________________________

L2 : ______________________________

(b) For point A, shown on the phase diagram, determine :

(i) The overall alloy composition ; **(1 mark)**

C_o =

(ii) The composition for the liquid and solid phases; **(1 mark)**

C_L =	C_α =

(iii) The liquid and solid phase weight fractions. **(2 marks)**

W_L =	W_α =

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QUESTION 8: Electrical Properties ***(10 points)***

(a) How will the conductivity be affected (i.e. increase, decrease or unchanged) in the following cases? **(5 marks)**

(i) Increase temperature of a semiconductor: ____________________

(ii) Increase dislocations in a metal: ____________________

(iii) Increase temperature of a metal: ____________________

(iv) Decrease impurity concentration in a metal: ____________________

(v) After heat treatment of a metal: ____________________

(b) An iron wire is required to conduct a 6.5 A current with a maximum voltage drop of 0.005 V/cm.

(i) Given that the electrical conducitivity of iron at room temperature is $1\text{x}10^7$ $(\Omega\text{-m})^{-1}$, what must be the minimum diameter of the iron wire in meters? **(3 marks)**

(ii) What would be the the ratio of wire diameters if the wires were made from iron and aluminum (conductivity $3.8\text{x}10^7$ $(\Omega\text{-m})^{-1}$ given that both wires perform identically? **(2 marks)**

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Potentially Useful Relations/Formulas and Constants *(you may tear-off this sheet only)*

$N_A = 6.023\times10^{23}$ mol^{-1} $k = 8.62\times10^{-15}$ eV/ K)

$\%IC = \{1-\exp[-0.25(X_A - X_B)^2]\}\times100$

$$E = \int F\,dr$$

$$APF = \frac{TotalSphereVolume}{TotalUnitCellVolume}$$

$$LD = \frac{NumberOfAtomsCentredOnDirectionVector}{LengthOfDirectionVector}$$

$$PD = \frac{NumberOfAtomsCentredOnAPlane}{AreaOfPlane}$$

$$V = \frac{4\pi r^3}{3} \qquad \rho = \frac{nA}{V_C N_A}$$

$$DP = \overline{M_n}/m \qquad \overline{M_n} = \Sigma x_i M_i \qquad \overline{M_w} = \Sigma w_i M_i$$

$$N_V = N\exp(-\frac{Q_v}{kT}) \qquad N_S = N\exp(-\frac{Q_S}{2kT}) \qquad N_{fr} = N\exp(-\frac{Q_{fr}}{2kT})$$

$$E = \frac{\sigma}{\varepsilon} \qquad \sigma = \frac{F}{A} \qquad \epsilon = \frac{\Delta l}{l} \qquad \tau = \frac{F}{A} \qquad \tau = G\gamma \qquad U_r = \frac{1}{2}\sigma_Y\varepsilon_Y$$

$$\%CW = \left(\frac{A_0 - A_d}{A_0}\right)\times100 \qquad G = E/(2(1+v)) \qquad \sigma_y = \sigma_0 + k_y d^{-1/2} \qquad \nu = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$$

$$\tau_R = \sigma\cos\phi\cos\lambda \qquad \sigma_y = \frac{\tau_{crss}}{(\cos\phi\cos\lambda)_{max}}$$

$$V = IR \qquad \rho = \frac{RA}{l} \qquad \sigma = \frac{1}{\rho} \qquad J = \sigma E \qquad E = \frac{V}{l}$$

$$v_d = \mu_e E \qquad \sigma = n|e|\mu_e$$

Given vectors **a** and **b**, the angle θ between the vectors is determined using

$$\theta = \cos^{-1}\left(\frac{u_1 u_2 + v_1 v_2 + w_1 w_2}{\sqrt{(u_1^2 + v_1^2 + w_1^2)(u_2^2 + v_2^2 + w_2^2)}}\right)$$