UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, 24 APRIL 2009

First Year

APS 104S

INTRODUCTION TO MATERIALS AND CHEMISTRY

Exam Type B

Examiners: G. Hibbard and K. Lian,

Question	Mark
Q1	/15
Q2	/13
Q3	/10
Q4	/17
Q5	/15
Q6	/20
Q7	/10
Total	/100

NAME: ____
Last First

STUDENT NO:____

INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- Answer <u>all</u> 7 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*.

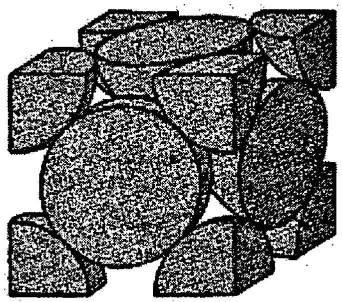
Name: ______________________

Student No: ______________________

QUESTION 1: ***Crystal Structures and Density (15 pts)***

1.1 A unit cell is shown here. Calculate:

a) the volume of the unit cell, assuming the diameter of the sphere is 0.5 nm. (***Indicate your answer in the box below)*** **(3 marks)**

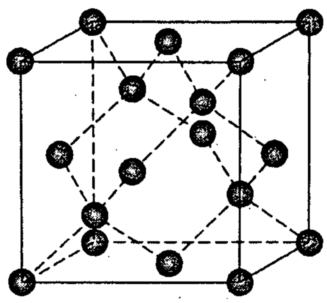


the volume of the unit cell:

b) the percentage of open space in this unit cell ***(Indicate your answer in the box below)*** **(3 marks)**:

percentage of open space:

1.2 The diamond structure is shown here. Its lattice constant is 0.357 nm. Calculate the density of diamond (For C: Aw = 12.01 g/mol)). ***(Indicate your answer in the box below)*** **(4 marks)**



the density of diamond

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1.3 How many planes are there in $\{111\}$ family for a cubic system? Write the Miller indices for all these planes **(5 marks).**

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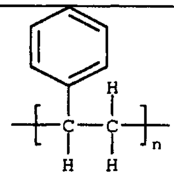
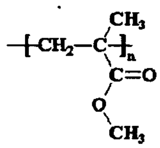
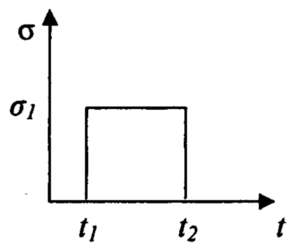
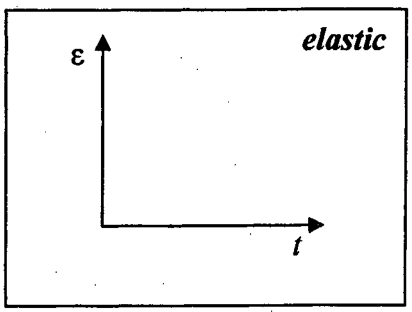
QUESTION 2: *Polymers (13 pts)*

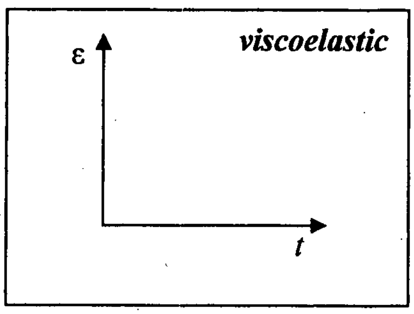
A) Complete the following table by either sketching the mer of the listed polymer or give the name of the polymer for the repeat unit shown. **(6 marks)**

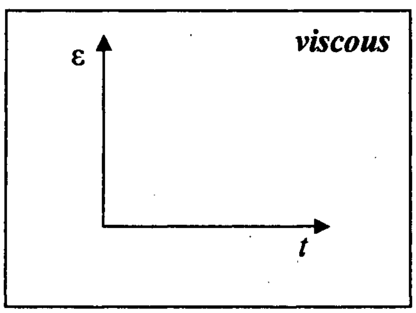
Polymer	Repeat unit
Polyethylene (PE)	
Polyvinyl chloride (PVC)	
Polytetrafluoroethylene (PTFE)	
Polypropylene (PP)	
	
	

B) Consider the following scenario: at time $t = 0$ a polymer bar is initially unloaded ($\sigma = 0$). At time $t = t_1$ the bar is loaded in tension to a stress of $\sigma = \sigma_1$. The bar is held at this constant stress until time $t = t_2$, at which point the load is released and the stress in the bar returns to zero. In the boxes provided below, plot the expected strain as a function of time for the following three types of polymer deformation: i) elastic, ii) viscoelastic, and iii) viscous. **(3 marks)**









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C) The table below provides the number-average molecular weight data for a polyethylene material. Determine i) the average degree of polymerizationa and ii) the average total chain length. The atomic weight of carbon is 12.01 g/mol, the atomic weight of hydrogen is 1.01 g/mol, the C-C bond length is 0.154 nm, and the C-C-C bond angle is 109°. ***Provide your answer in the boxes below.*** **(4 marks)**

Molecular weight range (kgmol)	x_i
10-20	0.03
20-30	0.09
30-40	0.15
40-50	0.25
50-60	0.22
60-70	0.14
70-80	0.08
80-90	0.04

***Degree of polymerization*:**	***Average total chain length*:**

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QUESTION 3: ***Point Defects (10 points)***

The Cu-Ni system is isomorphous, meaning there is complete solubility in the solid state over all temperatures and alloy compositions.

A) The Cu-Ni solid solution is: i) substitutional, or ii) interstitial ***(circle the correct answer).*** **(1 mark)**

B) There are several features of the solute and solvent atoms that determine the degree to which the solute can dissolve in the solvent. List three of these factors in the boxes below: **(3 marks)**

Factor 1:
Factor 2:
Factor 3:

C) Calculate the fraction of (1) vacant lattice sites and (2) self-interstitial sites for nickel at its melting temperature of 1728 K. Assume an energy of 0.7 eV/atom for vacancy formation and an energy of 1.4 eV/atom for self-interstitial formation. ***(Indicate your answers in the boxes below)*** **(4 marks)**

Vacancy fraction:	***Self-interstitial:***

D) Suppose that MgO was added as an impurity to Al_2O_3. If the Mg^{2+} substitues for Al^{3+}, i) what kind of vacancies would you expect to form, and ii) how many of these vacancies are created for every Mg^{2+} added? **(2 marks)**

Type of vacancy formed:
Number of vacancies per Mg^{2+} impurity:

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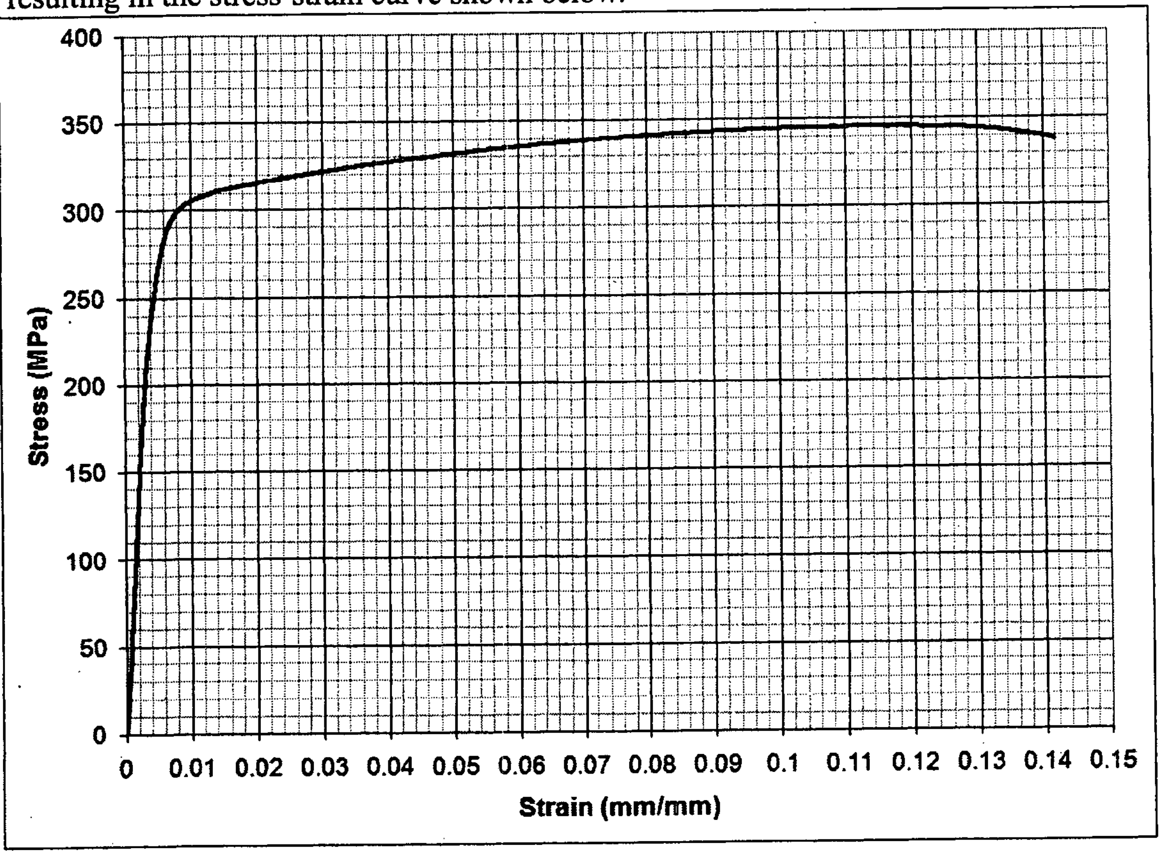
QUESTION 4: ***Mechanical Properties (17 pts)***

A cylindrical bar of aluminum (100 mm original length and 15 mm original diameter) is loaded in tension, resulting in the stress-strain curve shown below.



A) Using the stress-strain curve, give numerical values for the properties listed below: **(6 marks)**

Young's modulus	
Proportional limit	
0.2% offset yield strength	
Tensile strength	
Ductility	
Resilience	

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B) Using the stress-strain curve from the previous page, the cross-section of the tensile coupon begins to decrease by uniform plastic deformation at a strain of ____________ and by non-uniform plastic deformation at a strain of __________. **(2 marks)**

C) What is the total elastic strain energy (in J) stored in the aluminum bar if a tensile load of 200 MPa has been applied? ***(give your answer in the box below)*** **(4 marks)**

Total elastic strain energy:

D) Give the change in length and diameter (in mm) at a tensile load of 200 MPa. Assume a Poisson's ratio of 0.33 for aluminum. ***(provide your answer in the boxes below)*** **(2 marks)**

Diameter change:	***Length change:***

E) Circle the correct answers: **(3 marks)**

When an elastic tensile load is applied, the volume of a material having a Poisson's ratio of 0.33 will: i) increase, ii) decrease, or iii) remain the same.

When an elastic tensile load is applied, the volume of a material having a Poisson's ratio of 0.5 will: i) increase, ii) decrease, or iii) remain the same.

During elastic tensile deformation, the cross-sectional area of a material having a Poisson's ratio of less than zero will: i) increase, or ii) decrease.

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QUESTION 5: ***Deformation Mechanisms in Metals (15 pts)***

A) Below 912°C the stable crystal structure of Fe is BCC, while between 912°C and 1394°C the stable crystal structure is FCC. If the atomic radius of Fe is 0.124 nm, i) give the planar density on the (110) plane of BCC Fe and ii) give the planar density on the (111) plane of FCC Fe. ***Indicate your answers in the boxes provided below.*** **(6 marks)**

(110) planar density of BCC Fe:	***(111) planar density of FCC Fe:***

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B) Consider the case where a single crystal wire of FCC Fe has the [112] crystallographic direction oriented parallel to the wire length. If the wire is loaded in tension and dislocation slip occurs on the $(1\bar{1}1)$ plane, which slip direction the will have the highest resolved shear stress? ***Provide your answer in the box below.*** **(6 marks)**

Slip direction:

C) If the yield strength of Ni is 150 MPa at a grain size of 10 μm (1×10^{-5} m) and 400 MPa at a grain size of 200 nm (2×10^{-7} m), what is the expected yield strength for a grain size of 10 nm (1×10^{-8} m)? ***Indicate your answer in the box below.*** **(3 marks)**

Yield strength at 10 nm:

Name: ______________________

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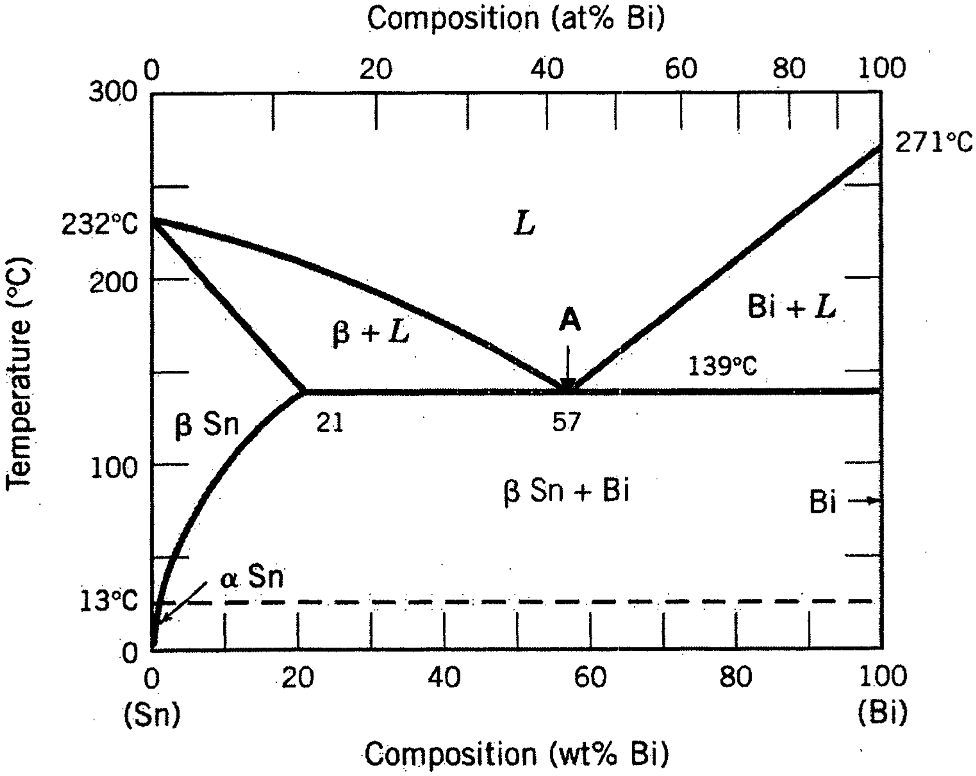
QUESTION 6: ***Phase Diagrams (20 points)***

Refer to the Sn-Bi phase diagram below, when answering this question.



(a) Determine the composition and phases present at equilibrium in a Sn-Bi alloy of composition **70 wt % Bi** and sketch the expected microstructure at the following temperatures **(8 marks)**:

200 ^{0}C
150^{0}C
100 ^{0}C

Name: ____________________

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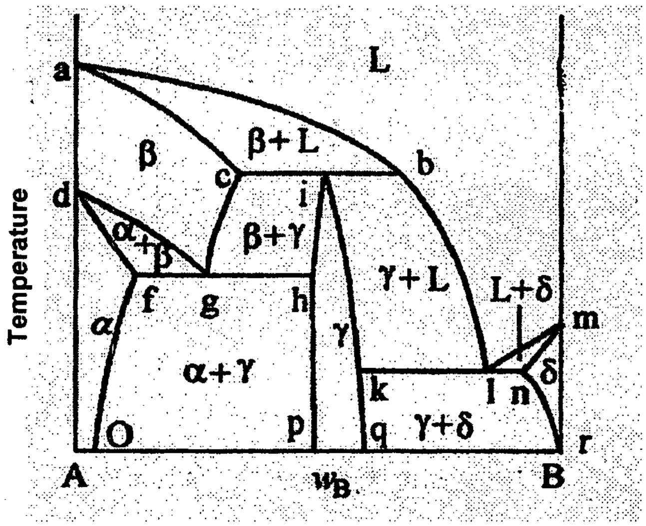
(b) Draw the microstructure at 1 degree below point A (139^{0}C). Write down the reaction that occurs at point A **(2 marks)**.

(c) Calculate the weight fraction of β-Sn and Bi at point A **(3 marks)**

Answer:

(d) "Under-the-hood" conditions in automotive applications means being able to withstand sustained temperatures of up to 150 ^{0}C. Would you recommend using this solder for "under-the-hood" automotive applications? **(1 mark)**

(e) Give the name and specific reaction for all the invariant points (e.g. eutectic, eutectoid and peritectic) shown on the phase diagram given below. (You may also indicate these points on the graph in addition to the (names and reactions) **(6 marks)**



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QUESTION 7: ***(10 points)***

7.1 a) If the diameter of a copper wire is 2 mm, what will be the diameter of aluminum wire to possess the same resistance? What will be the ratio of the two masses per unit length? ***(Indicate your answers in the boxes below)*** **(7 marks)**

Given: the conductivity of Cu is $6.0 \times 10^{7} (\Omega\text{-m})^{-1}$, the conductivity of Al is $3.8 \times 10^{7} (\Omega\text{-m})^{-1}$. The density of Cu is 8.9 Mg/m^3, the density of Al is 2.7 Mg/m^3

diameter of Al wire:	***ratio of the two masses per unit length***

b) For an overhead power cable application where weight is a primary concern, which material would you recommend **(1 mark)**?

7.2 Circle the correct answers: **(2 marks)**

a) When heating up a metal, the conductivity of the metal will i) increase, ii) decrease, or iii) remain the same.

b) When heating up a semiconductor, the conductivity of the semiconductor will i) increase, ii) decrease, or iii) remain the same.

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

$N_A = 6.023 \times 10^{23}\ mol^{-1}$ $\quad k = 1.38\times10^{-23}\ {}^{J}/_{K} = 8.62\times10^{-5}\ {}^{eV}/_{K}$ $\quad 1Pa = 1\ {}^{N}/_{m^2} = 1\ {}^{J}/_{m^3}$

$\rho = \frac{n \cdot A}{V_C \cdot N_A}$ $\quad A = \pi r^2$ $\quad V = \frac{4}{3}\pi r^3$ $\quad \rho = \frac{n'\left(\sum A_C + \sum A_A\right)}{V_C N_A}$ $\quad APF = \frac{V_S}{V_C}$

$\sigma = \frac{F}{A_o}$ $\quad \varepsilon = \frac{l_i - l_o}{l_o}$ $\quad \sigma = E\varepsilon$ $\quad \tau = \frac{F}{A_o}$ $\quad G = \frac{\tau}{\gamma}$ $\quad E = 2G(1+\nu)$

$\%RA = \frac{A_o - A_f}{A_o} x100$ $\quad \gamma = \tan\theta$ $\quad \%EL = \frac{L_f - L_o}{L_o} x100$ $\quad \nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$

$\cos\theta = \frac{h_1 h_2 + k_1 k_2 + l_1 l_2}{\sqrt{h_1^2 + k_1^2 + l_1^2}\sqrt{h_2^2 + k_2^2 + l_2^2}}$ $\quad \tau_R = \sigma \cos\phi \cos\lambda$ $\quad \sigma_y = \sigma_o + k_y \cdot d^{-1/2}$

$N_V = N \exp(-\frac{Q}{kT})$ $\quad DP = M_n/m$ $\quad r = d\sqrt{N}$

$\overline{M_n} = \sum x_i M_i$ $\quad L = N d \sin({}^{\theta}/_{2})$ $\quad n_n = \frac{\overline{M_n}}{\overline{m}}$ $\quad Ur = \frac{1}{2}\sigma_y \varepsilon_y$

$V = IR$ $\quad \rho = \frac{RA}{l} = \frac{VA}{Il}$ $\quad \sigma = \frac{1}{\rho}$ $\quad \sigma = n|e|\mu_e$ $\quad \rho_{total} = \rho_t + \rho_i + \rho_d$

$\rho_t = \rho_o + aT$ $\quad \rho_i = Ac_i(1 - c_i)$ $\quad \rho_i = \rho_\alpha V_\alpha + \rho_\beta V_\beta$

$$\text{Atomic Packing Factor} = \frac{\text{Total Sphere Volume}}{\text{Total Unit Cell Volume}}$$

$$\text{Linear Density} = \frac{\text{Number of Atoms Centred on Direction Vector}}{\text{Length of Direction Vector}}$$

$$\text{Planar Density} = \frac{\text{Number of Atoms Centred on Plane}}{\text{Area of Plane}}$$