UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION

13TH APRIL 2010

First Year

APS 104S

INTRODUCTION TO MATERIALS AND CHEMISTRY

Exam Type B

Examiners: K. Lian, N.P. Kherani

Question	Mark
Q1	/10
Q2	/20
Q3	/10
Q4	/11
Q5	/15
Q6	/19
Q7	/20
Q8	/10
Total	/115

NAME: _____

Last First

STUDENT NO: _____

INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- Answer all eight 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.
- Do not 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 Bonding in Solids (Chapter 2)*** [10 points]

a) Ti, O, In and Sb have the following electro-negativities: Ti =1.5, O=3.5, In = 1.9 and Sb = 1.9. Compare the bonding in TiO_2 and InSb, which one has the greater covalent character? Carry out the necessary calculations to support your claim. [4 points]

Answer

b) Compare HF versus. HCl, which one would you expect to have a higher boiling point? Explain in terms of secondary bonding. [2 points]

c) The net potential energy E_N between two adjacent ions is sometimes represented by the expression

$$E_N = -\frac{C}{r} + \frac{D}{r^n}$$

where r is the inter-ionic separation, and C, D, and n are constants whose values depend on the specific material.

i) Write an expression to show the net force as a function of r. [2 points]

ii) Given $C/D = 1x10^6$, and n = 8, calculate the equilibrium inter-ionic spacing r_0. [2 points]

Answer

Name: _____ *Student No:* _____

QUESTION 2: ***Crystal Structures (Chapter 3)*** [20 points]

A. Circle True or False, Circle the correct answer(s), Fill-in the blank(s), Quick calculation. [5 points]

1. The cubic lattice system consists of simple cubic, body-centered cubic, and face-centered cubic lattices.

True False

2. Amorphous materials are:
   (**a**) Crystalline;
   (**b**) Polycrystalline;
   (**c**) Non-crystalline;
   (**d**) All of the above;
   (**e**) None of the above

3. The coordination number in an FCC crystal structure is: _____.

4. A close-packed monolayer consists of 0.5×10^{15} atoms/cm^2. Estimate the atomic radius?

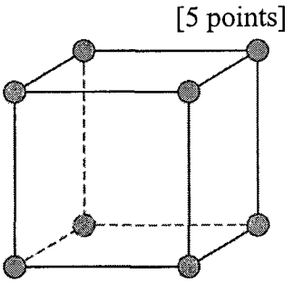
$R =$ _____

5. The coordination number of an octahedral site is _____.

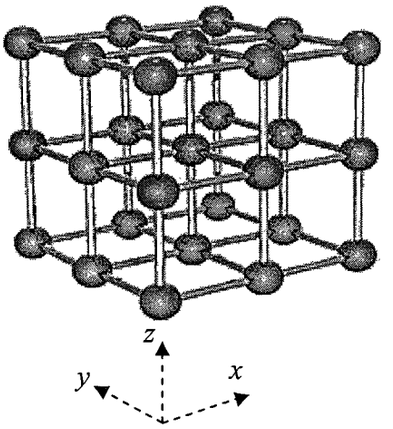
B. You will be interested to learn that polonium is a radioactive element (in fact, all its known isotopes are radioactive). Upon radioactive decay, polonium produces energetic alpha particles (i.e., helium nuclei, $^4He^{2+}$). Some interesting observations:

- Polonium is known to concentrate in the tobacco root and accordingly heavy smokers are said to be exposed to radiation equivalent to having 300 chest X-rays a year.
- The only recorded case of polonium poisoning relates to Alexander Litvinenko, On 1st November 2006 Litvinenko suddenly fell ill in London, England and was hospitalised in what was established as a case of poisoning by radioactive polonium-210 and resulted in his death on 23rd November.

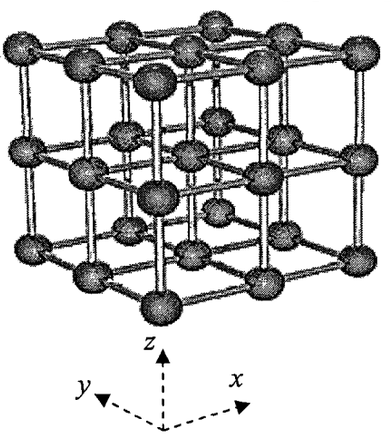
Now, the question: The alpha phase of polonium, using the reduced sphere representation, is shown below. It has an atomic weight of 209 g mol^{-1} and a density of 9.196 g cm^{-3}. Calculate an estimate of its atomic radius. [5 points]



C. Consider the (110) plane in the alpha phase of polonium. For this plane, calculate the planar density. Also, clearly mark the (110) plane and the [110] direction on the crystal structure shown below. [5 points]



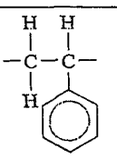
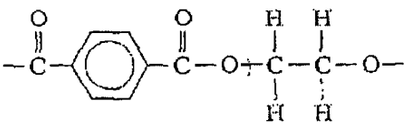
D. Consider the [210] direction in the alpha phase of polonium. For this direction, calculate the linear density. Also, clearly mark the [210] direction on the crystal structure shown below. [5 points]



Name: _____ *Student No:* _____

QUESTION 3: ***Polymer Structures (Chapter 4)*** [10 points]

a) Complete the following table. [4 points]

Polymer Name	Repeat Unit
Polypropylene	
	
polytetrafluoroethylene	
	

b) Molecular weight data for a particular polymer are tabulated below. Determine:

(i) the number-average molecular weight, [3 points] and

(ii) if it is known that this material's degree of polymerization is 477, which one of the polymers in the above table for question (a) is most likely to be the polymer? Show your justification. Note, the molar mass of C =12, H=1, O=16, and F =19. [3 points]

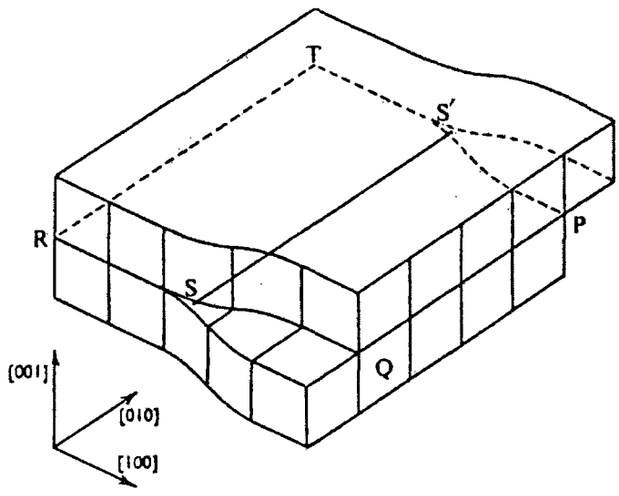
Molecular Weight Range (g/mol)	x_i
8,000–20,000	*0.05*
20,000–32,000	*0.15*
32,000–44,000	*0.21*
44,000–56,000	*0.28*
56,000–68,000	*0.18*
68,000–80,000	*0.10*
80,000–92,000	*0.03*

Answer

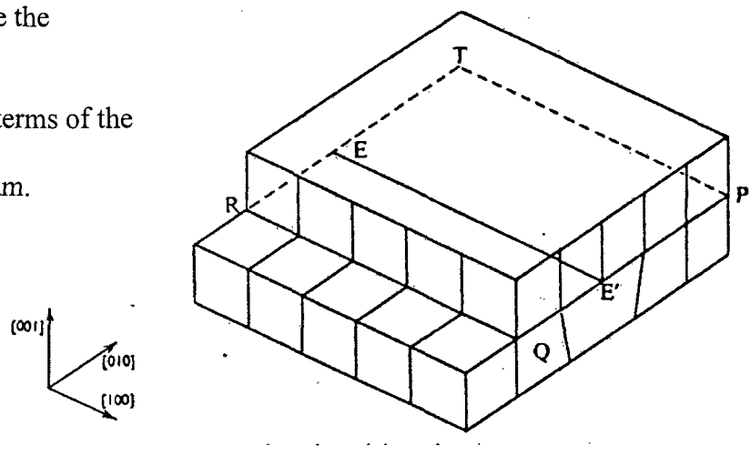
Name: _____ *Student No:* _____

QUESTION 4: ***Imperfections in Solids (Chapter 5)*** [11 points]

A. Consider the defect shown on the right. State the following [3 points]:
(a) The name of the defect *S-S'*;
(b) The direction of motion of the defect in terms of the given coordinate system; and
(c) Indicate the Burgers vector on the diagram.



B. Consider the defect shown on the right. State the following [3 points]:
(a) The name of the defect *E-E'*;
(b) The direction of motion of the defect in terms of the given coordinate system; and
(c) Indicate the Burgers vector on the diagram.



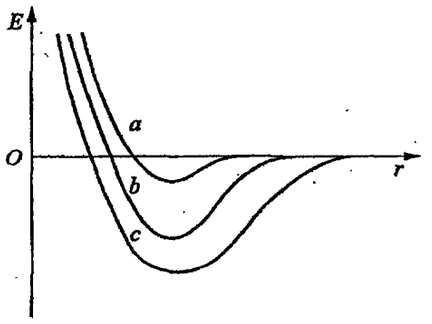
C. In the following list identify point defects as "P", line defects as "L", and areal defects as "A". Write the letters P, L, or A in each of the boxes shown below. [5 points]

i) Screw dislocation	☐	**ii)** Schottky defect	☐
iii) Twin boundary	☐	**iv)** Low angle boundary	☐
v) Vacancy	☐	**vi)** Edge dislocation	☐
vii) Interstitial impurity	☐	**viii)** Substitutional impurity	☐
ix) High angle boundary	☐	**x)** External surface	☐

Name: _____ Student No: _____

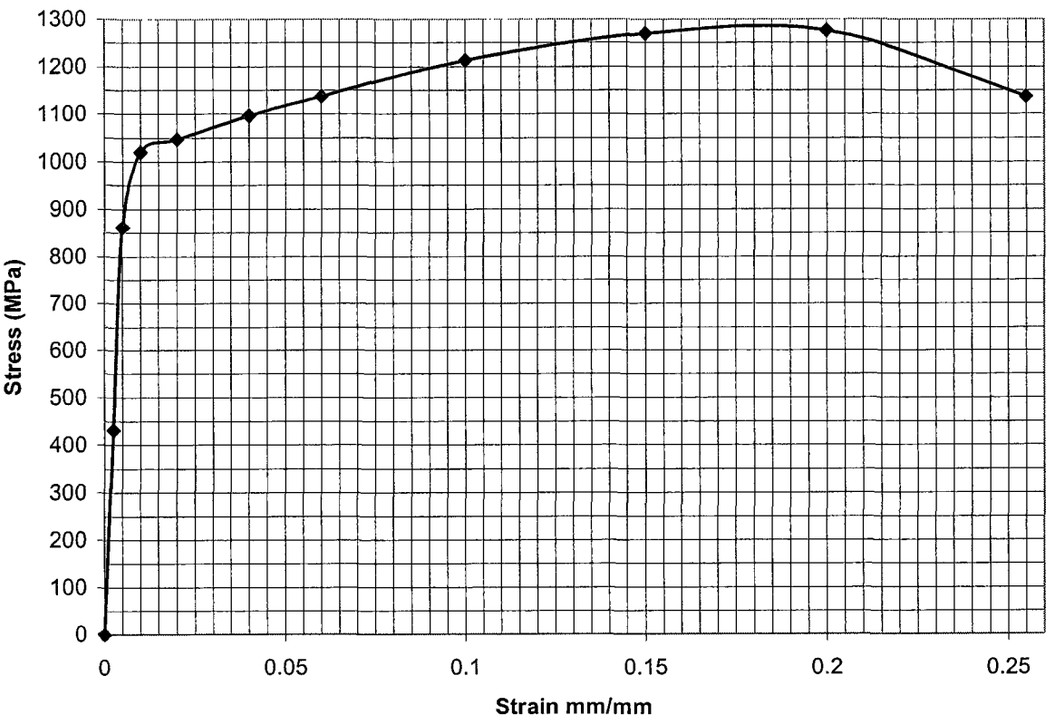
QUESTION 5: ***Mechanical Properties (Chapter 7)***[15 points]

a) In the following graph, the *E-r* (energy – inter-atomic separation) curves a, b, and c were obtained from 3 different materials. The 3 materials are: metal, ceramic and polymer. Identify which materials correspond to the three curves a, b and c. [3 points]



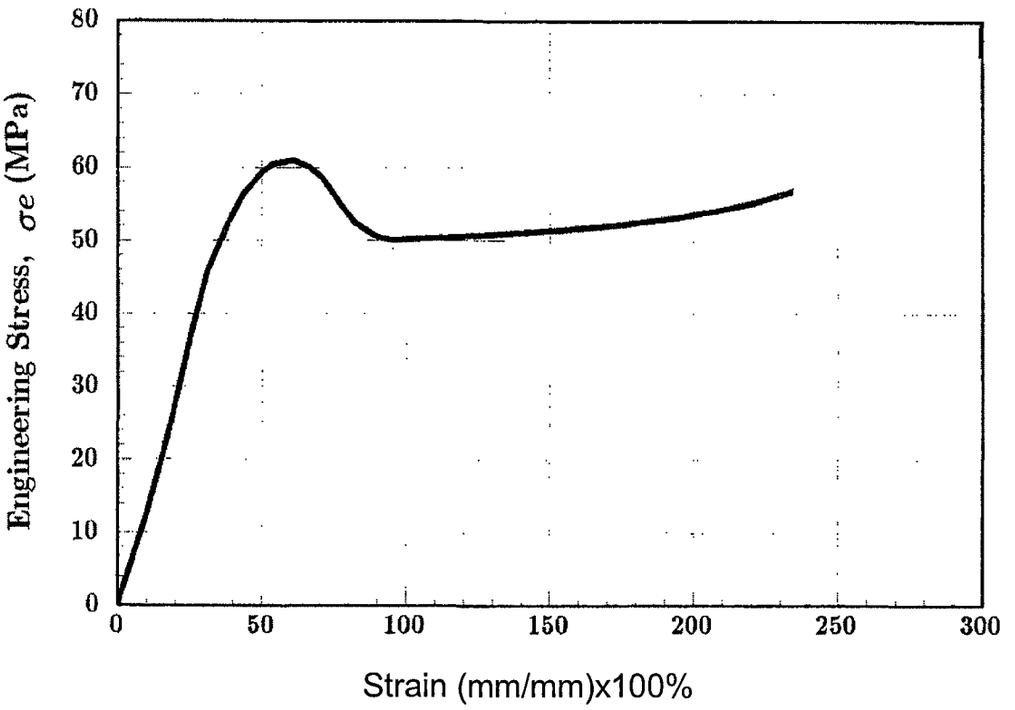
a	
b	
c	

b) A stress –strain curve (shown below) was obtained from a metal sample (1 cm x 1 cm original cross-sectional area and 4 cm long). Using this stress-strain curve, complete the following table (please provide numerical values and units). [7 points]



Elastic Modulus	
0.2% Offset yield strength	
The maximum load that the specimen has sustained	
The final length of the specimen at fracture	
Resilience	

c) A stress-strain curve of a polypropylene sample is shown below. [5 points]



i) Please mark yield strength (σ_y) and tensile strength (TS) on the graph.

ii) If the temperature is increased beyond the glass transition temperature, will the elastic modulus
a) increase;
b) decrease, or
c) remain the same?

iii) If Poisson's ratio is 0.4, what is the shear modulus of the material? Clearly show your calculation.

Answer

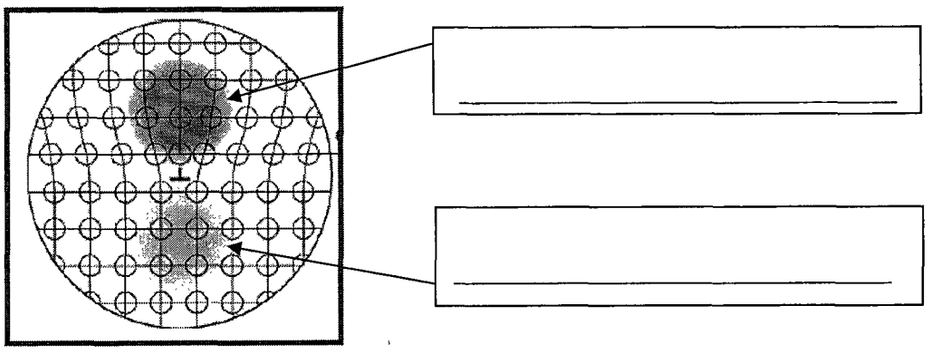
Name: _____ *Student No:* _____

QUESTION 6: ***Deformation and Strengthening (Chapter 8)*** [19 points]

A. Circle True or False, Circle the correct answer(s), Fill-in the blank(s), Quick calculation. [5 points]

1. Dislocation motion being the easiest in ionic ceramics is the reason for brittle failure in ceramics.
True **False**

2. Define the stresses in the two strain fields shown in the figure below.



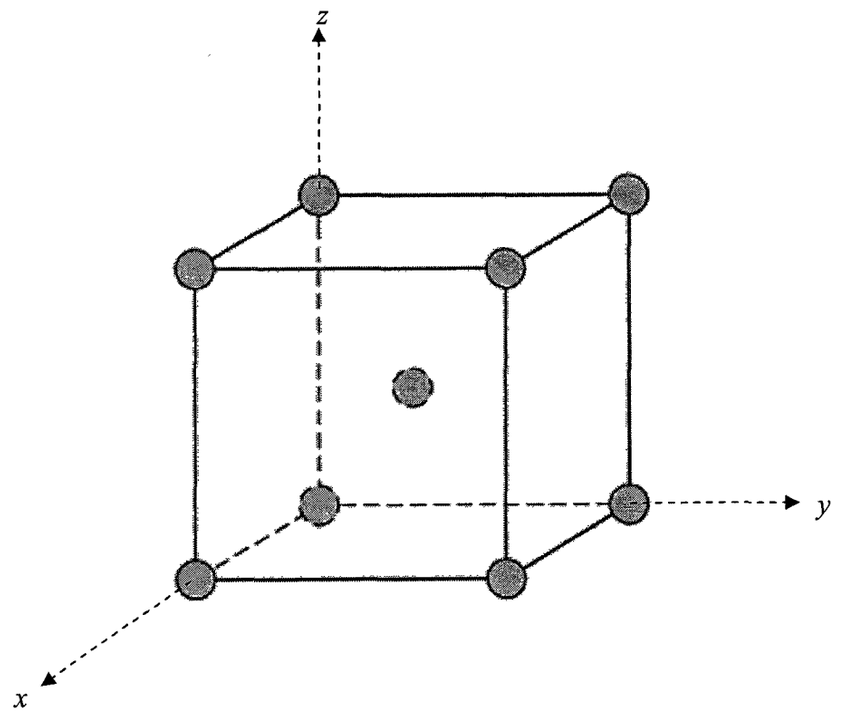
3. The family of slip planes in an FCC crystal structure is: _____.

4. The critical resolved shear stress, τ_{crss}, is the minimum shear stress required to initiate slip; this is a property of the material which on the stress-strain curve corresponds to the _____.

5. A copper rod, initially having a diameter of 10 mm, is subjected cold working which results in a final diameter of 7.5 mm. Calculate the percentage cold work (CW).
% CW = _____.

B. Single crystalline iron has a BCC crystal structure. A tensile stress is applied along a [010] direction. Slip occurs in the $[\bar{1}11]$direction.
[3 points]

1. On the reduced-sphere BCC unit cell drawing, shown below, clearly sketch the following:
(a) The slip plane (010) and the normal to this plane;
(b) The tensile stress direction [010];
(c) The slip direction $[\bar{1}11]$.



2. The angle between the direction of applied stress and the normal to the slip plane is defined to be ϕ. The angle between the direction of applied stress and the slip direction is defined to be λ.

The angle θ between any two vectors, $\boldsymbol{a} = (u_1\ v_1\ w_1)$ and $\boldsymbol{b} = (u_2\ v_2\ w_2)$, is computed using the following relationship:

$$\theta = \cos^{-1} \frac{u_1u_2 + v_1v_2 + w_1w_2}{\sqrt{(u_1^2 + v_1^2 + w_1^2)(u_2^2 + v_2^2 + w_2^2)}}$$

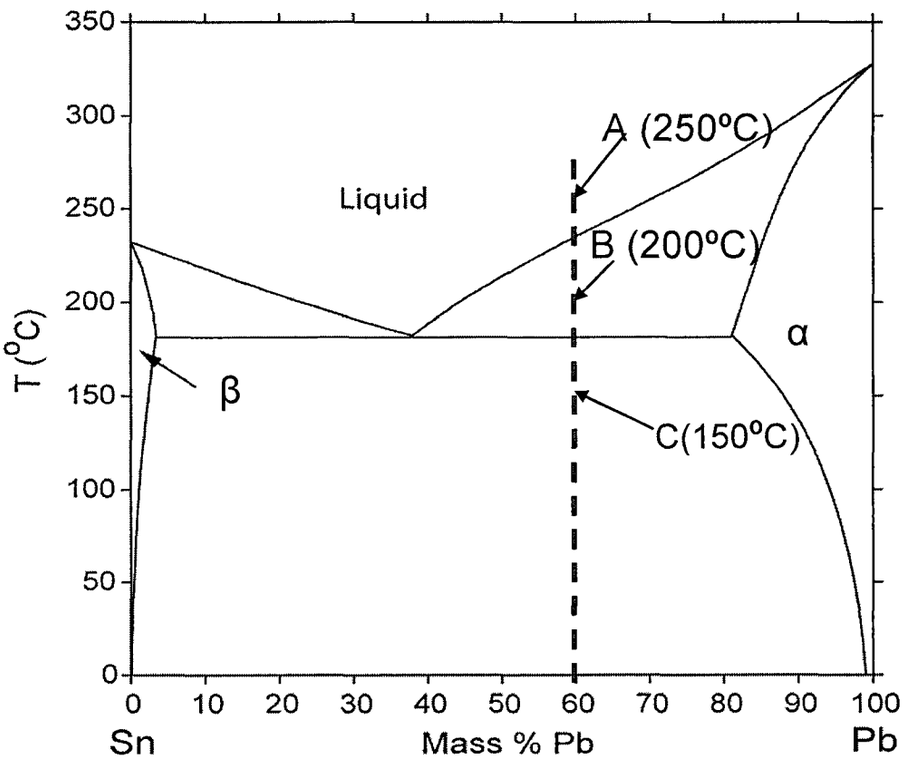
Calculate the angles ϕ and λ. [3 points]

3. The critical resolved shear stress is 35 MPa. If slip occurs on a (110) plane and in a direction $[\bar{1}11]$, calculate the magnitude of the applied tensile stress necessary to initiate yielding.
[4 points]

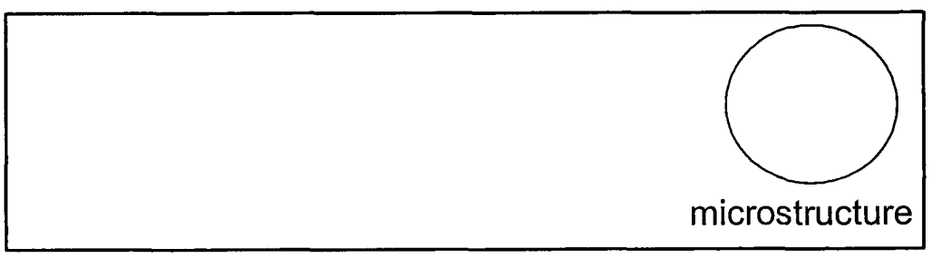
C. State 3 strengthening mechanisms. Also, state the basic idea common to all strengthening mechanisms.
[4 points]

QUESTION 7: ***Phase Diagrams (Chapter 10)*** [20 points]

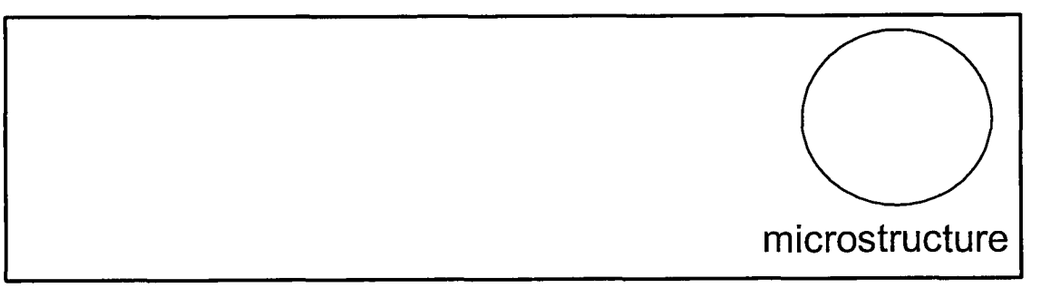
a) Refer to the following phase diagram and answer the following questions. [10 points]



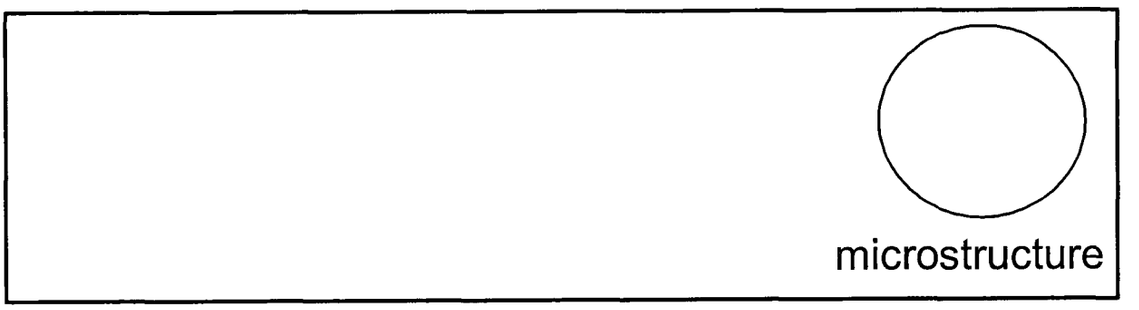
i) Please show the number of phase(s) and the respective composition(s) at point **A**. Please fill your answers and draw the microstructure in the following box.



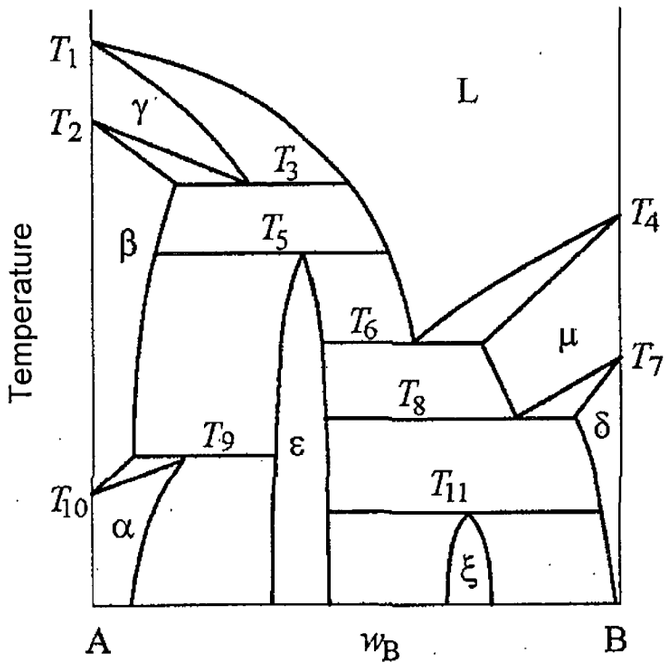
ii) Show the L and α phase compositions and phase fractions at point **B**. Show your calculation and answers and draw the microstructure in the following box.



iii) Show the α and β phase compositions and phase fractions at point **C**. Show your calculations and answers and draw the microstructure in the following box.



b) The following is a hypothetical binary phase diagram with various temperatures highlighted as (T_n) where n corresponds to a numeric value. Use the diagram to answer the following questions. [10 points]



1) How many solid phases are there in the diagram?

2) Identify the melting points of A and B?

3) How many eutectic points are there? Write the reaction(s).

4) How many eutectoid points are there? Write the reaction(s).

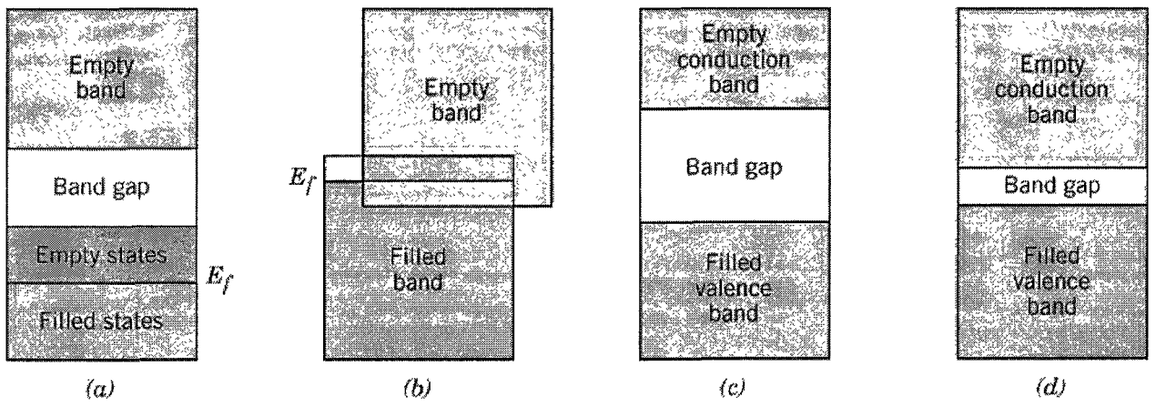
5) How many peritectic points are there? Write the reaction(s).

Name: _____ *Student No:* _____

QUESTION 8: ***Electrical Properties (Chapter 12)*** [10 points]

A. The band structures for various materials are schematically illustrated below. For each band structure, indicate whether it is a metal, an insulator, or a semiconductor.

[2 points]



_____ _____ _____ _____

B. State 3 factors or material properties that contribute to a decrease in the electron mobility. [3 points]

C. Consider a 14 AWG (American Wire Gauge) copper wire which is typically used in residential applications. The diameter of 14 gauge wire is 1.62 mm. The conductivity for copper at room temperature is $5 \times 10^7 (\Omega\ m)^{-1}$.

You run the 14 gauge copper cable, 10 metres in length, from the electrical panel to an outlet.

1. Calculate the resistance of the copper wire. [2 points]

2. You connect an appliance to the outlet which draws 4 amperes of current. What is the voltage drop from the panel to the outlet due to the resistance of the copper wire? [2 points]

3. If the voltage with respect to ground at the panel is 120 V, what is the voltage with respect to ground at the outlet? [1 point]

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

$N_A = 6.023 \times 10^{23}$ mol^{-1} $\quad k = 8.62 \times 10^{-15}$ eV/ K)

$\%IC = \{1 - \exp[-0.25(X_A - X_B)^2]\} \times 100$

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

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

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

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

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

$$DP = \overline{M}_n/m \qquad \overline{M}_n = \Sigma x_i M_i \qquad \overline{M}_w = \Sigma w_i M_i$$

$$N_V = N \exp(-\frac{Q_v}{kT}) \qquad N_S = N \exp(-\frac{Q_s}{kT})$$

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

$$\%CW = \left(\frac{A_0 - A_d}{A_0}\right) \times 100 \qquad G = E/(2(1+\nu)) \qquad \sigma_y = \sigma_0 + k_y d^{-1/2} \qquad \nu = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$$

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

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

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