Q1	/15
Q2	/10
Q3	/16
Q4	/9
Q5	/15
Q6	/15
Q7	/20
Total	/100

UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION

20 APRIL 2012

First Year

APS 104S

INTRODUCTION TO MATERIALS AND CHEMISTRY

Exam Type B

Examiners: N. P. Kherani, K. Lian, T. Mirkovic

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 where provided. 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*.

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QUESTION 1 (15 points): Materials Science

Part A. Multiple Choice (circle only one) – 5 points

(i) The equilibrium interatomic spacing between atoms in a molecule or solid is determined by:
a) Attractive forces; b) Repulsive forces; c) Attractive and repulsive forces; d) none of these.

(ii) Hydrogen bonding is a form of:
a) Ionic bonding; b) Covalent bonding; c) Dipole bonding; d) Metallic bonding.

(iii) The cesium cholride (CsCl) crystal structure can be described as having the cation at the cube-centre and the anions at the corners of the cube. The coordination number for both ion types is:
a) 4 ; b) 6 ; c) 8 ; d) 12.

(iv) The allotropes of carbon include:
a) Carbon nanotubes; b) graphite; c) fullerene; d) diamond; e) all of the preceding.

(v) Wood, rubber, cotton, wool and silk are:
a. Synthetic polymers; b) polymorphs; c) natural poymers; d) none of the preceding.

Part B. Calculations – 10 points

Gold has an FCC crystal structure with a lattice constant of 407.82 x 10^{-10} cm and an atomic mass of 196.66 g/mole.

a) Calculate the density of gold. Note: N_A = 6.023 x 10^{23} atoms $mole^{-1}$. (3 points)

b) Identify the family of planes and family of directions with the highest atomic planar density and atomic linear density, respectively. (2 points)

c) 24 karat gold is pure gold, while 18 karat gold is 75% pure (i.e., 18 parts pure gold and 6 parts other alloying elements such as silver, copper, and zinc)? From a mechanical perspective, what purpose do the alloying elements serve? (1 point)

d) Calculate the linear atomic density along the [110] direction? (1 point)

e) Calculate the atomic planar density for the (110) plane? (3points)

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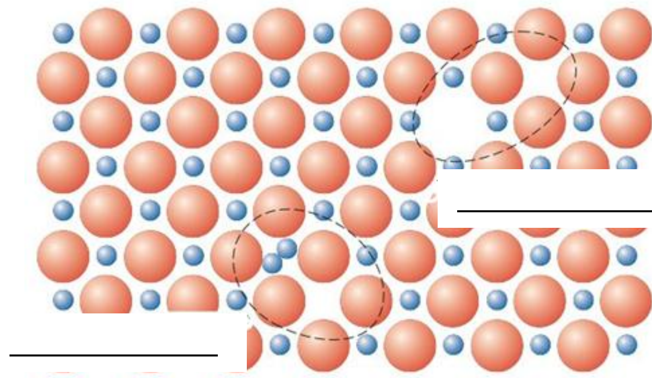
QUESTION 2 (10 points): Materials Science

a) The larger multiplicity of independent combination of slip planes and slip directions in FCC and BCC metals makes it more likely that one of these combinations will be favourably aligned under an applied stress and thus is the basis of these metals exhibiting ductile behaviour. (1 pt)

Circle One : **True** **False**

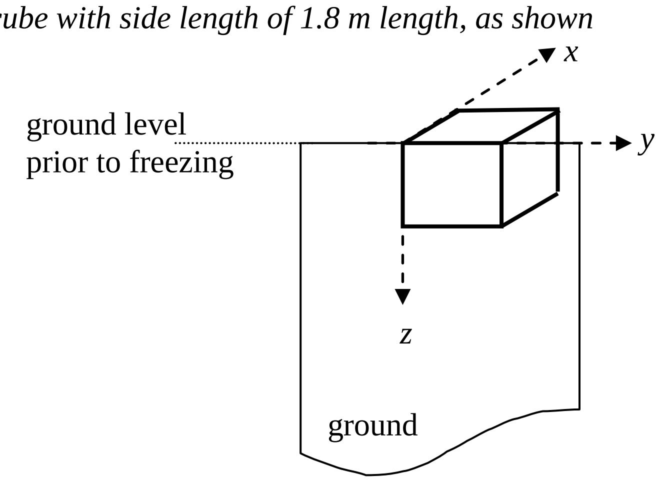
b) Define resilience (1 point).

c) Name the two defects in the diagram shown on the right. The larger circles are the anions and the smaller circles are the cations. (2 points)



d) The northern winters in Canada result in frost damage due to water expansion upon freezing, specifically about 9% increase in volume due to the phase change from liquid to solid. Frost damage occurs to buildings, roads, and equipment every winter. Smaller buildings and roads are particularly affected by ground movements due to frost heave. In southern Ontario the depth of ground freezing varies from 1.0 metre near Windsor to 1.8 metres in the Ottawa area.

(i) Consider the case where the ground freezes to a depth of 1.8 metres. Assuming that the ground comprises entirely of water, estimate the vertical movement of the ground. Assume that all the movement is upwards, that is the ground does not yield sideways or downwards. *Hint: Start with an unfrozen cube with side length of 1.8 m length, as shown below.* (3 points)



(ii) If the ground comprises of 50% water, estimate the vertical movement (1 point)

(iii) Explain why pot-holes get progressively larger during the winter season. (1 point)

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QUESTION 3 ***(16 points)*****: Thermodynamics**

(a) For an isothermal process explain why $|w|_{irrev} > |w|_{rev}$ for compression? Use a diagram to support your answer. (3 marks)

(b) State whether q, w, ΔU, ΔH and ΔS are positive (+), negative (-) or zero (0) for the reversible melting of ice at 1 atm and 0°C. (5 marks)

$q =$

$w =$

$\Delta U =$

$\Delta H =$

$\Delta S =$

(c) A mass of 30.0 g of H_2O (g) at 373 K (*called A*) flows into 300 g of H_2O (l) at 300 K (*called B*) and 1 atm.

Given: GMW (H_2O) = 18.02 g/mol $C_{P,m}$ ($H_2O_{(l)}$) = 75.291 J mol^{-1} K^{-1} ΔH_{vap} ($H_2O_{(l)}$)= 40.65 kJ/mol

i) Calculate the final temperature of the system once equilibrium has been reached. Assume that $C_{P,m}$ for H_2O is constant at its values for 298 K throughout the temperature range of interest. (3 marks)

ii) Calculate the entropy change of *A*, *B*, and the entire system. (5 marks)

QUESTION 4: *(9 points)* Thermodynamics

Consider: $Br_2\,(l) \rightleftharpoons Br_2\,(g)$

At 1 bar pressure liquid bromine boils at 58.2°C, and at 9.3°C its vapour pressure is 0.1334 bar.

(a) Write the expression for K_P for the above reaction. (1 mark)

(b) Calculate $\Delta G°$ for the above reaction at 58.2°C and at 9.3°C. (2 marks)

(c) Assuming $\Delta S°$ and $\Delta H°$ to be temperature independent, calculate their values. (3 marks)

(d) Calculate the vapour pressure and $\Delta G°$ at 25°C. (3 marks)

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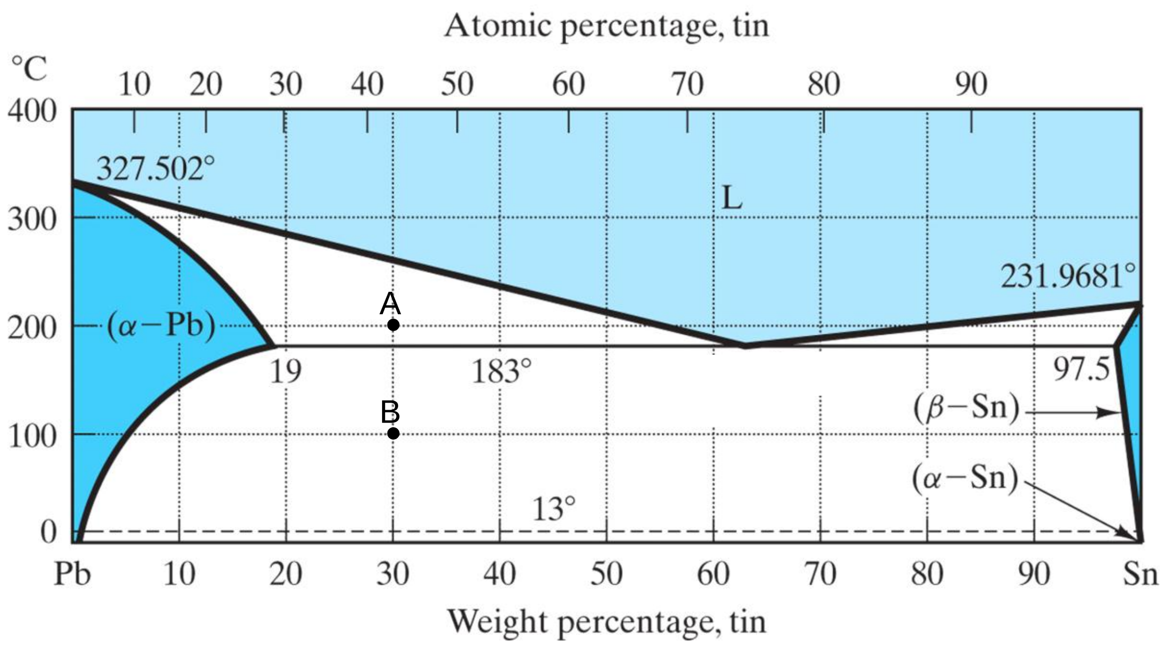
QUESTION 5 (15 points): Phase Diagrams

A) Identify "True" or "False" for the following statements (2 marks)

	True	**False**
(i.) At an invariant point, there are two phases at the equilibrium	[ ]	[ ]
(ii.) Eutectoid reaction is the transformation from one solid to two other solids.	[ ]	[ ]

B) Based on the phase diagram below, answer the following questions. (7 marks)



i) The melting point of Sn is ________________.

ii) The eutectic temperature is _________ and the eutectic composition is _______.

iii) For point **A** on the phase diagram,

a. Determine the phase compositions.

b. The relative fraction of each phase.

iv) For Point **B** on the phase diagram,

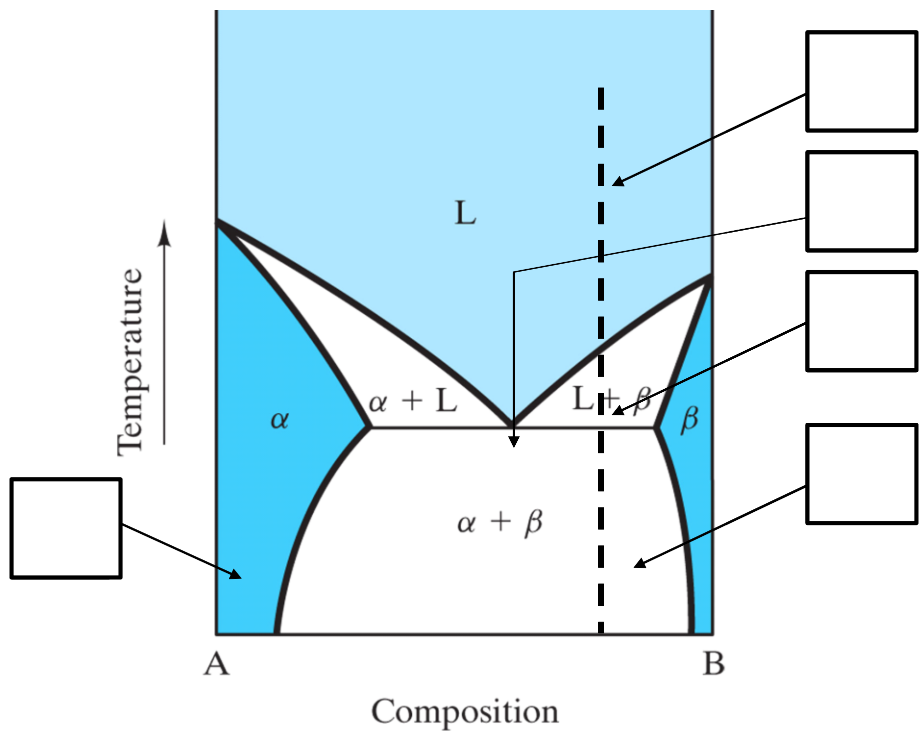
a. Determine the relative fraction of each phase in terms of α and the eutectic composition.

b. What is the maximum solubility of Sn in Pb at this temperature?

C) In a hypothetical phase diagram given below, please complete the following: (6 marks)

i) Draw the corresponding structures in the squares

ii) Write the eutectic reaction and mark the eutectic point on the graph



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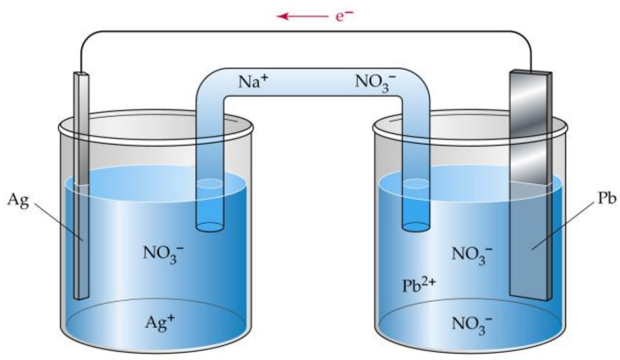
QUESTION 6 (15 points): Electrochemistry

Consider the galvanic cell depicted below.



$Ag^{+}_{(aq)} + e^{-} \rightarrow Ag_{(s)}$ $E° = +0.80$ V
$Pb^{2+}_{(aq)} + 2\,e^{-} \rightarrow Pb_{(s)}$ $E° = -0.13$ V

(a) Write the balanced reaction equation and shorthand cell expression for this cell. (3 marks)

(b) Assuming standard conditions, calculate $E°_{cell}$, K and $\Delta G°$ for this reaction? (6 marks)

(c) What is E_{cell} if the cathode ions are present at 5 M concentration, and anode ions are present at 1 M? (3 marks)

(d) Calculate the mass change (in grams) of the silver electrode after the cell has supplied a constant current of 10.0 A for 25 min? (3marks)

Given: atomic mass of Ag = 107.9 g/mol

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QUESTION 7 (20 points): Electricity & Magnetism

A) Identify "True" or "False" for the following statements (3 marks)

		True	False
i)	The energy band gap in intrinsic semiconductors is usually less than 2 eV	[ ]	[ ]
ii)	Permanent magnets are often composed of hard magnetic materials	[ ]	[ ]
iii)	At the Curie temperature, antiferromagetic turns into paramagtetic	[ ]	[ ]

B) Classify the following as diamagnetic, paramagnetic, ferromagnetic, antiferromagnetic or ferrimagnetic (4 marks)

i) Fe_3O_4 ______________________ **ii)** O_2 ______________________

iii) Argon ______________________ **iv)** MnO ______________________

C) Select the best answer for each question (2 marks)

i) Electrical conductivity increases with temperatures in which of the following materials: *(Circle one)*

a) conductor & semiconductor b) semiconductor & insulator c) conductor & insulator
d) all of the above

ii) Which statement(s) is(are) correct? *(Circle one or more)*
a) "Hole" has a positive charge
b) "Hole" has a negative charge
c) "Holes" are located in the conduction band
d) "Holes" are located in the valence band

D) i) Calculate the mass ratio of steel (Fe) and aluminum (Al) wires having the same resistance and same length**.**
Given σ_{Fe} = 1.1x10^7 (Ω-m)$^{-1}$; σ_{Al} = 3.8x10^7 (Ω-m)$^{-1}$**;** d_{Fe} = 7.9Mg/m^3; d_{Al} == 2.7Mg/m^3. (4 marks)

ii) If the price of Al wire is 5 times more than steel wire and based on your result in **D) i)**, which material would you recommend for streetcar cables (1mark)?

iii) In addition to the thermal effect, what other 2 factors influence/affect the resistivity of a material (2 marks)?

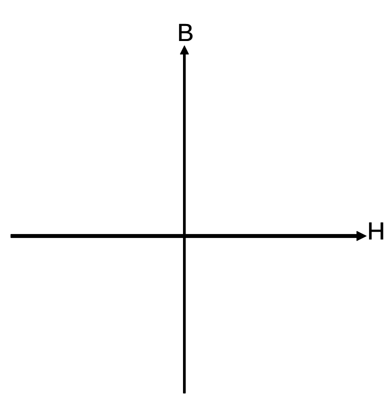
1) ______________________ 2) ______________________

E) Draw a hysteresis *B*-*H* loop (start from origin) for a ferromagnetic material and indicate on it (4 marks)

(*a*) the saturation induction B_s ,

(*b*) the remanence flux density B_r , and

(*c*) the coercive force H_c.



FORMULAE & CONSTANTS *(You may tear this sheet off.)*

Constants

R = 8.3145 J·K^{-1} mol^{-1} = 0.0820574587 L·atm· K^{-1} mol^{-1} = 0.083145 L·bar·K^{-1}·mol^{-1}

1 atm = 101.325 kPa = 1.01325 bar= 14.696 psi = 760 Torr = 760 mmHg

N_A = 6.022 x 10^{23} mol^{-1} k = 8.62 x 10^{-5} eV/K 1 eV = 1.60 x 10^{-19} J

T(K) = T(°C) + 273.15 K F = 9.6485309 × 10^{4} C mole^{-1} e = 1.60217733 × 10^{-19} C

Formulae from Callister

$$V = \frac{4\pi\ r^3}{3} \qquad \rho = \frac{nA}{V_C N_A} \qquad \%IC = \{1 - \exp[-0.25(X_A - X_B)^2]\}\times 100 \qquad E = \int F\ dr \qquad \frac{d}{dx}(x^n) = nx^{n-1}$$

$$APF = \frac{TotalSphereVolume}{TotalUnitCellVolume} \qquad LD = \frac{NumberOfAtomsCentredOnDirectionVector}{LengthOfDirectionVector}$$

$$PD = \frac{NumberOfAtomsCentredOnAPlane}{AreaOfPlane} \qquad DP = \frac{\overline{M_n}}{m} \qquad \overline{M_n} = \sum x_i M_i \qquad \overline{M_w} = \sum w_i M_i$$

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

$$E = \frac{\sigma}{\varepsilon} \quad \sigma = \frac{F}{A} \quad \in = \frac{\Delta l}{l} \quad \tau = \frac{F}{A} \quad \tau = G\gamma \quad U_r = \frac{1}{2}\sigma_Y \varepsilon_Y \quad \%CW = \left(\frac{A_0 - A_d}{A_0}\right)\times 100 \quad G = E/(2(1+\nu))$$

$$\sigma_y = \sigma_o + k_y d^{-1/2} \quad \nu = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z} \quad \tau_R = \sigma\ cos\phi\ cos\lambda \quad \sigma_y = \frac{\tau_{crss}}{(cos\phi\ cos\lambda)_{max}} \quad V = IR \quad \rho = \frac{RA}{l}$$

$$\sigma = \frac{1}{\rho} \quad J = \sigma E \quad E = \frac{V}{l} \quad v_d = \mu_e E \quad \sigma = n|e|\mu_e \quad \theta = \cos^{-1}\left(\frac{u_1 u_2 + v_1 v_2 + w_1 w_2}{\sqrt{(u_1^2 + v_1^2 + w_1^2)(u_2^2 + v_2^2 + w_2^2)}}\right)$$

Formulae from Engel & Reid

Idea gas equation of state: $PV = nRT$

Van der Waals equation of state:

$$P = \frac{nRT}{(V - nb)} - \frac{an^2}{V^2}$$

First law, closed systems

$\Delta U = q + w$ $dU = dq + dw$

$dw = -P_{ext}dV$

$dU = nC_{v,m}dT$

$H \equiv U + PV$

$dH = nC_{p,m}dT$

For ideal gases, $C_{p,m} = C_{v,m} + R$

Solids, Liquids, $C_{p,m} = C_{v,m}$

$G \equiv H - TS$

$$dS \equiv \frac{dQ_{reversible}}{T}$$

For a process at constant temperature

$\Delta G = \Delta H - T\Delta S$

For an isothermal reversible process (ideal gas):

$$W_{rev} = -\int_{V_1}^{V_2} \frac{nRT}{V} dV = -nRT \ln\frac{V_2}{V_1} = -nRT \ln\frac{P_1}{P_2}$$

Adiabatic reversible process (ideal gas):

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma} \qquad \left(\frac{\overline{C_P}}{\overline{C_V}}\right) = \gamma$$

$$T_1 V_1^{(\gamma-1)} = T_2\ V_2^{(\gamma-1)} \qquad T_1\ P_1^{[(1-\gamma)/\gamma]} = T_2\ P_2^{[(1-\gamma)/\gamma]}$$

υ_i: stoichiometric coefficient

Assuming no phase change, constant C_p

$\Delta H°_{rxn} = \Sigma\ \upsilon_i * \Delta H°_{f,i} + \Delta C_p*(T - 25°C)$

$\Delta C_p = \Sigma\ \upsilon_i * C_{p,i}$

Efficiency = $|w|/q_{in}$

ε(ideal) = $1 - T_C/T_H$

For solids or liquids: $\Delta S_m = C_m \ln\frac{T_f}{T_i}$

$$\Delta S = nR\ln\frac{V_f}{V_i} \quad \text{(isothermal)}$$

Phase transition $\Delta S_{trans} = \frac{\Delta H_{trans}}{T_{trans}}$

$$\Delta S = nC_v\ln\frac{T_f}{T_i} \quad \text{(change in T at const V)}$$

$$\Delta S = nC_p\ln\frac{T_f}{T_i} \quad \text{(change in T at const P)}$$

$$\Delta S°(T_2) = \Delta S°(T_1) + \int_{T_1}^{T_2} \Delta C_P \frac{dT}{T}$$

Standard entropy of the reaction $\Delta S°_{rxn} = \Sigma\ \upsilon_i * S_m°_i$

Standard free energy of a reaction: $\Delta G°_{rxn} = \Sigma\ \upsilon_i * \Delta G°_{f,i}$ or $\Delta G°_{rxn} = \Delta H°_{rxn} - T\Delta S°_{rxn}$

$\Delta G° = -RT\ln K$

Total free energy of the reaction aA +bB => cC +dD

$\Delta G_{rxn} = \Delta G_{rxn}^{\emptyset} + RT\ln(Q)$

$\Delta G_{rxn} = \Delta G_{rxn}^{\emptyset} + RT\ln(Q_P)$, where

$$Q_p = \frac{\left(\frac{P_C}{P°}\right)^c \left(\frac{P_D}{P°}\right)^d}{\left(\frac{P_A}{P°}\right)^a \left(\frac{P_B}{P°}\right)^b}$$

$where\ Q = \left[\frac{a_C^c a_D^d}{a_A^a a_B^b}\right]$ where a= activity (~ concentration)

$$\Delta G = -nFE \qquad E = E° - \frac{RT}{nF}\ln Q \qquad E = E^o - \frac{0.0592}{n} log\ Q \quad \text{at } 25°C \qquad I = \frac{nC}{t}$$