UNIVERSITY OF TORONTO

Tutorial Section Number:

FACULTY OF APPLIED SCIENCE AND ENGINEERING

Q1	/20
Q2	/20
Q3	/20
Q4	/20
Q5	/20
Q6	/20
Q7	/20
Q8	/20
Total	/140

FINAL EXAM

APRIL 2014

First Year

APS 104S

INTRODUCTION TO MATERIALS AND CHEMISTRY

Exam Type B

Examiners: T. Bender, N. P. Kherani, T. Mirkovic

NAME: ______________________________
Last First

STUDENT NO: ______________________________

INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- *Answer any 7 of the 8 questions.*
- If all 8 questions are answered, only the first 7 will be marked.
- 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 where applicable clearly "box" your numerical results.
- For additional space, you may use the back of the preceding page.
- Do not unstaple this exam booklet.
- A Formula Sheet and the periodic table are attached to the end of this exam booklet; if you wish, you may tear-off these sheets *only*.

Name: ________________________________ Student No: __________________________

QUESTION 1: (20 pts)

As appropriate circle the correct answer (from True/False or multiple choice), fill in the blank(s), provide a short answer with a sketch if required.

The following questions are worth one point each.

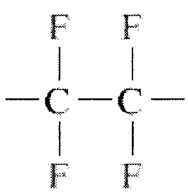
(a) Geckos, harmless tropical lizards, have very sticky feet due to strong covalent bonding. **TRUE** **FALSE**

(b) Ionic bonding is nondirectional. **TRUE** **FALSE**

(c) The coordination number for FCC is 12 while the atomic packing factor is 0.74. **TRUE** **FALSE**

(d) Circle all materials that form crystalline structures under normal solidification conditions:
- (i) Metals
- (ii) Many ceramics
- (iii) Certain polymers
- (iv) All composites
- (v) None of the above

(e) Correctly label the following polymers [(polyethylene (*PE*), poly-vinyl-chloride (*PVC*), polytetrafluoroethylene (*PTFE*)]:



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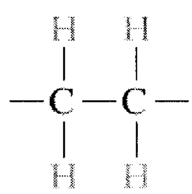

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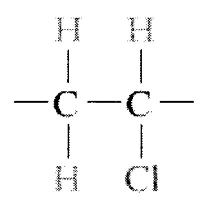

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(f) Circle the correct statement:
- (i) If $\Delta G > 0$ the process is exergonic;
- (ii) If $\Delta G < 0$ the process is endergonic;
- (iii) If $\Delta G = 0$ the process is exergonic and endergonic;
- (iv) If $\Delta G < 0$ the process is exergonic;
- (v) None of the above.

(g) Ammonia, produced using the Haber process, is used extensively as a fertilizer. **TRUE** **FALSE**

(h) Consider the following exothermic reaction: $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$. If the reaction temperature is raised the reaction rate will _____________.

(i) Lithium ion batteries when being drained are an example of galvanic cells and when being charged an example of electrolytic cells. **TRUE** **FALSE**

(j) The anode is
- (i) where oxidation occurs
- (ii) where electrons are generated
- (iii) the electrode with negative polarity
- (iv)all of the above
- (v) none of the above

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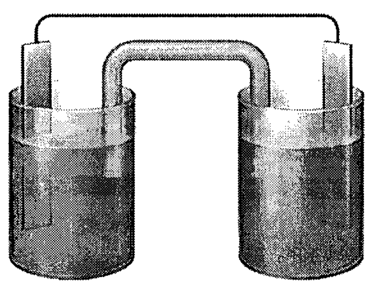
The following questions are worth two points each.

(k) Write the electronic configuration for aluminum:

____

(l) The winter season this year has been the coldest that we have experienced in 25 years. One evidence of this is the large number of pot holes in the streets of Toronto. Explain why this is the case (describing the properties of the relevant material(s) and the processes thereof).

(m) Consider the concentration cell based on the Cd/Cd^{2+} reaction shown below. In which direction will the electrons flow (*left to right* OR *right to left*)? What will be the cell voltage at equilibrium?

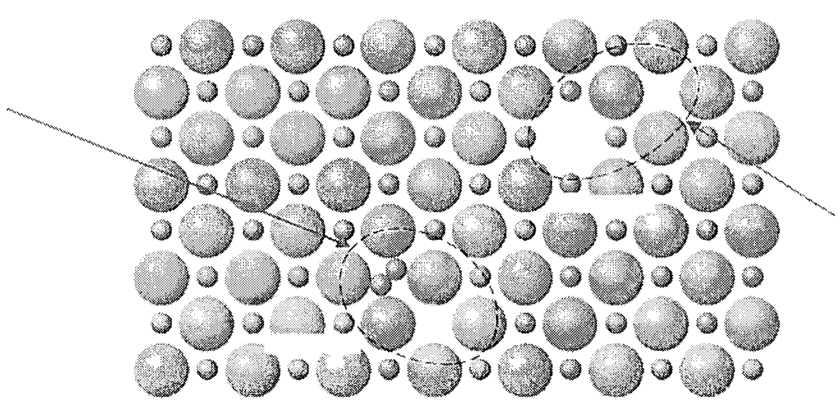


□ *left to right* □ *right to left*

$E_{\text{cell - equilibtium}}$ = __________

Cd/Cd^{2+} (0.1 M) Cd/Cd^{2+} (1.0 M)

(n) Identify the two defects shown in the diagram below.



(o) Consider the reaction $H_2 + ½O_2 \rightarrow H_2O$ with an enthalpy of reaction of 286 kJ/mol and Gibbs free energy of reaction of 237 kJ/mol.

(i) The reaction is carried out in a combustion chamber with $T_h = 950$ K and $T_c = 400$ K. Calculate the maximum thermal work that can be extracted.

(ii) The reaction is carried out in an electrolytic fuel cell. Calculate the maximum electrical work that can be extracted.

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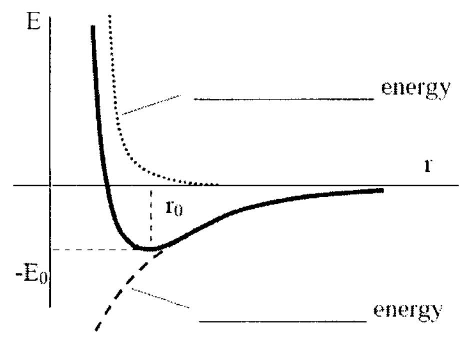
QUESTION 2: (20 pts)

A. State the type of bonding (ionic, covalent, metallic, van der Waals, hydrogen-bonding) for each of the materials listed in the table below. *Note*: Look at both the bond energy and substance. **(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	

B. 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)**



i) Label the two types of potential energy on the figure;

ii) State the equilibrium interatomic distance: ______;

iii) State the binding energy between the atoms: _____.

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

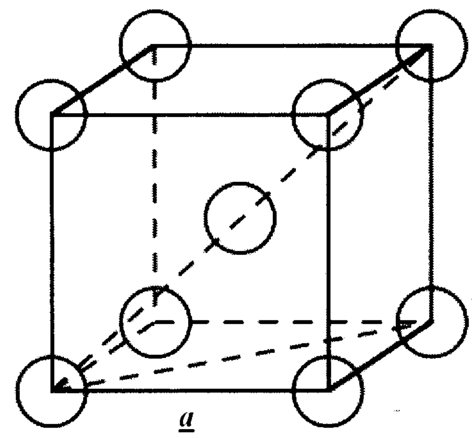
$$E(r) = -\frac{A}{r} + \frac{B}{r^8}$$

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)**

Name: ______________________ Student No: ______________________

D.

(a) Consider the body centered cubic crystal structure (shown in the small sphere representation on the right) with a unit cell edge length of ***a*** and atomic radius ***R***. Derive the expression for the lattice constant ***a*** in terms of the atomic radius ***R***. [3 marks]



(b) Calculate the atomic packing factor for the BCC crystal structure. [4 marks]

(c) Calculate the planar atomic density in the (1 1 0) plane of the BCC crystal structure. [3 marks]

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QUESTION 3: (20 pts)

A..Fill-in the blanks (1 mark each):

a. The reversible, non permanent deformation is called ____________________deformation.

b. For a material with poisson's ratio of 0.5, it's volume change is _____________.

c. Ductility is a measure of the degree of _____________deformation that has been sustained at fracture.

d. In general, the elastic modulus of ceramics is ___________ than that of polymers. Ceramics are dominated by _______ bonds, while polymers are dominated by ___________bonds.

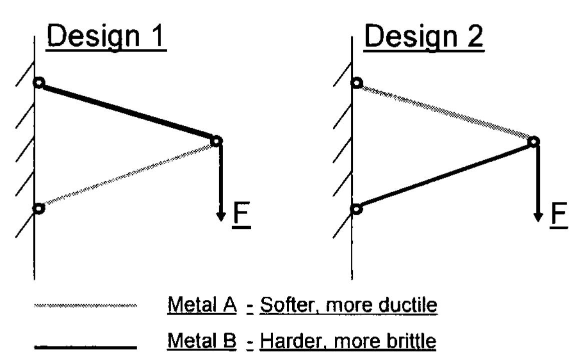
e. For a material with a poisson's ratio of 0.3, its shear modulus G is about _____E.

B..Answer the following questions:

(i) Two cylindrical nickel wires A and B have diameter ratio of 1:2 (i.e. $d_A:d_B = 1:2$). What is the ratio of their strain ($\varepsilon_A : \varepsilon_B$) when the same force is applied along the long axis? Assume that the deformation is elastic. **(2 marks)**

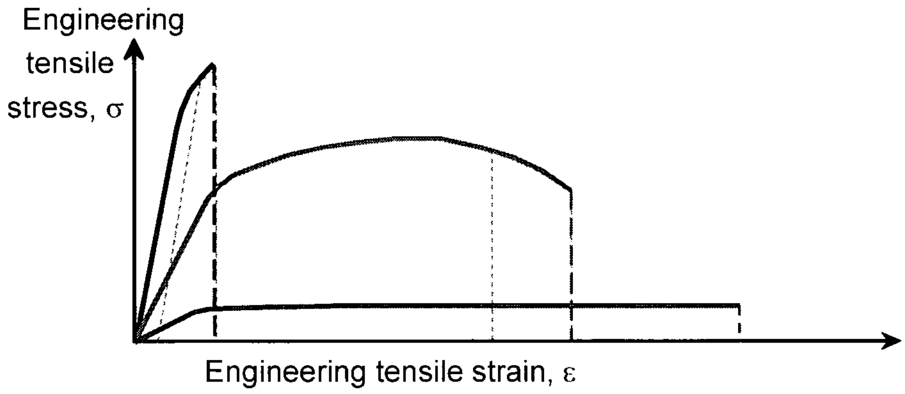
(ii) State two reasons where porosity negatively influences the flexural strength of ceramic materials. **(2 marks)**

(iii) The figure on the right shows two designs with the same parameters. Which one is better and why? **(2 marks)**



Name: ______________________________ Student No: ________________________

C... With reference to the following stress-strain curves:



(i) Identify which curve represents the following materials: ceramic, metal and polymer. Clearly indicate the material on the graph. **(3 marks)**

(ii) Mark the tensile strength on the stress-strain curve that represents metals. **(1 mark)**

D. Describe the following strengthening mechanisms, including an explanation as to how dislocations are involved in each of the strengthening techniques. **(3 marks - 1 mark each)**

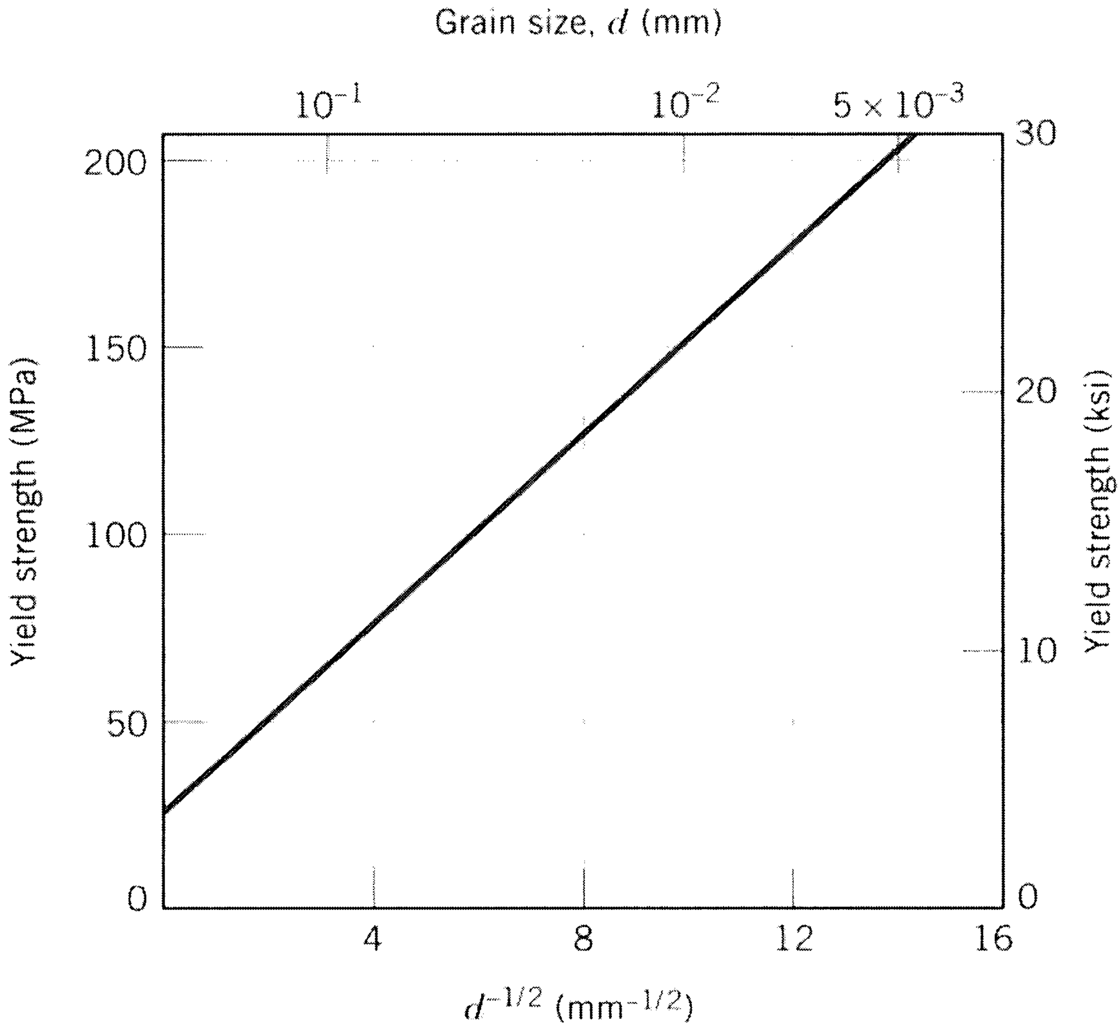
(i) Grain size reduction

(ii) Solid-solution strengthening

(iii) Strain hardening

E. From the plot below (see next page) of yield strength versus (grain diameter)$^{-1/2}$ for a 70Cu–30Zn cartridge brass, determine the values for the constants σ_0 and k_y in the equation $\boldsymbol{\sigma_y = \sigma_0 + k_y d^{-1/2}}$ **(3 marks)**

Name: ______________________________ Student No: ________________________

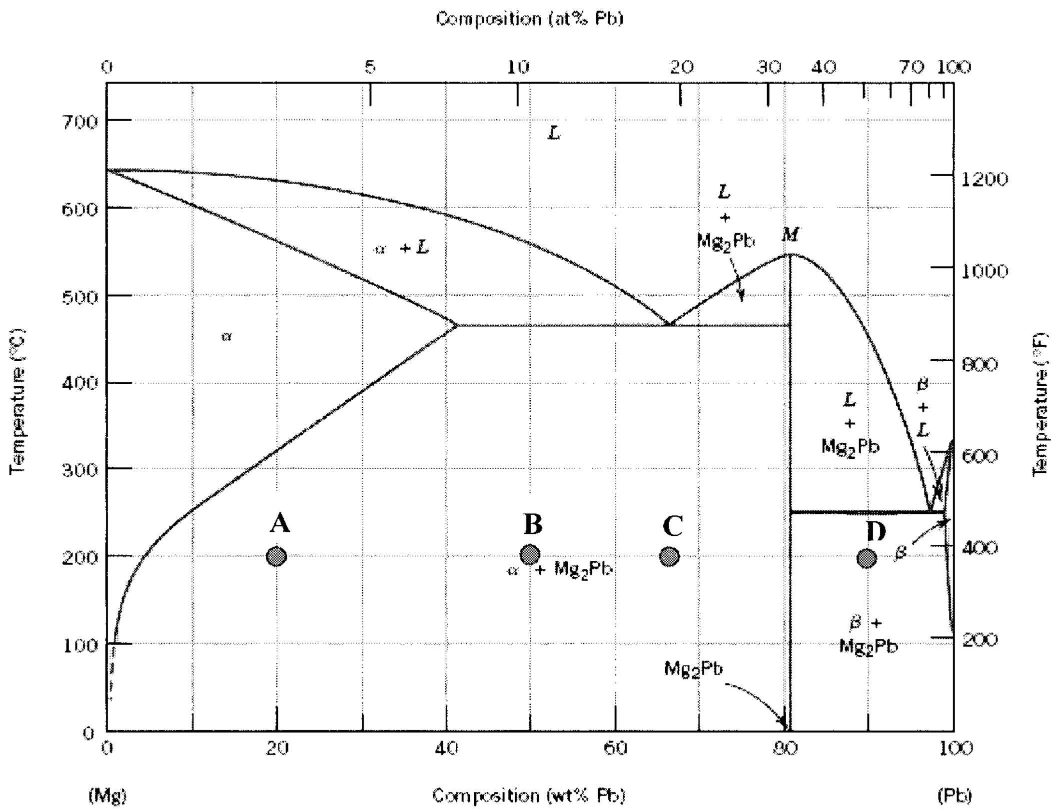


Plot showing the influence of grain size on the yield strength of a 70Cu-30Zn brass alloy. Note that the grain diameter increases from right to left and is not linear.

Name: ______________________ Student No: ______________________

QUESTION 4: (20 pts)

A. The magnesium-lead diagram is shown below. Use it to answer questions (a) – (e).



(a) Label clearly (i) the two eutectic points and (ii) the congruent point on the diagram above. [3 pts]

(b) What are the temperatures at the two eutectic isotherms? [2 pts]

(c) Write the eutectic reaction for the eutectic transformation that is occurring at

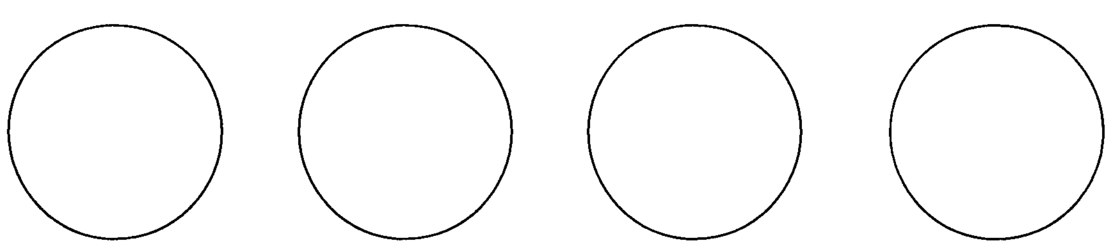
(i) the higher eutectic isotherm, and

(ii) the lower eutectic isotherm.

Specify the composition of all the phases. [4 pts]

(d) At the eutectic composition (associated with $T_{E(higher)}$), determine the amounts of each phase present, just below the eutectic isotherm. [2 pts]

(e) For points A-D on the graph above, sketch the correspond microstructures in the circles provided below. [4 pts]



A B C D

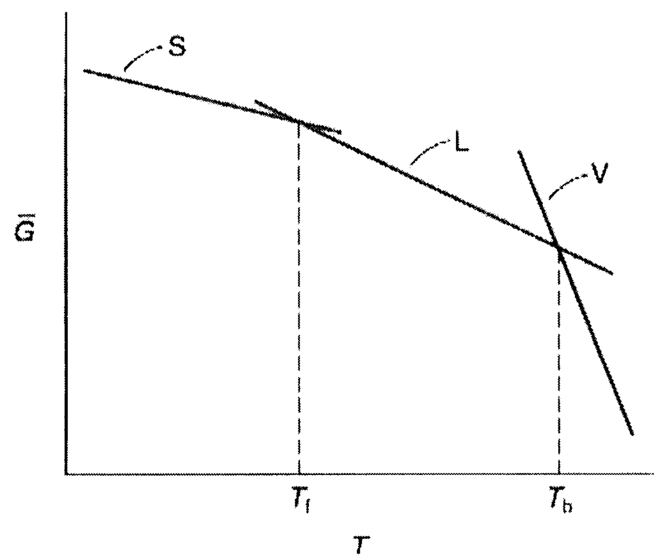
Name: ____________________ Student No: ____________________

B.

(f) **True** or **False**? Consider water and ice at equilibrium at some T and P, it then follows that $G_{ice} = G_{water}$. [1 pts]

(g) **True** or **False**? The chemical potential of water is higher than the chemical potential of an aqueous glucose solution. [1 pts]

(h) On the diagram below, if the pressure is increased, sketch the effect that it would have on the boiling point of this substance (i.e., sketch the new curves). What is the change in the boiling point? [3 pts]



Name: ______________________________ Student No: ______________________________

QUESTION 5: (20 pts)

(a) Write down the ΔH°_f reaction for HNO_3 (*aq*) [that is, chemical reaction for the standard enthalpy of formation of HNO_3 (*aq*)]. [2 pts]

(b) Set up a Hess's law cycle, and use the following information to calculate the ΔH°_f for aqueous nitric acid, HNO_3 (*aq*). You will need to use fractional coefficient for some equations. [6 pts]

$$3\,NO_2(g) + H_2O(l) \rightarrow 2\,HNO_3(aq) + NO(g) \qquad \Delta H^\circ = -138.4 \text{ kJ}$$
$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g) \qquad \Delta H^\circ = -114.0 \text{ kJ}$$
$$4\,NH_3(g) + 5\,O_2(g) \rightarrow 4\,NO(g) + 6\,H_2O(l) \qquad \Delta H^\circ = -1169.6 \text{ kJ}$$

Given: $NH_3(g)$ $\Delta H^\circ_f = -46.1$ kJ/mol
$H_2O(l)$ $\Delta H^\circ_f = -285.8$ kJ/mol

(c) Calculate ΔU for the reaction in (a). If you were not able to solve part (b) use $\Delta H^\circ_f = -200$ kJ/mol. [2 pts]

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(d) Use $NH_3(g)$ $\Delta H^\circ_f = -46.1$ kJ/mol to calculate ΔH of the following reaction at 1000 K

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

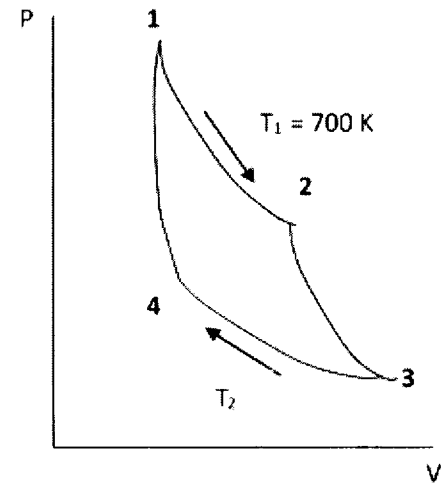
with $C_{p,m}$ = 3.502R, 3.466R, and 4.217R for $N_2(g)$, $H_2(g)$, and $NH_3(g)$, respectively. [6 pts]

(e) In a calorimetry experiment, 5.00 g of ammonia ($\Delta H^\circ_f = -46.1$ kJ/mol) are produced after stoichiometric amounts of nitrogen and hydrogen has reacted. Determine the combined heat capacity of the calorimeter and water, if the calorimeter and water-bath temperature rises by 0.42°C as a result of the production of 5.00 g of ammonia. [4 pts]

Name: ______________________________ Student No: ______________________________

QUESTION 6: Engle-Reid Chapter 5 (20 pts)

Consider the Carnot cycle shown on the right for 0.6 moles of an ideal ***monatomic*** gas for which you are given:



$T_1 = 700$ K, $V_2 = 2V_1$ and $V_3 = 1.5V_2$

(a) Calculate $w_{1\to2}$, $\Delta U_{1\to2}$, $q_{1\to2}$. [4 pts]

(b) Find T_2. [2 pts]

(c) What is the efficiency of a Carnot engine operating on this cycle? [2 pts]

(d) What is the total work around the cycle? [2 pts]

Name: ______________________________ Student No: ________________________

(e) How much heat is rejected at T_2? [2 pts]

(f) Evaluate $\Delta S_{3\to4}$. [2 pts]

(g) Describe on the molecular scale the sign of $\Delta S_{3\to4}$ calculated in (f). [3 pts]

(h) What is $\Delta S_{universe}$ for the whole cycle? Show your calculation or explain your result. [3 pts]

Name: ______________________________ Student No: ____________________________

QUESTION 7: (20 pts)

(A) Dinitrogen tetroxide is 18.46 per cent dissociated at 25°C and 1.00 bar in the equilibrium

$$N_2O_4(g) \leftrightarrow 2\ NO_2(g)$$

Calculate/determine the following:

(i) K at 25°C **[6 pts]**

(ii) $\Delta_r G^{\ominus}$ **[3 pts]**

(iii) $\Delta_r G$ **[2 pts]**

(iv) K at 100°C given that $\Delta_r H^{\ominus} = +57.2$ kJ mol^{-1} over the temperature range **[3 pts]**

Name: ______________________________ Student No: ________________________

(B) The standard Gibbs energy of formation of $NH_3(g)$ is -16.5 kJ mol^{-1} at 298 K.

(i) What is the reaction Gibbs energy when the partial pressure of the N_2, H_2, and NH_3 (treated as ideal gases) are 3.0 bar, 1.0 bar, and 4.0 bar, respectively? **[3 pts]**

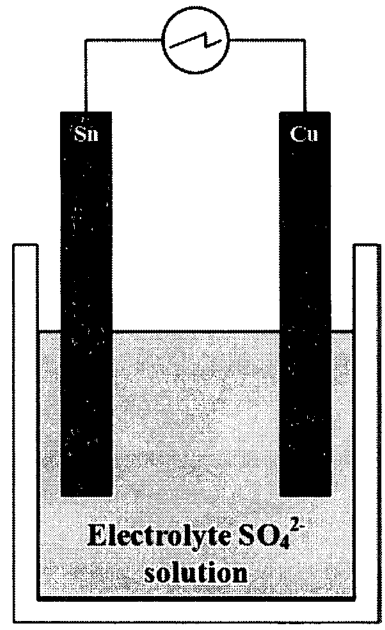
(ii) What is the spontaneous direction of the reaction in this case? Explain your answer. **[3 pts]**

Name: ________________ Student No: ________________

QUESTION 8: (20 pts)

(A) Consider the electrochemical cell on the right and the following data (at 25 °C):

	$E^{\varnothing}$
$Cu^{2+} + 2e^- \rightarrow Cu(s)$	+0.34 V
$Sn^{2+} + 2e^- \rightarrow Sn\ (s)$	-0.14 V



(i) Assuming that the electrolyte solution could be **either** $CuSO_4$ or $SnSO_4$, what is the spontaneous/voltaic electrochemical reaction that can occur for this cell? **[4 pts]**

(ii) What should be the electrolyte for the voltaic cell? **[1 pt]**

(iii) Which electrode is the cathode for the voltaic cell? **[1 pt]**

(iv) Which electrode is the anode for the voltaic cell? **[1 pt]**

(v) What is the equilibrium constant for the spontaneous reaction at 25 °C? **[4 pts]**

(vi) What will physically happen to the cathode during this process? **[1 pt]**

(vii) What will physically happen to the anode during this process? **[1 pt]**

Name: ______________________ Student No: ______________________

(B) Consider the following electrochemical reaction:

$$Pb(s) + Hg_2SO_4 \rightarrow PbSO_4 + 2\ Hg(l) \quad E = +\ 0.9647\ V$$

And given $\left(\frac{\partial E}{\partial T}\right)_p = 1.74\ x\ 10^{-4}\ V\ K^{-1}$

(i) Calculate ΔG_r for this reaction. **[2 pts]**

(ii) Calculate ΔS_r for this reaction. **[2 pts]**

(iii) Calculate ΔH_r for this reaction. **[2 pts]**

(iv) Is this process enthalpically or entropically driven? Why? **[1 pts]**

FORMULAE & CONSTANTS *(You may tear these sheets off.)*

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
STP: 273.15K, 1 atm ***SATP***: 298.15K, 1 bar 1L atm = 101.325 J

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

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

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

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

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

$$\sigma_y=\sigma_0+k_y d^{-1/2} \quad \nu=-\frac{\epsilon_L}{\epsilon}=-\frac{\epsilon_x}{\epsilon_z}=-\frac{\epsilon_y}{\epsilon_z} \quad \tau_R=\sigma\cos\phi\cos\lambda \quad \sigma_y=\frac{\tau_{crss}}{(\cos\phi\cos\lambda)_{max}}$$

$$\theta=\cos^{-1}\left(\frac{u_1u_2+v_1v_2+w_1w_2}{\sqrt{(u_1^2+v_1^2+w_1^2)(u_2^2+v_2^2+w_2^2)}}\right) \qquad \sigma=n|e|\mu_e$$

$$V=IR \quad \rho=\frac{RA}{l} \quad \sigma=\frac{1}{\rho} \quad J=\sigma E \quad E=\frac{V}{l} \quad v_d=\mu_e E \quad \sigma=n|e|\mu_e+p|e|\mu_h$$

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):
$$P_1V_1^{\gamma}=P_2V_2^{\gamma} \qquad \left(\frac{C_P}{C_V}\right)=\gamma$$
$$T_1V_1^{(\gamma-1)}=T_2V_2^{(\gamma-1)} \qquad T_1P_1^{[(1-\gamma)/\gamma]}=T_2P_2^{[(1-\gamma)/\gamma]}$$

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:

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

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

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

$$\Delta S°(T_2)=\Delta S°(T_1)+\int_{T_1}^{T_2}\Delta C_P\frac{dT}{T} \qquad \Delta S = nC_P\ln\frac{T_f}{T_i} \quad \text{(change in T at const P)}$$

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 $\Delta G°_{rxn} = \Delta H°_{rxn} - T\Delta S°_{rxn}$

$\Delta G° = -RT\ln K$ $$\ln\left(\frac{K_p(T_1)}{K_p(T_2)}\right)=-\frac{\Delta H^o_{reaction}}{R}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)$$ (assuming $\Delta H^o_{reaction}$ independent of T)

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

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

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

$\Delta G_{rxn} = \Delta G_{rxn}^{\emptyset} + RT\ln(Q_P)$, where $$Q_p=\frac{\left(\frac{P_C}{P°}\right)^c\left(\frac{P_D}{P°}\right)^d}{\left(\frac{P_A}{P°}\right)^a\left(\frac{P_B}{P°}\right)^b}$$

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

$$\Delta S_r=nF\left(\frac{\partial E}{\partial T}\right)_p \qquad K=\frac{[C]^c[D]^d}{[A]^a[B]^b} \qquad \ln K=\frac{-\Delta G^{\emptyset}}{RT} \qquad \ln K=\frac{nFE^{\emptyset}}{RT}$$

PERIODIC TABLE OF THE ELEMENTS

http://www.ktf-split.hr/periodni/en/

GROUP NUMBERS IUPAC RECOMMENDATION (1985) — 13
GROUP NUMBERS CHEMICAL ABSTRACT SERVICE (1986) — IIIA

ATOMIC NUMBER — 5
RELATIVE ATOMIC MASS (1) — 10.811
SYMBOL — B
ELEMENT NAME — BORON

PERIOD	GROUP 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 H HYDROGEN																	2 4.0026 He HELIUM
2	3 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM											5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON
3	11 22.990 Na SODIUM	12 24.305 Mg MAGNESIUM											13 26.982 Al ALUMINIUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULPHUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON
4	19 39.098 K POTASSIUM	20 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.693 Ni NICKEL	29 63.546 Cu COPPER	30 65.39 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON
5	37 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.906 Y YTTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIOBIUM	42 95.94 Mo MOLYBDENUM	43 (98) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON
6	55 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W TUNGSTEN	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON
7	87 (223) Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (261) Rf RUTHERFORDIUM	105 (262) Db DUBNIUM	106 (266) Sg SEABORGIUM	107 (264) Bh BOHRIUM	108 (277) Hs HASSIUM	109 (268) Mt MEITNERIUM	110 (281) Uun UNUNNILIUM	111 (272) Uuu UNUNUNIUM	112 (285) Uub UNUNBIUM		114 (289) Uuq UNUNQUADIUM				

LANTHANIDE

6	57 138.91 La LANTHANUM	58 140.12 Ce CERIUM	59 140.91 Pr PRASEODYMIUM	60 144.24 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 150.36 Sm SAMARIUM	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERBIUM	71 174.97 Lu LUTETIUM

ACTINIDE

7	89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)
Relative atomic mass is shown with five significant figures. For elements have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.
However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@nettlinx.com)