

FACULTY OF APPLIED SCIENCE AND ENGINEERING

TERM TEST 2  
28 MARCH 2013

First Year

APS 104S  
INTRODUCTION TO MATERIALS AND CHEMISTRY

Q1	/25
Q2	/10
Q3	/17
Q4	/18
Q5	/15
Q6	/20
	/105

Exam Type B

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

Duration: 1 hour 45 minutes

NAME: \_\_\_\_\_  
Last First

STUDENT NO: \_\_\_\_\_

INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- Answer all 6 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 **write (in ink) the answer in** the respective **boxes** where provided. 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*.

**QUESTION 1: (25 pts)****A.** Copper oxide occurs in two forms:

*cuprous oxide:*  $\text{Cu}_2\text{O}$  (also known as Copper (I) Oxide)

*cupric oxide:*  $\text{CuO}$  (also known as Copper (II) oxide)

Now consider pure cupric oxide which is exposed to a reducing atmosphere at an elevated temperature, and as a result some of the  $\text{Cu}^{2+}$  ion become  $\text{Cu}^+$ .

(i) Name two possible defects that can form in order to maintain charge neutrality. [4 pts]

(ii) For each of the defects identified in part (i), how many  $\text{Cu}^+$  ions are required? [1 pts]

(iii) Write a chemical formula to represent in general this nonstoichiometric material. [1 pts]

**B.** Define (succinctly in words or, and using a clearly labelled illustration) the following:

(i) Schottky defect [1 pt]

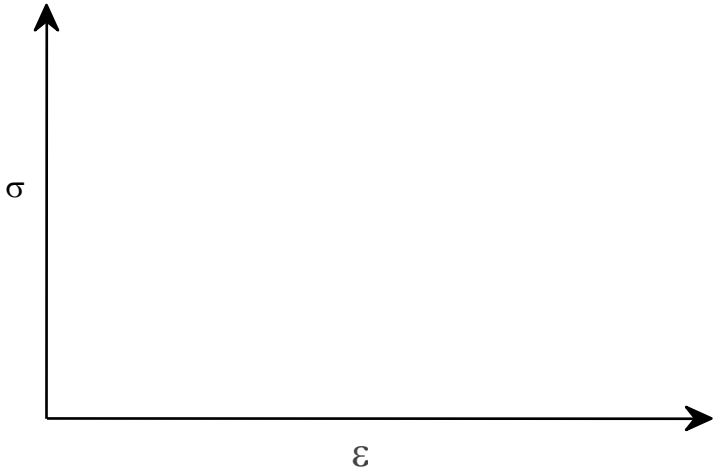
(ii) Grain boundary [1 pt]

(iii) Edge dislocation [1 pt]

(iv) Twin boundary [1 pt]

C. Consider a typical ceramic and a typical metal.

- (i) Draw the stress strain curves for the two materials on the graph provided on the right. Clearly draw the curves (solid lines) starting from the origin and ending at fracture, and label appropriately (i.e., ceramic or metal). Also, clearly show the strain at fracture (precisely indicated with dashed lines). [4 pts]



- (ii) Which material is tougher? [1 pt]

- (iii) Which material is more resilient? [1 pt]

- (iv) Provide an explanation (at an atomic level) for the differences in the stress-strain behaviour of the materials. [1 pt]

D. A bronze rod is 115 mm in length and 12.5 mm in diameter. The modulus of elasticity of this bronze alloy is 115 GPa. Further, plastic deformation begins at 275 MPa.

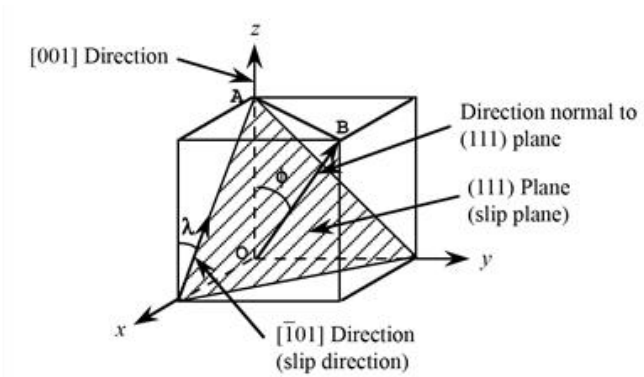
- (i) Calculate the maximum load that may be applied up to which point the material exhibits resiliency. [3pts]

- (ii) Calculate the total length of the rod just before the onset of plastic deformation. [3pts]

- (iii) Given a Poisson coefficient of 0.34, calculate the lateral strain. [2pts]

QUESTION 2: (10 pts)

A. A single crystal of silver is oriented such that a tensile stress is applied along a [001] direction, as illustrated in the diagram on the right. Slip occurs on a (111) plane and in the direction  $[\bar{1}01]$ . The critical resolved shear stress is 0.45 MPa. Calculate the yield stress for silver. [6 pts]



B. True or False? Circle the correct answer. [4 pts]

- (i) Generally, a fine-grained (i.e., small-grained) material is harder and stronger than a coarse-grained material.

TRUE      FALSE
- (ii) Alloying with impurity atoms which go into substitutional or interstitial solid solution is not a strengthening mechanism as these impurity atoms do not typically impose lattice strains on the surrounding host.

TRUE      FALSE
- (iii) Edge dislocations of the same sign (  $\perp + \perp$  ) and lying on the same slip plane will exert a mutually attractive force and upon meeting they will annihilate each other, thus rendering a region of perfect crystal.

TRUE      FALSE
- (iv) Cold working of 8mm diameter flexible copper pipe makes it harder and stronger.

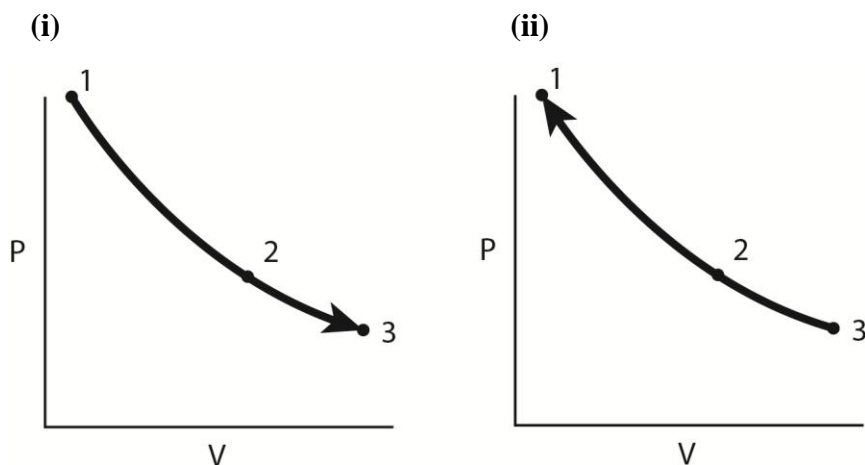
TRUE      FALSE

**QUESTION 3: (17 pts)**

The graphs below illustrate an isothermal reversible expansion **(i)** or isothermal reversible compression **(ii)** that goes through three points: 1, 2 and 3.

The temperature is kept at **300 K**, and the respective pressures at points 1, 2, and 3 are:  
 **$P_1 = 4 \text{ atm}$ ,  $P_2 = 2 \text{ atm}$ , and  $P_3 = 1 \text{ atm}$ .**

- (a) On the graphs below, sketch the work done in a two-step series of irreversible **expansion (i)** and irreversible **compression (ii)** processes at constant pressure. [4 pts]



- (b) Calculate the values of  **$w$ ,  $q$ ,  $\Delta H$  and  $\Delta U$**  for a reversible isothermal expansion of 1 mole of monatomic ideal gas. The gas is initially at point 1, where  $P_1 = 4 \text{ atm}$ , and expands to point 3, where  $P_3 = 1 \text{ atm}$ . [7 pts]

- (c) Calculate the work done for an **irreversible isothermal expansion** of 1 mole of monatomic ideal gas in the two-step process ( $1 \rightarrow 2 \rightarrow 3$ ) described in part (a). [3 pts]

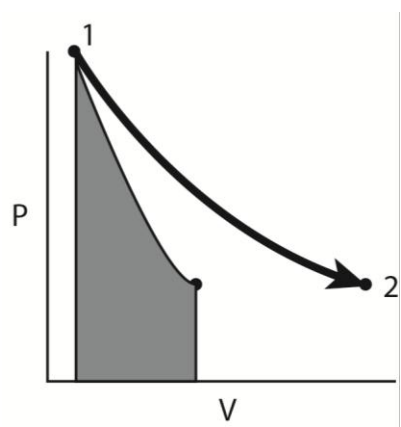
- (d) Calculate the work done for an **irreversible isothermal compression** of 1 mole of monatomic ideal gas in the two-step process ( $3 \rightarrow 2 \rightarrow 1$ ) described in part (a). [3 pts]

**QUESTION 4: (18 pts)**

In another experiment, one mole of an ideal monatomic gas is initially at 300 K and 4 atm and expands to a final pressure of 1 atm.

- (a) Calculate the values of  $w$ ,  $q$ ,  $\Delta H$  and  $\Delta U$  if the expansion occurred via an **adiabatic and reversible** path. [7 pts]

- (b) Use a PV-diagram to illustrate the difference in values for work that you obtained in question 4(a) (reversible adiabatic expansion) and 3(b) (reversible isothermal expansion). Note that both processes had the same starting point, and the gases expanded to the same final pressure. [4 pts]



- (c) Calculate the values of  $w$ ,  $q$ ,  $\Delta H$  and  $\Delta U$  if the expansion occurred via an **adiabatic and irreversible** path. [7 pts]

QUESTION 5: (15 pts)

- A. When 120 mg of naphthalene ( $C_{10}H_8(s)$ ) was burned in a constant pressure calorimeter the temperature rose by 3.05 K.
- (i) Given  $\Delta H_{c, \text{naphthalene}} = -5157 \text{ kJ mol}^{-1}$ , calculate the heat capacity of the calorimeter.[3pts]
- 
- (ii) How much will the temperature rise in the same calorimeter if 10 mg of phenol ( $C_6H_6O(s)$ ) is burned in the same calorimeter ( $\Delta H_{c, \text{phenol}} = -3054 \text{ kJ mol}^{-1}$ )? [2pts]
- 

- B. Calculate  $\Delta_r H^\circ$  for the following reaction: [4pts]
- $KCl(s) + 3/2 O_2(g) \rightarrow KClO_3(s)$
- 
- given the following thermodynamic data:

	$\Delta_f H^\circ \text{ (kJ mol}^{-1}\text{)}$
$K(s) + 1/2 Cl_2(g) \rightarrow KCl$	-436.75
$K(s) + 1/2 Cl_2(g) + 3/2 O_2(g) \rightarrow KClO_3$	-392.1

- C. Calculate  $\Delta_f H^\circ$  for sodium bicarbonate ( $NaHCO_3$ ) from the following thermodynamic data: [6pts]
- 

	$\Delta H^\circ \text{ (kJ mol}^{-1}\text{)}$
$Na(s) + 1/2 O_2(g) + 1/2 H_2(g) \rightarrow NaOH(s)$	-425.61
$NaHCO_3(s) \rightarrow NaOH(s) + CO_2(g)$	127.5
$C(s) + O_2(g) \rightarrow CO_2(g)$	-393.51

QUESTION 6: (20 pts)

A. Under standard conditions, predict whether the entropy change ( $\Delta S$ ) for the following processes or chemical reactions is positive, negative or approximately 0 (circle the appropriate response). [5pts]

- (i)  $\text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$

+

-

0
- (ii)  $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$

+

-

0
- (iii)  $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightarrow 2\text{HI}(\text{g})$

+

-

0
- (iv) the temperature of a mass of copper decreases

+

-

0
- (v)  $\text{C}_{\text{graphite}} \rightarrow \text{C}_{\text{diamond}}$

+

-

0

B. The enthalpy of the  $\text{C}_{\text{graphite}} \rightarrow \text{C}_{\text{diamond}}$  phase transition, which under 100 kbar occurs at 2000 K, is  $+1.9 \text{ kJ mol}^{-1}$ . Calculate the entropy of the transition. [2pts]

C. Calculate the standard change in entropy ( $\Delta S_{\text{m}}^\circ$ ) for the burning of glucose according to the following chemical reaction: [3pts]

$\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{s}) + 12 \text{ O}_2(\text{g}) \rightarrow 12 \text{ CO}_2(\text{g}) + 11 \text{ H}_2\text{O}(\text{l})$

given the following thermodynamic data:

	$\Delta_{\text{f}}S_{\text{m}}^\circ \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$
$\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{s})$	360.2
$\text{O}_2(\text{g})$	205.14
$\text{CO}_2(\text{g})$	213.74
$\text{H}_2\text{O}(\text{l})$	69.91

D. Water phase transition.

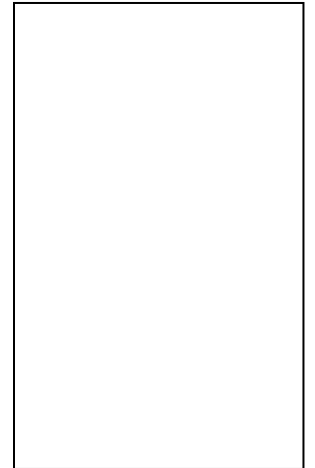
(i) Calculate the total change in entropy of 100 g of ice ( $\text{H}_2\text{O}(\text{s})$ ) at 0 °C as it is melted, heated to 100 °C and then vaporized at 100 °C. Assume the energy is supplied by a heater at a constant rate. The following is relevant thermodynamic data: [3pts]

$\Delta_{\text{fus}}H = 6.01 \text{ kJ mol}^{-1}; \Delta_{\text{vap}}H = 40.7 \text{ kJ mol}^{-1}; C_{\text{v,H}_2\text{O}(\text{l})} = 4.18 \text{ J K}^{-1} \text{ g}^{-1}.$

(ii) Sketch of graph of entropy as a function of temperature for the process outlined in part a. [2pts]



- E.** Consider a system consisting of 1.5 mol  $\text{CO}_2(\text{g})$ , initially at 15 °C and 9 atm and confined to a cylinder of cross-section  $100.0 \text{ cm}^2$ . It is allowed to expand adiabatically against an external pressure of 1.5 atm until the piston has moved outwards through 15 cm. Assume that  $\text{CO}_2(\text{g})$  may be considered a perfect gas with  $C_{V,m} = 28.8 \text{ J K}^{-1} \text{ mol}^{-1}$  (which remains constant over the temperature range of this problem) and calculate: (i)  $q$ , (ii)  $w$ , (iii)  $\Delta U$ , (iv)  $\Delta T$ , (v)  $\Delta S$ . [5pts]



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

<p><math>R = 8.3145 \text{ J}\cdot\text{K}^{-1} \text{ mol}^{-1} = 0.0820574587 \text{ L}\cdot\text{atm}\cdot\text{K}^{-1} \text{ mol}^{-1} = 0.083145 \text{ L}\cdot\text{bar}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}</math> <math>1 \text{ atm} = 101.325 \text{ kPa} = 1.01325 \text{ bar} = 14.696 \text{ psi} = 760 \text{ Torr} = 760 \text{ mmHg}</math> <math>N_A = 6.022 \times 10^{23} \text{ mol}^{-1} k = 8.62 \times 10^{-5} \text{ eV/K} \quad 1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}</math> <math>T(\text{K}) = T(^{\circ}\text{C}) + 273.15 \text{ K} = 9.6485309 \times 10^4 \text{ C mole}^{-1} e = 1.60217733 \times 10^{-19} \text{ C}</math> <b>STP:</b> 273.15K, 1 bar      <b>SATP:</b> 298.15K, 1 bar      1L atm = 101.325 J</p>	
<p><math>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}</math> <math>APF = \frac{\text{Total Sphere Volume}}{\text{Total Unit Cell Volume}} \quad LD = \frac{\text{Number Of Atoms Centred On Direction Vector}}{\text{Length Of Direction Vector}}</math> <math>PD = \frac{\text{Number Of Atoms Centred On A Plane}}{\text{Area Of Plane}} \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</math> <math>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})</math> <math>E = \frac{\sigma}{\epsilon} \sigma = \frac{F}{A} \epsilon = \frac{\Delta l}{l} \tau = \frac{F}{A} \tau = G \gamma U_r = \frac{1}{2} \sigma_Y \epsilon_Y \%CW = \left(\frac{A_0 - A_d}{A_0}\right) \times 100 \quad G = E/(2(1 + \nu))</math> <math>\sigma_y = \sigma_o + k_y d^{-1/2} \quad \nu = -\frac{\epsilon_L}{\epsilon} = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z} \tau_R = \sigma \cos \phi \cos \lambda \sigma_y = \frac{\tau_{crss}}{(\cos \phi \cos \lambda)_{max}} V = IR</math> <math>\rho = \frac{RA}{l} \sigma = \frac{1}{\rho} J = \sigma EE = \frac{V}{l} v_d = \mu_e E \sigma = n e  \mu_e \theta</math> <math>= \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)</math></p>	
<p>Idea gas equation of state: <math>PV = nRT</math> Van der Waals equation of state: <math>P = \frac{nRT}{(V - nb)} - \frac{an^2}{V^2}</math> First law, closed systems <math>\Delta U = q + w \quad dU = dq + dw</math> <math>dw = -P_{ext} dV</math> <math>dU = nC_{v,m} dT</math></p>	<p><math>H \equiv U + PV</math> <math>dH = nC_{p,m} dT</math> For ideal gases, <math>C_{p,m} = C_{v,m} + R</math> Solids, Liquids, <math>C_{p,m} = C_{v,m}</math>  <math>G \equiv H - TS</math> <math>dS \equiv \frac{dQ_{reversible}}{T}</math> For a process at constant temperature <math>\Delta G = \Delta H - T\Delta S</math></p>
<p>For an isothermal reversible process (ideal gas): <math>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}</math> Adiabatic reversible process (ideal gas): <math>P_1 V_1^\gamma = P_2 V_2^\gamma</math> <math>T_1 V_1^{(\gamma-1)} = T_2 V_2^{(\gamma-1)} \quad T_1 P_1^{[(1-\gamma)/\gamma]} = T_2 P_2^{[(1-\gamma)/\gamma]} \quad \left(\frac{\overline{C_p}}{\overline{C_v}}\right) = \gamma</math></p>	<p><math>v_i</math>: stoichiometric coefficient Assuming no phase change, constant <math>C_p</math> <math>\Delta H^{\circ}_{rxn} = \sum v_i \Delta H^{\circ}_{f,i} + \Delta C_p (T - 25^{\circ}\text{C})</math> <math>\Delta C_p = \sum v_i C_{p,i}</math>  Efficiency = <math> w /q_{in}</math>  <math>\epsilon(\text{ideal}) = 1 - T_C/T_H</math></p>
<p>For solids or liquids:</p> <div><div><p>Phase transition <math>\Delta S_{trans} = \frac{\Delta H_{trans}}{T_{trans}}</math></p><p><math>\Delta S^{\circ}(T_2) = \Delta S^{\circ}(T_1) + \int_{T_1}^{T_2} \Delta C_p \frac{dT}{T}</math></p><p>Standard entropy of the reaction <math>\Delta S^{\circ}_{rxn} = \sum v_i S^{\circ}_{m,i}</math></p></div><div><p><math>\Delta S = nR \ln \frac{V_f}{V_i} \quad (\text{isothermal})</math></p><p><math>\Delta S = nC_v \ln \frac{T_f}{T_i} \quad (\text{change in T at const V})</math></p><p><math>\Delta S = nC_p \ln \frac{T_f}{T_i} \quad (\text{change in T at const P})</math></p></div></div>	

