



NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF APPLIED SCIENCE

DEPARTMENT OF APPLIED CHEMISTRY

PHYSICAL CHEMISTRY I – SCH 2104

First Semester Examination Paper

December 2016

This examination paper consists of 6 pages

Time Allowed: 3 hours

Total Marks: 100

Special Requirements: Graph Paper (on request)

$R = 8.314 \text{ JK}^{-1} \text{ mol}^{-1} = 0.08206 \text{ dm}^3 \text{ atm K}^{-1} \text{ mol}^{-1}$

$F = eNA = 9.6500 \times 10^4 \text{ C mol}^{-1}$

$1 \text{ atm} = 760 \text{ torr} = 760 \text{ mmHg} = 101325 \text{ Pa}$

Examiner's Name: DR B N YALALA

### INSTRUCTIONS

1. Answer all questions from Section A and any three from Section B. Section A carries 40 marks and each question in Section B carries 20 marks.

### MARK ALLOCATION

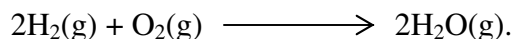
| QUESTION                    | MARKS      |
|-----------------------------|------------|
| 1.                          | 40         |
| 2.                          | 20         |
| 3.                          | 20         |
| 4.                          | 20         |
| 5.                          | 20         |
| <b>TOTAL POSSIBLE MARKS</b> | <b>100</b> |

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**SECTION A:**

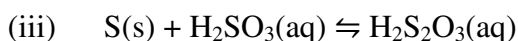
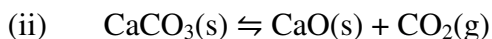
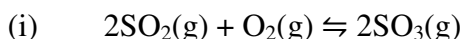
1. (a) Evaluate  $\Delta G^\circ$  for the reaction in which diatomic hydrogen and oxygen gases react to form water vapor at 298K, using values of  $\Delta H_f^\circ$  and  $S^\circ$ . Is the reaction spontaneous at 298K?



|                                | $\Delta H_f^\circ$ kJ/mol | $S^\circ$ J/mol K |
|--------------------------------|---------------------------|-------------------|
| $\text{H}_2(\text{g})$         | 0                         | 130.6             |
| $\text{O}_2(\text{g})$         | 0                         | 205               |
| $\text{H}_2\text{O}(\text{g})$ | -241.8                    | 188.7             |

(5 Marks)

- (b) Write both  $K_c$  and  $K_p$  expressions for the following reversible reactions:



(6 marks)

- (c) What is a phase diagram, and what information can be obtained from it?

(5 Marks)

- (d) The standard enthalpy of decomposition of the yellow complex  $\text{NH}_3\text{SO}_2$  into  $\text{NH}_3$  and  $\text{SO}_2$  is  $+40 \text{ kJ mol}^{-1}$ . Calculate the standard enthalpy of formation of  $\text{NH}_3\text{SO}_2$  given  $\Delta_f H^\circ(\text{NH}_3, (\text{g})) = -46.11 \text{ kJ mol}^{-1}$  and  $\Delta_f H^\circ(\text{SO}_2, (\text{g})) = -296.83 \text{ kJ mol}^{-1}$ .

(5 marks)

- (e) State Kelvin's and Clausius' statements of the Second Law of Thermodynamics.

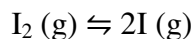
(4 Marks)

- (f) A solution containing 0.80 grams of a protein in 100 mL of a solution has an osmotic pressure of 2.06 torr at  $25.0^\circ\text{C}$ .

What is the molecular mass of the protein?

(5 Marks)

(g)  $K_c$  for the reaction



is  $5.6 \times 10^{-12}$  at 500K. A mixture has  $[\text{I}_2] = 0.0020 \text{ M}$  and  $[\text{I}] = 3.7 \times 10^{-7} \text{ M}$ . Is the reaction at equilibrium (at 500K)? If not, which way must the reaction proceed to attain equilibrium?

(4 Marks)

(h) A sample of 1.00 mol  $\text{H}_2\text{O}(\text{g})$  is condensed isothermally and reversibly to liquid water at  $100^\circ\text{C}$ . The standard enthalpy of vaporization of water at  $100^\circ\text{C}$  is  $40.656 \text{ kJ mol}^{-1}$ . Find  $w$ ,  $q$ ,  $\Delta U$ , and  $\Delta H$  for this process.

(6 Marks)

### **SECTION B:**

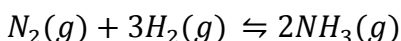
2. (a) Consider an ideal gas that occupies 2.25 L at 1.33 bar. Calculate the work required to compress the gas isothermally to a volume of 1.5 L at a constant pressure of 2.0 bar followed by another isothermal compression to 0.8 L at a constant pressure of 2.5 bar.

(6 Marks)

(b) What is the work for compressing the gas isothermally and reversibly from 2.25 L to 0.8 L?

(4 Marks)

(c) Consider the following reaction:



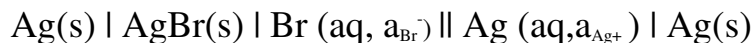
At 1000 Kelvin,  $\Delta H^\circ_{\text{rxn}} = -123.77 \text{ kJ mol}^{-1}$ . What is the enthalpy of formation for  $\text{NH}_3$  (gas) at 300 Kelvin? Consider the following molar heat capacities:  $C_{p,m} = 3.502R$ ,  $3.466R$ , and  $4.217R$  for  $\text{N}_2(\text{g})$ ,  $\text{H}_2(\text{g})$ , and  $\text{NH}_3(\text{g})$ , respectively. State any approximations you invoke.

(5 Marks)

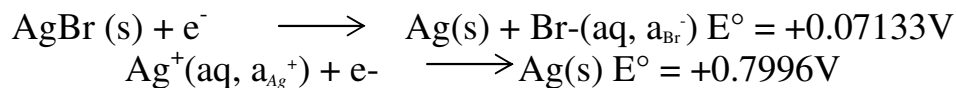
(d) Sulphur transforms from the rhombic form to the monoclinic form under a pressure of 1 bar at  $95.4^\circ\text{C}$ . Its reported enthalpy of transition is  $0.38 \text{ kJ mol}^{-1}$ . What is the entropy of transition?

(5 Marks)

3. (a) The following cell is useful for the determination of the solubility of silver bromide.



- (i) What is the overall reaction for this cell, as written, given the following electrode potential



- (ii) What is the standard voltage of this cell at 298.15 K, assuming no junction potential?  
 (iii) What is the standard Gibbs energy change for the cell reaction, as written, at 298.15 K?  
 (iv) What is  $K_{\text{sp}}$  for the AgBr at 298.15 K?

(10 Marks)

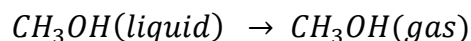
- (b) Determine the amount of heat required to raise the temperature of 1.768 moles of liquid Ni from 2000 K to 2500 K, as accurately as you can. Use the heat capacity of nickel ( $C_{pm}^\theta$ )  $38.91103 \text{ J K}^{-1} \text{ mol}^{-1}$ .  
 [Assume that the pressure remains constant at 1 bar during the process].

(5 points)

- (c) Calculate the standard molar Gibbs energy of vaporization of methanol at 298.15 K using the following values:

$$\Delta_f G_m^\theta (\text{liquid}) = -166.6 \text{ KJ}$$

$$\Delta_f G_m^\theta (\text{gas}) = -162.3 \text{ KJ}$$



(5 Marks)

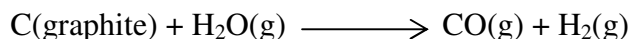
4. (a) Benzene ( $P^\bullet = 96.4 \text{ torr}$ ) and toluene ( $P^\bullet = 28.9 \text{ torr}$ ) form a nearly ideal solution over a wide range. For purposes of this question, you may assume that a solution of the two is ideal.
- What is the total vapour pressure of the above solution containing 5.00 moles of benzene and 3.25 moles of toluene?
  - What is mole fraction of benzene in the vapour of the above solution?
- (5 Marks)

- (b) The vapor pressure over ice has been measured at several different temperatures. At 220 K it is 2.732 torr and at 230 K it is 9.195 torr. Determine the enthalpy of sublimation of ice in this region of temperature. One must use the Clausius-Clapeyron equation to solve this problem. Assuming the enthalpy of sublimation is temperature independent, one has the equation:

$$\ln\left(\frac{P_2}{P_1}\right) = -\frac{\Delta_{sub}H}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

(5 Marks)

- (c) Calculate  $\Delta H$  and  $\Delta U$  at 298 K and  $\Delta H$  at 378 K for the reaction



Assume all heat capacities to be constant over the temperature range involved.

Given:  $\Delta_f H$ : C(graphite) = 0 kJ mol<sup>-1</sup>, H<sub>2</sub>O(g) = -241.82 kJ mol<sup>-1</sup>,  
CO(g) = -110.53 kJ mol<sup>-1</sup>, and H<sub>2</sub>(g) = 0 kJ mol<sup>-1</sup>.

$C_{p,m}$  : C(graphite) = 8.53 J K<sup>-1</sup> mol<sup>-1</sup>, H<sub>2</sub>O(g) = 33.58 J K<sup>-1</sup> mol<sup>-1</sup>,  
CO(g) = 29.14 J K<sup>-1</sup> mol<sup>-1</sup> and H<sub>2</sub>(g) = 28.83 J K<sup>-1</sup> mol<sup>-1</sup>.

All values are at 298 K.

(10 Marks)

5. (a) Calculate the lattice enthalpy of MgBr<sub>2</sub> from the following data:

|   | $\Delta H(\text{KJ mol}^{-1})$ |
|---|--------------------------------|
| Sublimation of Mg(s)  | +148                           |
| Ionization of Mg(g) to Mg <sup>2+</sup> (g)                           | +2187                          |
| Vaporization of Br <sub>2</sub> (l)                                   | +31                            |
| Dissociation of Br <sub>2</sub> (g)                                   | +193                           |
| Electron attachment to Br(g)  | -331                           |
| Formation of MgBr <sub>2</sub> (s) from Mg(s) and Br <sub>2</sub> (l) | -524                           |

(10 Marks)

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(b) Antimony (m.p  $630^{\circ}\text{C}$ ) and lead (m.p  $326^{\circ}\text{C}$ ) form one eutectic mixture at  $246^{\circ}\text{C}$  which is 81 mole percent lead, but do not form any solid solutions. Draw a temperature – composition diagram, assuming that the liquidus lines are linear, and label each region indicating which phases are in equilibrium under the conditions that the regions represent. For a mixture containing 50 mole percent lead determine,

(a) the temperature at which solid first crystallizes out,

(b) the nature and proportion of solid in the mixture at  $300^{\circ}\text{C}$

(10 Marks)

**END OF QUESTION PAPER**

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