

*Please mark X to indicate your tutorial section.
Failure to do so will result in a deduction of 5 marks.*

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
TERM TEST 2
15 March 2016
APS 104S
INTRODUCTION TO MATERIALS AND CHEMISTRY
Exam Type B

Examiners: G. Azimi, C. Chin, P. Yaneff, J. Nogami

TUT 01	
TUT 02	
TUT 03	
TUT 04	
TUT 05	
TUT 06	
TUT 07	
TUT 08	
TUT 09	
TUT 10	
TUT 11	
TUT 12	

NAME: _____
Last First

STUDENT NO: _____

)

Q1	/20
Q2	/20
Q3	/20
Q4	/20
Q5	/20
Total	/100

INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- Answer all 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. All answers should include the relevant units.
- 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*.
- Exam papers filled out in pencil **will not be eligible for regrading**.

Name: _____

Student No: _____

QUESTION 1: (20 pts). A (variable volume, e.g., balloon) vessel filled with 30 mol of O₂ (g) undergoes adiabatic expansion. Initially, the temperature of the vessel is 400 K.

1a (5 pts). Determine the final volume of the vessel after the expansion, at which the vessel reaches a final state at standard conditions (273 K, 1 atm).

$$\text{PV} = nRT$$

$$1\text{atm } V = 30\text{mol } 0.0803 \frac{\text{atm L}}{\text{mol K}} 273\text{K}$$

$$V = 657 \text{ L}$$

657 L

1b (5 pts). Determine the initial pressure of the vessel, given that the vessel reaches a final state at standard conditions (273 K, 1 atm) after the adiabatic expansion.

$$T_1 P_1^{\frac{1-\gamma}{\gamma}} = T_2 P_2^{\frac{1-\gamma}{\gamma}}$$

$$\text{O}_2 \text{ diatomic gas } \gamma = 1.4$$

$$T_1 = 400\text{K}$$

$$T_2 = 273\text{K}$$

$$P_2 = 1\text{atm}$$

$$400\text{K } P_1^{\frac{1-1.4}{1.4}} = 273\text{K (1atm)}^{\frac{1-1.4}{1.4}}$$

3.82 atm

Page 2 of 18

$$P_1^{-0.285} = 0.6825$$

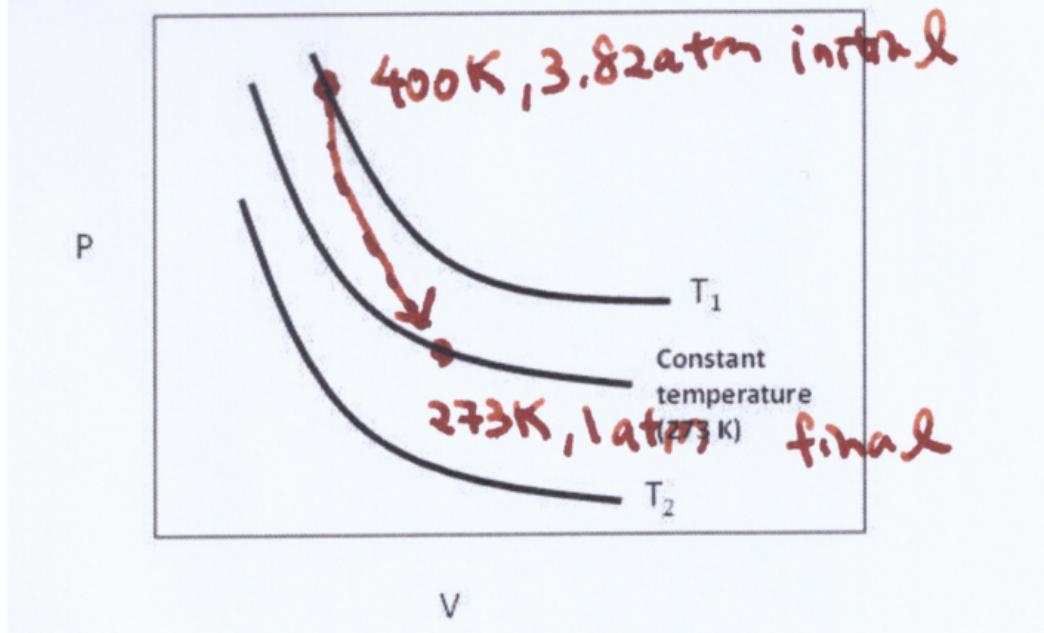
$$P_1 = 3.82 \text{ atm}$$

atm

1c (5 pts). In the PV diagram below, sketch the adiabatic expansion step, clearly indicate the initial and final state.

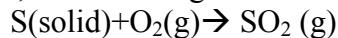
Name: _____

Student No: _____



1d (5 pts). In a separate experiment, you have decided to add 200 g of solid sulfur compound into the vessel (while it is at the standard conditions, 273 K, 1 atm) and then heat the vessel up to 800 K and with a pressure of 50 atm.

During the heating process, the following reaction occurs and the reaction goes to completion:



Determine the mole fractions of SO₂ at the end of the reaction.

$$200\text{ g S} = 200\text{ g} \frac{\text{mol}}{32\text{ g}} = 6.25\text{ mol}$$

6.25 mol S reacts with 6.25 mol O₂ form 6.25 mol SO₂

End of reaction = 23.75 mol O₂ and 6.25 mol SO₂

$$\frac{6.25\text{ mol SO}_2}{6.25\text{ mol SO}_2 + 23.75\text{ mol O}_2} =$$

0.208

Name: _____

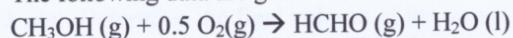
Student No: _____

Name: _____

Student No: _____

QUESTION 2: (20 pts) Thermochemistry2a. [2 pts] Write the chemical equation for the combustion of 1 mol of methanol (CH_3OH).2b. [5 pts] Determine the heat of methanol (CH_3OH) combustion at the standard state (298.15 K, 1 bar, products and reactants are both in the gas phase).

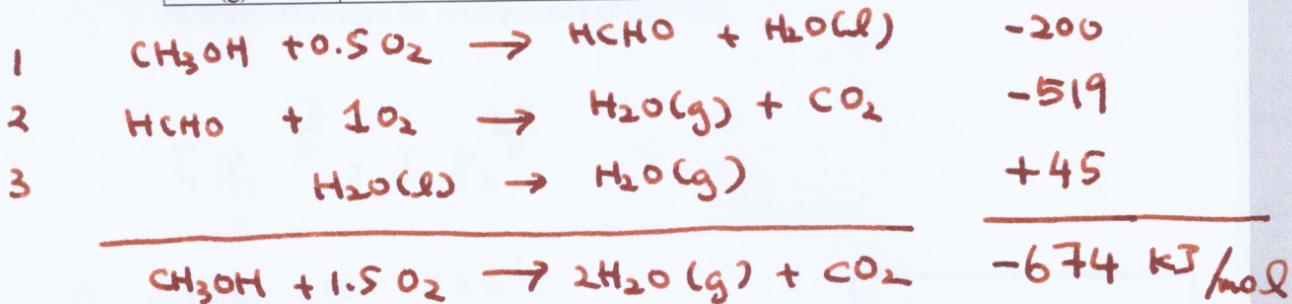
The following data are given:



$$\Delta H_{rxn}^0 = -200 \text{ kJ (mol}^{-1})$$

Thermodynamic Data

	Heat of formation at standard state, $\Delta H_f^0 (\text{kJ mol}^{-1})$ 298.15 K, 1 bar
$\text{H}_2\text{O}(\text{g})$	-241
$\text{H}_2\text{O}(\text{l})$	-286
$\text{O}_2(\text{g})$	0
$\text{CH}_2\text{O}(\text{g})$	-115
$\text{CO}(\text{g})$	-111

Reaction 2

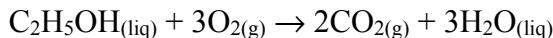
$$-241 - 393 + 115 = -519$$

kJ/mol CH_3OH

Name: _____

Student No: _____

2c. [8 pts] Using bond enthalpy values from the given below, estimate the standard molar enthalpy of combustion of ethanol at 25°C according to



At 25°C the standard enthalpies of vaporization of liquid water and of liquid ethanol are 44.01 kJ mol⁻¹ and 42.59 kJ mol⁻¹, respectively. The enthalpies of complete atomization of gaseous CO₂ and gaseous H₂O are 1609 kJ mol⁻¹ and 920 kJ mol⁻¹, respectively.

Bond Enthalpies (kJ mol⁻¹)

C-H 412, C-C 348, C-O 360, O-H 437.7, O=O 498.36



Bonds broken (reactants):

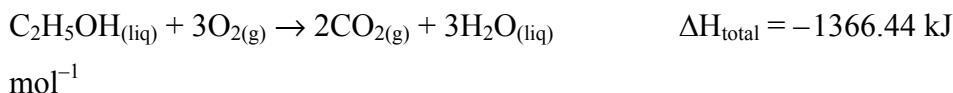
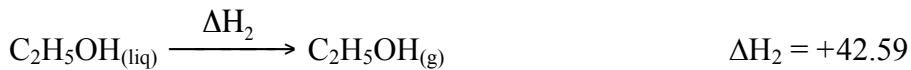
$$\begin{aligned} \text{C-H} \quad 5 \times 412 &= 2060 \quad (\text{Table 2}) \\ \text{C-C} \quad 1 \times 348 &= 348 \quad (\text{Table 2}) \\ \text{C-O} \quad 1 \times 360 &= 360 \quad (\text{Table 2}) \\ \text{O-H} \quad 1 \times 437.7 &= 438 \quad (\text{Table 1}) \\ \text{O=O} \quad 3 \times 498.36 &= 1495 \quad (\text{Table 1}) \\ &\quad 4701 \end{aligned}$$

Bonds made (products):

$$\begin{aligned} \text{C=O=O} \quad 2 \times (-1609) &= -3218 \quad (\text{given as data}) \\ \text{H-O-H} \quad 3 \times (-920) &= -2760 \quad (\text{given as data}) \\ &\quad -5978 \end{aligned}$$

Therefore, $\Delta H_1 = 4701 - 5978 = -1277 \text{ kJ mol}^{-1}$

Adding reactions:



Ans: -1.366 MJ mol⁻¹

FYI: From standard enthalpies of formation at 25°C the actual value is

$$2(-393.509) + 3(-285.830) - (-277.69) - 3(0) = -1366.82 \text{ kJ mol}^{-1} = -1.367 \text{ MJ mol}^{-1}$$

Name: _____ Student No: _____

QUESTION 3 (20 pts): First law of thermodynamics

10 moles of neon gas (ideal gas) is taken from 1.0 bar pressure and 350 K to 1.143 bar pressure and 400 K. The volume is held constant and the gas is heated directly to 400 K.

3a. [6 pts] Calculate q , w , and ΔU

$$3a) \quad \begin{array}{ccc} 350 \text{ K} & \xrightarrow{\text{Const. V}} & 400 \text{ K} \\ 1 \text{ bar} & & 1.143 \text{ bar} \end{array}$$

$$V = \text{constant} \rightarrow w = -P_{\text{ext}} \Delta V = 0 \quad 1 \text{ pts}$$

$$\Delta U = n \bar{C}_V \Delta T = 10 \times \frac{3}{2} (8.314) (50) = 6235.5 \text{ J} \quad 1 \text{ pts}$$

$$q = \Delta U = 6235.5 \text{ J} \quad 1 \text{ pts}$$

3b. [15 pts] A piston/cylinder contains one mole of a monoatomic ideal gas that is initially at 300 K. It is subjected to the following processes. Calculate the final temperature (in K) for each process.

Process 1 :

$$\begin{array}{l} q = -425 \text{ J} \\ w = 185 \text{ J} \end{array}$$

$$\rightarrow \Delta U = -240$$

$$n \bar{C}_V \Delta T = \Delta U$$

$$1 \times \frac{3}{2} R (T_2 - 300) = -240 \rightarrow T_2 = \underbrace{280.3}_{\text{K}}$$

Process 2 :

$$\begin{array}{l} q = 315 \text{ J} \\ w = -315 \text{ J} \end{array}$$

$$\rightarrow \Delta U = 0 \rightarrow \Delta T = 0 \rightarrow T_2 = \underbrace{300 \text{ K}}_{\text{K}}$$

Process 3 :

$$\begin{array}{l} q = 0 \\ w = 225 \text{ J} \end{array}$$

$$\rightarrow \Delta U = n \bar{C}_V \Delta T = 225$$

$$1 \times \frac{3}{2} \times 8.314 (T_2 - 300) = 225$$

$$T_2 = \underbrace{318.0}_{\text{K}}$$

Name: _____

Student No: _____

3c. [8 pts] Two moles of O₂ gas (ideal gas) is initially at 27 °C and 1.5 bar. It is heated up to 150°C at a constant pressure process. Calculate ΔH, ΔU, q, and w for this process.

$$T_1 = 300.15 \text{ K}$$

$$T_2 = 423.15$$

$$P_1 = 1.5 \text{ bar}$$

P = Constant

$$\underline{\underline{q_p}} = \underline{\underline{\Delta H}} = n \bar{C}_p \Delta T = 2 \times \frac{7}{2} \times 8.314 \times 123 = 7158.35 \text{ J}$$

$$\underline{\underline{\Delta U}} = n \bar{C}_V \Delta T = 2 \times \frac{5}{2} \times 8.314 \times 123 = 5113.11 \text{ J}$$

$$\underline{\underline{\Delta U}} = \underline{\underline{q}} + \underline{\underline{w}} \rightarrow \underline{\underline{w}} = 5113.11 - 7158.4 = -2045.24 \text{ J}$$

3e. [1 pts] Circle the correct answer:

- a) 1 mole of an ideal gas expands from an initial condition to a final condition once in a reversible isothermal process and once in a reversible adiabatic process. The work done in the second process (adiabatic) is more than that of isothermal.
- b) If a process is adiabatic and expansion against or into a vacuum, the process is isothermal.
- c) Both w+q and U+q are path dependent functions.

QUESTION 4 (30 pts): Second and Third law of thermodynamics

4a. [14 pts] 1.5 moles of a monoatomic ideal gas is expanded from 50°C and 5 bar to 3 bar in the following two processes. Surroundings is at 25°C.

Calculate ΔS_{system}, ΔS_{surroundings}, and ΔS_{universe} for each process. Is the process spontaneous or non-spontaneous?

2 pts for each ΔS and one point for spontaneous or non-spontaneous

Name: _____

Student No: _____

$$(4a) \quad \begin{array}{ccc} T_1 = 323.15 & \longrightarrow & T_2 \\ P_1 = 5 \text{ bar} & & P_2 = 3 \text{ bar} \end{array}$$

Process 1: Reversible isothermal $T_2 = T_1$

$$\Delta U = 0 \rightarrow q = -W = -(-nR\bar{T} \ln \frac{P_1}{P_2}) = 1.5 \times 8.314 \times 323.15 \ln \frac{5}{3} = 2058.6 \text{ J}$$

$$\Delta S_{sys} = n\bar{C}_p \ln \frac{T_2}{T_1} - nR \ln \frac{P_2}{P_1} = 1.5 \times 8.314 \times \ln \frac{3}{5} = 6.37 \text{ J/K}$$

$$\Delta S_{sur} = -\frac{q_{rev,sys}}{T_{sur}} = \frac{-2058.6}{298.15} = -6.90 \text{ J/K}$$

$$\Delta S_{univ} = \Delta S_{sys} + \Delta S_{sur} = -0.53 \rightarrow \text{non-spontaneous}$$

Process 2: adiabatic $\rightarrow q = 0$

$$\Delta U = W \rightarrow n\bar{C}_V \Delta T = -2000 \rightarrow \Delta T = -6.67 \rightarrow T_2 = 216.2 \text{ K}$$

$$\Delta S_{sys} = n\bar{C}_p \ln \frac{T_2}{T_1} - nR \ln \frac{P_2}{P_1} = 1.5 \times \frac{5}{2} \times 8.314 \times \ln \frac{216.2}{323.15} = 1.5 \times 8.314 \ln \frac{3}{5} = -6.2 \text{ J/K}$$

$$\Delta S_{sur} = -\frac{q_{rev,sys}}{T_{sur}} = 0$$

$$\Delta S_{univ} = \Delta S_{sys} + \Delta S_{sur} = -6.2 \text{ J/K} \rightarrow \text{non-spontaneous}$$

$$\text{Process 3: Const. } V \rightarrow \frac{T_1}{P_1} = \frac{T_2}{P_2} \rightarrow T_2 = \frac{323.5 \times 3}{5} = 193.9 \text{ K}$$

$$\Delta S_{sys} = n\bar{C}_V \ln \frac{T_2}{T_1} = 1.5 \times \frac{3}{2} \times 8.314 \times \ln \frac{193.9}{323.15} = -9.6 \text{ J/K}$$

$$W = 0 \rightarrow q = \Delta U = n\bar{C}_V \Delta T = 1.5 \times \frac{3}{2} R \times (193.9 - 323.15) = -2417.8 \text{ J}$$

$$\Delta S_{sur} = -\frac{q_{sys}}{T_{sur}} = \frac{2417.8}{298.15} = 8.1 \text{ J/K}$$

$$\Delta S_{univ} = \Delta S_{sys} + \Delta S_{sur} = -1.5 \rightarrow \text{non-spontaneous}$$

Name: _____ Student No: _____

4b. [16 pts] The following reaction involves decomposition of $\text{CaCO}_{3(\text{s})}$. The thermodynamic data required to solve this problem are provided in the following Table.



Compound	ΔH_f° (kJ/mol)	S° (J/mol.K)	ΔG_f° (kJ/mol)
$\text{CaCO}_{3(\text{s})}$	-1206.92	?	-1128.79
$\text{CaO}_{(\text{s})}$	-635.09	39.75	-604.03
$\text{CO}_{2(\text{g})}$	-393.509	213.74	-394.359

4C)

$$A) \Delta H^\circ = \Delta H_{f,\text{CO}_2}^\circ + \Delta H_{f,\text{CaO}}^\circ - \Delta H_{f,\text{CaCO}_3}^\circ = 178.321 \text{ kJ/mol}$$

$$B) \Delta S^\circ = S_{\text{CaO}}^\circ + S_{\text{CO}_2}^\circ - S_{\text{CaCO}_3}^\circ$$

$$160.59 = 213.74 + 39.75 - S_{\text{CaCO}_3}^\circ$$

$$S_{\text{CaCO}_3}^\circ = 92.9 \text{ J/mol}\cdot\text{K}$$

$$C) \Delta G^\circ = \Delta H^\circ - T \Delta S^\circ = 178.321 - 298.15 \left(\frac{160.59}{1000} \right) = 130.44 \text{ kJ/mol}$$

or

$$\Delta G^\circ = \Delta G_{f,\text{CO}_2}^\circ + \Delta G_{f,\text{CaO}}^\circ - \Delta G_{f,\text{CaCO}_3}^\circ = 130.4 \text{ kJ/mol}$$

$$D) \Delta G^\circ < 0 \rightarrow \Delta H^\circ - T \Delta S^\circ < 0 \rightarrow T \Delta S^\circ > \Delta H^\circ$$

$$T \left(\frac{160.59}{1000} \right) > 178.321 \rightarrow T > 1110.4 \text{ K} \text{ or } 837.3^\circ\text{C}$$