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FIRST NAME ________________ LAST NAME ______________________________

STUDENT NUMBER____________________________

UNIVERSITY OF TORONTO

FINAL EXAM, APRIL 24, 2001

CHE 150F - CHEMISTRY

EXAMINERS - M.T. Kortschot, R.R. Farnood, W.H. Burgess

1. Do all six questions. The marking scheme for each question is indicated in the margin. The marks add up to 100.

2. Calculator Type 2 - Non-programmable calculators are allowed. No programmable calculators are allowed. No other aids are allowed.

3. **ALL WORK IS TO BE DONE ON THESE SHEETS!** Use the back of the page if you need more space. Be sure to indicate clearly if your work continues elsewhere. **DO NOT SEPARATE THE SHEETS EXCEPT FOR PAGE 8 WHICH IS BLANK AND MAY BE SEPARATED AND USED AS SCRAP. PAGE 8 WILL NOT BE MARKED. ALWAYS PUT YOUR FINAL ANSWERS IN THE BOXES PROVIDED.**

$dU = TdS - PdV$

$H = U + PV$

$G = H + TS$

$A = U - TS$

$\Delta G = \Delta G^\circ + RT\ln Q$

$\Delta G^\circ = -RT\ln K$

$\eta = 1 - \frac{T_c}{T_h}$

$\ln\left(\frac{P_{vap2}}{P_{vap1}}\right) = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$

$\ln\left(\frac{K_{p2}}{K_{p1}}\right) = \frac{\Delta H^\circ_{rxn}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$

$R = 8.314 J/(mol K)$

$1 atm = 101.3 kPa = 760 mmHg$

$273.15 K = 0°C \quad 1 m^3 = 1000 L$

Molar Masses (g/mol)
H = 1.0, C = 12.0, O = 16.0, N = 14.0

Marks

1	
2	
3	
4	
5	
6	
TOTAL	

Problem 1 [20 marks total]

A camp stove burns gaseous propane (C_3H_8) with a 40% excess of air to CO_2 (g) and H_2O (g) (air has a composition of 79 mol% N_2 and 21 mol% O_2). The stove is used to heat up 900 g of liquid water (mm = 18.0 g/mol) in a 270 g aluminum pot (mm= 27.0 g/mol). The temperature of the propane and air feed is 25°C. The temperature of the water and pot is initially 25°C, and the water and pot heat up together. Assume that products of combustion (including N_2 and excess O_2) leave the stove at 250°C, and the remaining heat of combustion is transferred to the pot/water combination. Calculate:

a) The heat transferred to the pot/water combination per mole of propane burned.
b) The number of moles of propane needed to heat the water to 100°C,
c) The enthalpy of vapourization of water at 100°C, and
d) The number of moles of propane needed to boil the pot dry.

Data: mm Al = 27.0 g/mol, mm H_2O = 18.0 g/mol

	ΔH_f° (kJ/mol)	C_p° (J/mol K)
C_3H_8(g)	-103.9	73.5
O_2 (g)	0	29.4
N_2 (g)	0	29.1
CO_2 (g)	-393.5	37.1
Al (s)	0	24.2
H_2O (l)	-285.8	75.3
H_2O (g)	-241.8	33.6

ANSWERS:	a) q =	kJ	b) n =	mol
	c) ΔH_{vap}° =	kJ/mol	d) n =	mol

Problem 2 [14 marks total]

a) An ore contains $BaCO_3$ together with other non-barium compounds. A sample of this ore weighing 1.624 g was treated with HCl to dissolve the $BaCO_3$. The resulting solution was filtered to remove insoluble material and then treated with H_2SO_4 to precipitate pure $BaSO_4$ (mm = 233.4 g/mol). The precipitate was filtered and dried, and was found to weigh 1.60 g. What was the percentage by mass of barium (mm = 137.3 g/mol) in the ore?

b) A mixture of SO_2 (mm = 64.0 g/mol) and air contains 40.0 mol% SO_2 (air has a composition of 79 mol% N_2 and 21 mol% O_2). The gas is passed through an absorption tower and some of the SO_2 is absorbed. The exit gas leaves the tower at 98.5 kPa and 35°C and at a density of 1.245 kg/m^3. Calculate the number of moles of SO_2 absorbed in the tower per 100 moles of feed gas.

ANSWERS: a) percentage =	%	b) n_{SO_2} =	mol

Problem 3 [16 marks total]

Professors M.T. Schortkut, W.H.Bogus, and R.R.Farout claim that they have developed a powerful new catalyst that makes it possible to synthesize NH_3 with a 50.0% yield in a reactor operating at 600K and 5.0 atm and having a feed consisting of N_2 and H_2 in stoichiometric ratio. For $NH_3(g)$ at 600K: $\Delta G^\circ_f = 16.070$ kJ/mol and $\Delta H^\circ_f = -51.170$ kJ/mol.

a) Calculate K_p for the reaction $\frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \Leftrightarrow NH_3(g)$ at 600K.
b) Show that their claim is thermodynamically impossible.

A 50% yield can be achieved by either <u>increasing</u> the pressure or <u>reducing</u> the temperature.

c) Determine the minimum increase in pressure required for a 50.0% yield. Assume the composition of the feed and the temperature remain unchanged.
d) Determine the minimum reduction in temperature required for a 50% yield. Assume the composition of the feed and the pressure remain the same.

ANSWER:	(a)	(b)
	(c)	(d)

Problem 4 [16 marks total]

a) A railroad tank car contains propane in equilibrium with its vapour at 20°C. Calculate the pressure in the tank car. ΔH°_{vap} of propane at its normal boiling point (-42.1°C) is 18.77 kJ/mol.

b) A solution of NaOH (mm= 40.01 g) in water is 36.0% by mass NaOH and has a molarity of 12.51 M at 20°C. Calculate: i) its molality, and ii) its density at 20°C.

c) A Carnot engine delivers 150 kJ of work to the surroundings per cycle. If its heat sink is at 10°C and the heat engine has an efficiency of 35%, calculate the temperature of the heat source and the amount of heat supplied by the heat source.

ANSWERS:	a) P =	atm.				
	b) i) molality =		molal	ii) density =		kg/m^3
	c) T_h =	K	q_h =	kJ		

Problem 5 [16 marks total]

a) Plot a schematic P-X diagram showing the total vapour pressure for an ideal solution of A and B (i.e. Raoult's law) and the partial pressures of each component (i.e. P_A and P_B) as the composition of the liquid phase (X_A) changes from 0 to 1. Assume that vapour pressure of pure A and B are P^*_A and P^*_B, respectively.

b) One mole of an equimolar gaseous mixture of A and B is initially at 100 kPa and 100 °C. This mixture is then cooled at constant pressure to 25 °C, and is partly condensed. The vapour pressures of pure A and pure B at 25 °C are 50 and 200 kPa, respectively. Using Raoult's law, determine the amoun of condensate (in moles)

c) If the cooling process is carried out reversibly, calculate the volume of the system before and after cooling and estimate the amount of work done on the system during cooling for part (b). Assume ideal gas and neglect the volume of liquid.

ANSWER: b) n =	mol	c) w =		J

Problem 6 [18 marks total]

a) Starting with dU = T dS – P dV and the definition of Helmholtz free energy (A) and by writing the expression for the total differential (dA), show that:

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

b) Show that:

$$\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_v - P$$

c) Based on part (b), calculate ΔU for the isothermal compression of one mole of an ideal gas.

d) Based on part (b), calculate ΔU for the isothermal compression of one mole of a van der Waals gas. The van der Waals equation for one mole of gas is:

$$P = \frac{RT}{V-b} - \frac{a}{V^2}$$

ANSWERs: c) ΔU =	d) ΔU =

ROUGH WORK (THIS PAGE WILL NOT BE MARKED)