

LAST NAME: _____

FIRST NAME: _____

Student Number: _____

CHM 1311 B

Midterm #2

Fall 2014

Please keep your work covered at all times and keep your eyes on your own paper! Cheating or any appearance of cheating will result in an F in the course and possible expulsion from the university.

There are 8 pages in this test. The last page includes equations covered in the course, and data that may be useful for some questions. You may rip this page off of the midterm and use it to cover your work during the test.

You must show all work to receive partial credit.

Marks may be deducted if an unreasonable number of sig figs are shown in your final answer.

You have 75 minutes to complete this test.

Question	Points Possible	Points Earned
1	13	
2	11	
3	13	
4	8	
TOTAL	45	

Question #1. Short Answer Questions

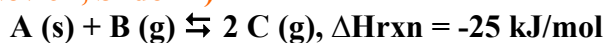
- a) Under constant pressure conditions, 0.200 m^3 of an ideal gas decreases in volume to a final volume of 0.100 m^3 . If $q_{\text{surr}} = 365 \text{ kJ}$, and $p = 1.0 \text{ atm}$, what is ΔU of the gas for this process? (4 marks) (Oct 20th, slide 4)

$$\begin{aligned}\Delta U &= q + w \\ q_{\text{sys}} &= -q_{\text{surr}} = -365 \text{ kJ} \\ w &= -p\Delta V = -(1 \text{ atm})(101325 \text{ Pa atm}^{-1})(0.100 \text{ m}^3 - 0.200 \text{ m}^3)(10^{-3} \text{ J kJ}^{-1}) = 10.1 \text{ kJ} \\ \Delta U &= q + w = -365 \text{ kJ} + 10.1 \text{ kJ} \\ &= -355 \text{ kJ} \\ \Delta U &= \underline{\hspace{2cm} -355 \text{ kJ} \hspace{2cm}}\end{aligned}$$

- b) What would be the value of K at 25°C for the reaction $2 \text{ A} \rightleftharpoons 2 \text{ B} + 3 \text{ C}$, given that $K = 25$ for the reaction $6 \text{ C} + 4 \text{ B} \rightleftharpoons 4 \text{ A}$ (2 marks) (Nov 3rd, Slide 9)

$$\begin{aligned}K' &= \frac{1}{K^{\frac{1}{2}}} = \frac{1}{\sqrt{25}} = 0.2 \\ K &= \underline{\hspace{2cm} 0.2 \hspace{2cm}}\end{aligned}$$

- c) Would you increase or decrease the temperature and reaction volume to increase the yield for the reaction: (2 marks) (Nov 6th, Slide 12)



Temperature: Decrease Volume: Increase

- d) Calculate K for the reaction $3 \text{ O}_2(\text{g}) \rightleftharpoons 2 \text{ O}_3(\text{g})$, given that $K_c = 3.65 \times 10^{-12}$ at 310 K . (2 marks) (Assignment 7 question)

$$\begin{aligned}\Delta n_{\text{gas}} &= 2 - 3 = -1 \\ K &= K_c (RT)^{\Delta n(\text{gas})} = \frac{(3.65 \times 10^{-12})}{(0.08314 \text{ L bar K}^{-1} \text{ mol}^{-1})(310 \text{ K})} = 1.42 \times 10^{-13} \\ K &= \underline{\hspace{2cm} 1.42 \times 10^{-13} \hspace{2cm}}\end{aligned}$$

- e) Label the acid, base, conjugate acid and conjugate base for the reaction: (2 marks) (Problem 16.25)



Base acid conjugate acid conjugate base

- f) Circle the part of the Arrhenius equation that can be used to calculate the fraction of reactants having a collision energy that is larger than the activation energy. (1 mark) (Oct 30, slide 1)

$$k = A e^{-\frac{E_a}{RT}}$$

Question #2. For the reaction $A(g) + 2B(g) \rightarrow 2C(g)$, the following data were obtained at a constant temperature:

Experiment	Initial rate (mol/L/min)	Initial [A] (mol/L)	Initial [B] (mol/L)
1	5.00	0.100	0.100
2	11.3	0.100	0.150
3	22.5	0.200	0.150
4	10.0	0.200	0.100

(Based on problem 14.34)

a) What is the order with respect to each reactant? (3 marks)

$$\frac{\text{Rate 3}}{\text{Rate 2}} = \left(\frac{[A]_3}{[A]_2} \right)^m$$

$$\frac{22.5}{11.3} = \left(\frac{0.200}{0.100} \right)^m$$

$$2 = (2)^m$$

$$m = 1$$

$$\frac{\text{Rate 2}}{\text{Rate 1}} = \left(\frac{[B]_2}{[B]_1} \right)^n$$

$$\frac{11.3}{5.00} = \left(\frac{0.150}{0.100} \right)^n$$

$$2.26 = (1.5)^n$$

$$\log 2.26 = n \log 1.5$$

$$n = 2$$

The reaction is first order in A, and second order in B.

b) Write the rate law for this reaction. (1 mark)

$$\text{Rate} = k[A][B]^2$$

c) Calculate k for this reaction. (2 marks)

Using data from experiment 1 (this will work for data from any experiment):

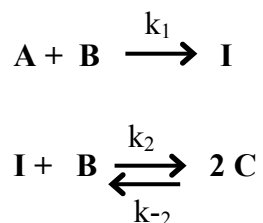
$$k = \frac{\text{Rate}}{[A][B]^2} = \frac{5.00 \text{ mol/L/min}}{(0.100 \text{ mol/L})(0.100 \text{ mol/L})^2} = 5000 \text{ L}^2/\text{mol}^2/\text{min}$$

d) Does a plot of $\ln[A]$ versus time give rise to a straight line? Why or why not? (2 marks)
(Oct 27, Slide 7)

This reaction is first order for A. The integrated rate law for a first order reaction is $\ln \left(\frac{[A]_t}{[A]_o} \right) = kt$,

which could be written as $\ln[A]_t = kt + \ln[A]_o$. This has the form of an equation of a straight line with $y = \ln[A]$ and $x = t$, with a slope of k . Therefore, a plot of $\ln[A]$ versus time will be a straight line.

- e) Is the following mechanism consistent with your answer in a) if $k_1 \ll k_2 < k_{-2}$? Provide a brief explanation for your answer. (3 marks)



(Based on Oct 30th, slide 14)

Since k_1 is the smallest rate constant, therefore the first step is the slowest, and rate limiting step. This means that the overall reaction rate will be determined by the rate of the first step, which can be written as:

$$\text{Rate} = k_1 [\text{A}][\text{B}]$$

However, the reaction in a) is second order in B, which does not match this rate equation. Therefore this mechanism is not consistent with the answer in a).

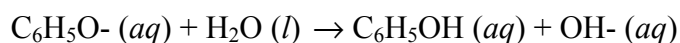
Question #3. Answer the following questions for a 0.350 mol/L solution of sodium phenolate ($\text{C}_6\text{H}_5\text{ONa}$), given that the pK_a of phenol ($\text{C}_6\text{H}_5\text{OH}$) at 25°C is 10.0. (Based on question from Assignment 8.)

- a) What is the K_b of phenolate? (2 marks)

$$K_b = \frac{K_w}{K_a} = \frac{K_w}{10^{-\text{pK}_a}} = \frac{10^{-14}}{10^{-10}} = 10^{-4}$$

- b) Write the net ionic chemical equation for the reaction of sodium phenolate with water. (2 marks)

Sodium phenolate dissociates into Na^+ and $\text{C}_6\text{H}_5\text{O}^-$ when dissolved in water. Since sodium does not participate in the base ionization reaction, it is not included in the net ionic chemical equation:



c) What is the pH of this solution? Be sure to show that any assumptions you make in the calculation are valid. (6 marks)

	$C_6H_5O^-$	C_6H_5OH	OH^-
Initial	0.350	0	~ 0
Change	-x	+x	+x
Equil.	$0.350 - x$	x	x

Can we assume that $[C_6H_5O^-] = [C_6H_5O^-]_0$?

$$\frac{[A]_0}{K_b} = 3500 \gg 400$$

Therefore this assumption is valid.

$$K_b = \frac{[C_6H_5OH][OH^-]}{[C_6H_5O^-]} = \frac{x^2}{0.350}$$

$$x = \sqrt{K_b(0.350)} = 0.00592 \text{ M} = [OH^-]$$

$$pOH = -\log[OH^-] = -\log(0.0187) = 2.23$$

$$pH = pK_w - pOH = 14.00 - 2.23 = 11.8$$

d) What is the K_b of phenolate at 60.0°C , given that the enthalpy for the base ionization reaction is $\Delta H_{rxn} = 56 \text{ kJ/mol}$? (3 marks) (Based on assignment 7 question.)

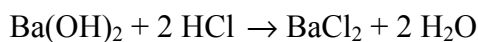
K_b at 25°C (298 K) is 10^{-4} , need to find K_b at 60°C (333 K):

$$\begin{aligned} \ln\left(\frac{K_2}{K_1}\right) &= -\frac{\Delta H_{rxn}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \\ \ln K_2 &= -\frac{\Delta H_{rxn}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) + \ln K_1 \\ &= -\frac{56000 \text{ J}}{8.314 \text{ J K}^{-1} \text{ mol}^{-1}}\left(\frac{1}{333 \text{ K}} - \frac{1}{298 \text{ K}}\right) + \ln 10^{-4} \\ &= -6.835 \\ K_2 &= e^{-9.137} = 1.1 \times 10^{-3} \end{aligned}$$

Therefore the new K_b is 1.1×10^{-3} .

Question #4. When 50.0 mL of 0.150 mol/L Ba(OH)₂ is mixed with 25.0 mL of 0.250 mol/L HCl in a coffee-cup calorimeter, you find that the temperature of the solution increases by 1.1°C. What is the ΔH of the reaction in kJ/mol of H₂O formed? (8 marks)

(Oct 20th, slide 14)



$$\begin{aligned} n_{\text{Ba(OH)}_2} &= cV & n_{\text{HCl}} &= cV \\ &= (0.150 \text{ mol/L})(0.050 \text{ L}) & &= (0.250 \text{ mol/L})(0.025 \text{ L}) \\ &= 0.0075 \text{ mol} & &= 0.00625 \text{ mol} \\ n_{\text{H}_2\text{O}} &= n_{\text{Ba(OH)}_2} \times \frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol Ba(OH)}_2} & n_{\text{H}_2\text{O}} &= n_{\text{HCl}} \times \frac{2 \text{ mol H}_2\text{O}}{2 \text{ mol HCl}} \\ &= 0.015 \text{ mol} & &= 0.00625 \text{ mol} \end{aligned}$$

Since HCl makes less product, it is the limiting reagent.

$$\begin{aligned} q_{\text{rxn}} &= -q_{\text{solution}} \\ &= -mc\Delta T \\ &= -(50 \text{ mL} + 25 \text{ mL})(1.00 \text{ g/mL})(4.184 \text{ J g}^{-1} \text{ K}^{-1})(1.1 \text{ K}) \\ &= -345 \text{ J} \end{aligned}$$

According to the calculations above, 0.00625 mol of water will be produced in this reaction:

$$\frac{q_{\text{rxn}}}{n_{\text{H}_2\text{O}}} = \frac{-345 \text{ J}}{0.00625 \text{ mol}} = -55200 \text{ J mol}^{-1} = -55 \text{ kJ mol}^{-1}$$

Constants and Conversion Factors

1 mmHg = 1 torr	760 mmHg = 1 atm	1 atm = 101.325 kPa	1 atm = 1.013125 bar
1 cm ³ = 1 mL	1 dm ³ = 1000 mL = 1 L		1 m ³ = 1000 L
1 cal = 4.184 J			
Avogadro's Number	<i>N</i>	6.022x10 ²³ mol ⁻¹	
Atomic mass unit	<i>u</i>	1.66054x10 ⁻²⁷ kg	
Gas constant	<i>R</i>	8.31451 J·K ⁻¹ ·mol ⁻¹	
	<i>R</i>	0.08206 atm·L·K ⁻¹ ·mol ⁻¹	
	<i>R</i>	8.31451 m ³ Pa·K ⁻¹ ·mol ⁻¹	
	<i>R</i>	0.0831451 bar L·K ⁻¹ ·mol ⁻¹	

Data For Water

Density = 1.00 g/mL (at 25°C) *c* = 4.184 J g⁻¹ K⁻¹ (liquid)

Equations Covered Since Midterm 1

$$w = -p\Delta V \qquad \Delta U = U_{final} - U_{initial} = q + w \qquad \Delta H = \Delta U + p\Delta V$$

$$\Delta_r H^\circ = \sum m\Delta_f H^\circ(\text{products}) - \sum n\Delta_f H^\circ(\text{reactants}) \qquad \Delta_r H^\circ = \sum mBE(\text{reactants}) - \sum nBE(\text{products})$$

$$q = c \times m \times \Delta T \qquad \text{Rate} = \frac{1}{\nu_X} \frac{\Delta[X]}{\Delta t} \qquad \text{Rate} = k[A]^m[B]^n \dots \qquad k = Ae^{-\frac{E_a}{RT}}$$

$$[A]_t - [A]_o = -kt \qquad \ln \frac{[A]_o}{[A]_t} = kt \qquad \frac{1}{[A]_t} - \frac{1}{[A]_o} = kt \qquad \ln \left(\frac{k_2}{k_1} \right) = -\frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

$$K = K_c (RT)^{\Delta n(\text{gas})} \qquad \ln \left(\frac{K_2}{K_1} \right) = -\frac{\Delta_r H^\circ}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \qquad ax^2 + bx + c = 0 \qquad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\text{pH} = -\log[H_3O^+] \qquad \text{pOH} = -\log[OH^-] \qquad \text{pH} + \text{pOH} = 14 \qquad K_a \times K_b = K_w$$

$$pK_a = -\log K_a \qquad pK_b = -\log K_b$$

Midterm 1 Equations

$$T(\text{in K}) = T(\text{in } ^\circ\text{C}) + 273.15 \text{ K} \qquad n = \frac{m}{M} \qquad \% \text{ Yield} = \frac{\text{actual yield}}{\text{theoretical yield}}$$

$$c(\text{mol/L}) = \frac{n}{V} \qquad m(\text{mol/kg}) = \frac{n_{solute}}{m_{solvent}} \qquad c_1V_1 = c_2V_2 \qquad pV = nRT$$

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} \qquad p_T = p_1 + p_2 + p_3 + \dots \qquad p_A = X_A \times p_T \qquad d = \frac{m}{V} = \frac{p \cdot MM}{RT}$$

$$E_K = \frac{1}{2}mv^2 \qquad u_{rms} = \sqrt{\frac{3RT}{M}} \qquad \frac{\text{Rate A}}{\text{Rate B}} = \sqrt{\frac{M_B}{M_A}} \qquad \left(p + \frac{n^2a}{V^2} \right) (V - nb) = nRT$$