

LAST NAME: _____

FIRST NAME: _____

Student Number: _____

CHM 1311 D
Prof. Goto
Midterm #2
Fall 2019

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 7 pages in this test, for a total of 39 marks. An equation sheet is provided at the end that may be removed from the exam and used to cover your work during the test. Any scratch work should be done on the back of the equation sheet.

Please show all work to receive partial credit.

Make sure that units are included in your final answer.

Take care to use appropriate sig figs.

You have 90 minutes to complete the test.

Warning:

Cellular phones, unauthorized electronic devices or course notes are not allowed during this exam. Phones and devices must be turned off and stored in your bag. Do not keep them in your possession, such as in your pockets. If caught with such a device or document, academic fraud allegations will be filed which may result in your obtaining a 0 (zero) for the midterm.

Question 1. Short answer questions (8 marks)

- a) What is the
- K_b
- of
- F^-
- , given that the
- pK_a
- of HF is 3.20?

$$pK_b = 14 - pK_a = 14 - 3.20 = 10.8$$

$$K_b = 10^{-10.8} = 1.58 \times 10^{-11}$$

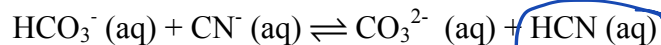
- b) Fill in the blanks in the sentence below using:
- increases
- ,
- decreases
- or
- does not change
- .

(Each option can be used more than once or not at all.)

Compared to the uncatalyzed reaction, the activation energy of the catalyzed reaction

DECREASES, and the energy of the products STAYS THE SAME.

- c) Equimolar amounts of sodium bicarbonate and sodium cyanate were added to a solution and allowed to come to the equilibrium below, with
- $K > 1$
- . What is the conjugate acid that will be present in larger concentration at equilibrium?



- d) If a graph of
- $[A]^{-1}$
- versus time gives rise to a straight line, then the reaction order is
- 2
- .

- e) What is the rate constant for the radioactive decay of
- ^{131}I
- , that has a half-life of 8.02 days?

$$t_{1/2} = \frac{\ln 2}{k} \quad k = \frac{\ln 2}{t_{1/2}} = 8.64 \times 10^{-2} \text{ day}^{-1}$$

- f) Suppose a reaction vessel containing the equilibrium reaction:
- $A_2(g) + B_2(s) \rightleftharpoons 2 AB(g)$
- is
- expanded**
- . Is
- Q
- greater than
- K
- or less than
- K
- before the system returns to equilibrium?
- V↑ ∴ PRODUCTS FAVORED**

$Q < K$ (MORE REACTANTS THAN AT EQUILIBRIUM ∴ IT SHIFTS TOWARDS PRODUCTS)

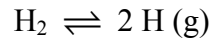
- g) What is the order of a gas phase reaction that has a rate constant with units of
- $\text{atm}^{-2} \text{ hour}^{-1}$
- ?

$$\text{RATE} = k [A]^y \quad \text{UNITS } [A]^y = \frac{\text{atm hour}^{-1}}{\text{atm}^{-2} \text{ hour}^{-1}} = \text{atm}^3$$

$$[A]^y = \frac{\text{RATE}}{k} \quad \therefore 3^{\text{rd}} \text{ ORDER}$$

- h) Number these salts according to the pH of the solution they would make, from lowest pH (1) to highest pH (3):

2 LiBr1 NH_4ClO_4 3 NaCN

Question 2. Short questions (2 marks each)a) What is the equilibrium pressure of H_2 (g) produced by the reaction:starting with 6.5×10^{-5} bar of $H(g)$, under conditions where $K_p = 7 \times 10^{-21}$?

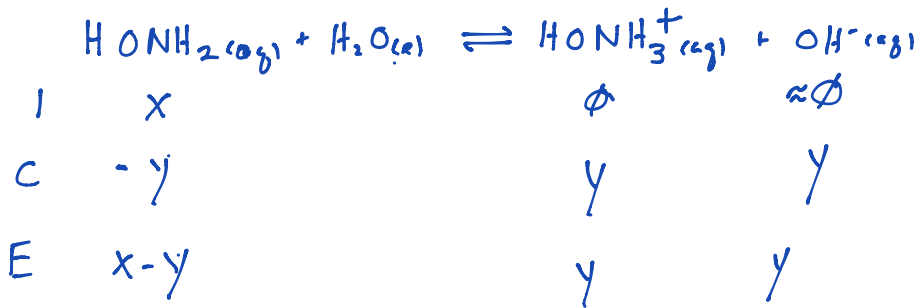
✓ RXN WILL GO ALMOST TO COMPLETION ON REACTANT SIDE

$$\therefore P_{H_2, eq} = \frac{1}{2} P_{H, INITIAL} = \frac{1}{2} (6.5 \times 10^{-5} \text{ bar}) = 3.3 \times 10^{-5} \text{ bar}$$

b) Write the balanced chemical equation for the reaction associated with K_{b2} of sulfite ion SO_3^{2-} .**Question 3.** (4 marks)Hydroxylamine ($HONH_2$) has a K_b of 8.7×10^{-9} . What concentration of hydroxylamine will produce a solution with pH 8.56?

$$pOH = 14 - 8.56 = 5.44 \quad [OH^-] = 10^{-5.44}$$

$$= 3.631 \times 10^{-6} M = y$$



$$K_b = \frac{[HONH_3^+][OH^-]}{[HONH_2]} = \frac{y^2}{x-y}$$

$$(x-y)K_b = y^2$$

$$x = \frac{y^2}{K_b} + y = \frac{(3.631 \times 10^{-6})^2}{8.7 \times 10^{-9}} + 3.631 \times 10^{-6} = 1.5 \times 10^{-3} M$$

$\therefore 1.5 \text{ mM } HONH_2$
SOLUTION HAS pH 8.56

Question 5. (4 marks)

The rate of cricket chirping changes with temperature, and follows Arrhenius behavior with an activation energy of 52 kJ mol^{-1} . Knowing that the rate of cricket chirping at 10.0°C is 92 chirps per minute, calculate the temperature of a cricket that chirps 44 times in 15 seconds.

$$\text{RATE}_2 = \frac{44}{15 \text{ SEC}} \times \frac{60 \text{ S}}{1 \text{ min}} = 176 \text{ CHIRPS / min}$$

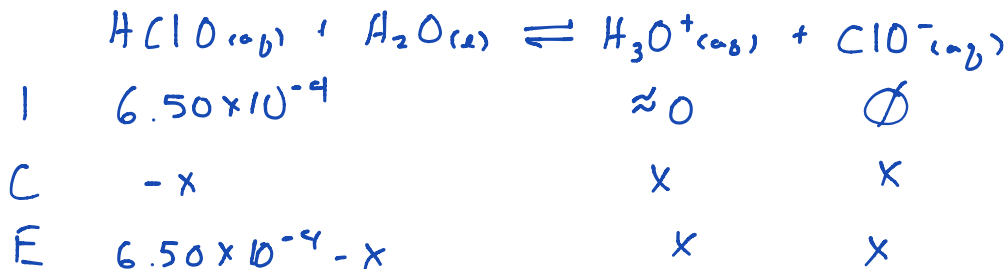
$$\text{RATE}_1 = 92 \text{ CHIRPS min}^{-1}$$

$$\ln \frac{\text{RATE}_2}{\text{RATE}_1} = \frac{-E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

$$\begin{aligned} \frac{1}{T_2} &= -\frac{R}{E_a} \ln \left(\frac{\text{RATE}_2}{\text{RATE}_1} \right) + \frac{1}{T_1} \\ &= \frac{-8.314 \text{ J K}^{-1} \text{ mol}^{-1}}{52 \times 10^3 \text{ J mol}^{-1}} \ln \left(\frac{176}{92} \right) + \frac{1}{(273.15 + 10.0) \text{ K}} = 3.428 \times 10^{-3} \text{ K}^{-1} \\ T_2 &= 292 \text{ K} \end{aligned}$$

Question 6.

a) What is the percent ionization of a 0.000650 M solution of HClO ($K_a = 3.98 \times 10^{-8}$)? (4 marks)



$$K_a = \frac{[\text{H}_3\text{O}^+][\text{ClO}^-]}{[\text{HClO}]} = \frac{x^2}{6.50 \times 10^{-4} - x} \approx \frac{x^2}{6.50 \times 10^{-4}} = 3.98 \times 10^{-8}$$

$$\% \text{ IONIZED} = \frac{[\text{H}_3\text{O}^+]}{[\text{HClO}]} \times 100\% = \frac{5.086 \times 10^{-4}}{6.50 \times 10^{-4}} \times 100\% = 0.782\%$$

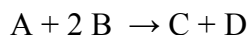
$$x = \sqrt{(3.98 \times 10^{-8})(6.50 \times 10^{-4})} = 5.086 \times 10^{-6} \text{ M}$$

b) Calculate the percent error for $[\text{H}_3\text{O}^+]_{\text{eq}}$ that comes from the assumption that $[\text{H}_3\text{O}^+]_0 = 0$. (1 mark)

$$\begin{aligned} \% \text{ ERROR} &= \frac{10^{-7}}{x + 10^{-7}} \times 100\% = \frac{10^{-7}}{5.086 \times 10^{-6} + 10^{-7}} \times 100\% \\ &= 1.93\% \end{aligned}$$

Question 7.

The data in the table was acquired for this reaction:



Experiment	[A] (M)	[B] (M)	Rate (M/s)
1	0.260	0.400	0.0171
2	0.260	0.800	0.0342
3	0.520	0.400	0.00855

a) What is the rate equation for this reaction? (3 marks)

$$\frac{\text{RATE 2}}{\text{RATE 1}} = \left(\frac{[B]_2}{[B]_1} \right)^y = \frac{0.0342}{0.0171} = \left(\frac{0.800}{0.400} \right)^y$$

$2 = 2^y \quad \therefore 1^{\text{st}} \text{ ORDER}$

$$\frac{\text{RATE 3}}{\text{RATE 1}} = \left(\frac{[A]_3}{[A]_1} \right)^x = \left(\frac{0.00855}{0.0171} \right) = \left(\frac{0.520}{0.260} \right)^x$$

$$\frac{1}{2} = 2^x \quad x = -1 \quad \therefore \text{RATE} = k \frac{[B]}{[A]}$$

b) What is the rate constant? (Be sure to include units in your answer.) (2 mark)

$$k = \text{RATE} \frac{[A]}{[B]} = 0.0171 \frac{\text{M}}{\text{s}} \frac{(0.260 \text{ M})}{(0.400 \text{ M})} = 1.11 \times 10^{-2} \text{ M s}^{-1}$$

c) Is it possible that the elementary reaction is the same as the overall reaction? Give 2 reasons that support your answer. (3 marks).

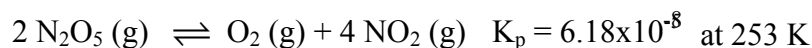
NO BECAUSE A PHYSICALLY REASONABLE ELEMENTARY REACTION SHOULD HAVE NO MORE THAN 3 MOLECULES COLLIDE WITH EACH OTHER IN A SINGLE STEP ALSO, THE PREDICTED RATE EQUATION WOULD BE

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

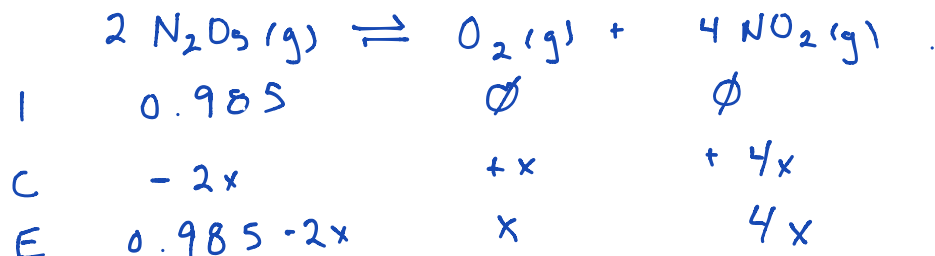
BUT THIS IS NOT THE RATE EQUATION THAT WAS OBTAINED FROM THE EXPERIMENTAL DATA.

Question 8.

For the reaction



a) Suppose 0.985 bar of N_2O_5 is introduced into a flask. What is the total pressure of gas inside the flask when the reaction comes to equilibrium? (5 marks)



$$K_p = \frac{P_{\text{O}_2} P_{\text{NO}_2}^4}{P_{\text{N}_2\text{O}_5}^2} = \frac{x (4x)^4}{(\underbrace{0.985 - 2x}_{\approx 0.985})^2} = \frac{256x^5}{0.985^2} = 6.18 \times 10^{-8}$$

$$x = \left(\frac{(6.18 \times 10^{-8})(0.985)^2}{256} \right)^{\frac{1}{5}}$$

$$= 0.01186$$

$$p_T = 0.985 - 2x + x + 4x$$

$$= 0.985 + 3x$$

$$= 1.021 \text{ bar}$$

b) If 0.050 bar of each gas is added to an empty reaction flask at 253 K, would the reaction proceed in the direction of the reactants or the products? Justify your answer. (2 mark)

$$Q = \frac{P_{\text{NO}_2}^4 P_{\text{O}_2}}{P_{\text{N}_2\text{O}_5}^2} = (0.050)^3$$

$$= 1.3 \times 10^{-7}$$

$$Q > K$$

\therefore TOWARDS
REACTANTS

Selected Constants and Conversion Factors

$$1 \text{ mmHg} = 1 \text{ torr} \quad 760 \text{ mmHg} = 1 \text{ atm} \quad 1 \text{ atm} = 101.325 \text{ kPa} \quad 1 \text{ atm} = 1.013125 \text{ bar}$$

$$1 \text{ bar} = 10^5 \text{ Pa} \quad 1 \text{ cm}^3 = 1 \text{ mL} \quad 1 \text{ dm}^3 = 1000 \text{ mL} = 1 \text{ L} \quad 1 \text{ m}^3 = 1000 \text{ L} \quad 1 \text{ cal} = 4.184 \text{ J}$$

Avogadro's Number	N_A	$6.022 \times 10^{23} \text{ mol}^{-1}$
Gas constant	R	$8.31451 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
	R	$0.08206 \text{ atm} \cdot \text{L} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
	R	$8.31451 \text{ L} \cdot \text{kPa} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
	R	$0.0831451 \text{ bar} \cdot \text{L} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$

Equations Covered Since Midterm 1

$$\text{Rate} = \frac{1}{\nu_X} \frac{\Delta[X]}{\Delta t} \quad \text{Rate} = k[A]^y[B]^z \dots \quad \frac{\text{Initial Rate 1}}{\text{Initial Rate 2}} = \frac{k[A]_1^y[B]_1^z \dots}{k[A]_2^y[B]_2^z \dots} \quad k = Ae^{-\frac{E_a}{RT}}$$

$$[A]_t = [A]_o - akt \quad \ln \frac{[A]_o}{[A]_t} = akt \quad \frac{1}{[A]_t} - \frac{1}{[A]_o} = 2kt \quad \ln \left(\frac{k_2}{k_1} \right) = -\frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

$$t_{\frac{1}{2}} = \frac{[A]_o}{2ak} \quad t_{\frac{1}{2}} = \frac{\ln 2}{ak} \quad t_{\frac{1}{2}} = \frac{1}{2k[A]_o} \quad K_{eq} = \frac{[C]_{eq}^c [D]_{eq}^d}{[A]_{eq}^a [B]_{eq}^b} \quad K_{eq} = \frac{P_{C,eq}^c P_{D,eq}^d}{P_{A,eq}^a P_{B,eq}^b}$$

$$Q = \frac{P_C^c P_D^d}{P_A^a P_B^b} \quad Q = \frac{[C]^c [D]^d}{[A]^a [B]^b} \quad K_{eq} = K_1 \times K_2 \times K_3 \times \dots \quad K_{eq,reverse} = \frac{1}{K_{eq,forward}} \quad K_{eq,new} = (K_{eq,old})^n$$

$$\text{pH} = -\log[H_3O^+] \quad \text{pOH} = -\log[OH^-] \quad \text{pH} + \text{pOH} = 14 \quad K_a \times K_b = K_w = 10^{-14} = [H_3O^+][OH^-]$$

$$\text{p}K_b = -\log K_b \quad \text{p}K_a = -\log K_a \quad ax^2 + bx + c = 0 \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\% \text{ error} = 100\% \times \frac{\text{difference from assumed value}}{\text{actual value}} \quad \% \text{ HA hydrolyzed} = 100\% \times \frac{[H_3O^+]_{eq}}{[HA]_{initial}}$$

Midterm 1 Equations

$$T(\text{in K}) = T(\text{in } ^\circ\text{C}) + 273.15 \text{ K} \quad n = \frac{m}{M} = \frac{N}{N_A} \quad \% \text{ Yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% \quad c(\text{mol/L}) = \frac{n}{V}$$

$$c_1V_1 = c_2V_2 = n \quad p = \frac{mg}{A} \quad p = dgh \quad pV = nRT \quad \frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} \quad p_T = p_1 + p_2 + p_3 + \dots$$

$$p_A = X_A \times p_T \quad X_A = \frac{n_A}{n_T} \quad d = \frac{m}{V} = \frac{p \cdot M}{RT} \quad E_K = \frac{1}{2}mv^2 \quad \bar{E} = \frac{3RT}{2N_A} \quad \bar{v} = \sqrt{\frac{3RT}{M}}$$

$$\frac{\text{Rate A}}{\text{Rate B}} = \sqrt{\frac{M_B}{M_A}} \quad p = \frac{nRT}{(V - nb)} - a \frac{n^2}{V^2} \quad \Delta E = w + q \quad w = F \times d = -p\Delta V$$

$$q_{\text{calorimeter}} = C_{\text{cal}}\Delta T \quad q = mC\Delta T \quad \Delta E_{\text{reaction}} = \sum BE_{\text{reactant bonds broken}} - \sum BE_{\text{product bonds formed}} \quad \Delta E_{\text{molar}} = \frac{\Delta E}{n}$$

$$\Delta H_{\text{reaction}}^{\circ} = \sum \nu_p \Delta H_{f,p}^{\circ} - \sum \nu_r \Delta H_{f,r}^{\circ} \quad \Delta H_{\text{reaction}} = \Delta E_{\text{reaction}} + RT\Delta n_{\text{gas}} \quad H = E + pV$$