

Surname: _____ Given name: _____

Student number: _____

Chemistry 1311D

Test 1 V2, October 20, 2016

80 minutes

You may remove the last 2 pages

Professor: Wendy Pell

1. (5 points) A commercial solution contains ammonia, NH_3 , in methanol, CH_3OH . The density of the solution is 1.685 g/ml. Calculate the molarity, molality, % weight, if the ammonia mole fraction in the solution is 0.0373.

$$\begin{aligned}\text{NH}_3 \quad M &= 17.03 \text{ g/mol} \\ \text{CH}_3\text{OH} \quad M &= 32.04 \text{ g/mol} \\ d &= 1.685 \text{ g/ml} \\ X &= 0.0373\end{aligned}$$

Assume 1 mole total

$$n_{\text{NH}_3} = X_{\text{NH}_3} \times n_T = 0.0373$$

$$m_{\text{NH}_3} = 0.0373 \times 17.03 \text{ g} = 0.634 \text{ g}$$

$$n_{\text{CH}_3\text{OH}} = n_T - n_{\text{NH}_3} = 1 - 0.0373 = 0.9627$$

$$m_{\text{CH}_3\text{OH}} = n_{\text{CH}_3\text{OH}} \times M = 0.9627 \times 32.04 = 30.81 \text{ g} = 0.03081 \text{ kg}$$

$$m_T = m_{\text{CH}_3\text{OH}} + m_{\text{NH}_3} = 0.634 + 30.81 = 31.44 \text{ g}$$

$$V_{\text{soln}} = m_T / d = 31.44 \text{ g} / 1.685 = 18.65 \text{ ml} = 0.01865 \text{ L}$$

$$\text{Molarity} = \frac{n_{\text{NH}_3}}{V_{\text{soln}}} = \frac{0.0373}{0.01865} = 2.00 \text{ M}$$

$$\text{Molality} = \frac{n_{\text{NH}_3}}{\text{kg CH}_3\text{OH}} = \frac{0.0373}{0.0308} = 1.21 \text{ molal}$$

$$\% \text{ wt} = \frac{m_{\text{NH}_3}}{\text{total mass}} \times 100 = \frac{0.634}{31.44} \times 100 = 2.02 \%$$

BONUS: What is the molecular formula of your favourite molecule? And how many atoms does it contain?

2. (10 points) In 1978, scientists extracted a compound with antitumor and antiviral properties from marine animals in the Caribbean Sea. A sample of the compound didemnin-A of mass 3.56 mg underwent combustion analysis in excess oxygen to yield 2.650 μL of H_2O (l) at 20 $^\circ\text{C}$ ($1 \mu\text{L} = 1 \times 10^{-3} \text{ ml}$) density of water at 20 $^\circ\text{C} = 0.9982 \text{ g/ml}$; 4.452 ml of CO_2 (g) at 20 $^\circ\text{C}$ and 1 bar; and 0.276 ml of each of NO_2 (g) and NO (g), also at 20 $^\circ\text{C}$ and 1 bar. The experimental molar mass of the compound was determined in a separate experiment to be 942 g mol^{-1} .

a) (2 points) Determine the number of moles of H in the 3.56 mg sample of didemnin-A

$$V = 2.650 \times 10^{-6} \text{ L} \quad m_{\text{H}_2\text{O}} = \rho \times V = 2.650 \times 10^{-6} \times 998.2 = 2.646 \times 10^{-3} \text{ g}$$

$$d = 0.9982 \text{ g/ml} \quad n_{\text{H}_2\text{O}} = m/M = 2.646 \times 10^{-3} / 18.025 \text{ g/mol} = 1.468 \times 10^{-4} \text{ moles}$$

$$= 9.982 \text{ g/L} \quad n_{\text{H}} = 2 \times n_{\text{H}_2\text{O}} = 2.936 \times 10^{-4} \text{ moles}$$

b) (2 points) Determine the number of moles of C in the 3.56 mg sample didemnin A

$$V = 4.452 \times 10^{-3} \text{ L} \quad n_{\text{C}} = n_{\text{CO}_2} = \frac{PV}{RT} = \frac{1 \text{ bar} (4.452 \times 10^{-3})}{0.08314 (293)}$$

$$P = 1 \text{ bar} \quad = 1.848 \times 10^{-4} \text{ moles}$$

$$T = 293 \text{ K}$$

c) (1 points) Determine the number of moles of N in the 3.56 mg sample of didemnin A

$$V_{\text{NO}} = V_{\text{NO}_2} = 0.276 \times 10^{-3} \text{ L} \quad n_{\text{N}} = n_{\text{NO}} + n_{\text{NO}_2} = \frac{P(V_{\text{NO}} + V_{\text{NO}_2})}{RT}$$

$$P = 1 \text{ bar} \quad = \frac{1.0 \text{ bar} (2 \times 0.276 \times 10^{-3})}{0.08314 (293)}$$

$$T = 293 \text{ K} \quad = 2.26 \times 10^{-5} \text{ moles}$$

d) (2 point) Determine the number of moles of O in the 3.56 mg sample of didemnin A

$$\text{mass O} = \text{mass T} - \text{mass H} - \text{mass C} - \text{mass N}$$

$$= 3.56 \times 10^{-3} = (2.936 \times 10^{-4} \times 1.007) - (1.848 \times 10^{-4} \times 12.01) - (2.26 \times 10^{-5} \times 14.01)$$

$$= 0.726 \text{ mg}$$

$$n_{\text{O}} = 0.726 \times 10^{-3} / 15.999 = 4.53 \times 10^{-5} \text{ moles}$$

e) (2 points) What is the empirical formula of didemnin A?

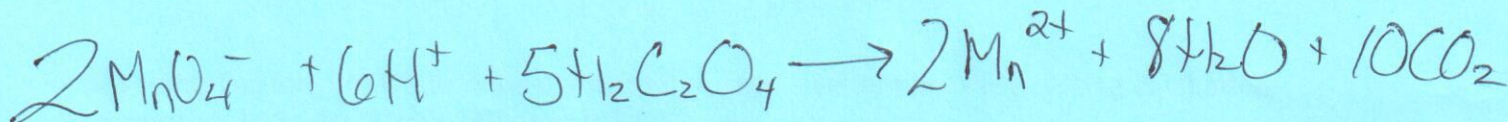
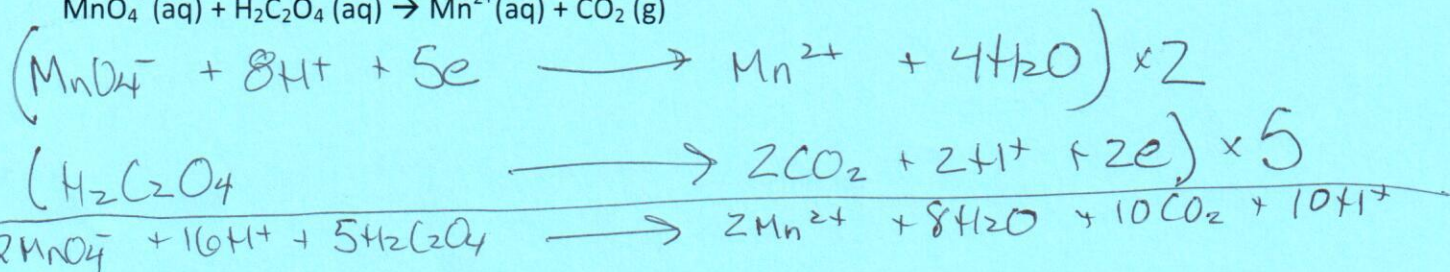
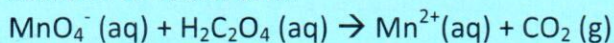
$$\begin{array}{l} \text{H} \quad 29.36 / 2.26 = 13.0 \\ \text{C} \quad 18.48 / 2.26 = 8.2 \\ \text{N} \quad 2.26 / 2.26 = 1 \\ \text{O} \quad 4.53 / 2.26 = 2 \end{array} \quad \text{C}_8 \text{H}_{13} \text{N}_1 \text{O}_2 \quad M = 155 \text{ g/mol}$$

f) (1 point) What is the molecular formula of didemnin A?

$$f = \frac{942}{155} = 6 \quad \text{C}_{48} \text{H}_{78} \text{N}_6 \text{O}_{12}$$

3. (10 points) Permanganate ions, MnO_4^- , are used in water treatment facilities, in addition, the permanganate ion will readily react with oxalic acid, $\text{H}_2\text{C}_2\text{O}_4$.

a) (4 points) Balance the net ionic reaction that occurs when KMnO_4 salt is added to an acidic aqueous solution of oxalic acid:



b) (5 points) Determine the volume of CO_2 produced when 95 g KMnO_4 react with 175 ml of 5.5 M oxalic acid in acidic aqueous solution collected at 725 mm Hg and 35 °C

$$95 \text{ g } \text{KMnO}_4, M_{\text{KMnO}_4} = 158 \text{ g/mol} \quad n_{\text{KMnO}_4} = \frac{95}{158} = 0.601 \text{ moles}$$

$$175 \text{ ml } 5.5 \text{ M } \text{H}_2\text{C}_2\text{O}_4 \quad n_{\text{H}_2\text{C}_2\text{O}_4} = C \times V = 5.5 \times 0.175 = 0.9625 \text{ moles}$$

Limiting Reagent?

$$n_{\text{H}_2\text{C}_2\text{O}_4} \text{ to use all } \text{MnO}_4^- = 0.601 \times \frac{5 \text{ H}_2\text{C}_2\text{O}_4}{2 \text{ MnO}_4^-} = 1.502 \text{ moles}$$

I only have 0.96, so $\text{H}_2\text{C}_2\text{O}_4$ is limiting

$$n_{\text{CO}_2} = n_{\text{H}_2\text{C}_2\text{O}_4} \times \frac{10 \text{ CO}_2}{5 \text{ H}_2\text{C}_2\text{O}_4} = 0.9625 \times 2 = 1.925 \text{ moles}$$

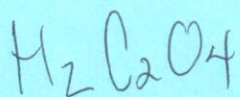
$$\rightarrow V = \frac{nRT}{P} = \frac{1.925 (0.08314) (308)}{0.966}$$

$$P = \frac{725 \text{ mmHg} \times \frac{1 \text{ bar}}{750.06}}{1} = 0.966$$

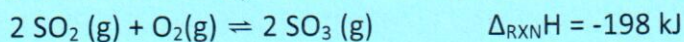
$$= 50.5 \text{ L}$$

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No limiting.

c) (1 point) Identify the reducing agent in the above reaction:



4. (10 points) K_c for the oxidation of SO_2 , as shown below, at 600 K is 1.7×10^8 .



a) (4 points) If 400 bar of $\text{SO}_3(\text{g})$ and 125 bar of $\text{O}_2(\text{g})$ are placed in a reaction vessel, determine the pressure of all species at equilibrium.

$$K_p = K_c (RT)^{\Delta n}$$

$$= 1.7 \times 10^8 (0.08314 \times 600)^{2-3}$$

$$= 3.41 \times 10^6$$

$$K_p = 3.41 \times 10^6 = \frac{P_{\text{SO}_3}^2}{P_{\text{SO}_2}^2 P_{\text{O}_2}} = \frac{(400)^2}{125 \cdot 4x^2}$$

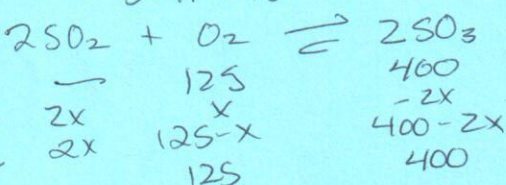
$$x^2 = 9.384 \times 10^{-5}$$

$$x = 0.0097 \text{ bar}$$

$$P_{\text{SO}_3} = 400 \text{ bar}$$

$$P_{\text{O}_2} = 125 \text{ bar}$$

$$P_{\text{SO}_2} = 0.0097 \text{ bar}$$



b) (5 points) The mixture is subsequently heated to 780 K. Determine the resulting equilibrium concentration (in moles/litre) of all species

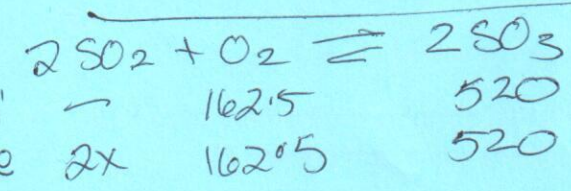
① 780

$$\ln\left(\frac{K_1}{K_2}\right) = \frac{\Delta H}{R} \left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$K_{780} = 359$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{125}{600} = \frac{x}{780} \quad x = 162.5 \text{ bar}$$

$$P = 400, \quad x = 520 \text{ bar}$$



$$P_{\text{SO}_3} = 520 - 2(1.08)$$

$$= 518 \text{ bar}$$

$$P_{\text{O}_2} = 162.5 - 1.1$$

$$= 161.4 \text{ bar}$$

$$P_{\text{SO}_2} = 2.16 \text{ bar}$$

$$359 = \frac{(520)^2}{162.5 \cdot 4x^2}$$

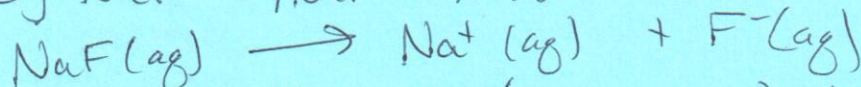
$$x^2 = 1.159$$

$$x = 1.08$$

c) (1 point) Explain the significance of activity in equilibrium calculations and how it might change the answer to the above question.

5. (10 points) a) (5 points) What is the pH of a solution formed when 58.0 g of solid sodium fluoride, NaF, is added to sufficient distilled water to make 750 ml of solution. K_a of HF is 6.60×10^{-4} . You may assume that the initial concentration of OH^- or H_3O^+ due to the autoionization of water is negligible.

$$58.0 \text{ g NaF} \quad M_{\text{NaF}} = 41.98$$



$$[\text{Na}^+] = [\text{F}^-] = [\text{NaF}] = \left(\frac{58.0 \text{ g}}{41.98 \text{ g/mol}} \right) / 0.75 \text{ L} = 1.842 \text{ M}$$

$$K_b \text{ F}^- = \frac{K_w}{K_a \text{ HF}} = 10^{-14} / 6.6 \times 10^{-4} = 1.52 \times 10^{-11}$$



i	1.842	—	—	—
c	—x	—	x	x
e	1.842 - x = 1.842	—	x	x

$$K_b = 1.52 \times 10^{-11} = \frac{x^2}{1.842}$$

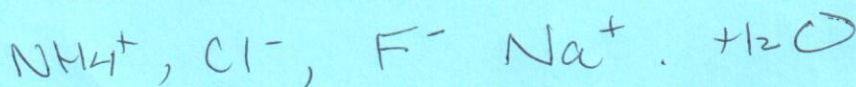
$$x = 5.29 \times 10^{-6} \text{ M}$$

$$\text{pOH} = -\log(5.29 \times 10^{-6}) = 5.28$$

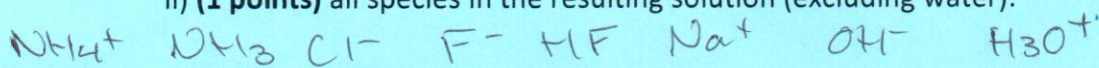
$$\text{pH} = 14 - \text{pOH} = 8.72$$

b) If solid ammonium chloride (NH_4Cl) is added to the above solution, identify

i) (1 point) the major species in the resulting solution (prior to any reaction):



ii) (1 point) all species in the resulting solution (excluding water):



iii) (2 points) the net ionic reaction occurring in the solution:



iv) (1 point) How would you predict the pH of a solution if equimolar quantities of NH_4Cl and KF are added to 1 L of water?

Compare $K_b \text{ F}^-$ to $K_a \text{ NH}_4^+$, which ever is larger wins.