CH 223 Spring 2024:

Problem Set #1

Instructions

Step One (all sections):

- **Learn the material** for Problem Set #1 by **reading Chapter 13** of the textbook and/or by watching the videos found on our website (https://mhchem.org/223)
- **Try the problems** for Problem Set #1 found on the next pages on your own first. Use separate paper and write out your answers, showing all of your work. If you write the answers on the problem set itself, you will receive fewer points. Include your name on your problem set!

Step Two:

Section 01 and H1: We will go over Problem Set #1 during recitation. ***Self correct all problems*** of your problem set before turning it in at the end of recitation.

- *Section 01:* due **Monday, April 8 at 1:10 PM**
- *Section H1:* due **Wednesday, April 10 at 1:10 PM**

Section W1: **Watch the recitation video** for Problem Set #1:

http://mhchem.org/v/m.htm

- **Self correct *all* of the problems** while viewing the video. Mark correct problems with a star (or other similar mark), and correct all incorrect problems (show the correct answer and the steps required to achieve it.)
- **Submit Problem Set #1 via email (mike.russell@mhcc.edu) as a single PDF file** (use CamScanner (https://camscanner.com), CombinePDF (https://combinepdf.com), etc.) **by 11:59 PM Wednesday, April 10.**

If you have any questions regarding this assignment, please email (mike.russell@mhcc.edu) the instructor! Good luck on this assignment!

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** Complete problem set on separate pieces of paper showing all work, circling final answers, etc.*
** Self correct your work before turning it in to the instructor.*

Covering: **Chapter Thirteen** *and* **Chapter Guide One**
Important Tables and/or Constants: **R = 0.082057 L atm mol^{-1} K^{-1}, 760 mm Hg = 1 atm**

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1. Write equilibrium constant expressions for the following reactions. For gases use either pressures or concentrations.
   a. $3\ O_2(g) \rightleftharpoons 2\ O_3(g)$
   b. $Fe(s) + 5\ CO(g) \rightleftharpoons Fe(CO)_5(g)$
   c. $(NH_4)_2CO_3(s) \rightleftharpoons 2\ NH_3(g) + CO_2(g) + H_2O(g)$
   d. $Ag_2SO_4(s) \rightleftharpoons 2\ Ag^+(aq) + SO_4^{2-}(aq)$
2. The equilibrium constant, *K*, for the reaction:
   $$2\ NOCl(g) \rightleftharpoons 2\ NO(g) + Cl_2(g)$$
   is 3.9×10^{-3} at 300 °C. A mixture contains the gases at the following concentrations: [NOCl] = 5.0×10^{-3} M, [NO] = 2.5×10^{-3} M, and [Cl_2] = 2.0×10^{-3} M. Is the reaction at equilibrium at 300 °C? If not, in which direction does the reaction proceed to come to equilibrium?
3. An equilibrium mixture of SO_2, O_2 and SO_3 at 1000 K contains the gases at the following concentrations: [SO_2] = 3.77×10^{-3} M, [O_2] = 4.30×10^{-3} M, and [SO_3] = 4.13×10^{-3} M. Calculate the equilibrium constant, K_c, for the reaction:
   $$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$$
4. You place 3.00 mol of pure SO_3 in an 8.00 L flask at 1150 K. At equilibrium, 0.58 mol of O_2 has formed. Calculate K_c for the reaction at 1150 K using the reaction:
   $$2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$$
5. Cyclohexane, C_6H_{12}, a hydrocarbon, can isomerize or change into methylcyclopentane, $C_5H_9CH_3$, a compound of the same formula but with a different molecular structure. The equilibrium constant has been estimated to be 0.12 at 25 °C. If you originally placed 0.045 mol of cyclohexane in a 2.8 L flask, what would be the concentrations of cyclohexane and methylcyclopentane when equilibrium is established? Use the equation:
   $$C_6H_{12}(g) \rightleftharpoons C_5H_9CH_3(g)$$
6. K_p for the following reaction is 0.16 at 25 °C:
   $2\ NOBr(g) \rightleftharpoons 2\ NO(g) + Br_2(g)$

   The enthalpy change for the reaction at standard conditions is +16.3 kJ. Predict the effect of the following changes on the position of the equilibrium; that is, state which way the equilibrium will shift (left, right, or no change) when each of the following changes is made.
   a. adding more $Br_2(g)$
   b. removing some NOBr(g)
   c. decreasing the temperature
   d. increasing the container volume

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7. The decomposition of NH_4HS is an endothermic process:
   $NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$
   a. Using Le Chatelier's principle, how would increasing the temperature affect the equilibrium?
   b. How would K be affected if additional NH_3 is placed in the flask?
   c. What will happen to the pressure of NH_3 if some H_2S is removed from the flask?
8. The equilibrium constant for the reaction
   $$N_2(g) + O_2(g) \rightleftharpoons 2\,NO(g)$$
   is 1.7×10^{-3} at 2300 K.
   a. What is K for the reaction when written as follows:
   $$\tfrac{1}{2}\,N_2(g) + \tfrac{1}{2}\,O_2(g) \rightleftharpoons NO(g)$$
   b. What is K for the following reaction?
   $$2\,NO(g) \rightleftharpoons N_2(g) + O_2(g)$$
9. The equilibrium constant K for the reaction
   $$CO_2(g) \rightleftharpoons CO(g) + \tfrac{1}{2}\,O_2(g)$$
   is 6.66×10^{-12} at 1000 K. Calculate K for the reaction
   $$2\,CO(g) + O_2(g) \rightleftharpoons 2\,CO_2(g)$$
10. Ammonium iodide dissociates reversibly to ammonia and hydrogen iodide if the salt is heated to a sufficiently high temperature. Some ammonium iodide is placed in a flask, which is then heated to 400 °C. If the total pressure in the flask when equilibrium has been achieved is 705 mm Hg, what is the value of K_p (when partial pressures are in atmospheres)?
    $$NH_4I(s) \rightleftharpoons NH_3(g) + HI(g)$$
11. In the gas phase, acetic acid exists as an equilibrium of monomer and dimer molecules. The dimer consists of two molecules of acetic acid linked through hydrogen bonds. The equilibrium constant, K, for the monomer-dimer equilibrium shown below has been determined to be 3.2×10^4. Assume that acetic acid is present initially at a concentration of 5.4×10^{-4} M at 25 °C and that no dimer is present initially.
    $$2\,CH_3CO_2H(g) \rightleftharpoons (CH_3CO_2H)_2(g)$$
    a. What percentage of the acetic acid is converted to the dimer?
    b. As the temperature increases, in which direction does the equilibrium shift? (Recall that hydrogen bond formation is an exothermic process.)
12. At 450 °C, 3.60 mol of ammonia is placed in a 2.00 L flask and allowed to decompose into the elements. If the experimental value of K_c is 6.3 for this reaction at this temperature, calculate the equilibrium concentration of each reagent. What is the total pressure in the flask? The reaction:
    $$2\,NH_3(g) \rightleftharpoons N_2(g) + 3\,H_2(g)$$

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13. K_c for the decomposition of ammonium hydrogen sulfide is 1.8×10^{-4} at 25 °C. The reaction:

$$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$$

   a. When the pure salt decomposes in a flask, what are the equilibrium concentrations of NH_3 and H_2S?
   b. If NH_4HS is placed in a flask already containing 0.020 M of NH_3 and then the system is allowed to come to equilibrium, what are the equilibrium concentrations of NH_3 and H_2S?

14. The dissociation of calcium carbonate has an equilibrium constant $K_p = 1.16$ at 800. °C.

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$$

   a. What is K_c for the reaction?
   b. If you place 22.5 g of $CaCO_3$ in a 9.56 L container at 800. °C, what is the pressure of CO_2 in the container?
   c. What percentage of the original 22.5 g sample of $CaCO_3$ remains undecomposed at equilibrium?