CH 223 Practice Problem Set #2

*This is a **practice problem set** and not the actual graded problem set that you will turn in for credit.*
Answers to each problem can be found at the end of this assignment.

Covering: **Chapter Thirteen** *and* **Chapter Guide Two**

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. $2\ H_2O_2(g) \rightleftharpoons 2\ H_2O(g) + O_2(g)$
   b. $CO(g) + {}^1/_2\ O_2(g) \rightleftharpoons CO_2(g)$
   c. $C(s) + CO_2(g) \rightleftharpoons 2\ CO(g)$
   d. $NiO(s) + CO(g) \rightleftharpoons Ni(s) + CO_2(g)$
2. $K = 5.6 \times 10^{-12}$ at 500 K for the dissociation of iodine molecules to iodine atoms.

   $$I_2(g) \rightleftharpoons 2\ I(g)$$

   A mixture has $[I_2] = 0.020$ mol/L and $[I] = 2.0 \times 10^{-8}$ mol/L. Is the reaction at equilibrium (at 500 K)? If not, which way must the reaction proceed to reach equilibrium?
3. The reaction

   $$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

   was examined at 250 °C. At equilibrium, $[PCl_5] = 4.2 \times 10^{-5}$ mol/L, [PCl3] = 1.3×10^{-2} mol/L, and $[Cl_2] = 3.9 \times 10^{-3}$ mol/L. Calculate K for the reaction.
4. The value of K for the interconversion of butane and isobutane is 2.5 at 25 °C.

   $$\text{butane}(g) \rightleftharpoons \text{isobutane}(g)$$

   If you place 0.017 mol of butane in a 0.50 L flask at 25 °C and allow equilibrium to be established, what will be the equilibrium concentrations of the two forms of butane?
5. The equilibrium constant for the dissociation of iodine molecules to iodine atoms

   $$I_2(g) \rightleftharpoons 2\ I(g)$$

   is 3.76×10^{-3} at 1000 K. Suppose 0.105 mol of I_2 is placed in a 12.3 L flask at 1000 K. What are the concentrations of I_2 and I when the system comes to equilibrium?
6. Dinitrogen trioxide decomposes to NO and NO_2 in an endothermic process ($\Delta H = 40.5$ kJ/mol).

   $$N_2O_3(g) \rightleftharpoons NO(g) + NO_2(g)$$

   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 $N_2O_3(g)$
   b. adding more $NO_2(g)$
   c. increasing the volume of the reaction flask
   d. lowering the temperature
7. Consider the isomerization of butane with an equilibrium constant of $K = 2.5$ (see question #4, above.) The system is originally at equilibrium with [butane] = 1.0 M and [isobutane] = 2.5 M.
   a. If 0.50 mol/L of isobutane is suddenly added and the system shifts to a new equilibrium position, what is the equilibrium concentration of each gas?
   b. If 0.50 mol/L of butane is added and the system shifts to a new equilibrium position, what is the equilibrium concentration of each gas?

8. Which of the following correctly relates the equilibrium constants for the two reactions shown?

$$A + B \rightleftharpoons 2C \qquad K_1$$
$$C \rightleftharpoons {}^1/_2\, A + {}^1/_2\, B \qquad K_2$$

a. $K_2 = 1/(K_1)^{1/2}$ c. $K_2 = K_1^2$
b. $K_2 = 1/K_1$ d. $K_2 = -K_1^{1/2}$

9. Calculate K for the reaction

$$SnO_2(s) + 2\ CO(g) \rightleftharpoons Sn(s) + 2\ CO_2(g)$$

given the following information:

$SnO_2(s) + 2\ H_2(g) \rightleftharpoons Sn(s) + 2\ H_2O(g)$ $K = 8.12$
$H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g)$ $K = 0.771$

10. Ammonium hydrogen sulfide decomposes on heating. $NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$ If K_p for this reaction is 0.11 at 25 °C (when the partial pressures are measured in atmospheres), what is the total pressure in the flask at equilibrium?

11. Sulfuryl chloride, SO_2Cl_2, is a compound with very irritating vapors; it is used as a reagent in the synthesis of organic compounds. When heated to a sufficiently high temperature it decomposes to SO_2 and Cl_2.

$$SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g) \qquad K = 0.045 \text{ at } 375\ °C$$

a. Suppose 6.70 g of SO_2Cl_2 is placed in a 1.00 L flask and then heated to 375 °C. What is the concentration of each of the compounds in the system when equilibrium is achieved? What fraction of SO_2Cl_2 has dissociated?

b. What are the concentrations of SO_2Cl_2, SO_2, and Cl_2 at equilibrium in the 1.00 L flask at 375 °C if you begin with a mixture of SO_2Cl_2 (6.70 g) and Cl_2 (1.00 atm)? What fraction of SO_2Cl_2 has dissociated?

c. Compare the fractions of SO_2Cl_2 in parts (a) and (b). Do they agree with your expectations based on Le Chatelier's principle?

12. Neither $PbCl_2$ nor PbF_2 is appreciably soluble in water. If solid $PbCl_2$ and solid PbF_2 are placed in equal amounts of water in separate beakers, in which beaker is the concentration of Pb^{2+} greater? Equilibrium constants for these solids dissolving in water are as follows:

$PbCl_2(s) \rightleftharpoons Pb^{2+}(aq) + 2\ Cl^-(aq)$ $K = 1.7 \times 10^{-5}$
$PbF_2(s) \rightleftharpoons Pb^{2+}(aq) + 2\ F^-(aq)$ $K = 3.7 \times 10^{-8}$

13. Characterize each of the following as product- or reactant- favored.

a. $CO(g) + {}^1/_2\, O_2(g) \rightleftharpoons CO_2(g)$ $K_p = 1.2 \times 10^{45}$
b. $H_2O(g) \rightleftharpoons H_2(g) + {}^1/_2\, O_2(g)$ $K_p = 9.1 \times 10^{-41}$
c. $CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$ $K_p = 6.5 \times 10^{11}$

14. The reaction of hydrogen and iodine to give hydrogen iodide has an equilibrium constant, K_c, of 56 at 435 °C.

a. What is the value of K_p?

b. Suppose you mix 0.45 mol of H_2 and 0.45 mol of I_2 in a 10.0 L flask at 435 °C. What is the total pressure of the mixture before and after equilibrium is achieved?

c. What is the partial pressure of each gas at equilibrium?

15. Calculate $\Delta G°$ and K_p at 25 °C for the reaction: $2\ HBr(g) + Cl_2(g) \rightarrow 2\ HCl(g) + Br_2(l)$ Is the reaction predicted to be product-favored under standard conditions? Comment on the sign of $\Delta G°$ and the magnitude of K_p.

16. 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?

17. 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?

18. 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

19. The equilibrium constant K for the reaction

$$CO_2(g) \rightleftharpoons CO(g) + {}^1/_2\, O_2(g)$$

   is 6.66×10^{-12} at 1000 K. Calculate K for the reaction: $\mathbf{2\ CO(g) + O_2(g) \rightleftharpoons 2\ CO_2(g)}$

20. 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:

$$2\ NH_3(g) \rightleftharpoons N_2(g) + 3\ H_2(g)$$

Answers to the Practice Problem Set:

1. *Answers:*

a. $K = \dfrac{[H_2O]^2[O_2]}{[H_2O_2]^2}$ $\qquad K_p = \dfrac{P^2_{H_2O} P_{O_2}}{P^2_{H_2O_2}}$

b. $K = \dfrac{[CO_2]}{[CO][O_2]^{1/2}}$ $\qquad K_p = \dfrac{P_{CO_2}}{P_{CO} P^{1/2}_{O_2}}$

c. $K = \dfrac{[CO]^2}{[CO_2]}$ $\qquad K_p = \dfrac{P^2_{CO}}{P_{CO_2}}$

d. $K = \dfrac{[CO_2]}{[CO]}$ $\qquad K_p = \dfrac{P_{CO_2}}{P_{CO}}$

2. No, Q = 2.0 x 10^{-14}, and Q < K, so to the right (more products)
3. K = 1.2
4. [isobutane] = 0.024 M, and [butane] = 0.010 M
5. $[I_2]$ = 0.00614 and [I] = 0.00480 M
6. a. right b. left c. right d. left
7. a. [butane] = 1.1 M, [isobutane] = 2.9 M; b. [butane] = 1.1 M, [isobutane] = 2.9 M
8. equation (a)
9. 13.7
10. 0.66 atm
11. a. $[SO_2Cl_2]$ = 0.020 M, $[SO_2]$ = $[Cl_2]$ = 0.030 M, and fraction = 0.60 b. $[SO_2Cl_2]$ = 0.025 M, $[SO_2]$ = 0.025 M, $[Cl_2]$ = 0.044 M, and fraction = 0.50 c. Yes, Le Chatelier's principle predicts equilibrium moves to the reactant side, confirmed
12. $PbCl_2$
13. a. product favored b. reactant favored c. product favored
14. a. K_p = 56 b. *before:* 5.2 atm *after:* 5.2 atm c. $P_{H2} = P_{I2}$ = 0.55 atm, P_{HI} = 4.1 atm
15. ΔG^o = –83.74 kJ; K_p = 4.8 × 10^{14} Negative ΔG and large K_p indicate product-favored reaction
16. a. 0.013 M (both species) b. $[H_2S]$ = 0.0067 M, $[NH_3]$ = 0.027 M
17. a. 0.013 b. 1.16 c. 47% undecomposed
18. a. K shifts right b. K would not be affected (only T affects K), but reaction shifts to left c. P would increase
19. 2.25 × 10^{22}
20. $[NH_3]$ = **0.66 M,** $[N_2]$ = **0.57 M,** $[H_2]$ = **1.7 M,** P_{total} = **170 atm**