**Chapter 13 Problem Set**  **Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**Chemical Equilibrium Due Date : Monday, March 19, 2012**

***Circle/Box* all final answers to calculation based problems unless they are already boxed!!!**

***The Equilibrium Constant***

1. Write the equilibrium expression (*K*) for each of the following gas-phase reactions.

 a) N2 (g) + O2 (g) ⬄ 2 NO(g)  e) 2 NH3 (g) + CO2 (g) ⬄ N2CH4O(s) + H2O(g)

 b) N2O4 (g) ⬄ 2 NO2 (g) f) 2 NBr3 (s) ⬄ N2 (g) + 3 Br2 (g)

 c) SiH4 (g) + 2 Cl2 (g) ⬄ SiCl4 (g) + 2 H2 (g) g) 2 KClO3 (s) ⬄ 2 KCl (s) + 3 O2 (g)

 d) 2 PBr3 (g) + 3 Cl2 (g) ⬄ 2 PCl3 (g) + 3 Br2 (g) h) CuO (s) + H2 (g) ⬄ Cu (l) + H2O (g)

2. At a given temperature, *K* = 1.3 x 10-2 for the reaction

N2 (g)  + 3 H2 (g)  ⬄ 2 NH3 (g)

 Calculate the values of *K* for the following reactions at this temperature.

 a) ½ N2 (g)  + 3/2 H2 (g)  ⬄ NH3 (g)

 b) 2 NH3 (g) ⬄ N2 (g)  + 3 H2 (g)

 c) NH3 (g) ⬄ ½ N2 (g)  + 3/2 H2 (g)

 d) 2 N2 (g)  + 6 H2 (g)  ⬄ 4 NH3 (g)

3. For the reaction: H2 (g) + Br2 (g) ⬄ 2 HBr (g), Kp = 3.5 x 104 at 1495 K. What is the value of Kp for the following

 reactions at 1495 K?

 a) HBr (g) ⬄ ½ H2 (g) + ½ Br2 (g)

 b) 2HBr (g) ⬄ H2 (g) + Br2 (g)

 c) ½ H2 (g) + ½ Br2 (g) ⬄ HBr (g)

4. For the reaction

N2 (g) + 3 Cl2 (g) ⬄ 2 NCl3 (g)

 an analysis of an equilibrium mixture is performed at a certain temperature. It is found that [NCl3 (g)] = 1.9 x 10-1 M,

 [N2 (g)] = 1.4 x 10-3 M, and [Cl2 (g)] = 4.3 x 10-4 M. Calculate *K* for the reaction at this temperature.

5. a) At a particular temperature a 2.00 L flask at equilibrium contains 2.80 x 10-4 mol N2, 2.50 x 10-5 mol O2, and

 2.00 x 10-2 mol N2O. Calculate *K* at this temperature for the reaction

2 N2 (g) + O2 (g) ⬄ 2 N2O (g)

 b) If [N2] = 2.00 x 10-4 M, [N2O] = 0.200 M, and [O2] = 0.00245 M, does this represent a system at equilibrium?

6. The following equilibrium pressures were observed at a certain temperature for the reaction

N2 (g) + 3 H2 (g) ⬄ 2 NH3 (g)

PNH3 = 0.031 atm

PN2 = 0.85 atm

PH2 = 0.0031 atm

 a) Calculate the value for the equilibrium constant Kp at this temperature.

 b) If PN2 = 0.525 atm, PNH3 = 0.0167 atm, and PH2 = 0.00761 atm, does this represent a system at equilibrium?

7. At 1100 K, Kp = 0.25 for the reaction

2 SO2 (g) + O2 (g) ⬄ 2 SO3 (g)

 What is the value of K at this temperature?

8. In a study of the reaction

3 Fe (s) + 4 H2O (g) ⬄ Fe3O4 (s) + 4 H2 (g)

At 1200 K it was observed that when the equilibrium partial pressure of water vapor is 15.0 torr, the total pressure at equilibrium is 36.3 torr. Calculate the value of Kp for this reaction at 1200 K. *Hint:* Apply Dalton’s law of partial pressures.

***Equilibrium Calculations***

9. The equilibrium constant, Kp, is 2.4 x 103 at a certain temperature for the reaction

2 NO (g) ⬄ N2 (g) + O2 (g)

For which of the following sets of conditions is the system at equilibrium? For those that are not at equilibrium, in which direction will the system shift?

a) PNO = 0.010 atm, PN2 = 0.11 atm, PO2 = 2.0 atm

b) PNO = 0.0078 atm, PN2 = 0.36 atm, PO2 = 0.67 atm

c) PNO = 0.0062 atm, PN2 = 0.51 atm, PO2 = 0.18 atm

10. Ethyl acetate is synthesized in a nonreacting solvent (not water) according to the following reaction:

CH3CO2H + C2H5OH ⬄ CH3CO2C2H5 + H2O *K* = 2.2

 acetic acid ethanol ethyl acetate

For the following mixtures (a-d), will the concentration of water increase, decrease, or remain the same as equilibrium is established. Note: In this case water is a product, it is not simply a solvent. Therefore, water should be included in the equilibrium expression.

a) [CH3CO2C2H5] = 0.22 M, [H2O] = 0.10 M, [CH3CO2H] = 0.010 M, [C2H5OH] = 0.010 M

b) [CH3CO2C2H5] = 0.22 M, [H2O] = 0.0020 M, [CH3CO2H] = 0.0020 M, [C2H5OH] = 0.10 M

c) [CH3CO2C2H5] = 0.88 M, [H2O] = 0.12 M, [CH3CO2H] = 0.044 M, [C2H5OH] = 6.0 M

d) [CH3CO2C2H5] = 4.4 M, [H2O] = 4.4 M, [CH3CO2H] = 0.88 M, [C2H5OH] = 10.0 M

e) What must the concentration of water be for a mixture with [CH3CO2C2H5] = 2.0 M, [CH3CO2H] = 0.10 M,

 [C2H5OH] = 5.0 M at equilibrium?

11. The reaction

2 NO (g) + Br2 (g) ⬄ 2 NOBr (g)

 has Kp = 109 at 25°C. If the equilibrium partial pressure of Br2 is 0.0159 atm and the equilibrium partial pressure of

 NOBr is 0.0768 atm, calculate the partial pressure of NO at equilibrium.

12. A 1.00 L flask was filled with 2.00 mol gaseous SO2 and 2.00 mol gaseous NO2 and heated. After equilibrium was reached, it was found that 1.30 mol gaseous NO was present. Assume that the reaction

SO2 (g) + NO2 (g) ⬄ SO3 (g) + NO (g)

occurs under these conditions. Calculate the value of the equilibrium constant, *K*, for this reaction.

13. At a certain temperature, 4.0 mol NH3 is introduced into a 2.0 L container, and the NH3 partially dissociates by the reaction

2 NH3 (g) ⬄ N2 (g) + 3 H2 (g)

At equilibrium, 2.0 mol NH3 remains. What is the value of *K* for this reaction?

14. An initial mixture of nitrogen gas and hydrogen gas is reacted in a rigid container at a certain temperature by the reaction

N2 (g) + 3 H2 (g) ⬄ 2 NH3 (g)

At equilibrium, the concentrations are [H2] = 5.0 M, [N2] = 8.0 M, and [NH3] = 4.0 M. What were the concentrations of nitrogen gas and hydrogen gas that were reacted initially?

15. At a particular temperature, *K* = 1.00 x 102 for the reaction

H2 (g) + I2 (g) ⬄ 2 HI (g)

In an experiment, 1.00 mol H2, 1.00 mol I2, and 1.00 mol HI are introduced into a 1.00 L container. Calculate the concentrations of all species when equilibrium is reached.

16. At 25°C, *K* = 0.090 for the reaction

H2O (g) + Cl2O (g) ⬄ 2 HOCl (g)

Calculate the concentrations of all species at equilibrium for each of the following cases.

a) 1.0 g H2O and 2.0 g Cl2O are mixed in a 1.0 L flask.

b) 1.0 mol pure HOCl is placed in a 2.0 L flask.

17. At a particular temperature, Kp = 0.25 for the reaction

N2O4 (g) ⬄ 2 NO2 (g)

 a) A flask containing only N2O4 at an initial pressure of 4.5 atm is allowed to reach equilibrium. Calculate the

 equilibrium partial pressures of the gases.

 b) A flask containing only NO2 at an initial pressure of 9.0 atm is allowed to reach equilibrium. Calculate the

 equilibrium partial pressures of the gases.

 c) From your answers to parts a and b, does it matter from which direction an equilibrium position is reached?

18. At a particular temperature, *K =* 4.0 x 10-7 for the reaction

N2O4 (g) ⬄ 2 NO2 (g)

 In an experiment, 1.0 mol N2O4 is placed in a 10.0 L vessel. Calculate the concentrations of N2O4 and NO2 when this

 reaction reaches equilibrium.

19. Lexan is a plastic used to make compact discs, eyeglass lenses, and bullet-proof glass. One of the compounds used to

 make Lexan is phosgene (COCl2), an extremely poisonous gas. Phosgene decomposes by the reaction

COCl2 (g) ⬄ CO (g) + Cl2 (g)

 for which Kp = 6.8 x 10-9 at 100°C. If pure phosgene at an initial pressure of 1.0 atm decomposes, calculate the

 equilibrium pressures of all species.

20. A sample of solid ammonium chloride was placed in an evacuated container and then heated so that it decomposed to

 ammonia gas and hydrogen chloride gas. After heating, the total pressure in the container was found to be 4.4 atm.

 Calculate Kp at this temperature for the decomposition reaction

NH4Cl (s) ⬄ NH3 (g) + HCl (g)

***Le Chatelier’s Principle***

21. Predict the shift in the equilibrium position that will occur for each of the following reactions when the volume of the reaction container is increased.

 a) N2 (g) + 3 H2 (g) ⬄ 2 NH3 (g) d) COCl2 (g) ⬄ CO (g) + Cl2 (g)

 b) PCl5 (g) ⬄ PCl3 (g) + Cl2 (g)  e) CaCO3 (s) ⬄ CaO (s) + CO2 (g)

 c) H2 (g) + F2 (g) ⬄ 2 HF (g)

22. For the scenarios listed, what will happen to the number of moles of SO3 in equilibrium with SO2 and O2 in the reaction

2 SO3(g) ⬄ 2 SO2 (g) + O2 (g) ΔH° = +197 kJ

 a) Oxygen gas is added? d) The temperature is decreased.

 b) The pressure is increased by adding argon gas. e) Gaseous sulfur dioxide is removed.

 c) The pressure is increased by decreasing the volume of the reaction container

23. Hydrogen for use in ammonia production is produced by the reaction

Ni

CH4 (g) + H2O (g) 🡸===🡺 CO(g) + 3 H2 (g)

750°C

 What will happen to a reaction mixture at equilibrium if

 a) H2O (g) is removed? d) CO (g) is removed?

 b) an inert gas is added? e) the volume of the container is tripled?

 c) the temperature is increased (the reaction is endothermic)?

24. Old-fashioned “smelling salts” consist of ammonium carbonate, (NH4)2CO3. The reaction for the decomposition of

 ammonium carbonate is endothermic:

(NH4)2CO3 (s) ⬄ 2 NH3 (g) + CO2 (g) + H2O (g)

 Would the smell of ammonia increase or decrease as the temperature is increased?

25. Ammonia is produced by the Haber process, in which nitrogen and hydrogen are reacted directly using an iron mesh

 impregnated with oxides as a catalyst. For the reaction

N2 (g) + 3 H2 (g) ⬄ 2 NH3 (g)

 equilibrium constants (Kp values) as a function of temperature are

 300°C, 4.34 x 10-3

 500°C, 1.45 x 10-5

 600°C, 2.25 x 10-6

 Is the reaction exothermic or endothermic?

***Answers to Selected Problems***

2. a) 0.11; b) 77; c) 8.8; d) 1.7 x 10-4

3. a) 5.3 x 10-3; b) 2.9 x 10-5; c) 190

4. K = 3.2 x 1011

5. a) K = 4.08 x 108

6. a) Kp = 3.80 x 104

7. K = 23

8. Kp = 4.07

11. PNO = 0.0583 atm

12. K = 3.45

13. K = 1.7

14. [H2]o = 11.0 M; [N2]o = 10.0 M

15. [H2] = [I2] = 0.25 M; [HI] = 2.50 M

16. a) [H2O] = 0.050M; [Cl2O] = 0.018M; [HOCl] = 0.0092 M; b) [H2O] = [Cl2O] = 0.22 M; [HOCl] = 0.06 M

17. a) PN2O4 = 4.0 atm; PNO2 = 1.0 atm; b) PN2O4 = 4.0 atm; PNO2 = 1.0 atm

18. [N2O4] = 0.10 M; [NO2] = 2.0 x 10-4 M

19. PCOCl2 = 1.0 atm; PCO = PCl2 = 8.2 x 10-5 atm

20. Kp = 4.8