AP Chemistry

Name ___________________________________
Period ___ Date ___/___/___

8 – General Equilibrium/Solubility Equilibrium

WS#1: Introduction to Equilibrium

1. For the following three reactions,
   a. Write the K_{eq} expression in terms of concentration, K_c.
   b. Given the equilibrium concentrations, state whether each equilibrium is product-favored, reactant-favored, or fairly even ([products] ≈ [reactants]).
   c. Calculate the value of K_c.
      i. $N_2(g) + 3\ H_2(g) \leftrightarrow 2\ NH_3(g)$

At equilibrium:	$[N_2] = 1.50M$ $[H_2] = 2.00M$ $[NH_3]= 0.01M$

      ii. $HF(aq) \leftrightarrow H^+(aq) + F^{1-}(aq)$

At equilibrium:	$[HF] = 0.55M$ $[H^+] = 0.001M$ $[F^{1-}]= 0.001M$

      iii. $Fe^{3+}(aq) + SCN^{1-}(aq) \leftrightarrow FeSCN^{2+}(aq)$

At equilibrium:	$[Fe^{3+}] = 0.55M$ $[SCN^{1-}] = 0.001M$ $[FeSCN^{2+}]= 0.001M$

Summarize:

Fill in the blanks with product-favored, reactant-favored, and approximately equal.

K_c	State of Equilibrium
$K_c >> 1$	
$K_c << 1$	
$K_c \approx 1$	

2. Knowing that pure water has a density of 1g/1mL calculate the mass of 1.00 Liter of water.
   a. Calculate the number of moles in 1.00 L of H_2O.
   b. What is the concentration (M) of water in water?
   c. At this temperature, can you get more moles of water into this Liter of water?
      The $[H_2O]$ ________ (is / is not) constant.

Important Note:

Since the concentrations of solids and liquids are constant, they are incorporated into the equilibrium constant, K_{eq}. That means, just leave them out of the K_c or K_p expression. Only include (g) and (aq)!

3. Write equilibrium expressions for each of the following reactions:
   a. $CaCO_3(s) \leftrightarrow CaO(s) + CO_2(g)$
   b. $Ni(s) + 4CO(g) \leftrightarrow Ni(CO)_4(g)$
   c. $5CO(g) + I_2O_5(s) \leftrightarrow I_2(g) + 5CO_2(g)$
   d. $Ca(HCO_3)_2(aq) \leftrightarrow CaCO_3(s) + H_2O(l) + CO_2(g)$
   e. $AgCl(s) \leftrightarrow Ag^+(aq) + Cl^{1-}(aq)$
4. Write the equilibrium expression in terms of partial pressures (K_p) for each of the following reactions.

Rate the reactions in order of their increasing tendency to proceed toward completion: ___ ___ ___ ___

a. $4NH_3(g) + 3O_2(g) \leftrightarrow 2N_2(g) + 6H_2O(g)$ $K_p = 1x10^{228}$ atm
b. $N_2(g) + O_2(g) \leftrightarrow 2NO(g)$ $K_p = 5x10^{-31}$
c. $2HF(g) \leftrightarrow H_2(g) + F_2(g)$ $K_p = 1x10^{-13}$
d. $2NOCl(g) \leftrightarrow 2NO(g) + Cl_2(g)$ $K_p = 4.7x10^{-4}$ atm

A Question That You Should Be Able To Answer:

Why don't the K_p's in (b) and (c) have units?

7. a. Write the K_c expression for
   $$2\ SO_2(g) + O_2(g) \leftrightarrow 2\ SO_3(g)$$
   Calculate the value of K_c:

At equilibrium:	$[SO_2] = 1.50M$ $[O_2] = 1.25M$ $[SO_3] = 3.50M$

   b. If we **reverse** the equation, it is:
   $$2\ SO_3(g) \leftrightarrow 2\ SO_2(g) + O_2(g)$$
   Write the K_c expression for this equation and calculate the new value of K_c:
   How does the expression and the value of K_c in 7(b) compare with those in 7(a)?
   c. If we now **multiply all of the coefficients by ½:**
   $$SO_3(g) \leftrightarrow SO_2(g) + \tfrac{1}{2}\ O_2(g)$$
   Write the K_c expression for this equation and calculate the new value of K_c:
   How do they compare with 7(b)?
   d. What would happen to the K_c expression and its value if we **doubled** the coefficients?

Summarize:

Equation	K_c expression & Value
doubled	
reversed	
halved	

8. Consider an equilibrium that occurs in two steps:
   $$H_2S(aq) \leftrightarrow H^+(aq) + HS^{1-}(aq)$$
   $$\underline{HS^{1-}(aq) \leftrightarrow H^+(aq) + S^{2-}(aq)}$$
   a. Write the overall reaction.
   b. How do the K_c's for the two steps (K_{c1} & K_{c2}) relate to the K_c of the overall reaction (K_c)?

WS#2: EQUILIBRIUM (K_{EQ}) EXPRESSION

1. Write the expressions for the equilibrium constant K_c for the following reactions:
   a. $4NH_3(g) + 7O_2(g) \leftrightarrow 4NO_2(g) + 6H_2O(l)$
   b. $3O_2(g) \leftrightarrow 2O_3(g)$
2. Write the equilibrium constant expressions for the following reactions. How are they related to one another?
   a. $2N_2O(g) + 3O_2(g) \leftrightarrow 4NO_2(g)$
   b. $N_2O(g) + {}^3/_2O_2(g) \leftrightarrow 2NO_2(g)$
   c. $4NO_2(g) \leftrightarrow 2N_2O(g) + 3O_2(g)$
3. Put the following K values in order of increasing product-favored ability.
   a. $K = 4x10^{-5}$
   b. $K = 2x10^{-9}$
   c. $K = 7x10^{-5}$
   d. $K = 3x10^{-3}$
4. Which of the following equations does $K_c = K_p$?
   a. $PCl_5(g) \leftrightarrow PCl_3(g) + Cl_2(g)$
   b. $2NOCl(g) \leftrightarrow 2NO(g) + Cl_2(g)$
   c. $CaCO_3(s) \leftrightarrow CaO(s) + CO_3(g)$
   d. $H_2O(g) + CO \leftrightarrow H_2(g) + CO_2(g)$
   e. $2NO(g) \leftrightarrow N_2(g) + O_2(g)$
5. If the mechanism of a chemical equilibrium consists of two reversible elementary steps, each with its own equilibrium constant K_{c1} and K_{c2}, what expression relates the equilibrium constant K_c for the overall equilibrium to the two constants K_{c1} and K_{c2}?
6. Given the following equations:
   $H_2O(g) + CO(g) \leftrightarrow H_2(g) + CO_2(g)$ $K_c = 4.8$
   $FeO(s) + CO(g) \leftrightarrow Fe(s) + CO_2(g)$ $K_c = 0.48$
   Calculate the K_c value for: $Fe(s) + H_2O(g) \leftrightarrow FeO(s) + H_2(g)$ $K_c = ?$ (Ans: 9.984)
7. Consider the equilibrium: $2 SO_2(g) + O_2(g) \leftrightarrow 2 SO_3(g)$ $K_c = 4.36$
   Calculate the value of "Q" for a situation in which $[SO_2] = 2.00M$, $[O_2] = 1.50M$, and $[SO_3] = 1.25M$.
   Does this mixture shift toward the reactants or products to reach equilibrium? ____________________
8. When converting K_c to K_p use the equation $K_p = K_c(RT)^{\Delta n}$. Where $R = 0.0821$, T is in Kelvin, and Δn is the difference in moles of gas between products and reactants ($\Delta n = n_{products} - n_{reactants}$) . Write the K_p expression for the reaction in question (7) and calculate its value at 0^oC.
   (Ans: 0.195)
9. The equation $2NH_3(g) \leftrightarrow N_2(g) + 3H_2(g)$ has a value of $K_c = 2.7x10^{-4}$. At STP, what is the value of K_p? (Ans: 0.136)
10. For the equation, $NH_4I(s) \leftrightarrow NH_3(g) + HI(g)$, the total pressure is 4.2atm at equilibrium. What is K_p?
    (Ans: 4.41)

WS#3: RICE TABLES

1. Consider the equilibrium: $2N_2O(g) + O_2(g) \leftrightarrow 4NO(g)$. 3.00 moles of $NO(g)$ are introduced into a 1.00-Liter evacuated flask. When the system comes to equilibrium, 1.00 mole of $N_2O(g)$ has formed. Determine the equilibrium concentrations of each substance. Calculate the K_c for the reaction based on these data.

	$2 N_2O$	O_2	$4 NO$
initial			
change			
equilibrium			

Remember: The "ice" box may be used with moles, molarity, or Liters (for gaseous equilibria)… never grams.

2. For the equation, $H_2O(g) + CO(g) \leftrightarrow CO_2(g) + H_2(g)$ $K_c = 0.235$. If 2.00 moles of each H_2O and CO are put into a 10.0L container, what is the concentration of all species at equilibrium?(Ans: $[CO_2] = [H_2] = 0.065$; $[H_2O] = [CO] = 0.135$)
3. For the equation, $SO_2Cl_2\ (g) \leftrightarrow SO_2(g) + Cl_2(g)$ $K_p = 4.8$. If enough SO_2Cl_2 is put into a container so its pressure is 8.00atm, what is the equilibrium pressure of all species? What is the total pressure? (Ans: $P_{SO2} = P_{Cl2} = 4.25$atm, $P_{SO2CL2} = 3.75$, $P_T = 12.25$atm.)
4. For the reaction: $PCl_5(g) \leftrightarrow PCl_3(g) + Cl_2(g)$, if the initial pressure of PCl_5 is 2.00atm and at equilibrium it is 15% dissociated, what is K_p? (Ans: 0.0529)
5. Chlorine molecules will dissociate at high temperatures into chlorine atoms. At 3000^oC, for example, K_c for the equilibrium shown is 0.55. If the partial pressure of chlorine molecules is 1.5atm, calculate the partial pressure of the chlorine atoms: $Cl_2(g) \leftrightarrow 2Cl(g)$. (Ans: 15atm)
6. Suppose that 0.50 moles of hydrogen gas, 0.50 moles of iodine gas, and 0.75 moles of hydrogen iodide gas are introduced into a 2.0 Liter vessel and the system is allowed to reach equilibrium. $H_2(g) + I_2(g) \leftrightarrow 2 HI(g)$. Calculate the concentrations of all three substances at equilibrium. At the temperature of the experiment, K_c equals $2.0x10^{-2}$. (Ans: $[H_2] = [I_2] = 0.41M$ and $[HI] = 0.06M$)

7. When 2.0mol of carbon disulfide and 4.0mol of chlorine are placed in a 1.0 Liter flask, the following equilibrium system results. At equilibrium, the flask is found to contain 0.30mol of carbon tetrachloride. What quantities of the other components are present in this equilibrium mixture? $CS_2(g) + 3Cl_2(g) \leftrightarrow S_2Cl_2(g) + CCl_4(g)$ (Ans: $[CS_2] = 1.7M$, $[Cl_2] = 3.1M$, and $[S_2Cl_2] = 0.30M$)
8. 3.0 moles each of carbon monoxide, hydrogen, and carbon are placed in a 2.0 Liter vessel and allowed to come to equilibrium according to the equation: $CO(g) + H_2(g) \leftrightarrow C(s) + H_2O(g)$. If the equilibrium constant at the temperature of the experiment is 4.0, what is the equilibrium concentration of water vapor? (Ans: $[H_2O] = 1.0M$)
9. Nitrosyl chloride NOCl decomposes to nitric oxide and chlorine when heated: $2NOCl(g) \leftrightarrow 2NO(g) + Cl_2(g)$. At 600K, the equilibrium constant K_p is 0.060. In a vessel at 600K, there is a mixture of all three gases. The partial pressure of NOCl is 675torr, the partial pressure of NO is 43torr and the partial pressure of chlorine is 23torr.
   a. What is the value of the reaction quotient? (Ans: 0.093)
   b. Is the mixture at equilibrium? (Ans: no)
   c. In which direction will the system move to reach equilibrium? (Ans: shift to left, $Q > K$)
   d. When the system reaches equilibrium, what will be the partial pressures of the components in the system? (Ans: $P_{NOCl} = 681$torr, $P_{NO} = 37$torr, and $P_{Cl2} = 20.$torr)
10. Sulfuryl chloride decomposes at high temperatures to produce sulfur dioxide and chlorine gases: $SO_2Cl_2(g) \leftrightarrow SO_2(g) + Cl_2(g)$. At 375°C, the equilibrium constant K_c is 0.045. If there are 2.0 grams of sulfuryl chloride, 0.17 gram of sulfur dioxide, and 0.19 grams of chlorine present in a 1.0 Liter flask,
    a. What is the value of the reaction quotient? (Ans: 4.8×10^{-4})
    b. Is the system at equilibrium? (Ans: no)
    c. In which direction will the system move to reach equilibrium? (Ans: $Q < K$, so it will shift right)
11. Ammonium chloride is placed inside a closed vessel where it comes into equilibrium at 400°C according to the equation shown. Only these three substances are present inside the vessel. If K_p for the system at 400°C is 0.640, what is the pressure inside the vessel? $NH_4Cl(s) \leftrightarrow NH_3(g) + HCl(g)$ (Ans: 1.60atm)
12. Bromine and chlorine react to produce bromine monochloride according to the equation, $Br_2(g) + Cl_2(g) \leftrightarrow 2BrCl(g)$ and $K_c = 36.0$ under the conditions of the experiment. If 0.180 moles of bromine gas and 0.180 moles of chlorine gas are introduced into a 3.0 Liter flask and allowed to come to equilibrium, what is the equilibrium concentration of the bromine monochloride? How much BrCl is produced? (Ans: $[BrCl] = 0.090M$ and 0.27 mol)
13. When ammonia is dissolved in water, the following equilibrium is established. If the equilibrium constant is 1.8×10^{-5}, calculate the hydroxide ion concentration in the solution if 0.100mol of ammonia is dissolved in sufficient water to make 500 mL of solution. $NH_3(aq) + H_2O(l) \leftrightarrow NH_4^+(aq) + OH^-(aq)$ (Ans: $0.0019M$)

WS#4: LE CHATELIER'S PRINCIPLE

1. Consider the equilibrium $PCl_3(g) + Cl_2(g) \leftrightarrow PCl_5(g)$.
   How would the following changes affect the partial pressures of each gas at equilibrium?
   (↑ = increase; ↓ = decrease; — = unchanged) $PCl_3(g) + Cl_2(g) \leftrightarrow PCl_5(g)$

	$PCl_3(g)$	$Cl_2(g)$	$PCl_5(g)$
a. addition of PCl_3	____	____	____
b. removal of Cl_2	____	____	____
c. removal of PCl_5	____	____	____
d. decrease in the volume of the container	____	____	____
e. addition of He without change in volume	____	____	____

2. How will each of the changes in question (3) affect the K_{eq}? (↑ = increase; ↓ = decrease; — = unchanged)
   a. ___ b. ___ c. ___ d. ___ e. ___
3. Indicate how each of the following changes affects the amount of each gas in the system below, for which $\Delta H_{reaction} = +9.9$ kcal.
   (↑ = increase; ↓ = decrease; — = unchanged)

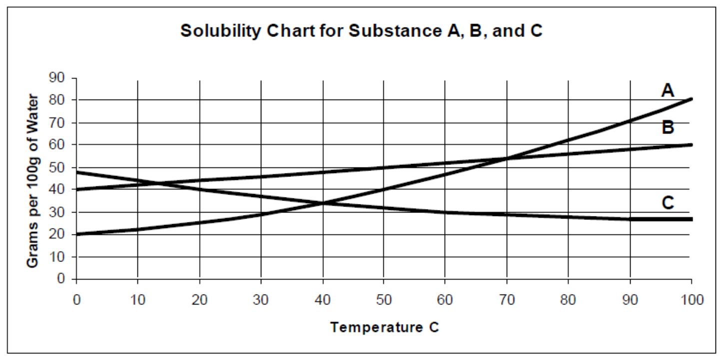
	$H_2(g)$ +	$CO_2(g)$ ↔	$H_2O(g)$ +	$CO(g)$
a. addition of CO_2	___	___	___	___
b. addition of H_2O	___	___	___	___
c. addition of a catalyst	___	___	___	___
d. increase in temperature	___	___	___	___
e. decrease in the volume of the container	___	___	___	___

4. How will each of the changes in question (13) affect the equilibrium constant?
   (↑ = increase; ↓ = decrease; — = unchanged).
   a. ___ b. ___ c. ___ d. ___ e. ___

5. Consider the equilibrium: $2N_2O(g) + O_2(g) \leftrightarrow 4NO(g)$
   How will the amount of chemicals at equilibrium be affected by
   a. adding N_2O ___ ___ ___
   b. removing O_2 ___ ___ ___
   c. increasing the volume of the container ___ ___ ___
   d. adding a catalyst ___ ___ ___
6. For the reaction, $4NH_3(g) + 3O_2(g) \leftrightarrow 2N_2(g) + 6H_2O(l)$
   How will the concentration of each chemical be affected by
   a. adding O_2 to the system ___ ___ ___ ___
   b. adding N_2 to the system ___ ___ ___ ___
   c. removing H_2O from the system ___ ___ ___ ___
   d. decreasing the volume of the container ___ ___ ___ ___
7. The following reaction is exothermic: $Ti(s) + 2\ Cl_2(g) \leftrightarrow TiCl_4(g)$. List all the ways the yield of the product $TiCl_4$ could be increased.

WS#5: Reading a Solubility Curve

Look at the solubility curves on the graph below and then answer the following questions.



1. Which substance is the most soluble at 0°C? At 100°C?
2. How many grams of substance "B" will dissolve in 100g of water at 60°C? How about in 400g of water at the same temperature?
3. Which substance shows the least change in solubility form 0°C – 100°C ?
4. As you increase the temperature of the water, what happens to the solubility of "A"?
5. As you increase the temperature of the water, what happens to the solubility of "B"?
6. As you increase the temperature of the water, what happens to the solubility of "C"?
7. Which substance(s) are probably a solid?
8. Which substance(s) are probably a gas?
9. If you put 40g of "A" into 100g of water at 50°C the solution would be?
10. If you put 40g of "B" into 100g of water at 50°C the solution would be?
11. If you put 40g of "A" into 100g of water at 20°C the solution would be?
12. Describe how to make a supersaturated solution of "B" at 50°C.

WS#6: Solubility, K_{sp}, and Common Ion Effect

Write a net ionic equation and the solubility product expression (K_{sp}) for the following precipitation reaction.

1. Solutions of sodium sulfate and calcium bromide are mixed.
2. Solutions of aluminum (III) acetate and lithium hydroxide are mixed.
3. Solutions of iron (III) sulfate and sodium sulfide are mixed.
4. Solutions of aluminum (III) sulfate and calcium hydroxide are mixed.
5. Solutions of potassium chromate and lead (II) acetate are mixed.
6. Solutions of silver (I) nitrate and ammonium sulfide are mixed.
7. Write the dissociation equation, solubility expression (K_{sp}), and appropriate substitution scenario (x^2, $4x^3$, $27x^4$, or $108x^5$) for the following ionic solids (x^2, $4x^3$, $27x^4$, or $108x^5$).
   a. $CaCO_3$ b. $Al(OH)_3$ c. $Mg_3(PO_4)_2$ d. $Ag_2C_2O_4$
8. Determine the K_{sp} of silver (I) bromide, AgBr, given that its molar solubility is 5.71×10^{-7} moles per liter. (Ans: 3.26×10^{-13})
9. Determine the K_{sp} of zinc (II) bromide ($ZnBr_2$), given that its molar solubility is 2.52×10^{-8} mole per liter.(Ans: 6.40×10^{-23})
10. Silver chloride, AgCl, has a $K_{sp} = 1.77\times10^{-10}$. Calculate its solubility in moles per liter. (Ans: 1.33×10^{-5}mol/L)
11. Aluminum phosphate, $AlPO_4$, has a K_{sp} of 9.83×10^{-21}. What is its molar solubility in pure water? (Ans: 9.91×10^{-11}mol/L)
12. A 100.0mL sample is removed from a sea water solution saturated in MgF_2 at 18°C. The water is completely evaporated from the sample and a 7.6mg deposit of $MgF_2(s)$ is obtained. What is the K_{sp} for MgF_2? (Ans:)
13. Calculate the molar solubility of silver (I) chromate in water at 25°C. Find the K_{sp} for silver (I) chromate in the solubility table. (Ans:)
14. Calculate the solubility of solid $Ca_3(PO_4)_2$ ($K_{sp} = 1.3\times10^{-32}$) in a 0.20$M$ Na_3PO_4 solution. (Ans:)

15. The solubility of $Ce(IO_3)_3$ in a 0.20*M* KIO_3 solution is $4.4x10^{-8}$mol/L. Calculate K_{sp} for $Ce(IO_3)_3$. (Ans:)
16. A solution contains $1.0x10^{-5}$*M* Na_3PO_4. What is the minimum concentration of $AgNO_3$ that would cause precipitation of solid Ag_3PO_4 (K_{sp} = $1.8x10^{-18}$)? (Ans:)
17. A solution is $1x10^{-4}$*M* in NaF, Na_2S, and Na_3PO_4. What would be the order of precipitation as a source of Pb^{2+} is added gradually to the solution? The relevant K_{sp} values are K_{sp} (PbF_2) = $4x10^{-8}$, K_{sp} (PbS) = $7x10^{-29}$, and K_{sp} ($Pb_3(PO_4)_2$) = $1x10^{-54}$. (Ans:)

Answer Key

WS#3

1. NA
2. $4.0x10^{-8}$
3. $7.26x10^{-9}$
4. $6.54x10^{-5}$*M*
5. $1.1x10^{-73}$
6. $3.3x10^{-8}$mol/L
7. $6.4x10^{-8}$mol/L
8. $2.3x10^{-11}$mol/L
9. $3.5x10^{-10}$

WS#4

1. Q_{sp} = $5.32x10^{-10}$, yes a ppt will form
2. $[Mg^{2+}]$ = $2.1x10^{-6}$*M*, $[F^{1-}]$ = $5.50x10^{-2}$*M*
3. $[I^{1-}]$ = $2.6x10^{-3}$*M* for PbI_2 and $[I^{1-}]$ = $5.3x10^{-8}$*M* for CuI; CuI will ppt first
4. $[AgNO_3]$ > $5.6x10^{-5}$*M*
5. PbS(*s*) will ppt first, followed by $Pb_3(PO_4)_2$(*s*) and PbF_2 will ppt last.