(#11-2 #11-1)

Modeling and determining equilibrium of solubility

larger amount on bottom

A salt KOH is dissolved by the following reaction.

lots of ions! $K^+ + OH^{-1} \Leftrightarrow KOH_{(s)}$ $K = \frac{1}{[K^+][OH^-]}$

a. Write out the equilibrium expression

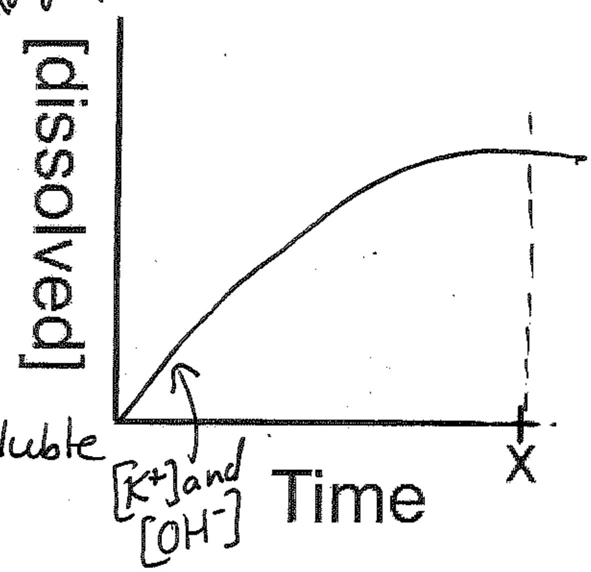
b. What happens to the value of K if this substance is really soluble? K is small

A salt KOH is dissolved by the following reaction.

Use this one! $\boxed{KOH_{(s)} \Leftrightarrow K^+ + OH^{-1}}$ $K = \frac{[K^+][OH^-]}{1}$

a. Write out the equilibrium expression.

b. What happens to the value of K if the substance is really soluble. K is <u>large</u> if really soluble



To allow K to correspond with solubility, industrial scientist who created this method chose to always write the dissolving reaction with the solid on the left as see below. $KOH(s) \Leftrightarrow K^+(aq) + OH^{-1}$ *To distinguish this method they gave it a special name "solubility product"* $Ksp = [K^+][OH^{-1}]$

You take a sample of salt (table) NaCl and you start to dissolve it in water. You continue to add and stir the solution. After a period of time it appears solid is forming on the bottom.

a. Write the (Ksp) solubility equation. $NaCl \Leftrightarrow Na^{+1} + Cl^{-1}$

$Ksp = [Na^{+1}][Cl^-]$

b. This chemical reaction goes to (completion/equilibrium).

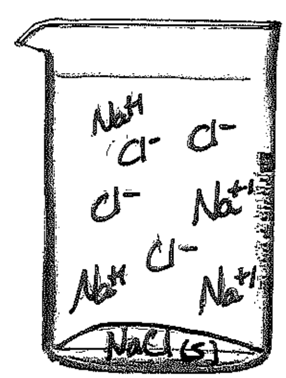
c. To the right draw a picture of table salt dissolving. The reaction gets saturated at time X.

same

d. A student hypothesizes that stirring increases solubility. Confirm or $\boxed{\text{counter}}$ this statement. Stirring will increase the rate of dissolving, but will not affect solubility

e. How might you increase the solubility of table salt in water. increase temperature

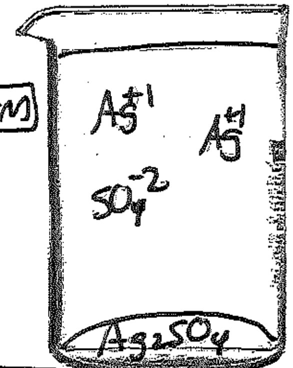
f. Draw the picture of table salt in the beaker to the right at time X.



$\frac{5g}{1} \cdot \frac{1 mol}{311.9g} = 0.016 mol$ $((107.9 \times 2) + 32 + (4 \times 16)$ Ag_2SO_4 $311.9 g/mol$

A student dissolved Ag_2SO_4 in 100mL of water. The student added 5g of silver sulfate to the solution and measured the concentration of SO_4^{-2} to be 0.0135M and solid is on the bottom. Answer the following questions. $0.0135M = \frac{x}{0.1L}$

a. Draw the beaker. $Ag_2SO_4 \rightleftharpoons 2Ag^{+1} + SO_4^{-2}$



100mL

b. Based on your picture, if the $SO4^{-2}$ = 0.0135, what is the $[Ag^{+}]$? $2 \times 0.0135 =$

$[Ag^{+1}]$ will be 2x's the concentration of SO_4^{-2} $\boxed{0.027M}$

c. How might these concentrations change if 5 more grams of solid is added? No Change. The solution is already saturated (solid on bottom)

d. Create an ISE reaction table, Fill it out and determine the K value.

moles in 1L

	$Ag_2SO_4 \rightleftharpoons$	$2Ag^{+1}$	$+ SO_4^{-2}$
I		0	0
S		+0.027	+0.0135
E		0.027	0.0135

$K_{sp} = [Ag^{+1}]^2[SO_4^{-2}]$

$K_{sp} = [0.027]^2[0.0135] = \boxed{9.8E-6}$

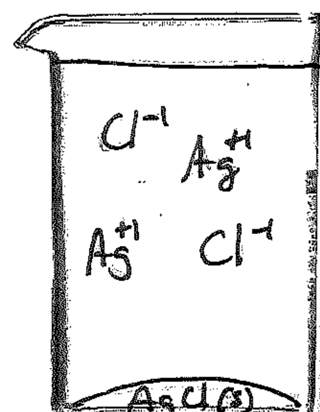
Two salts are dissolving, AgBr (Ksp = 5E-13) and AgCl (Ksp = 1.6E-10), Answer the following questions.

a. Write out the dissolving equation for each.

$AgBr \rightleftharpoons Ag^{+1} + Br^{-1}$ $AgCl \rightleftharpoons Ag^{+1} + Cl^{-1}$

b. Write out the solubility expression.

$K_{sp} = [Ag^{+1}][Br^{-1}]$ $K_{sp} = [Ag^{+1}][Cl^{-1}]$



c. A large K value means what relative to solubility?

A large K means lots of ions (as product) + is very soluble

d. Which of the two salts is more soluble?

Ksp = 1.6E-10 is larger than Ksp = 5E-13

AgCl is more soluble than AgBr

e. Draw a saturated solution of the *more* soluble salt.

AgCl

A student comes across a solution that is saturated solution of lead(II) chloride. The lead ion has a concentration of 1.5E-5M. Answer the following questions.

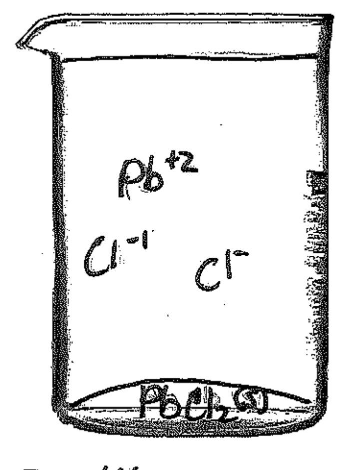
a. Write out the solubility reaction.

$PbCl_{2(s)} \rightleftharpoons Pb^{+2} + 2Cl^{-1}$

x 2x

b. Write out the solubility equilibrium expression.

$K_{sp} = [Pb^{+2}][Cl^{-1}]^2$



c. Draw a picture of this reaction mixture.

d. What is the concentration of the Chloride ion?

$[Pb^{+2}] = 1.5E-5M$

$[Cl^{-1}] = 2(1.5E-5M) = \boxed{3.0E-5M}$

e. What is the equilibrium constant for this reaction?

$K_{sp} = [Pb^{+2}][Cl^{-1}]^2 = [1.5E-5][3.0E-5M]^2 = 1.35E-14$

(#11-2)
Equilibrium: Concentration Determination

1.(brown574) For the Haber process, $N_{2(g)} + 3H_{2(g)} \leftrightarrow 2NH_{3(g)}$ K_p = 1.45E-5 @ 500°C. In an equilibrium mixture of the three gases, the partial pressure of H_2 is 0.928atm and that of N_2 is 0.432 atm.

a. Write the equilibrium expression for the reaction.

$$K_p = \frac{(P_{NH_3})^2}{(P_{N_2})(P_{H_2})^3}$$

$N_2 + 3H_2 \rightleftarrows 2NH_3$

I			
S			
E	0.432	0.928	P_{NH_3}

atm ?

b. What is the partial pressure of NH_3 in this equilibrium mixture?

$$1.45E\text{-}5 = \frac{(P_{NH_3})^2}{(0.432)(.928)^3}$$

$(P_{NH_3})^2 = (1.45E\text{-}5)(0.432)(0.928)^3$ $\sqrt{(P_{NH_3})^2} = \sqrt{5.0E\text{-}6}$ $\boxed{P_{NH_3} = 0.0022 \text{ atm}}$

2. Nitrogen gas is mixed with oxygen gas to from nitrogen monoxide. (gas)

$N_2 + O_2 \leftrightarrow 2NO$ Kc 4.1 E-4

In a 2L rigid tank, 0.5mol of $N_2$is mixed with 0.86 mol of O_2 gas at 2000.K. The two gases react forming an equilibrium.

a. Write out the equilibrium expression. $K_c = \frac{[NO]^2}{[N_2][O_2]}$

Completion (moles)

	N_2 +	O_2 →	2NO
I	0.5	0.86	0
S	-0.5	-0.5	+1.0
E	0	0.36	1.0

b. If this reaction were to go to completion, what is the value of "x"?

X is the Stoich. Change "S" or Shift $X = 0.5$

c. Based upon the size of K the value of "x" is (big, small, very small)?

$K_c = 4.1E\text{-}4$ Reactant Favored very small

Equilibrium (moles in 1L (also M))

	N_2 +	O_2 →	2NO
I	0.25	0.43	
S	-x	-x	+2x
E	0.25-x	0.43-x	2x

negligible

d. Determine the final concentrations of each species at equilibrium.

$K_c = \frac{[NO]^2}{[N_2][O_2]}$ $\frac{(4.1E\text{-}4)(0.25)(0.43)}{4} = \frac{4x^2}{4}$

$4.1E\text{-}4 = \frac{(2x)^2}{(0.25)(0.43)}$ $\sqrt{x^2} = \sqrt{1.1E\text{-}5}$ $x = 0.0033$ $[NO] = 2x = 2(0.0033) = \boxed{0.0066M\ NO}$

3. The reversible reaction $CH_{4(g)} + H_2O_{(g)} \leftrightarrow CO_{(g)} + 3H_{2(g)}$ has been used as a commercial source of hydrogen. At 1500°C, an equilibrium mixture of these gases was found to have the following concentrations: [CO] = 0.300M, [H_2] = 0.800M, [CH_4] = 0.400M. At 1500°C Kc = 5.67 for this reaction.

$CH_4 + H_2O \rightleftarrows CO + 3H_2$

	CH_4	H_2O	CO	$3H_2$
I				
S				
E	0.400		0.300	0.800

a. Write the equilibrium expression. $K_c = \frac{[CO][H_2]^3}{[CH_4][H_2O]}$

b. If this reaction went to completion, how big would "x" be? "x" is the variable in the ISE table.

c. Does this reaction go to an equilibrium? yes -- it has a value for K_c

d. Approximate the size of "x", can this value be ignored in the ISE table (use the short cut rule).

Solve for ~~Kc~~ $[H_2O]$

e. Solve for "x", using the quadratic if you can. Otherwise set it up for the quadratic.
What was the equilibrium concentration of $H_2O_{(g)}$ in this mixture?

$K_c = 5.67 = \frac{(0.3)(0.8)^3}{(0.4)\,x}$ $x = \frac{(0.3)(0.8)^3}{(5.67)(0.4)} = 0.068M\ H_2O$

(#11-2)
Equilibrium: K Determination

1. (brown570) A mixture of Hydrogen and nitrogen in a reaction vessel is allowed to attain equilibrium at 472°C. The equilibrium mixture of gases was analyzed and found to contain 0.1207M H_2, 0.0402M N_2, and 0.00272 MNH_3. From this data calculate the equilibrium constant Kc for $N_{2(g)} + 3H_{2(g)} \leftrightarrow 2NH_{3(g)}$

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(0.00272)^2}{(0.0402)(0.1207)^3}$$

I			
S			
E	0.0402	0.1207	0.00272

← moles in 1L

$K_c = 0.105$

2. (brown 571)A mixture of 5.000x 10^{-3} mol of H_2 and 1.000 x 10^{-2} mol of I_2 is placed in 5.000L container at 448°C and allowed to come to equilibrium. Analysis of the equilibrium mixture shows that the concentration of HI is 1.87E-3M. Calculate K_c at 448°C for the reaction

$H_{2(g)} + I_{2(g)} \leftrightarrow 2HI_{(g)}$

$[H_2] = \frac{5.000E3}{5L} = 1.000E\text{-}3M$

$[I_2]\ \frac{1.000E\text{-}2}{5L} = 2.000E\text{-}3M$

$$K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{(1.87E\text{-}3)^2}{(6.5E\text{-}5)(1.065E\text{-}3)} = \boxed{50.5}$$

moles in 1L

	$H_2(g)$	+ $I_2(g)$	$\leftrightarrow 2HI(g)$
I	1.000E-3	2.000E-3	
S	$-x$ (-9.35E-4)	$-x$ (-9.35E-4)	$+2x$ (1.87E-3)
E	6.5E-5	1.065E-3	1.87E-3

$2x = 1.87E\text{-}3 \quad x = 9.35E\text{-}4$

3. A reaction mixture of three gases, A, B, and C are all 1.0 M at 200K. The reaction below runs for a period of time and forms an equilibrium balance where a little solid formed on the bottom. The concentration of A at equilibrium is .5M.

$2A_{(g)} + B_{(g)} \leftrightarrow C_{(g)} + D_{(s)}$

a. Write the equilibrium expression. $K_c = \frac{[C]}{[A]^2[B]}$
b. Complete an ISE table below the equation.
c. Determine K.

	$2A_{(g)}$	$B_{(g)}$	$C_{(g)}$	$D_{(s)}$
I	1M	1M	1M	
S	$-2x$ (0.5)	$-x$ (0.25)	$+x$ (0.25)	
E	0.5	0.75	1.25	

moles in 1L

no Molarity for solid

$2x = 0.5$
$x = 0.25$

$$K_c = \frac{(1.25)}{(0.5)^2(0.75)} = 6.67$$

4. The following reaction goes to equilibrium at 500K.
Original pressure of A is .55atm and reduces to .15atm at equilibrium.

$A_{(g)} \leftrightarrow 2B_{(g)} + C_{(s)}$

a. Write the Kp equilibrium expression. $K_p = \frac{(P_B)^2}{(P_A)}$

b. Complete an ICE table below the reaction.

P in atm

	$A_{(g)}$	$2B_{(g)}$	$C_{(s)}$
I	0.55	0	
S	$-x$	$+2x$	
E	0.15	0.8	

$0.55 - x = 0.15$
$x = 0.4$
$2x = 0.8$

c. Determine Kp. $K_p = \frac{(0.8)^2}{0.15} = 4.3$

d. (Challenge) If the container is 1L in size, determine the mass of C (carbon) produced at equilibrium?

$PV = nRT$ (n_B)

$P_B = 0.8\,atm$
$V = 1L$
$R = 0.0821 \frac{atm \cdot L}{mol \cdot K}$
$T = 500K$
$n_B = ?$

$(0.8)(1L) = n_B(0.0821)(500)$

$n_B = \frac{(0.8)(1L)}{(0.0821)(500)} = 0.019$ mol B

$0.019\text{ mol B} \times \frac{1C}{2B} = 0.0095$ mol Carbon

Stoich ratio

$0.0095\text{ mol C} \times \frac{12g}{1mol} = \boxed{0.11g\ C}$

Equilibrium Quiz prep

$$A(s) + 2B(aq) \Leftrightarrow C(aq) \quad 200°C$$

1. For the reaction listed above the concentrations at equilibrium of B = 0.5M and C = 0.25M and solid A. Determine Kc for the reaction.

$K_c = \frac{[C]}{[B]^2} = \frac{(0.25)}{(0.5)^2} = 1$

	$A(s) + 2B(aq) \Leftrightarrow$	$C(aq)$
I		
S		
E	0.5	0.25

moles in 1L

2. For the reaction given above at 200°C, the concentration of C = 0.5M. What must be the concentration of B?

$\boxed{\text{same reaction at same temp} \therefore \text{same } K_c}$

$K = 1 = \frac{(0.5)}{[B]^2}$ $\sqrt{[B]^2} = \sqrt{0.5}$

$[B] = 0.71 M$

3. In a different experiment, the reaction above is run at 300C with 0.2M of B, 0.2M of C, and some solid A are placed in a container. After a period of time, the concentration of C = 0.15M.

	$A(s) + 2B(aq) \Leftrightarrow$	$C(aq)$
I	0.2	0.2
S	$+x = +0.1$	$-x = -0.05$
E	0.3	0.15

mol in 1L

a. What is the reaction quotient?

$Q = \frac{[C]}{[B]^2} = \frac{(.2)}{(.2)^2} = 5$

b. What is the concentration of B at equilibrium?

0.3M (see ISE) →

c. What is the K value at this new temperature?

$K = \frac{[C]}{[B]^2} = \frac{(0.15)}{(0.3)^2} = 1.67$

4. At very low temperatures the reaction above has a K value equaling 1.5E-4.

a. Is this reactant or product favored?

1.5E-4 is less than 1, reactant favored

b. If the 0.5M B is placed in a beaker determine the

$K = 1.5E-4 = \frac{x}{(0.5)^2}$ $x = 3.75E-5$

i. Concentration of B and C at equilibrium

$[B] = 0.5M$ $[C] = x = 3.75E-5M$

	$A(s) + 2B(aq) \Leftrightarrow$	$C(aq)$
I	0.5	0
S	$-2x$	$+x$
E	$0.5 - 2x$	x

negligible

5. Silver sulfate(Ag_2SO_4) is dissolved in water.

a. Write out the solubility reaction.

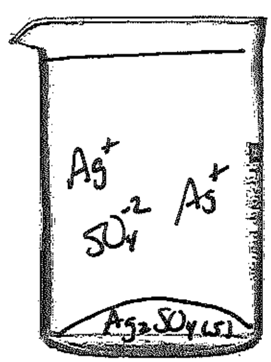
b. Draw the reaction equilibrium in the beaker to the right.

c. If the concentration of SO_4^{-2} = X, what is the concentration of Ag^+ ions?

d. With the variables in "c" solve for Ksp.

a. → $Ag_2SO_{4(s)} \rightleftharpoons 2Ag^{+1} + SO_4^{-2}$

I			
S		$+2x$	$+x$
E		$2x$	x



c. If $[SO_4^{-2}] = x$, then $[Ag^{+1}] = 2x$

d. $K_{sp} = [Ag^{+1}]^2[SO_4^{-2}] = (2x)^2 \cdot x$

$= 4x^2 \cdot x = 4x^3$