Chapter 7.6
Solubility Equilibria and the Solubility Product Constant

Learning Goals: I will be able to …

1. **identify** solubility product constant, K_{sp}, and write the expression for it
2. **solve** problems related to solubility equilibrium by **performing** calculations involving concentrations of reactants and products
3. **predict** whether a precipitate will form when two solutions are mixed
4. **predict** the equilibrium shift when a common ion is added to an equilibrium system

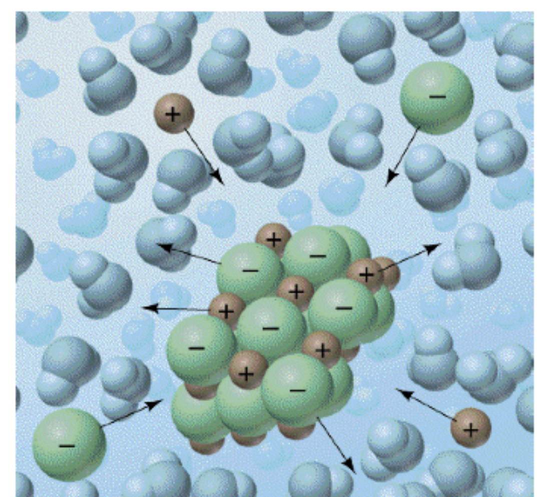
Solubility Equilibria of Ionic Compounds

- **Solubility** is the quantity of solute that dissolves in a given quantity of solvent at a particular temperature
- A **solubility equilibrium** is a dynamic equilibrium between a solute and a solvent in a saturated solution in a closed system

$$AgI(s) \rightleftharpoons Ag^{+}(aq) + I^{-}(aq)$$

Saturated Solution

Figure 1.1 Figure 1.2 Figure 1.3



The Solubility Product Constant (K_{sp})

- The **Solubility Product Constant (K_{sp})** is the value obtained from the equilibrium law applied to a saturated solution

$$AgI_{(s)} \rightleftharpoons Ag^{+}_{(aq)} + I^{-}_{(aq)}$$

In any solubility equilibrium, the reactant is a solid

$$K = \frac{[Ag^{+}_{(aq)}][I^{-}_{(aq)}]}{[AgI_{(s)}]}$$

Remember: solids are not included in the equilibrium law because their concentrations do not change

$$K_{sp} = [Ag^{+}_{(aq)}][I^{-}_{(aq)}]$$

The K_{sp} of $AgI_{(s)}$ is 8.3×10^{-17} at 25°C

Table 16.2 Solubility Products of Some Slightly Soluble Ionic Compounds at 25°C

Compound	K_{sp}	Compound	K_{sp}
Aluminum hydroxide [$Al(OH)_3$]	1.8×10^{-33}	Lead(II) chromate ($PbCrO_4$)	2.0×10^{-14}
Barium carbonate ($BaCO_3$)	8.1×10^{-9}	Lead(II) fluoride (PbF_2)	4.1×10^{-8}
Barium fluoride (BaF_2)	1.7×10^{-6}	Lead(II) iodide (PbI_2)	1.4×10^{-8}
Barium sulfate ($BaSO_4$)	1.1×10^{-10}	Lead(II) sulfide (PbS)	3.4×10^{-28}
Bismuth sulfide (Bi_2S_3)	1.6×10^{-72}	Magnesium carbonate ($MgCO_3$)	4.0×10^{-5}
Cadmium sulfide (CdS)	8.0×10^{-28}	Magnesium hydroxide [$Mg(OH)_2$]	1.2×10^{-11}
Calcium carbonate ($CaCO_3$)	8.7×10^{-9}	Manganese(II) sulfide (MnS)	3.0×10^{-14}
Calcium fluoride (CaF_2)	4.0×10^{-11}	Mercury(I) chloride (Hg_2Cl_2)	3.5×10^{-18}
Calcium hydroxide [$Ca(OH)_2$]	8.0×10^{-6}	Mercury(II) sulfide (HgS)	4.0×10^{-54}
Calcium phosphate [$Ca_3(PO_4)_2$]	1.2×10^{-26}	Nickel(II) sulfide (NiS)	1.4×10^{-24}
Chromium(III) hydroxide [$Cr(OH)_3$]	3.0×10^{-29}	Silver bromide ($AgBr$)	7.7×10^{-13}
Cobalt(II) sulfide (CoS)	4.0×10^{-21}	Silver carbonate (Ag_2CO_3)	8.1×10^{-12}
Copper(I) bromide ($CuBr$)	4.2×10^{-8}	Silver chloride ($AgCl$)	1.6×10^{-10}
Copper(I) iodide (CuI)	5.1×10^{-12}	Silver iodide (AgI)	8.3×10^{-17}
Copper(II) hydroxide [$Cu(OH)_2$]	2.2×10^{-20}	Silver sulfate (Ag_2SO_4)	1.4×10^{-5}
Copper(II) sulfide (CuS)	6.0×10^{-37}	Silver sulfide (Ag_2S)	6.0×10^{-51}
Iron(II) hydroxide [$Fe(OH)_2$]	1.6×10^{-14}	Strontium carbonate ($SrCO_3$)	1.6×10^{-9}
Iron(III) hydroxide [$Fe(OH)_3$]	1.1×10^{-36}	Strontium sulfate ($SrSO_4$)	3.8×10^{-7}
Iron(II) sulfide (FeS)	6.0×10^{-19}	Tin(II) sulfide (SnS)	1.0×10^{-26}
Lead(II) carbonate ($PbCO_3$)	3.3×10^{-14}	Zinc hydroxide [$Zn(OH)_2$]	1.8×10^{-14}
Lead(II) chloride ($PbCl_2$)	2.4×10^{-4}	Zinc sulfide (ZnS)	3.0×10^{-23}

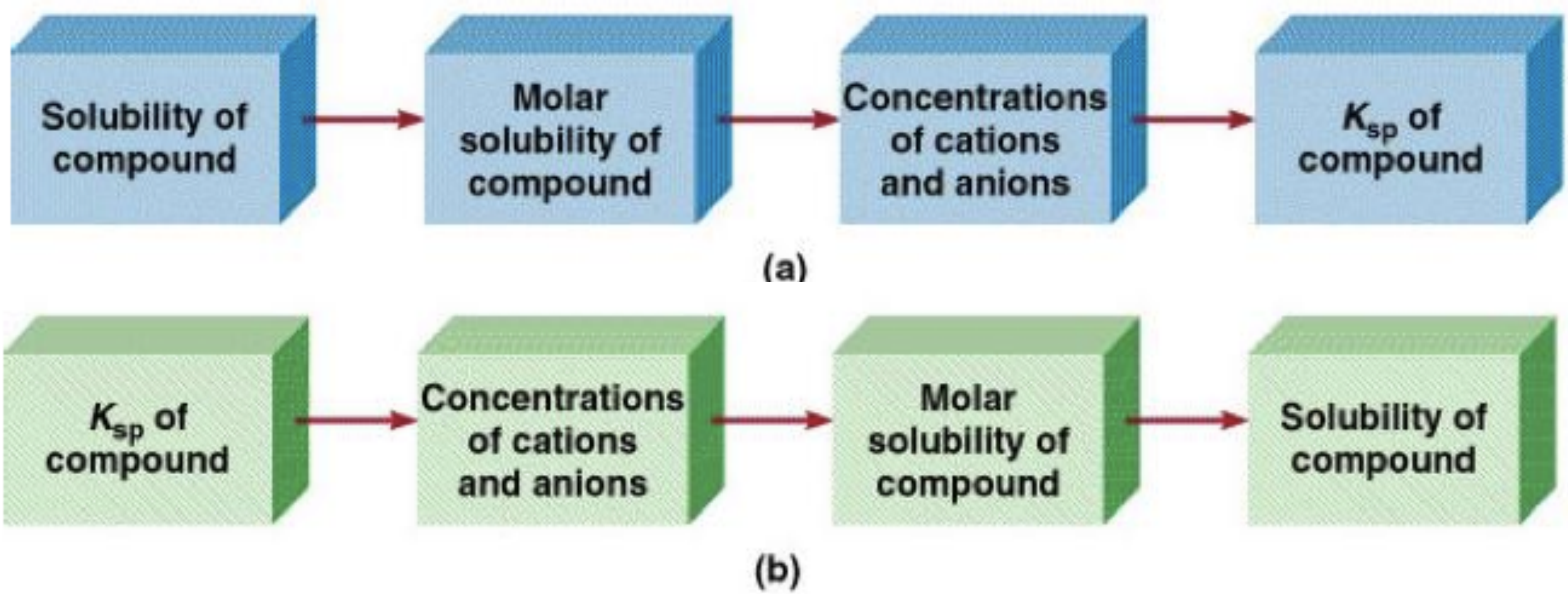
K_{sp} values for a number of different solids are found in your textbook on page 725

Practice

- Write the solubility product constant equation for each of the following:
  a) $MgF_{2(s)} \rightleftharpoons Mg^{2+}{}_{(aq)} + 2F^{-}{}_{(aq)}$
  b) $Ag_2CO_{3(s)} \rightleftharpoons 2Ag^{+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$
  c) $Ca_3(PO_4)_{2(s)} \rightleftharpoons 3Ca^{2+}{}_{(aq)} + 2PO_4{}^{3-}{}_{(aq)}$

Solubility and the Solubility Product Constant

- Solubility can be expressed in two ways:
  1. **Molar solubility** is the number of <u>*moles*</u> of solute dissolved in a given volume of a saturated solution
  2. **Mass per volume Solubility** is the number of <u>*grams*</u> of solute dissolved in a given volume of a saturated solution
- It is possible to convert between either solubility and



Example 1

The molar solubility of $Pb_3(PO_4)_2$ is 6.2 x 10^{-12} mol/L. Calculate the K_{sp} value.

Example 2

What is the solubility of silver chloride in g/L if $K_{sp} = 1.6 \times 10^{-10}$?

Predicting Precipitation

- Last year, we used solubility tables, like the one below to predict whether two solutions would form a precipitate

Table 3 Solubility of Some Ionic Compounds at SATP

	Cations	
Anions	**high solubility $\geq$ 0.1 mol/L at SATP**	**low solubility < 0.1 mol/L at SATP**
F^-	most	Li^+, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Fe^{2+}, Hg_2^{2+}, Pb^{2+}
Cl^-, Br^-, I^-	most	Ag^+, Pb^{2+}, Tl^+, Hg_2^{2+}, Hg^+, Cu^+
S^{2-}	Group 1, Group 2, NH_4^+	most
OH^-	Group 1, NH_4^+, Sr^{2+}, Ba^{2+}, Tl^+	most
SO_4^{2-}	most	Ag^+, Pb^{2+}, Ca^{2+}, Ba^{2+}, Sr^{2+}, Ra^{2+}
CO_3^{2-}, PO_4^{3-}, SO_3^{2-}	Group 1, NH_4^+	most
$C_2H_3O_2^-$	most	Ag^+
NO_3^-	all	none
IO_3^-	NH_4^+, K^+, Na^+	most

- Ex: copper (II) nitrate + magnesium chloride $\rightarrow$

The Trial Ion Product (Q)

- When we know the concentrations of ions in aqueous solution, we can use a *quantitative* method to predict whether a precipitate will form
- The **trial ion product (Q)** is the concentration of ions in a specific solution raised to powers equal to their coefficients in a balanced chemical equation (essentially it is the reaction quotient for a solubility equilibrium)
- The trial ion product can be compared to the solubility product constant (K_{sp}) to determine whether a precipitate will form

$$CaF_2(s) \rightleftharpoons Ca^{2+}(aq) + 2\,F^-(aq) \qquad Q = [Ca^{2+}(aq)][F^-(aq)]^2$$

If $Q < K_{sp}$

If $Q = K_{sp}$

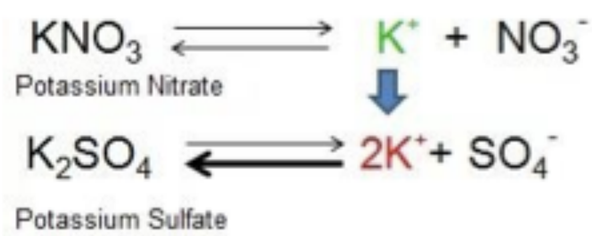
If $Q > K_{sp}$

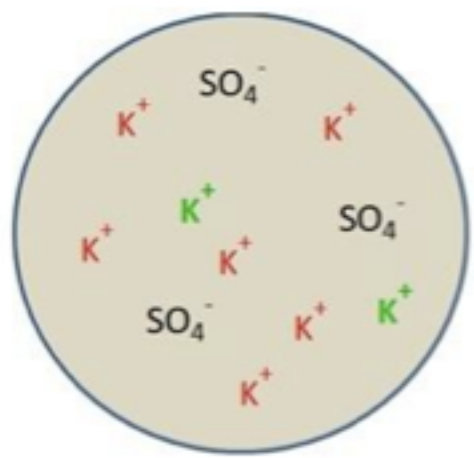
Example 3

- If 2.00 mL of 0.200 M NaOH are added to 1.00 L of 0.100 M $CaCl_2$, will a precipitate of $Ca(OH)_2$ form? K_{sp} of $Ca(OH)_2 = 8.0 \times 10^{-6}$

The Common Ion Effect

- The common ion effect is a reduction in the solubility of an ionic compound due to the presence of a common ion in solution





Example 4

- What is the molar solubility of AgBr in

a) Pure water?

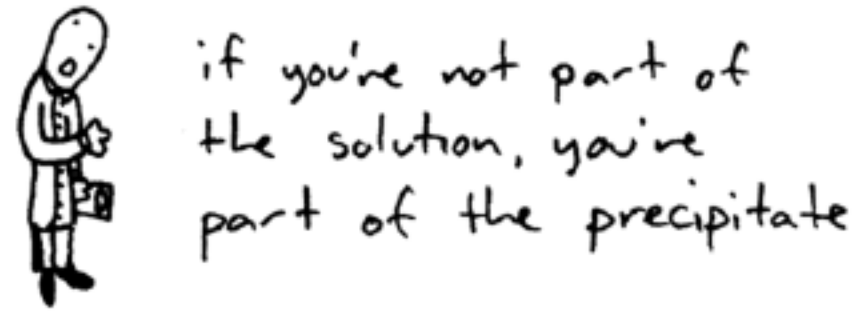
b) 0.0010 M NaBr?

HOMEWORK

Required Reading:

p. 460 – 471

(remember to supplement your notes!)



Questions:

P. 462 #1-3

P. 464 #1-4

P. 468 #1-4

P. 470 #1-3