# Solubility Equilibria and the Solubility Product Constant

Chapter 7.6

#### 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

$$AgI(s) \Longrightarrow Ag^+(aq) + I^-(aq)$$

Saturated Solution



Figure 1.1



Figure 1.2



Figure 1.3



## The Solubility Product Constant (K<sub>sp</sub>)

The Solubility Product Constant (K<sub>sp</sub>) is the value obtained from the equilibrium law applied to a saturated solution

$$AgI(s) \Longrightarrow Ag^+(aq) + I^-(aq)$$

In any solubility equilibrium, the reactant is a solid <sup>(</sup>

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

 $K_{\rm sp} = \lfloor {\rm Ag}^+({\rm aq}) \rfloor \lfloor {\rm I}^-({\rm aq}) \rfloor$ 

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

Compound	K <sub>sp</sub>	Compound	K <sub>sp</sub>
Aluminum hydroxide [Al(OH) <sub>3</sub> ]	$1.8  imes 10^{-33}$	Lead(II) chromate (PbCrO <sub>4</sub> )	$2.0  imes 10^{-14}$
Barium carbonate (BaCO <sub>3</sub> )	$8.1 imes10^{-9}$	Lead(II) fluoride (PbF <sub>2</sub> )	$4.1 imes10^{-8}$
Barium fluoride (BaF <sub>2</sub> )	$1.7  imes 10^{-6}$	Lead(II) iodide (PbI <sub>2</sub> )	$1.4 imes10^{-8}$
Barium sulfate (BaSO <sub>4</sub> )	$1.1  imes 10^{-10}$	Lead(II) sulfide (PbS)	$3.4 imes10^{-28}$
Bismuth sulfide (Bi <sub>2</sub> S <sub>3</sub> )	$1.6  imes 10^{-72}$	Magnesium carbonate (MgCO₃)	$4.0 imes10^{-5}$
Cadmium sulfide (CdS)	$8.0  imes 10^{-28}$	Magnesium hydroxide [Mg(OH) <sub>2</sub> ]	$1.2  imes 10^{-11}$
Calcium carbonate (CaCO <sub>3</sub> )	$8.7 imes10^{-9}$	Manganese(II) sulfide (MnS)	$3.0 imes10^{-14}$
Calcium fluoride (CaF <sub>2</sub> )	$4.0  imes 10^{-11}$	Mercury(I) chloride (Hg <sub>2</sub> Cl <sub>2</sub> )	$3.5  imes 10^{-18}$
Calcium hydroxide [Ca(OH) <sub>2</sub> ]	$8.0 imes10^{-6}$	Mercury(II) sulfide (HgS)	$4.0 imes10^{-54}$
Calcium phosphate $[Ca_3(PO_4)_2]$	$1.2  imes 10^{-26}$	Nickel(II) sulfide (NiS)	$1.4  imes 10^{-24}$
Chromium(III) hydroxide [Cr(OH) <sub>3</sub> ]	$3.0  imes 10^{-29}$	Silver bromide (AgBr)	$7.7  imes 10^{-13}$
Cobalt(II) sulfide (CoS)	$4.0  imes 10^{-21}$	Silver carbonate ( $Ag_2CO_3$ )	$8.1  imes 10^{-12}$
Copper(I) bromide (CuBr)	$4.2 imes10^{-8}$	Silver chloride (AgCl)	$1.6 imes10^{-10}$
Copper(l) iodide (Cul)	$5.1  imes 10^{-12}$	Silver iodide (AgI)	$8.3  imes 10^{-17}$
Copper(II) hydroxide [Cu(OH) <sub>2</sub> ]	$2.2  imes 10^{-20}$	Silver sulfate (Ag <sub>2</sub> SO <sub>4</sub> )	$1.4 imes10^{-5}$
Copper(II) sulfide (CuS)	$6.0  imes 10^{-37}$	Silver sulfide (Ag <sub>2</sub> S)	$6.0 imes10^{-51}$
Iron(II) hydroxide [Fe(OH) <sub>2</sub> ]	$1.6  imes 10^{-14}$	Strontium carbonate (SrCO <sub>3</sub> )	$1.6 imes10^{-9}$
lron(III) hydroxide [Fe(OH)₃]	$1.1  imes 10^{-36}$	Strontium sulfate (SrSO <sub>4</sub> )	$3.8 imes10^{-7}$
lron(II) sulfide (FeS)	$6.0  imes 10^{-19}$	Tin(II) sulfide (SnS)	$1.0  imes 10^{-26}$
Lead(II) carbonate (PbCO <sub>3</sub> )	$3.3  imes 10^{-14}$	Zinc hydroxide [Zn(OH) <sub>2</sub> ]	$1.8  imes 10^{-14}$
Lead(II) chloride (PbCl <sub>2</sub> )	$2.4 imes10^{-4}$	Zinc sulfide (ZnS)	$3.0  imes 10^{-23}$

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

 $K_{sp}$  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 *moles* of solute dissolved in a given volume of a saturated solution
  - 2) Mass per Volume Solubility is the number of *grams* of solute dissolved in a given volume of a saturated solution
- It is possible to convert between either solubility and K<sub>sp</sub>



The molar solubility of Pb<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub> is 6.2 x 10<sup>-12</sup> mol/L.
 Calculate the K<sub>sp</sub> value.

• 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

	Cations		
Anions	high solubility $\geq 0.1 \text{ mol/L}$ at SATP	low solubility < 0.1 mol/L at SATP	
F⁻	most	Li <sup>+</sup> , Mg <sup>2+</sup> , Ca <sup>2+</sup> , Sr <sup>2+</sup> , Ba <sup>2+</sup> , Fe <sup>2+</sup> , Hg <sub>2</sub> <sup>2+</sup> , Pb <sup>2+</sup>	
CI-, Br-, I-	most	$\begin{array}{l} Ag^{+}, Pb^{2+}, TI^{+}, H{g_{2}}^{2+}, \\ Hg^{+}, Cu^{+} \end{array}$	
S <sup>2-</sup>	Group 1, Group 2, $NH_4^+$	most	
OH-	Group 1, $NH_4^+$ , $Sr^{2+}$ , $Ba^{2+}$ , $TI^+$	most	
S04 <sup>2-</sup>	most	$Ag^{+}$ , $Pb^{2+}$ , $Ca^{2+}$ , $Ba^{2+}$ , $Sr^{2+}$ , $Ra^{2+}$	
CO <sub>3</sub> <sup>2-</sup> , PO <sub>4</sub> <sup>3-</sup> , SO <sub>3</sub> <sup>2-</sup>	Group 1, NH <sub>4</sub> <sup>+</sup>	most	
$C_2H_3O_2^-$	most	Ag <sup>+</sup>	
NO <sub>3</sub> <sup>-</sup>	all	none	
10 <sub>3</sub> <sup>-</sup>	$\rm NH_4^+, \rm K^+, \rm Na^+$	most	

Table 3 Solubility of Some Ionic Compounds at SATP

• 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<sub>sp</sub>) to determine whether a precipitate will form

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

$$If Q < K_{sp}$$

$$If Q = K_{sp}$$

$$If Q > K_{sp}$$

• If 2.00 mL of 0.200 *M* NaOH are added to 1.00 L of 0.100 *M* CaCl<sub>2</sub>, will a precipitate of Ca(OH)<sub>2</sub>form?  $K_{sp}$  of Ca(OH)<sub>2</sub> = 8.0 x 10<sup>-6</sup>

## 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







- 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
- p. 471 #1-11



if you're not part of the solution, you're part of the precipitate