Equilibrium 9.7

The Solubility Product Constant (K_{sp})
Predicting Precipitates

The Solubility Product (K_{sp})

- This is K_{eq} for ionic compounds in water.

$$CaCO_{3(s)} \rightleftharpoons Ca^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)}$$
$$\boldsymbol{K_{sp} = [Ca^{2+}]\,[CO_3^{2-}]}$$

$$PbCl_{2(s)} \rightleftharpoons Pb^{2+}_{(aq)} + 2Cl^{-}_{(aq)}$$
$$\boldsymbol{K_{sp} = [Pb^{2+}]\,[Cl^{-}]^2}$$

Solubility

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

- The solubility is the maximum molar concentration of formula units that will dissolve at a given temperature.
  - For every 1 mole of $PbCl_{2(s)}$ that dissolves, 1 mole of $Pb^{2+}_{(aq)}$ ions and 2 moles of $Cl^{-}_{(aq)}$ ions enter the solution.
  - Solubility of $PbCl_2$ = $[Pb^{2+}]$ = ½ $[Cl^{-}]$
    - when the **solution is saturated**.

Ex1) Solubility Product (K_{sp})

Ex1) The solubility product constant for lead (II) fluoride is 3.6×10^{-8} at 25°C.

a) Write the balanced chemical equation.
b) Write the equilibrium expression.
c) Find the maximum molar concentrations of the ions in solution and the molar solubility of the solution.

Ex1) Solubility Product (cont.)

a)

b)

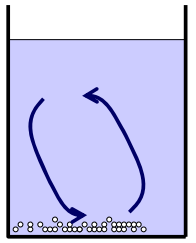
c)

Saturation and Equilibrium

- **Saturated Solution**
  - The solvent has dissolved the maximum amount of solute that is can at a certain temperature, and some solid solute remains on the bottom.

- **A solution is at equilibrium when it is saturated.**

A Saturated Solution is at Equilibrium



$AB_{(s)} \rightleftharpoons A^+_{(aq)} + B^-_{(aq)}$

In a saturated solution, an equilibrium is created between the solid and aqueous states.

Solids are constantly dissolving to form aqueous components, and aqueous components are solidifying at the same rate.

Q and K_{sp}

If $Q = K_{sp}$

- The system is at equilibrium.
- It is a saturated solution with solid and aqueous species.

If $Q > K_{sp}$, a precipitate will form.

- The reaction will proceed to the left until the system reaches equilibrium.

If $Q < K_{sp}$, no precipitate forms.

- The solution is unsaturated.
- All of the ions will remain in solution.

Ex1) Predicting Possible Precipitates

a) Find K_{sp} for a saturated solution of $PbCl_2$ if the concentration of $Cl^-_{(aq)}$ is found to be 0.0325 *M*.

b) Will a precipitate of $PbCl_2$ form when 200.0mL of 3.78 x 10^{-2} *M* NaCl is mixed with 100.0mL of 2.45 x 10^{-2} *M* $Pb(NO_3)_2$. Assume that the temperature of the resulting solution is the same as that from part a.

Ex1) Predicting Possible Precipitates

a) $PbCl_{2(s)} \rightleftharpoons Pb^{2+}_{(aq)} + 2\ Cl^-_{(aq)}$

Ex1) Predicting Possible Precipitates

b) Step 1, Find $[Cl^-]$

Ex1) Predicting Possible Precipitates

b) Step 2, Find $[Pb^{2+}]$

Ex1) Predicting Possible Precipitates

b) Step 3, Find *Q* for the lead (II) chloride solution

Ex2) Predicting Precipitates

Ex2) If 0.15 *M* NaOH is slowly poured into a beaker containing 0.14 *M* $Ca(NO_3)_2$ and 0.25 *M* $Fe(NO_3)_2$, which precipitate will form first?

K_{sp} for $Ca(OH)_2 = 8.0 \times 10^{-6}$
K_{sp} for $Fe(OH)_2 = 1.6 \times 10^{-14}$

Ex2) Predicting Precipitates (cont.)

$Ca(OH)_{2(s)} \rightleftharpoons Ca^{2+}_{(aq)} + 2\ OH^-_{(aq)}$

Step 1) Find $[OH^-]_{max}$ for $Ca(OH)_2$

Ex2) Predicting Precipitates (cont.)

$Fe(OH)_{2(s)} \rightleftharpoons Fe^{2+}_{(aq)} + 2\ OH^-_{(aq)}$

Step 2) Find $[OH^-]_{max}$ for $Fe(OH)_2$