Skills to Develop

- Quantitatively related $\langle K_{\text{sp}} \rangle$ to solubility

Considering the relation between solubility and $\langle K_{\text{sq}} \rangle$ is important when describing the solubility of slightly ionic compounds. However, this article discusses ionic compounds that are difficult to dissolve; they are considered "slightly soluble" or "almost insoluble." Solubility product constants $\langle K_{\text{sq}} \rangle$ are given to those solutes, and these constants can be used to find the molar solubility of the compounds that make the solute. This relationship also facilitates finding the $\langle K_{\text{sq}} \rangle$ of a slightly soluble solute from its solubility.

Introduction

Recall that the definition of *solubility* is the maximum possible concentration of a solute in a solution at a given temperature and pressure. We can determine the solubility product of a slightly soluble solid from that measure of its solubility at a given temperature and pressure, provided that the only significant reaction that occurs when the solid dissolves is its dissociation into solvated ions, that is, the only equilibrium involved is:

$$\ce{M_pX_q(s) \rightleftharpoons pM^{m+}(aq) + qX^{n-}(aq)}$$

In this case, we calculate the solubility product by taking the solid’s solubility expressed in units of moles per liter (mol/L), known as its molar solubility.

Example \(\PageIndex{1}\): Calculation of $K_{\text{sp}}$ from Equilibrium Concentrations

We began the chapter with an informal discussion of how the mineral fluorite is formed. Fluorite, CaF$_2$, is a slightly soluble solid that dissolves according to the equation:

$$\ce{CaF2(s) \rightleftharpoons Ca^{2+}(aq) + 2F^-(aq)}$$

The concentration of Ca$^{2+}$ in a saturated solution of CaF$_2$ is $2.1 \times 10^{-4}$ M; therefore, that of F$^-$ is $4.2 \times 10^{-4}$ M, that is, twice the concentration of Ca$^{2+}$. What is the solubility product of fluorite?

Solution

First, write out the $K_{\text{sp}}$ expression, then substitute in concentrations and solve for $K_{\text{sp}}$:

$$\langle K_{\text{CaF2}} \rangle = \langle \text{Ca}^{2+} \rangle \langle \text{F}^- \rangle^2$$

A saturated solution is a solution at equilibrium with the solid. Thus:

$$\langle K_{\text{sp}} \rangle = \langle \text{Ca}^{2+} \rangle \langle \text{F}^- \rangle^2 = (2.1 \times 10^{-4})(4.2 \times 10^{-4})^2 = 3.7 \times 10^{-11}$$

As with other equilibrium constants, we do not include units with $K_{\text{sp}}$.

Exercise \(\PageIndex{1}\)
In a saturated solution that is in contact with solid Mg(OH)₂, the concentration of Mg²⁺ is 3.7 × 10⁻⁵ M. What is the solubility product for Mg(OH)₂?

\[
\text{\ce{Mg(OH)2}(s)} \rightleftharpoons \text{\ce{Mg^2+}(aq)} + \text{\ce{2OH-}(aq)}
\]

**Answer**

2.0 × 10⁻¹³

**Example**: Determination of Molar Solubility from \(K_{sp}\)

The \(K_{sp}\) of copper(I) bromide, CuBr, is 6.3 × 10⁻⁹. Calculate the molar solubility of copper bromide.

**Solution**

The solubility product constant of copper(I) bromide is 6.3 × 10⁻⁹.

The reaction is:

\[
\text{\ce{CuBr}(s)} \rightleftharpoons \text{\ce{Cu^+}(aq)} + \text{\ce{Br-}(aq)}
\]

First, write out the solubility product equilibrium constant expression:

\[
K_{sp} = \text{\ce{[Cu^+][Br^-]}}
\]

Create an ICE table (as introduced in the chapter on fundamental equilibrium concepts), leaving the CuBr column empty as it is a solid and does not contribute to the \(K_{sp}\):

<table>
<thead>
<tr>
<th>Initial concentration (M)</th>
<th>Cu⁺</th>
<th>Br⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>CuBr</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Change (M)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Equilibrium concentration (M)</td>
<td>0 + x = x</td>
<td>0 + x = x</td>
</tr>
</tbody>
</table>

At equilibrium:

\[
K_{sp} = [\text{Cu⁺}][\text{Br⁻}]
\]

\[
6.3 \times 10^{-9} = (x)(x) = x^2
\]

\[
x = \sqrt{(6.3 \times 10^{-9})} = 7.9 \times 10^{-5}
\]

Therefore, the molar solubility of CuBr is 7.9 × 10⁻⁵ M.

**Summary**

Solubility is defined as the maximum amount of solute that can be dissolved in a solvent at equilibrium. Equilibrium is the state at which the concentrations of products and reactant are constant after the reaction has taken place. The solubility product constant (\(K_{sp}\)) describes the equilibrium between a solid and its constituent ions in a solution. The value of the constant identifies the degree to which the compound can dissociate in water. The higher the \(K_{sp}\), the more soluble the compound is. \(K_{sq}\) is defined in terms of activity rather than concentration because it is a measure of...
a concentration that depends on certain conditions such as temperature, pressure, and composition. It is influenced by surroundings. \(K_{sp}\) is used to describe the saturated solution of ionic compounds. (A saturated solution is in a state of equilibrium between the dissolved, dissociated, undissolved solid, and the ionic compound.)

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