8.8 Solubility Product
- More Examples
- Relative Solubility
- Effect of pH on Solubility
- Effect of Common Ion on Solubility

Sections to Skip: 8.3, 8.7, 8.9, and 8.10

More Examples of $K_{sp}$

What is the molar solubility of AgCl(s)?

$$\text{AgCl(s) } \rightleftharpoons \text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq})$$

$$K_{sp} = [\text{Ag}^+] \times [\text{Cl}^-] = 1.6 \times 10^{-10}$$

Solve on board

Notice format of this equilibrium:

$$AB \rightleftharpoons A^+ + B^-$$

More Analysis of $K_{sp}$

<table>
<thead>
<tr>
<th>Salt Format</th>
<th>$K_{sp}$ Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AB$</td>
<td>$[A^+] \times [B^-] = s^2$</td>
</tr>
<tr>
<td>$AB_2$</td>
<td>$[A^+] \times [B^-]^2 = s \times (2s)^2 = 4s^3$</td>
</tr>
</tbody>
</table>

What is the $K_{sp}$ when the salt has a different stoichiometric format?
More Examples of $K_{sp}$

<table>
<thead>
<tr>
<th>Reaction</th>
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</tr>
</thead>
<tbody>
<tr>
<td>$X_3Y_2(s)$</td>
<td>$3X^{2+}(aq) + 2Y^-(aq)$</td>
</tr>
<tr>
<td>$Ca_3(PO_4)_2(s)$</td>
<td>$3Ca^{2+}(aq) + 2PO_4^{3-}(aq)$</td>
</tr>
</tbody>
</table>

$[Ca^{2+}] = 3 \times [Ca_3(PO_4)_2] = 3s$

$[PO_4^{3-}] = 2 \times [Ca_3(PO_4)_2] = 2s$

$K_{sp} = 1.3 \times 10^{-32} = [Ca^{2+}]^3 \times [PO_4^{3-}]^2$

$K_{sp} = 1.3 \times 10^{-32} = (3s)^3 \times (2s)^2 = 27s^3 \times 4s^2 = 108s^5$

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Solubility

What is the solubility of $Ca_3(PO_4)_2$?

$Ca_3(PO_4)_2(s) \leftrightarrow 3Ca^{2+}(aq) + 2PO_4^{3-}(aq)$

$K_{sp} = 1.3 \times 10^{-32} = (3s)^3 \times (2s)^2 = 27s^3 \times 4s^2 = 108s^5$

$s = \sqrt[5]{\frac{1.3 \times 10^{-32}}{108}}$

$s = 1.6 \times 10^{-7} M$

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More Analysis of $K_{sp}$

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<td>$A_2B$</td>
<td>$108s^5$</td>
</tr>
<tr>
<td>$A_2B_2$</td>
<td>$4s^3$</td>
</tr>
</tbody>
</table>
### Relative Solubility

<table>
<thead>
<tr>
<th>Salt</th>
<th>$K_{sp}$</th>
<th>Solubility, M</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgI</td>
<td>$1.5 \times 10^{-16}$</td>
<td>$1.2 \times 10^{-4}$</td>
</tr>
<tr>
<td>Cul</td>
<td>$5.0 \times 10^{-12}$</td>
<td>$2.2 \times 10^{-4}$</td>
</tr>
<tr>
<td>CaSO$_4$</td>
<td>$6.1 \times 10^{-5}$</td>
<td>$7.8 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

As $K_{sp}$ increases, solubility also increases.

Notice how all salts being compared here have this format: $AB \rightleftharpoons A^+ + B^-$

Solve for solubility when comparing salts with different formats.

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### Effect of pH on Solubility

- Many solids dissolve more readily in acidic solutions than in water.
  
  $$Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2 \text{OH}^-(aq)$$
  
  $$[Zn^{2+}][OH^-]^2 = K_{sp} = 4.5 \times 10^{-17}$$

  As pH decreases (i.e. as soln is made more acidic):
  
  - $[H^+]$ increases
  - $[OH^-]$ decreases
  - Equilibrium shifts to RIGHT
  - More Zn(OH)$_2$ dissolves

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### Effect of pH on Solubility

- Estimate the molar solubility of Fe(OH)$_3$ in water.
- Estimate the molar solubility of Fe(OH)$_3$ in a solution that is buffered to a pH of 2.9.

  - $K_{sp} = 1.1 \times 10^{-36}$
  
  $$Fe(OH)_3(s) \rightleftharpoons Fe^{3+}(aq) + 3 \text{OH}^- (aq)$$
  
  Solve on board
Common Ion on Solubility

- If a solution and a solid salt to be dissolved in it have an ion in common, then the solubility of the salt is depressed.

\[ \text{AB (s)} \leftrightarrow \text{A}^+ (aq) + \text{B}^- (aq) \]

What happens if some extra A\(^+\) or B\(^-\) is added from another source?

The \( K_{sp} \) of thallium(I) iodate (\( \text{TlIO}_3 \)) is \( 3.1 \times 10^{-6} \) at 25°C. Determine the molar solubility of \( \text{TlIO}_3 \) in 0.050 M \( \text{KIO}_3 \) at 25°C.

\[ \text{TlIO}_3(s) \leftrightarrow \text{Tl}^+ (aq) + \text{IO}_3^- (aq) \]

<table>
<thead>
<tr>
<th></th>
<th>( [\text{Tl}^+] ) (mol L(^{-1}))</th>
<th>( [\text{IO}_3^-] ) (mol L(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0 mol L(^{-1})</td>
<td>0.050 mol L(^{-1})</td>
</tr>
<tr>
<td>Change</td>
<td>( +s )</td>
<td>( +s )</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>( s )</td>
<td>( 0.050 + s )</td>
</tr>
</tbody>
</table>

PRS Question

- Which salt \( \text{MCO}_3 \) or \( \text{M}_2\text{CO}_3 \) is more soluble in water? "M" denotes a metal.

1. \( \text{MCO}_3 \) \( K_{sp} = 4.0 \times 10^{-10} \)
2. \( \text{M}_2\text{CO}_3 \) \( K_{sp} = 3.2 \times 10^{-11} \)

Solve on board
For Mg(OH)$_2$(s), ($K_{sp} = 1.2 \times 10^{-11}$), as the pH is raised, the solubility of Mg(OH)$_2$ in water should:

1. Decrease
2. Increase
3. Remain the same

**HINT**

Mg(OH)$_2$(s) $\leftrightarrow$ Mg$^{2+}$(aq) + 2 OH$^-$ (aq)

$[\text{Mg}^{2+}][\text{OH}^-]^2 = K_{sp} = 1.2 \times 10^{-11}$