

**Problem Solutions**

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**Practice Problems 3.3.1 — Calculating $K_{sp}$ from Solubility**

1. Calculate the $K_{sp}$ for each of the following:

   (a) $CaCO_3$ has a solubility of $6.1 \times 10^{-3}$ M.
   $CaCO_3(s) \rightleftharpoons Ca^{2+} + CO_3^{2-}$
   
   $K_{sp} = [Ca^{2+}][CO_3^{2-}] = (6.1 \times 10^{-3})(6.1 \times 10^{-3})$
   
   $K_{sp} = 3.7 \times 10^{-9}$

   (b) Ni(OH)$_2$ has a solubility of $3.6 \times 10^{-4}$ M.
   $Ni(OH)_2(s) \rightleftharpoons Ni^{2+} + 2OH^-$
   
   $K_{sp} = [Ni^{2+}][OH^-]^2 = (3.6 \times 10^{-4})(2 \times 3.6 \times 10^{-5})^2$
   
   $K_{sp} = 1.87 \times 10^{-12}$

   (c) The solubility of barium chromate is $1.8 \times 10^{-3}$ g/L. $BaCrO_4(s) \rightleftharpoons Ba^{2+} + CrO_4^{2-}$
   
   $K_{sp} = [Ba^{2+}][CrO_4^{2-}] = (1.8 \times 10^{-3})^2 = 1.22 \times 10^{-8}$

   (d) The solubility of silver oxide is 0.0035 g/L. $Ag_2O(s) \rightleftharpoons 2Ag^+ + O_2^-$
   
   $0.008/mL = \frac{1.09 \times 10^{-3}}{305.87} = 3.6 \times 10^{-8}$ M
   
   $K_{sp} = [Ag^+]^2[O_2^-] = (2 \times 1.09 \times 10^{-3})(1.09 \times 10^{-7}) = 5.1 \times 10^{-12}$

2. A student prepares a saturated solution by dissolving $3.5 \times 10^{-2}$ mmol of $Mg(OH)_2$ in 500 mL of solution. Calculate the $K_{sp}$ of $Mg(OH)_2$.

   $Mg(OH)_2(s) \rightleftharpoons Mg^{2+} + 2OH^-$
   
   $S = \frac{3.5 \times 10^{-2}}{500} = 0.0007 M$
   
   $K_{sp} = [Mg^{2+}][OH^-]^2 = (0.0007)(2 \times 0.0007)^2 = 8.32 \times 10^{-9}$

3. A student evaporated 150 mL of a saturated solution of $CaCO_3$. 40 grams of solids remains; calculate the $K_{sp}$ of $CaCO_3$.

   $CaCO_3(s) \rightleftharpoons Ca^{2+} + CO_3^{2-}$
   
   $\frac{40}{113.05} = \frac{0.097 g}{0.150 L}$
   
   $K_{sp} = 9.02 \times 10^{-5}$
Pracitce Problems 3.3.2 — Calculating Solubility from Ksp

1. Calculate the solubility of the following:
   \[ K_{sp} = [A^+]^2[C^-] \]
   \[ K_{sp} = 1.8 \times 10^{-10} \]
   \[ [A^+]^2[C^-] = \frac{1.8 \times 10^{-10}}{[A^+]} \]

   (a) Silver chloride in molarity:
   \[ K_{sp} = [Ag^+]^2[Cl^-] \]
   \[ K_{sp} = 1.8 \times 10^{-10} \]
   \[ [Ag^+]^2[Cl^-] = \frac{1.8 \times 10^{-10}}{[Ag^+]} \]
   \[ [Ag^+]^2[Cl^-] = \frac{1.8 \times 10^{-10}}{1.8 \times 10^{-10}} \]
   \[ [Ag^+]^2[Cl^-] = 1 \]
   \[ [Ag^+]^2[Cl^-] = 1 \]

   (b) solid at 1 atm:
   \[ K_{sp} = [Fe^{2+}]^2[S^2] \]
   \[ K_{sp} = 6.0 \times 10^{-19} \]
   \[ [Fe^{2+}]^2[S^2] = \frac{6.0 \times 10^{-19}}{[Fe^{2+}]} \]
   \[ [Fe^{2+}]^2[S^2] = \frac{6.0 \times 10^{-19}}{6.0 \times 10^{-19}} \]
   \[ [Fe^{2+}]^2[S^2] = 1 \]
   \[ [Fe^{2+}]^2[S^2] = 1 \]

   (c) lead(II) iodide in M:
   \[ K_{sp} = [Pb^+]^2[Cl^-]^2 \]
   \[ K_{sp} = 1.8 \times 10^{-5} \]
   \[ [Pb^+]^2[Cl^-]^2 = \frac{1.8 \times 10^{-5}}{[Pb^+]} \]
   \[ [Pb^+]^2[Cl^-]^2 = \frac{1.8 \times 10^{-5}}{1.8 \times 10^{-5}} \]
   \[ [Pb^+]^2[Cl^-]^2 = 1 \]
   \[ [Pb^+]^2[Cl^-]^2 = 1 \]

2. What is the concentration of hydroxide in a saturated solution of solid (I) hydrosol (H) water (H2O)? Use the dissociation equation and Ksp expression first. This example is different than the ones above.

3. What mass of calcium carbonate is dissolved in 1.5 L of saturated solution?

   \[ CaCO_3 \rightarrow Ca^{2+} + CO_3^{2-} \]
   \[ K_{sp} = [Ca^{2+}][CO_3^{2-}] = (x)(x) \]
   \[ K_{sp} = 2.6 \times 10^{-9} \]
   \[ x = \sqrt{\frac{2.6 \times 10^{-9}}{227} \frac{227}{227}} = 9.9 \times 10^{-5} \]

   \[ \text{mass of CaCO}_3 = \text{mass of Ca}^{2+} \times \text{CaO}_4 \]
   \[ \text{mass of CaCO}_3 = 9.9 \times 10^{-5} \times 120.1 \times 0.650 \text{ L} = 4.0 \times 10^{-3} \text{ g} \]
3.3 Review Questions

Ksp Problems

Write the equilibrium equations and the corresponding Ksp expressions for each of the following solutions in saturated aqueous solution.

(a) NH₄Cl = NH₄⁺ + Cl⁻
   \[ Ksp = [NH_4^+][Cl^-] \]

(b) Ca₃(PO₄)₂ = 3 Ca²⁺ + 2 PO₄³⁻
   \[ Ksp = [Ca^{2+}]^3[PO_4^{3-}]^2 \]

(c) Barium, Ba₃(AsO₄)₂ = Ba⁴⁺ + As₂O₄³⁻
   \[ Ksp = [Ba^{4+}][As_2O_4^{3-}] \]

(d) Calcium sulfate = Ca²⁺ + SO₄²⁻
   \[ Ksp = [Ca^{2+}][SO_4^{2-}] \]

(e) Lead II iodide = Pb²⁺ + 2 I⁻
   \[ Ksp = [Pb^{2+}][I^-]^2 \]

(f) Silver carbonate = Ag⁺ + CO₃²⁻
   \[ Ksp = [Ag^+][CO_3^{2-}] \]

2. Consider a saturated solution of BaSO₄.
   (a) Write the equation that represents the equilibrium in the solution.
      \[ BaSO₄(s) \rightleftharpoons Ba^{2+} + SO_4^{2-} \]

   (b) Explain the difference between the solubility and the solubility product constant of BaSO₄.

   Solubility: amount of a compound dissolved in a certain amount of a solution to form a saturated sol. expressed in moles or mass.
   \[ Ksp = [Ba^{2+}][SO_4^{2-}] \]

   a value obtained by multiplying 2 concentrations together.
1. A saturated solution of Li₂CO₃ was prepared by adding excess of Li₂CO₃ to water. The solution was analyzed and found to contain 2.11×10⁻⁴ M Li⁺, which is the \( K_p \) for Li₂CO₃.

\[
K_p = \frac{\text{[Li}^+\text{][CO}_3^{2-}\text{]}}{\text{[Li}_2\text{CO}_3\text{]}} = (2.11 \times 10^{-4})(1.1 \times 10^{-4}) = 2.32 \times 10^{-10}
\]

2. When a student evaporated 250 mL of a saturated solution of silver phosphates, 0.004 g of silver remained. Calculate the \( K_p \) for silver phosphates.

\[
Ag_2PO_4 = 2Ag^+ + PO_4^{3-}
\]

\[
K_p = \frac{\text{[Ag}^+\text{]}^2\text{[PO}_4^{3-}\text{]}}{\text{[Ag}_2\text{PO}_4\text{]}} = \frac{(3x)(x)}{(3.3 \times 10^{-5})} = 9.3 \times 10^{-5}
\]

3. Gypsum is used in drywall and plastics, and occurs naturally in sediment. It has the formula CaSO₄·2H₂O and as \( K_p \) is 5.1×10⁻⁶. What mass of gypsum is present in 0.36 mL of saturated solution?

\[
CaSO_4 \cdot 2H_2O = CaSO_4 + 2H_2O
\]

\[
K_p = \frac{[CaSO_4][H_2O]^2}{CaSO_4 \cdot 2H_2O} = x \cdot \sqrt{5.1 \times 10^{-6}}
\]

\[
x = 0.6 \times 10^{-3} M = \sqrt{K_p}
\]

4. Naturally occurring barite contains two forms of CaCO₃, calcium carbonate and magnesium. They differ in their crystal structure. High-grade calcite crystals were used in industry for pets. The calcite is made of CaCO₃, 3.4×10⁻⁰⁷ M.

\[
CaCO_3 = Ca^+ + CO_3^{2-}
\]

\[
K_p = \frac{\text{[Ca}^+\text{][CO}_3^{2-}\text{]}}{\text{[CaCO}_3\text{]}} = x \cdot x = 2.7 \times 10^{-7}
\]

5. Lead(II) arsenate, Pb₃(AsO₄)₂, was commonly used as an insecticide, especially against cockroaches. Because of the toxic nature of lead compounds, it was banned in the 1980s. It has a \( K_p \) of 1.2 × 10⁻¹³ M. Calculate the \( K_p \) of lead(II) arsenate.

\[
Pb_3(AsO_4)_2 \rightarrow 3Pb^{2+} + 2AsO_4^{3-}
\]

\[
3.0 \times 10^{-5} M = \frac{3.35 \times 10^{-5} M}{3.0 \times 10^{-5}} = x
\]

\[
K_p = \frac{[Pb^{2+}]^3[AsO_4^{3-}]^2}{[Pb_3(AsO_4)_2]} = (3x)^3(2x)^2 = \frac{1}{103} \times 5
\]

\[
K_p = (1.8 \times (3.35 \times 10^{-5}))^3 = 4.6 \times 10^{-36}
\]
3. A student determines the Ksp values of calcium carbonate (CaCO₃) and calcium hydroxide (Ca(OH)₂)
   \[ K_{sp} = [Ca^{2+}][CO_3^{2-}] \]
   \[ K_{sp} = [Ca^{2+}][OH^-]^2 \]
   \[ 1.8 \times 10^{-10} = x \cdot x \]
   \[ 7.2 \times 10^{-5} = x \cdot (2x)^2 \]
   \[ 3x + 2x^2 = x \]
   \[ x = [Ca^{2+}] = 8 \times 10^{-4} \]
   \[ Ca(OH)_2 \text{ is more soluble.} \]

4. Silver carbonate is used as an antibacterial agent in the production of concrete. What mass of silver carbonate must be dissolved to produce 2.5 L of saturated solution?
   \[ Ag_2CO_3 \rightleftharpoons 2Ag^+ + CO_3^{2-} \]
   \[ K_{sp} = [Ag^+][CO_3^{2-}] \]
   \[ 8.5 \times 10^{-12} = (2x)^2(x) \]
   \[ x = \sqrt{\frac{8.5 \times 10^{-12}}{4}} = 1.28 \times 10^{-6} \]
   \[ \text{Mass of Ag}_2\text{CO}_3 \text{ dissolved:} \]
   \[ 1.28 \times 10^{-6} \text{M} \times \frac{275.3}{1 \text{ mole}} \times 2.5 \text{ L} = 0.0887 \text{ g} \]