SOLUBILITY CONSTANT -1 CALCULATING SOLUBILITY CONSTANT

Dr. Sapna Gupta

SOLUBILITY

- Ionic salts can be soluble or insoluble in water.
- Solubility constants are just like K_c – except its called K_{sp}.
- One can use the K_{sp} values to determine the concentrations of ions.
- K_{sp} is also used to calculate the concentration of salts required for precipitation of a salt.
- Writing equations for solubility:

$$\mathrm{MX_n}(s) \rightleftharpoons \mathrm{M^{n+}}(aq) + \mathrm{nX^-}(aq)$$

- For the above reaction,

$$K_{\mathrm{sp}} = [\mathrm{M^{n+}}][\mathrm{X^-}]^{\mathrm{n}}$$

- The coefficients for the ions are used as powers for the ions.
- Solids and liquids are not included in the expressions.

EXAMPLE: WRITING K_{sp}

Write the solubility−product expression for the following salts:

a. Hg_2Cl_2

b. $HgCl_2$

Solution:

$$Hg_2Cl_2(s) \rightleftharpoons Hg_2^{2+}(aq) + 2Cl^-(aq)$$

$$K_{sp} = [Hg_2^{2+}][Cl^-]^2$$

(Note: Hg_2^{2+} is a polyatomic ion)

$$HgCl_2(s) \rightleftharpoons Hg^{2+}(aq) + 2Cl^-(aq)$$

$$K_{sp} = [Hg^{2+}][Cl^-]^2$$

SOME TERMS

- ***Molar solubility*** (s)– number of moles of solute in 1 L of a saturated solution (mol/L)
- ***Solubility* -** number of grams of solute in 1 L of a saturated solution (g/L)
- K_{sp} can be used to determine molar solubility (and solubility)
  - Handle as an equilibrium problem
  - Use an equilibrium table
- Molar solubility can be used to determine the value of the K_{sp}.

EXAMPLE: CALCULATING SOLUBILITY -1

Calculate the solubility of SnS in g/L at 25°C. $K_{sp} = 1.0 \text{ x } 10^{-26}$)

Solution:

$$\mathrm{SnS(s)} \rightleftharpoons \mathrm{Sn^{2+}} + \mathrm{S^{2-}(aq)}$$

Initial	0	0
Change	+s	+s
Eq conc	s	s

$$K_{\mathrm{sp}} = [\mathrm{Sn}^{2+}][\mathrm{S}^{2-}] = 1.0 \text{ x } 10^{-26}$$

$$1.0 \text{ x } 10^{-26} = (s)(s) = s^2$$

$$s = 1.0 \text{ x } 10^{-13}\ M$$

$$\text{solubility} = \frac{1.0 \text{ x } 10^{-13} \text{ mol}}{\text{L}} \text{ x } \frac{150.77\text{g}}{\text{mol}} = \frac{1.5 \text{ x } 10^{-11}\text{g}}{\text{L}}$$

EXAMPLE: CALCULATING SOLUBILITY - 2

Calomel, whose chemical name is mercury(I) chloride, Hg_2Cl_2, was once used in medicine (as a laxative and diuretic). It has a K_{sp} of 1.3×10^{-18}. What is the solubility of Hg_2Cl_2 in grams per liter?

Solution: $Hg_2Cl_2(s) \rightleftharpoons Hg_2^{2+}(aq) + 2Cl^{-}(aq)$

Initial	0	0
Change	+x	+2x
Eq conc	x	2x

$$K_{sp} = [Hg_2^{2+}][Cl^-]^2$$

$$K_{sp} = x(2x)^2$$

$$K_{sp} = x(4x^2)$$

$$K_{sp} = 4x^3$$

$$1.3 \times 10^{-18} = 4x^3$$

$$x^3 = 3.25 \times 10^{-19}$$

$$x = 6.88 \times 10^{-7}\ M$$

The molar solubility is 6.9×10^{-7} *M*, but we also need the solubility in g/L:

$$\frac{6.88 \times 10^{-7}\ \text{mol}}{\text{L}} \times \frac{472.086\,\text{g}}{1\,\text{mol}} = 3.2 \times 10^{-4}\ \text{g/L}$$

$$= 0.32\,\text{mg/L}$$

EXAMPLE: CALCULATING K_{sp} - 1

Exactly 0.133 mg of AgBr will dissolve in 1.00 L of water. What is the value of K_{sp} for AgBr?

Solution:

Solubility equilibrium: $AgBr(s) \rightleftharpoons Ag^+(aq) + Br^-(aq)$

Solubility–product constant expression: $K_{sp} = [Ag^+][Br^-]$

The solubility is given as 0.133 mg/1.00 L, but K_{sp} uses molarity:

$$\frac{0.133\times10^{-3}\ \text{g}}{1.00\ \text{L}}\times\frac{1\,\text{mol}}{187.77\ \text{g}}=7.083\times10^{-7}\ M$$

$$[Ag^+] = [Cl^-] = x = 7.083 \times 10^{-7}\ \text{M}$$

$$K_{sp} = (7.083 \times 10^{-7})^2$$

$$K_{sp} = 5.02 \times 10^{-13}$$

EXAMPLE: CALCULATING K_{sp} - 2

An experimenter finds that the solubility of barium fluoride is 1.1 g in 1.00 L of water at 25°C. What is the value of K_{sp} for barium fluoride, BaF_2, at this temperature?

Solution: $BaF_2(s) \rightleftharpoons Ba^{2+}(aq) + 2F^-(aq)$

Initial	0	0
Change	+x	+2x
Eq conc	x	2x

$$K_{sp} = [Ba^{2+}][F^-]^2$$

The solubility is given as 1.1 g/1.00 L, but K_{sp} uses molarity:

$$x = \frac{1.1\ g}{1.00\,L} \times \frac{1 mol}{175.32\,g} = 6.27 \times 10^{-3}\ M$$

$[Ba^{2+}] = x = 6.27 \times 10^{-3}$ M and $[F^-] = 2x = 2(6.27 \times 10^{-3}) = 1.25 \times 10^{-2}$ M

$$K_{sp} = (6.27 \times 10^{-3})(1.25 \times 10^{-2})^2$$

$$K_{sp} = 9.8 \times 10^{-7}$$

EXAMPLE: CALCULATING K_{SP} - 3

The solubility of lead(II) chromate ($PbCrO_4$) is 4.5 x 10^{-5} g/L. Calculate the solubility product (K_{sp}) of lead(II) chromate.

Solution:

$$s = \frac{4.5 \text{ x } 10^{-5} \text{ g}}{\text{L}} \text{ x } \frac{\text{mol}}{323.2 \text{ g}} = 1.4 \text{ x } 10^{-7} M$$

$$PbCrO_4(s) \rightleftharpoons Pb^{2+}(aq) + CrO_4^{2-}(aq)$$

$$K_{sp} = s^2 = [Pb^{2+}][CrO_4^{2-}]$$

$$K_{sp} = [1.4 \text{ x } 10^{-7} M][1.4 \text{ x } 10^{-7} M] = 2.0 \text{ x } 10^{-14}$$

K_{sp} FOR SOME SALTS

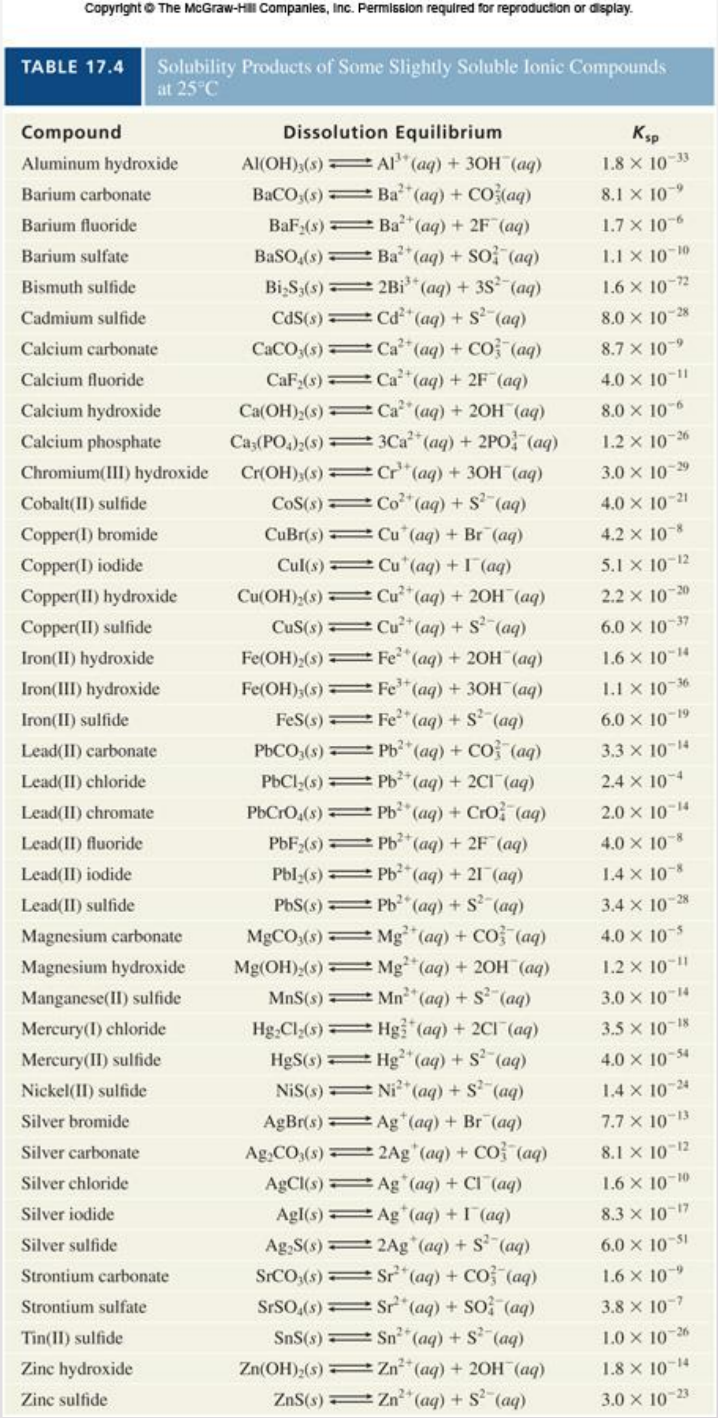

TABLE 17.4 Solubility Products of Some Slightly Soluble Ionic Compounds at 25°C

Compound	Dissolution Equilibrium	K_{sp}
Aluminum hydroxide	$Al(OH)_3(s) \rightleftharpoons Al^{3+}(aq) + 3OH^-(aq)$	1.8×10^{-33}
Barium carbonate	$BaCO_3(s) \rightleftharpoons Ba^{2+}(aq) + CO_3^{2}(aq)$	8.1×10^{-9}
Barium fluoride	$BaF_2(s) \rightleftharpoons Ba^{2+}(aq) + 2F^-(aq)$	1.7×10^{-6}
Barium sulfate	$BaSO_4(s) \rightleftharpoons Ba^{2+}(aq) + SO_4^{2-}(aq)$	1.1×10^{-10}
Bismuth sulfide	$Bi_2S_3(s) \rightleftharpoons 2Bi^{3+}(aq) + 3S^{2-}(aq)$	1.6×10^{-72}
Cadmium sulfide	$CdS(s) \rightleftharpoons Cd^{2+}(aq) + S^{2-}(aq)$	8.0×10^{-28}
Calcium carbonate	$CaCO_3(s) \rightleftharpoons Ca^{2+}(aq) + CO_3^{2-}(aq)$	8.7×10^{-9}
Calcium fluoride	$CaF_2(s) \rightleftharpoons Ca^{2+}(aq) + 2F^-(aq)$	4.0×10^{-11}
Calcium hydroxide	$Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2OH^-(aq)$	8.0×10^{-6}
Calcium phosphate	$Ca_3(PO_4)_2(s) \rightleftharpoons 3Ca^{2+}(aq) + 2PO_4^{3-}(aq)$	1.2×10^{-26}
Chromium(III) hydroxide	$Cr(OH)_3(s) \rightleftharpoons Cr^{3+}(aq) + 3OH^-(aq)$	3.0×10^{-29}
Cobalt(II) sulfide	$CoS(s) \rightleftharpoons Co^{2+}(aq) + S^{2-}(aq)$	4.0×10^{-21}
Copper(I) bromide	$CuBr(s) \rightleftharpoons Cu^+(aq) + Br^-(aq)$	4.2×10^{-8}
Copper(I) iodide	$CuI(s) \rightleftharpoons Cu^+(aq) + I^-(aq)$	5.1×10^{-12}
Copper(II) hydroxide	$Cu(OH)_2(s) \rightleftharpoons Cu^{2+}(aq) + 2OH^-(aq)$	2.2×10^{-20}
Copper(II) sulfide	$CuS(s) \rightleftharpoons Cu^{2+}(aq) + S^{2-}(aq)$	6.0×10^{-37}
Iron(II) hydroxide	$Fe(OH)_2(s) \rightleftharpoons Fe^{2+}(aq) + 2OH^-(aq)$	1.6×10^{-14}
Iron(III) hydroxide	$Fe(OH)_3(s) \rightleftharpoons Fe^{3+}(aq) + 3OH^-(aq)$	1.1×10^{-36}
Iron(II) sulfide	$FeS(s) \rightleftharpoons Fe^{2+}(aq) + S^{2-}(aq)$	6.0×10^{-19}
Lead(II) carbonate	$PbCO_3(s) \rightleftharpoons Pb^{2+}(aq) + CO_3^{2-}(aq)$	3.3×10^{-14}
Lead(II) chloride	$PbCl_2(s) \rightleftharpoons Pb^{2+}(aq) + 2Cl^-(aq)$	2.4×10^{-4}
Lead(II) chromate	$PbCrO_4(s) \rightleftharpoons Pb^{2+}(aq) + CrO_4^{2-}(aq)$	2.0×10^{-14}
Lead(II) fluoride	$PbF_2(s) \rightleftharpoons Pb^{2+}(aq) + 2F^-(aq)$	4.0×10^{-8}
Lead(II) iodide	$PbI_2(s) \rightleftharpoons Pb^{2+}(aq) + 2I^-(aq)$	1.4×10^{-8}
Lead(II) sulfide	$PbS(s) \rightleftharpoons Pb^{2+}(aq) + S^{2-}(aq)$	3.4×10^{-28}
Magnesium carbonate	$MgCO_3(s) \rightleftharpoons Mg^{2+}(aq) + CO_3^{2-}(aq)$	4.0×10^{-5}
Magnesium hydroxide	$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$	1.2×10^{-11}
Manganese(II) sulfide	$MnS(s) \rightleftharpoons Mn^{2+}(aq) + S^{2-}(aq)$	3.0×10^{-14}
Mercury(I) chloride	$Hg_2Cl_2(s) \rightleftharpoons Hg_2^{2+}(aq) + 2Cl^-(aq)$	3.5×10^{-18}
Mercury(II) sulfide	$HgS(s) \rightleftharpoons Hg^{2+}(aq) + S^{2-}(aq)$	4.0×10^{-54}
Nickel(II) sulfide	$NiS(s) \rightleftharpoons Ni^{2+}(aq) + S^{2-}(aq)$	1.4×10^{-24}
Silver bromide	$AgBr(s) \rightleftharpoons Ag^+(aq) + Br^-(aq)$	7.7×10^{-13}
Silver carbonate	$Ag_2CO_3(s) \rightleftharpoons 2Ag^+(aq) + CO_3^{2-}(aq)$	8.1×10^{-12}
Silver chloride	$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$	1.6×10^{-10}
Silver iodide	$AgI(s) \rightleftharpoons Ag^+(aq) + I^-(aq)$	8.3×10^{-17}
Silver sulfide	$Ag_2S(s) \rightleftharpoons 2Ag^+(aq) + S^{2-}(aq)$	6.0×10^{-51}
Strontium carbonate	$SrCO_3(s) \rightleftharpoons Sr^{2+}(aq) + CO_3^{2-}(aq)$	1.6×10^{-9}
Strontium sulfate	$SrSO_4(s) \rightleftharpoons Sr^{2+}(aq) + SO_4^{2-}(aq)$	3.8×10^{-7}
Tin(II) sulfide	$SnS(s) \rightleftharpoons Sn^{2+}(aq) + S^{2-}(aq)$	1.0×10^{-26}
Zinc hydroxide	$Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2OH^-(aq)$	1.8×10^{-14}
Zinc sulfide	$ZnS(s) \rightleftharpoons Zn^{2+}(aq) + S^{2-}(aq)$	3.0×10^{-23}

CONCEPT CHECK

Lead compounds have been used as paint pigments, but because the lead(II) ion is toxic, the use of lead paints in homes is now prohibited. Which of the following lead(II) compounds would yield the greatest number of lead(II) ions when added to the same quantity of water (assuming that some undissolved solid always remains): $PbCrO_4$, $PbSO_4$, or PbS?

Solution:

We can begin by identifying the value of K_{sp} for each compound:

$PbCrO_4$	1.8×10^{-14}
$PbSO_4$	1.7×10^{-8}
PbS	2.5×10^{-27}

Each salt produces two ions, so each has the same expression for the solubility–product constant: $K_{sp} = x^2$.

The solubility will be largest for $PbSO_4$.

KEY CONCEPTS

- Calculate molar solubility
- Calculate K_{sp}
- Predict relative solubilities