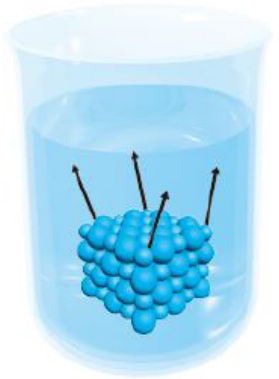
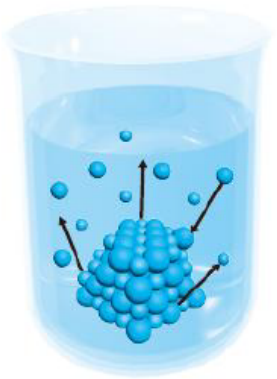
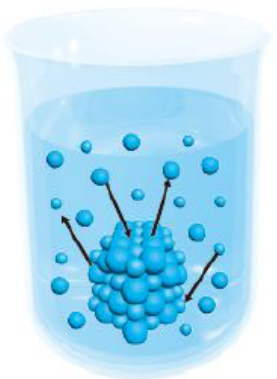
## Solubility

| Before equilibrium | | Equilibrium |
|---|---|---|
|  |  |  |
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**Solubility**: the maximum amount of solute can dissolve in the solution at a give temperature

Molar solubility:
Gram solubility:

Soluble or insoluble

## Solubility product

$$A_mB_{n(s)} \rightleftharpoons m\,A^{n+}_{(aq)} + nB^{m-}_{(aq)} \qquad K_{sp} = [A^{n+}]^m\,[B^{m-}]^n$$

$$Ag_2CrO_{4(s)} \rightleftharpoons 2\,Ag^{+}_{(aq)} + CrO^{2-}_{4(aq)} \qquad K_{sp} = [Ag^{+}]^2\,[CrO^{2-}_{4(aq)}]$$

## Solubility and Ksp

The solubility product constant of $CaF_2$ is 3.9 x$10^{-11}$. Calculate the concentration of $Ca^{2+}$ and $F^-$ in a saturated solution of $CaF_2$ and determine the solubility of $CaF_2$ in grams per liter of solution

| Example | $K_{sp}$ and solubility (s) | |
|---|---|---|
| $AgCl_{(s)} \rightleftharpoons Ag^+ + Cl^-$ | $K_{sp} = s \times s = s^2$ | $s = \sqrt{K_{sp}}$ |
| Equilibrium concentration : s s | | |
| $Ag_2CrO_{4(s)} \rightleftharpoons 2\,Ag^+ + CrO_4^{2-}$ | $K_{sp} = (2s)^2 \times s = 4s^3$ | $s = \sqrt[3]{\frac{Ksp}{4}}$ |
| Equilibrium concentration : 2s s | | |
| $Al(OH)_{3(s)} \rightleftharpoons Al^{3+} + 3OH^-$ | $K_{sp} = s \times (3s)^3 = 27\,s^4$ | $s = \sqrt[4]{\frac{K_{sp}}{27}}$ |
| Equilibrium concentration : s 3s | | |
| $Ca_3(PO_4)_{2(s)} \rightleftharpoons 3\,Ca^{2+} + 2\,PO_4^{3-}$ | $K_{sp} = (3s)^3 \times (2s)^2 = 108\,s^5$ | $s = \sqrt[5]{\frac{K_{sp}}{108}}$ |
| Equilibrium concentration : 3s 2s | | |

$Ag_2CrO_4$ is a red solid that dissolves in water to the extent of 0.029g/L, calculate $K_{sp}$

Precipitation reaction quotient

A precipitation reaction is one in which two soluble salts are combined in aqueous solution to produce an insoluble substance

$AgNO_3$ NaCl $Q_{sp} = [Ag^+] [Cl^-]$

**$Q_{sp} < K_{sp}$ : no ppt**

**$Q_{sp} >$ or $= K_{sp}$ : ppt**

Suppose 500ml of a solution of $CaCl_2$with $Cl^-$ concentration of $8.00 \times 10^{-6}$ M is added to 300ml of a 0.00400M solution of $AgNO_3$.
(a) will a precipitate of $AgCl_{(s)}$ have formed when equilibrium is reached?
(b) Calculate the equilibrium concentrations of $Ag^+$ and $Cl^-$ ions resulting from the precipitation reaction ($K_{sp}$ of AgCl = $1.6 \times 10^{-10}$)

## Common ion effect

$AgCl_{(s)} \leftrightarrow Ag^{+}_{(aq)} + Cl^{-}_{(aq)}$ $K_{sp}=1.6x10^{-10}$

$NaCl_{(s)} \leftrightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$

Suppose $AgCl_{(s)}$ is added to a 0.100M NaCl solution. What is its solubility

**Effect of pH on solubility:** pH can affect the solubility of a salt

1. Solubility of metal hydroxide

$Zn(OH)_{2(s)} \leftrightarrow Zn^{2+}_{(aq)} + 2\ OH^{-}_{(aq)}$ $K_{sp} = 1.2x10^{-17}$

pH< 7 (acidic solution): $H^+$ will interact with $OH^-$ ions, solubility of the salt increases
pH> 7 (basic solution): There are $OH^-$ ions, solubility of the salt decreases

2. Solubility of metal salts of the conjugate base of weak acid

$CaF_{2(s)} \leftrightarrow Ca^{2+}_{(aq)} + 2\ F^{-}_{(aq)}$ $K_{sp} = 3.9x10^{-11}$

pH< 7 (acidic solution): $H^+$ will interact with conjugated base, solubility of the salt increases

pH> 7 (basic solution): solubility is not affected

3. Solubility of metal salts of the conjugate base of strong acid

$AgCl_{(s)} \leftrightarrow Ag^{+}_{(aq)} + Cl^{-}_{(aq)}$ $K_{sp} = 1.6x10^{-10}$

pH< 7 (acidic solution): solubility is not affected

pH> 7 (basic solution): solubility is not affected

| Anion of metal salt | Acid/base | Solubility |
|---|---|---|
| OH- | acid | increase |
| | base | decrease |
| Conjugate base of weak acid | acid | increase |
| | base | No effect |
| Conjugate base of strong acid | acid | No effect |
| | base | No effect |

Compute the solubility of $Fe(OH)_3$ in pure water and compare it with a solution buffer at pH=11 ($K_{sp} = 4x10^{-38}$)

How to judge a compound soluble or insoluble?

| ions | soluble | | | | ppt | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $1A^+$,$NH_4^+$ | All anions | | | | $Li_2CO_3$, $Li_3PO_4$ | | | | | | |
| $NO_3^-$,$ClO_4^-$,$CH_3COO^-$ | All cations | | | | | | | | | | |
| | | | | | | | | | | | |
| $F^-$ | All other cations | | | | | | | $Ca^{2+}$ | $Sr^{2+}$ | $Ba^{2+}$ | $Pb^{2+}$ |
| $Cl^-$, $Br^-$,$I^-$ | | | | | $Ag^+$ | $Cu^+$ | $Hg^{2+}$ | | | | $Pb^{2+}$ |
| $SO_4^{2-}$ | | | | | | | | | $Sr^{2+}$ | $Ba^{2+}$ | $Pb^{2+}$ |
| $C_2O_4^{2-}$ | | | | | | | | $Ca^{2+}$ | $Sr^{2+}$ | $Ba^{2+}$ | |
| $CrO_4^{2-}$ | | | | | $Ag^+$ | | | | | $Ba^{2+}$ | $Pb^{2+}$ |
| | | | | | | | | | | | |
| $OH^-$ | $1A^+$ | $NH_4^+$ | $Sr^{2+}$ | $Ba^{2+}$ | All other cations | | | | | | |
| $S^{2-}$ | $1A^+$ | $NH_4^+$ | $2A^{2+}$ | | | | | | | | |
| $CO_3^{2-}$, $PO_4^{3-}$ | $1A^+$ | $NH_4^+$ | | | | | | | | | |
| $SO_3^{2-}$ | $1A^+$ | $NH_4^+$ | | | | | | | | | |