UNIVERSITY OF SOUTH CAROLINA

Stephen L. Morgan Analytical Chemistry

Solubility Rules!

A basic knowledge of which compounds are soluble in aqueous solutions is essential for predicting whether a given reaction might involve formation of a precipitate (an insoluble compound).

The following guidelines are generalizations. A substance is classified as insoluble if it precipitates when equal volumes of 0.1 M solutions of its components are mixed. Keep in mind, however, that no substance is completely insoluble. Substances listed as insoluble are, at some level, partially soluble. The magnitude of the ion product constant (K_{sp}) for the appropriate solubility equilibrium should be examined. Larger K_{sp} values indicate greater solubility; smaller K_{sp} values indicate lesser solubility.

The symbol "<=>" is used here to signify the 'double-arrrow' symbol for a chemical equilibrium. The symbol "=>" is used here to signify the 100% dissociation of a compound into its electrolyte ions in aqueous solution. The subscript "(s)" following a species indicates that it is a solid. The subscript "(aq.)" following a species indicates that it is in aqueous solution.

Rule 1. All compounds of Group IA elements (the alkali metals) are soluble.

For example, $NaNO_3$, KCl, and LiOH are all soluble compounds. This means that an aqueous solution of KCl really contains the predominant species K^+ and Cl^- and, because KCl is soluble, no KCl is present as a solid compound in aqueous solution:
$KCl_{(s)} \Rightarrow K^+_{(aq.)} + Cl^-_{(aq.)}$

Rule 2. All ammonium salts (salts of NH_4^+) are soluble.

For example, NH_4OH is a soluble compound. Molecules of NH_4OH completely dissociate to give ions of NH_4^+ and OH^- in aqueous solution.

Rule 3. All nitrate (NO_3^-), chlorate (ClO_3^-), perchlorate (ClO_4^-), and acetate (CH_3COO^- or $C_2H_3O_2^-$, sometimes abbreviated as Oac^-) salts are soluble.

For example, KNO_3 would be classified as completely soluble by rules 1 and 3. Thus, KNO_3 could be expected to dissociate completely in aqueous solution into K^+ and NO_3^- ions: $KNO_3 \Rightarrow K^+_{(aq.)}) + NO^{3-}$
(aq.)

Rule 4. All chloride (Cl^-), bromide (Br^-), and iodide (I^-) salts are soluble except for those of Ag^+, Pb^{2+}, and Hg_2^{2+}.

For example, AgCl is a classic insoluble chloride salt:

$AgCl_{(s)} \Leftrightarrow Ag^+_{(aq.)} + Cl^-_{(aq.)}$ (K_{sp} = 1.8 x 10^{-10}).

Rule 5. All sulfate ($SO_4^=$) compounds are soluble except those of Ba^{2+}, Sr^{2+}, Ca^{2+}, Pb^{2+}, Hg_2^{2+}, and Hg^{2+}, Ca^{2+} and Ag^+ sulfates are only moderately soluble.

For example, $BaSO_4$ is insoluble (only soluble to a very small extent):

$BaSO_{4(s)}$ <=> $Ba^{2+}_{(aq.)}$ + $SO_4^{2-}_{(aq.)}$ (K_{sp} = 1.1 x 10^{-10}).
Na_2SO_4 is completely soluble:
$Na_2SO_{4(s)}$ => 2 $Na^+_{(aq.)}$ + $SO_4^{2-}_{(aq.)}$.

Rule 6. All hydroxide (OH^-) compounds are insoluble except those of Group I-A (alkali metals) and Ba^{2+}, Ca^{2+}, and Sr^{2+}.

For example, $Mg(OH)_2$ is insoluble (K_{sp} = 7.1 x 10^{-12}).
NaOH and $Ba(OH)_2$ are soluble, completely dissociating in aqueous solution:
$NaOH_{(s)}$ => $Na^+_{(aq.)}$ + $OH^-_{(aq.)}$, a strong base
$Ba(OH)_{2(s)}$ => $Ba^{2+}_{(aq.)}$ + $2OH^-_{(aq.)}$ (K_{sp} = 3 x 10^{-4})

Rule 7. All sulfide (S^{2-}) compounds are insoluble except those of Groups I-A and II-A (alkali metals and alkali earths).

For example, $Na_2S_{(s)}$ <=> $2Na^+_{(aq.)}$ + $S^{2-}_{(aq.)}$
MnS is insoluble (K_{sp} = 3 x 10^{-11}).

Rule 8. All sulfites ($SO_3^=$), carbonates ($CO_3^=$), chromates ($CrO_4^=$), and phosphates (PO_4^{3-}) are insoluble except for those of NH_4^+ and Group I-A (alkali metals)(see rules 1 and 2).

For example, calcite, $CaCO_{3(s)}$ <=> $Ca^{2+}_{(aq.)}$ + $CO_3^=_{(aq.)}$ (K_{sp} = 4.5 x 10^{-9}).