

## Solubility Rules!

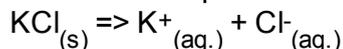
A basic knowledge of which compounds are soluble in aqueous solutions is essential for predicting whether a given reaction might involve formation of a precipitate (an insoluble compound).

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 " $\rightleftharpoons$ " is used here to signify the 'double-arrow' symbol for a chemical equilibrium. The symbol " $\Rightarrow$ " 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,  $\text{NaNO}_3$ ,  $\text{KCl}$ , and  $\text{LiOH}$  are all soluble compounds. This means that an aqueous solution of  $\text{KCl}$  really contains the predominant species  $\text{K}^+$  and  $\text{Cl}^-$  and, because  $\text{KCl}$  is soluble, no  $\text{KCl}$  is present as a solid compound in aqueous solution:



**Rule 2.** All ammonium salts (salts of  $\text{NH}_4^+$ ) are soluble.

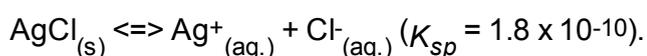
For example,  $\text{NH}_4\text{OH}$  is a soluble compound. Molecules of  $\text{NH}_4\text{OH}$  completely dissociate to give ions of  $\text{NH}_4^+$  and  $\text{OH}^-$  in aqueous solution.

**Rule 3.** All nitrate ( $\text{NO}_3^-$ ), chlorate ( $\text{ClO}_3^-$ ), perchlorate ( $\text{ClO}_4^-$ ), and acetate ( $\text{CH}_3\text{COO}^-$  or  $\text{C}_2\text{H}_3\text{O}_2^-$ , sometimes abbreviated as  $\text{Oac}^-$ ) salts are soluble.

For example,  $\text{KNO}_3$  would be classified as completely soluble by rules 1 and 3. Thus,  $\text{KNO}_3$  could be expected to dissociate completely in aqueous solution into  $\text{K}^+$  and  $\text{NO}_3^-$  ions:  $\text{KNO}_3 \Rightarrow \text{K}^+_{(aq.)} + \text{NO}_3^-_{(aq.)}$

**Rule 4.** All chloride ( $\text{Cl}^-$ ), bromide ( $\text{Br}^-$ ), and iodide ( $\text{I}^-$ ) salts are soluble except for those of  $\text{Ag}^+$ ,  $\text{Pb}^{2+}$ , and  $\text{Hg}_2^{2+}$ .

For example,  $\text{AgCl}$  is a classic insoluble chloride salt:

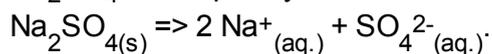


**Rule 5.** All sulfate ( $\text{SO}_4^{2-}$ ) compounds are soluble except those of  $\text{Ba}^{2+}$ ,  $\text{Sr}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Hg}_2^{2+}$ , and  $\text{Hg}^{2+}$ ,  $\text{Ca}^{2+}$  and  $\text{Ag}^+$  sulfates are only moderately soluble.

For example,  $\text{BaSO}_4$  is insoluble (only soluble to a very small extent):



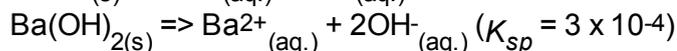
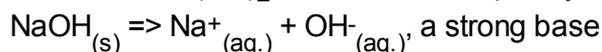
$\text{Na}_2\text{SO}_4$  is completely soluble:



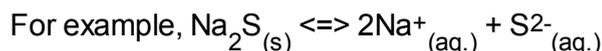
**Rule 6.** All hydroxide ( $\text{OH}^-$ ) compounds are insoluble except those of Group I-A (alkali metals) and  $\text{Ba}^{2+}$ ,  $\text{Ca}^{2+}$ , and  $\text{Sr}^{2+}$ .

For example,  $\text{Mg}(\text{OH})_2$  is insoluble ( $K_{sp} = 7.1 \times 10^{-12}$ ).

$\text{NaOH}$  and  $\text{Ba}(\text{OH})_2$  are soluble, completely dissociating in aqueous solution:



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



$\text{MnS}$  is insoluble ( $K_{sp} = 3 \times 10^{-11}$ ).

**Rule 8.** All sulfites ( $\text{SO}_3^-$ ), carbonates ( $\text{CO}_3^-$ ), chromates ( $\text{CrO}_4^-$ ), and phosphates ( $\text{PO}_4^{3-}$ ) are insoluble except for those of  $\text{NH}_4^+$  and Group I-A (alkali metals)(see rules 1 and 2).

For example, calcite,  $\text{CaCO}_{3(s)} \rightleftharpoons \text{Ca}^{2+}_{(aq)} + \text{CO}_3^{2-}_{(aq)} \quad (K_{sp} = 4.5 \times 10^{-9})$ .

