

Solubility Rules

When a substance is mixed with a solvent, there are several possible results. The determining factor for the result is the solubility of the substance, which is defined as the maximum possible concentration of the solute. The solubility rules help determine which substances are soluble, and to what extent.

Solubility Effects on Reactions

Depending on the solubility of a solute, there are three possible results:

- 1) if the solution has less solute than the maximum amount that it is able to dissolve (its solubility), it is a dilute solution;
- 2) if the amount of solute is exactly the same amount as its solubility, it is saturated;
- 3) if there is more solute than is able to be dissolved, the excess solute separates from the solution. If this separation process includes crystallization, it forms a precipitate. Precipitation lowers the concentration of the solute to the saturation in order to increase the stability of the solution.

Solubility Rules

The following are the solubility rules for common ionic solids. If there two rules appear to contradict each other, the preceding rule takes precedence.

1. Salts containing Group I elements (Li^+ , Na^+ , K^+ , Cs^+ , Rb^+) are soluble . There are few exceptions to this rule. Salts containing the ammonium ion (NH_4^+) are also soluble.
2. Salts containing nitrate ion (NO_3^-) are generally soluble.
3. Salts containing Cl^- , Br^- , or I^- are generally soluble. Important exceptions to this rule are halide salts of Ag^+ , Pb^{2+} , and $(\text{Hg}_2)^{2+}$. Thus, AgCl , PbBr_2 , and Hg_2Cl_2 are insoluble.

4. Most silver salts are insoluble. AgNO_3 and $\text{Ag}(\text{C}_2\text{H}_3\text{O}_2)$ are common soluble salts of silver; virtually all others are insoluble.
5. Most sulfate salts are soluble. Important exceptions to this rule include CaSO_4 , BaSO_4 , PbSO_4 , Ag_2SO_4 and SrSO_4 .
6. Most hydroxide salts are only slightly soluble. Hydroxide salts of Group I elements are soluble. Hydroxide salts of Group II elements (Ca, Sr, and Ba) are slightly soluble. Hydroxide salts of transition metals and Al^{3+} are insoluble. Thus, $\text{Fe}(\text{OH})_3$, $\text{Al}(\text{OH})_3$, $\text{Co}(\text{OH})_2$ are not soluble.
7. Most sulfides of transition metals are highly insoluble, including CdS , FeS , ZnS , and Ag_2S . Arsenic, antimony, bismuth, and lead sulfides are also insoluble.
8. Carbonates are frequently insoluble. Group II carbonates (CaCO_3 , SrCO_3 , and BaCO_3) are insoluble, as are FeCO_3 and PbCO_3 .
9. Chromates are frequently insoluble. Examples include PbCrO_4 and BaCrO_4 .
10. Phosphates such as $\text{Ca}_3(\text{PO}_4)_2$ and Ag_3PO_4 are frequently insoluble.
11. Fluorides such as BaF_2 , MgF_2 , and PbF_2 are frequently insoluble.

References

1. Petrucci, Ralph H., F. Geoffrey Herring, Jeffrey D. Madura and Carey Bissonette. General Chemistry: Principles and Modern Applications. 10th ed. Upper Saddle River, New Jersey: Pearson Education, 2011.
2. Nathan, Harold D., and Charles Henrickson. Chemistry. New York: Wiley, 2001.

Problems

1. Is FeCO₃ soluble?

According to Rule #8, carbonates tend to be insoluble. Therefore, FeCO₃ is likely to form a precipitate.

2. Does ClO₄⁻ tend to form a precipitate?

This is perchlorate, which according to Rule #3 is likely to be soluble. Therefore, it will not form a precipitate.

3. Which of these substances is likely to form a precipitate?

- a) CaSO₄ b) table salt c) AgBr

Letters a and c are both likely to form precipitates.

Concerning a) CaSO₄, although sulfates tend to be soluble, Rule #5 indicates that calcium sulfate is an important exception to this rule.

For b), Rule #1 indicates that table salt (NaCl) is soluble because it is a salt of an alkali metal.

c) Rule #3 states that bromides are usually soluble, but it states that salts of silver are insoluble, also rule #4 supports that, the compound is insoluble and will form a precipitate.

4. Predict whether a precipitate will form as a result of this reaction:



The products of the reaction must be examined; if either of the substances formed in the reaction is insoluble, a precipitate will form.

Considering NaNO₃, there are two rules support each other, rule #1 states that sodium salts tend to be soluble, and rule #2 states that nitrates tend to be soluble. A precipitate of this compound will not form.

Next, consider Ag_2S . According to Rule #7, that sulfides tend to be insoluble. Therefore, because of this compound, a precipitate will form in the course of this reaction.

5. Predict if a precipitate will form as a result of this reaction:



Consider again the products of the reaction: if either is insoluble, a precipitate will form.

The first product, KOH , is an example of two rules contradicting each other. Although Rule #6 says that hydroxides tend to be insoluble, Rule #1 states that salts of alkali metal cations tend to be soluble, and Rule #1 precedes Rule #6. Therefore, this compound will not contribute to any precipitation being formed.

The second product, Na_2CrO_4 , also adheres to Rule #1, which states that salts of alkali metals tend to be soluble.

Because both products are soluble, no precipitate form as a result of this reaction.