

# Solubility Rules and Net Ionic Equations

## Why?

Solubility of a salt depends upon the type of ions in the salt. Some salts are soluble in water and others are not. When two soluble salts are mixed together in water they may form a third insoluble salt. Net ionic equations are a way of showing the reactions that take place between two substances dissolved in water.

## Learning Objectives

- Students will write simple net ionic equations for double displacement (replacement) reactions

## Success criteria

- Students will be able to correctly predict the products of a double displacement (replacement) reaction.
- Students will be able to write the net ionic equation(s), given the reaction equation.

## Prerequisites

- Naming of compounds and writing chemical formulae
- Writing and balancing chemical reactions
- Names of polyatomic ions
- Classifying types of reactions

## Vocabulary

- Cation
- Anion
- Soluble
- Insoluble
- Precipitate
- Double replacement or double displacement reaction

## Definitions

- An *aqueous* solution is a solution with water as the solvent.
- A compound is said to be *soluble* if it readily dissolves in water and does not *precipitate* if left undisturbed for an extended period of time.
- A *spectator ion* is an ion that is present during a reaction but does not take part in the reaction.
- A *net ionic equation* is an equation that only shows the ions that undergo changes during a chemical reaction. (Spectator ions are omitted from net ionic equations.)

## Model I: Rules of Solubility in Aqueous Solutions

Several solid compounds are placed in water to determine if they are soluble. The results are shown in the chart below. An **X** indicates that the compound **does not** dissolve in water. If it does dissolve no mark is made.

The top row shows the cation in the compound. The far left column shows the anion in the compound. For example:  $\text{Mg}(\text{OH})_2$  is insoluble,  $\text{MgBr}_2$  is soluble,  $\text{AgCl}$  is insoluble.

**Table 1** - This table presents an overview of solubility of selected salts in water.

	$\text{NH}_4^+$	$\text{Li}^+$	$\text{Na}^+$	$\text{K}^+$	$\text{Mg}^{+2}$	$\text{Ca}^{2+}$	$\text{Sr}^{2+}$	$\text{Ba}^{2+}$	$\text{Ag}^+$	$\text{Pb}^{2+}$	$\text{Hg}_2^{2+}$	$\text{Fe}^{3+}$	$\text{Cu}^{2+}$	$\text{Zn}^{2+}$
$\text{NO}_3^-$														
$\text{C}_2\text{H}_3\text{O}_2^-$														
$\text{Cl}^-$									X	X	X			
$\text{Br}^-$									X	X	X			
$\text{I}^-$									X	X	X			
$\text{SO}_4^{2-}$						X	X	X	X	X				
$\text{OH}^-$					X				X	X	X	X	X	X
$\text{S}^{2-}$					X	X	X	X	X	X	X	X	X	X
$\text{CO}_3^{2-}$					X	X	X	X	X	X	X	X	X	X
$\text{PO}_4^{3-}$					X	X	X	X	X	X	X	X	X	X

### Key Questions

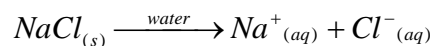
1. Is calcium carbonate soluble or insoluble?
2. Is silver bromide soluble or insoluble?
3. Is iron (III) sulfate soluble or insoluble?
4. For what cations and anions are the compounds always soluble in water?
5. (a) For what anions are most of the compounds usually soluble?  
(b) For those anions that usually form soluble compounds, which cations result in the formation of insoluble compounds? List each cation separately.
6. For what anions are most of their compounds usually insoluble?
7. What patterns can be found in your answers to questions 4 and 5? Consider the location of the elements on the Periodic Table as you develop your response.

## Exercises

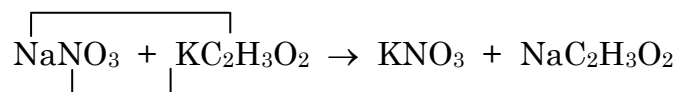
1. Write a short set of rules (three-five) that summarize which compounds are soluble and which are not. Make your rules specific.
2. Using your rules from Exercise 1, indicate whether the following compounds are soluble (S) or insoluble (I). Double check by consulting the table in the Model.
  - a. Calcium carbonate
  - b. Strontium hydroxide
  - c. Silver chloride
  - d. Silver iodide
  - e. Calcium sulfate
  - f. Potassium nitrate
  - g. Sodium phosphate
  - h. Barium acetate
  - i. Iron (III) nitrate
  - j. Lead (II) carbonate
  - k. Rubidium hydroxide
  - l. Magnesium phosphate
3. Using your rules from above, write the chemical formula of **five** compounds that are **insoluble**, other than those found in Exercise 2 (a-i).
4. Using your rules from above, write the chemical formulae of **five** compounds that are **soluble**, other than those found in Exercise 2 (a-i).

**Model 2: Net ionic reactions**

When a soluble salt is placed in water, it separates into its ions. For example, sodium chloride is soluble.

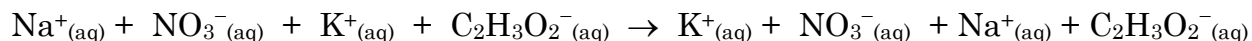
**Example 1: Sodium nitrate reacts with potassium acetate in an aqueous solution.**

In *double displacement (replacement)* reactions, two ionic compounds react and switch ions.

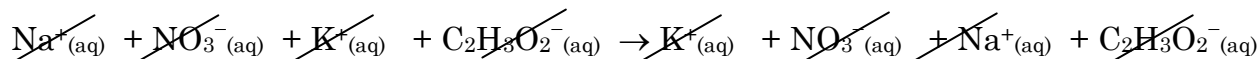


According to this “pencil and paper” reaction, potassium nitrate and sodium acetate are produced. However, if this reaction is actually carried out in an aqueous solution, nothing appears to happen.

If we investigate this system using the concept of a net ionic reaction we can see why it appears that nothing happens. First, we write all of the compounds in the equation, showing the ions that are formed when the reaction is carried out in water.

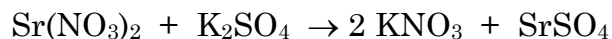


Next, we cross out any ions that are present on both the left (reactant) side and right (product) side of the reaction.

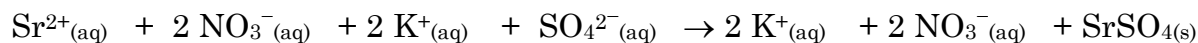


The ions we cross out, which are the same on both sides, are called *spectator ions* (they are just “standing around watching”, hence the term spectator).

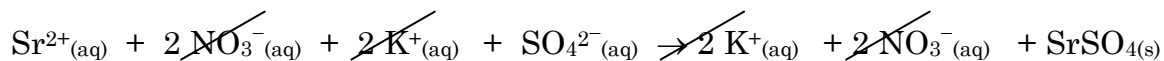
Both of the compounds on the left hand side of the reaction (reactants) and the right hand side of the reaction (products) are soluble. Therefore, no solid forms and *no reaction occurs*. The ions are all simply floating around together in the solution.

**Example 2: Strontium nitrate solution reacts with potassium sulfate solution.**

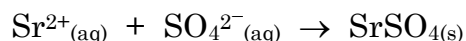
Predict products



Write soluble compounds as ions and insoluble compounds in combined form.



Cross out spectator ions



Final net ionic equation

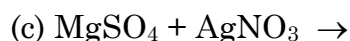
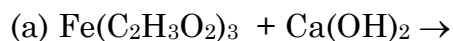
In this example, writing a net ionic equation is useful because it indicates those chemical species that participate in the chemical reaction and form an insoluble product.

**Key Questions**

1. In Example 1, what ions are spectators?
2. In Example 2, what ions are spectators?
3. In Example 2, what insoluble compound is formed?
4. Why is there no reaction when solutions of  $\text{NaNO}_3$  and  $\text{KC}_2\text{H}_3\text{O}_2$  are mixed?

**Exercises**

1. Use the steps as shown in Example 2 to help you predict the products and write the net ionic equation for each of the following reactions. Make sure your net ionic equation is properly balanced.



(d) Dilute potassium sulfide is added to a solution of barium chloride.

(e) A solution of calcium hydroxide is added to a solution of potassium sulfate

2. In Model 2, Example 1, solutions of sodium nitrate and potassium acetate are mixed together forming soluble products. If the solution were to be evaporated to dryness, name all of the compounds that might be found in the container.