# Double Replacement Reactions

## Objectives

The objectives of this lab are to:
a) Perform and observe the results of a variety of double replacement reactions,
b) Become familiar with some of the observable signs of these reactions,
c) Identify the products formed in each of these reactions,
d) Write balanced chemical equations for each double replacement reaction studied.

## Background

During a chemical reaction both the form and composition of matter are changed. Old substances are converted to new substances, which have unique physical and chemical properties of their own. Some of the observable signs that a chemical reaction has occurred include:

- metallic deposit appears
- bubbles appear
- temperature change occurs
- color change occurs
- precipitate (cloudy, tiny particles) appears

Note that there are other observable signs for chemical reactions, but these are most likely to be seen in this lab.

### Double Replacement Reactions

All double replacement reactions have the general form: **AB + CD → AD + CB**

Reactions that can be classified as double replacements include **precipitation** reactions, **neutralization** reactions and **gas forming** reactions.

### Precipitation Reactions

Here AB and CD are usually aqueous ionic compounds (or acids) consisting of aqueous ions ($A^+$ and $B^-$, $C^+$ and $D^-$). When a double replacement reaction occurs, the cations and anions switch partners, resulting in the formation of two new ionic compounds AD and CB, one of which is in the solid state. This solid product is an insoluble ionic compound called a **precipitate**. To determine whether a product ionic compound will be soluble or insoluble, consult the *Solubility Rules* provided at the end of the Background section. Note that if both of the predicted products are soluble, a precipitation reaction will not occur.

Example 1: aqueous lead (II) nitrate + aqueous sodium chloride

The predicted products are lead (II) chloride (insoluble) and sodium nitrate (soluble). Since one of the predicted products is insoluble, a precipitation reaction is will occur.

Reaction Equation: $Pb(NO_3)_2$ (*aq*) + 2 NaCl (*aq*) → 2 $NaNO_3$ (*aq*) + **$PbCl_2$ (*s*)**

## Neutralization Reactions

Here AB is an acid (consisting of $H^+$ and $X^-$ aqueous ions) and BC is a base (consisting of $M^+$ and $OH^-$ ions). When a double replacement reaction occurs, the cations and anions switch partners, resulting in the formation of water and a new ionic compound (or salt), which is usually soluble. Neutralization reactions are **exothermic**, and are generally accompanied by a noticeable release of heat.

Example 2: sulfuric acid + aqueous lithium hydroxide

The predicted products are water and lithium sulfate.

Reaction Equation: $H_2SO_4\ (aq) + 2\ LiOH\ (aq) \rightarrow Li_2SO_4\ (aq) + 2\ H_2O\ (l)$

## Gas Forming Reactions

In these reactions one of the products (AD or CB) after the double replacement is in the gaseous state, such as hydrogen sulfide ($H_2S$) or ammonia ($NH_3$). One of the products could also be carbonic acid ($H_2CO_3$) or sulfurous acid ($H_2SO_3$). Both carbonic acid and sulfurous acid are unstable and will decompose to form carbon dioxide and sulfur dioxide gases, respectively:

Carbonic acid

$H_2CO_3\ (aq) \rightarrow H_2O\ (l) + CO_2\ (g)$

Sulfurous Acid

$H_2SO_3\ (aq) \rightarrow H_2O\ (l) + SO_2\ (g)$

Example 3: nitric acid + aqueous sodium bicarbonate

The predicted products are carbonic acid and sodium nitrate. However carbonic acid decomposes to carbon dioxide and water:

Reaction Equation: $2\ HNO_3\ (aq) + NaHCO_3\ (aq) \rightarrow 2\ NaNO_3\ (aq) + \mathbf{H_2CO_3\ (aq)}$

**decomposes**

Final Equation: $2\ HNO_3\ (aq) + NaHCO_3\ (aq) \rightarrow 2\ NaNO_3\ (aq) + \mathbf{H_2O\ (l) + CO_2\ (g)}$

## Writing Equations for Reactions

- Write chemical formulas for each reactant and place a yield arrow ($\rightarrow$) after the last reactant.
- Identify the reaction type – precipitation, neutralization or gas forming.
- If you determine that a reaction will occur, write the correct formula(s) of the products after the arrow. If you determine that a reaction will not occur, write "no reaction" after the arrow.
- Balance the equation (to ensure mass conservation).
- Be sure to include the physical states of all reactants and products in your final equation.

## Review: Chemical Formulas and Names of Ionic Compounds

**Ionic compounds** are formed when positive cations and negative anions are attracted to each other via strong electrostatic forces. This attraction is called an **ionic bond**.

The basic rules for writing the chemical formulas of ionic compounds:
1. Determine the formulas and charges on the cation and anion involved in the compound.
2. Combine the ions in a ratio that results in the formation of a neutral ionic compound. The total charge of all the positive cations must equal the total charge of all the negative anions in the compound. The numbers of each element present in the compound become subscripts in the chemical formula.

Example 4: Write the formula for iron (III) chloride

First identify the cation and the anion in this compound.
cation = iron (III) = $Fe^{+3}$ anion = chloride = $Cl^{-1}$
For a neutral compound, one $Fe^{+3}$ is needed for every 3 $Cl^{-1}$
The formula of the compound is $FeCl_3$

Example 5: Write the formula for magnesium phosphate.

First identify the cation and anion in this compound.
cation = magnesium = $Mg^{+2}$ anion = phosphate = $PO_4^{-3}$
For a neutral compound, three $Mg^{+2}$ are needed for every 2 $PO_4^{-3}$
The formula of the compound is $Mg_3(PO_4)_2$

The basic rules for writing names of ionic compounds:
1. Both the cation and anion must be named.
2. Always name the cation first, then the anion.

Example 6: Name the ionic compound $Al(NO_3)_3$.
First identify the cation and anion in this compound.
cation = $Al^{+3}$ = aluminum anion = $NO_3^{-1}$ = nitrate
The name of this compound is aluminum nitrate

**SOLUBILITY RULES for IONIC COMPOUNDS**

1. Alkali metal compounds, acetates, nitrates, and ammonium compounds are all soluble.
2. Hydroxides of alkali metals and $NH_4^{+1}$, $Ca^{+2}$, $Sr^{+2}$, and $Ba^{+2}$ are soluble. All others are **in**soluble.
3. All halides (chlorides etc.) are soluble except for those containing $Ag^{+1}$, $Pb^{+2}$, and $Hg_2^{+2}$.
4. Most sulfates are soluble, except for $BaSO_4$, $SrSO_4$, $Ag_2SO_4$, $PbSO_4$, and $CaSO_4$.
5. Most phosphates, carbonates, chromates and sulfides are **in**soluble (except those of the alkali metals and ammonium).
6. In addition, all acids are soluble!

## Procedure

### Safety

Be especially cautious when using the 6M HCl, 3M $H_2SO_4$ and 6M NaOH as they can burn your skin. Also be aware that skin discoloration will result from contact with $AgNO_3$. If you feel any tingling sensations or see any color changes on your skin, flush with water immediately for a minimum of 15 minutes. Inform your instructor of any chemical contact as soon as possible.

Personal Protective Equipment (PPE) required: safety goggles, lab coat, closed-toe shoes

## Materials and Equipment

Solids: solid sodium bicarbonate

Solutions: 6 M sodium hydroxide, 3 M sulfuric acid, 6 M hydrochloric acid; all other solutions are 0.1 M and include silver nitrate, sodium chloride, iron (III) chloride, ammonium hydroxide, sodium carbonate, cobalt (II) nitrate, sodium phosphate, copper (II) sulfate, potassium nitrate, nickel (II) nitrate, barium chloride.

Equipment: 9 small test tubes, plastic test tube rack

### Instructions for Performing Reactions

- Use ***approximately*** 3-mL quantities of all solutions. A good estimate is to use three full dropper squirts of each chemical.
- Perform the following reactions, and record your observations for each on the data sheet. If results are not obtained immediately, give the reaction some time. Some reactions take longer than others. ***All waste is to be disposed of in the plastic container in the hood*!**

    1. Aqueous sodium chloride + aqueous silver nitrate
    2. Aqueous sodium phosphate + aqueous copper (II) sulfate
    3. Hydrochloric acid + solid sodium bicarbonate (*just a small scoop*)
    4. Aqueous nickel (II) nitrate + aqueous sodium hydroxide
    5. Aqueous barium chloride + sulfuric acid
    6. Hydrochloric acid + aqueous sodium hydroxide
    7. Aqueous sodium carbonate + aqueous cobalt (II) nitrate
    8. Aqueous sodium chloride + aqueous potassium nitrate
    9. Aqueous iron (III) chloride + aqueous ammonium hydroxide

- When finished, complete the data sheet by writing the balanced equation for each reaction.