Experiment 7

Double Displacement Reactions

Pre-Lab Assignment

Before coming to lab:

- Read the lab thoroughly.
- Answer the pre-lab questions that appear at the end of this lab exercise.

Purpose

A set of double displacement reactions will be performed and their products both predicted beforehand and observed afterward. The results will be expressed appropriately in molecular, total, and net ionic equations.

Background

A double displacement, or metathesis, reaction involves two ionic compounds "switch partners". The cation of the first molecule exchanges for the anion of the second, and the cation of the second for the anion of the first in the general form in Eqn. 1.

$$AX + BY \rightarrow AY + BX \text{ where A,B = cations and X,Y = anions} \qquad \text{Eqn. 1}$$

A specific example of a double displacement reaction is shown in Eqn. 2 between magnesium nitrate and sodium carbonate.

$$Mg(NO_3)_2(aq) + K_2CO_3(aq) \rightarrow MgCO_3(s) + 2\ KNO_3(aq) \qquad \text{Eqn. 2}$$

Here, Mg^{2+} and K^+ are the cations (A and B) and NO_3^- and CO_3^{2-} are the anions (X and Y). Since $MgCO_3(s)$ is an insoluble precipitate in aqueous solution, the reaction is also said to be a precipitation reaction.

There are three different ways that double displacement reactions can be expressed. The first, called the **molecular equation**, has all species written in their undissociated or ionic forms where their overall charges are neutral. Phases and stoichiometric coefficients are also clearly indicated. This is seen in Eqn. 2. This equation expresses the chemicals in the form that they are labeled with and used in the laboratory.

The second way is called the **complete** or **total ionic equation**. In this equation, all species are written in the form in which they predominately exist in solution. Insoluble compounds, such as solid precipitates, weak electrolytes, or pure gases and liquids, are written in their undissociated forms. Soluble compounds, such as strong electrolytes, are written in their dissociated or ionic forms. Charges and phases are clearly written. Notice that the stoichiometric coefficients remain to keep the equation balanced. Rewriting Eqn. 2 as a complete ionic equation is shown in Eqn. 3.

$$Mg^{2+}(aq) + 2\ NO_3^-(aq) + 2\ K^+(aq) + CO_3^{2-}(aq) \rightarrow MgCO_3(s) + 2\ K^+(aq) + 2\ NO_3^-(aq) \qquad \text{Eqn. 3}$$

Remember that strong acids and bases are considered to be strong electrolytes, so would be shown in the complete ionic equation in their dissociated ionic form. Weak acids are weak electrolytes so should be written in molecular form.

The third way to write a double displacement reaction is called the **net ionic equation**. In this form, only reacting ions and their product(s) are written exactly how they appear in the complete ionic equation. Spectator ions are any ions that do not change throughout the course of the reaction. These are not shown in the net ionic equation as they were not involved in the actual reaction. The net ionic equation can be seen in Eqn. 4.

$$Mg^{2+}(aq) + CO_3^{2-}(aq) \rightarrow MgCO_3(s) \qquad \text{Eqn. 4}$$

The net ionic equation shows clearly that a reaction has occurred but does not indicate any context. All three equations are needed to express a single double displacement reaction as each tells a different layer of information.

If either product (AX or BY) from a double displacement reaction forms an insoluble precipitate, the reaction is additionally classified as a precipitation reaction. The solid is called the **precipitate** and the liquid solution is the **supernatant**. A **clear** solution is one that does not contain any precipitate. A **colorless** solution is a solution that is absent of color. The color of the precipitate may be different than the color of the supernatant. Eqn. 4 indicates that the reaction between $Mg(NO_3)_2$ and K_2CO_3 is a precipitation reaction since $MgCO_3(s)$ is formed. The solubility of some ionic compounds in aqueous solution is expressed in Table 1.

If either product (AX or BY) is a gas, it is called a gas evolution reaction. The most common gases produced in gas evolution and double displacement reactions are $CO_2(g)$, $SO_2(g)$, $NH_3(g)$, and $H_2S(g)$. The first three are produced via the immediate breakdown of gas evolution intermediates, or compounds that, when formed via a double displacement reaction, undergo an immediate second decomposition reaction. These are seen in Eqns. 5-7. Hydrogen sulfide ($H_2S(g)$) is naturally a gas in normal conditions.

$$H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g) \qquad \text{Eqn. 5}$$

$$H_2SO_3(aq) \rightarrow H_2O(l) + SO_2(g) \qquad \text{Eqn. 6}$$

$$NH_4OH(aq) \rightarrow H_2O(l) + NH_3(g) \qquad \text{Eqn. 7}$$

If the reaction produces heat (is exothermic) and a weak electrolyte, it is an acid-base neutralization. Acids are compounds that release H^+ in aqueous solution and bases release OH^-. When combined, H^+ and OH^- neutralize one another to make $H_2O(l)$, as in Eqn. 8. Since the production of $H_2O(l)$ in aqueous solution cannot be easily observed, an increase in solution temperature indicating an exothermic reaction will instead be used as evidence for a successful acid-base neutralization.

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l) \qquad \text{Eqn. 8}$$

If both products (AY and BX) are soluble, then no reaction is said to have occurred and no net ionic equation can be written as all ions will be spectators.

Example Problem: Writing Molecular, Total, and Net Ionic Equations

Write the molecular, total, and net ionic equation for the reaction between barium carbonate and nitric acid.

Step 1: Write the molecular equation

Balance all charges and the reaction and indicate all phases by checking the solubility table. Note: acids are always (aq).
$BaCO_3(s) + 2\ HNO_3(aq) \rightarrow H_2CO_3(aq) + Ba(NO_3)_2(aq)$
Since H_2CO_3 is a gas evolution intermediate, it cannot be shown as a product.
$BaCO_3(s) + 2\ HNO_3(aq) \rightarrow H_2O(l) + CO_2(g) + Ba(NO_3)_2(aq)$

Step 2: Write the total ionic equation

Split all (aq) species into separate ions. Leave (s), (l), and (g) intact.
$BaCO_3(s) + 2\ H^+(aq) + 2\ NO_3^-(aq) \rightarrow H_2O(l) + CO_2(g) + Ba^{2+}(aq) + 2\ NO_3^-(aq)$

Step 3: Write the net ionic equation

Cancel out spectator ions (ions that are unchanged from reactants → products). Write only what is left.
$BaCO_3(s) + 2\ H^+(aq) \rightarrow H_2O(l) + CO_2(g) + Ba^{2+}(aq)$

Table 1: Solubility of Ions in Aqueous Solution

	$C_2H_3O_2^-$	AsO_4^{3-}	Br^-	CO_3^{2-}	Cl^-	CrO_4^{2-}	OH^-	I^-	NO_3^-	$C_2O_4^{2-}$	O^{2-}	PO_4^{3-}	SO_4^{2-}	S^{2-}	SO_3^{2-}
Al^{3+}	aq	I	aq	–	aq	–	I	aq	aq	–	I	I	aq	d	–
NH_4^+	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	–	aq	aq	aq	aq
Ba^{2+}	aq	I	aq	I	aq	I	*s*	aq	aq	I	*s*	I	I	d	I
Bi^{3+}	I	*s*	d	I	d	–	I	I	d	I	I	aq	d	I	–
Ca^{2+}	aq	I	aq	I	aq	aq	I	aq	aq	I	I	I	I	d	I
Co^{2+}	aq	I	aq	I	aq	I	I	aq	aq	I	I	I	aq	I	I
Cu^{2+}	aq	I	aq	I	aq	I	I	–	aq	I	I	I	aq	I	–
Fe^{2+}	aq	I	aq	*s*	aq	–	I	aq	aq	I	I	I	aq	I	aq
Fe^{3+}	I	I	aq	I	aq	–	I	–	aq	aq	I	I	aq	I	–
Pb^{2+}	aq	I	I	I	I	I	I	I	aq	I	I	I	I	I	I
Mg^{2+}	aq	aq	aq	I	aq	aq	I	aq	aq	I	I	I	aq	d	aq
Hg^{2+}	aq	I	I	I	aq	*s*	I	I	aq	I	I	I	d	I	–
K^+	aq	*s*	*s*	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq
Ag^+	aq	I	I	I	I	I	–	I	aq	I	I	I	I	I	I
Na^+	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq
Zn^{2+}	aq	aq	aq	I	aq	I	aq	aq	aq	I	I	I	aq	I	I

aq = soluble in aqueous solution
I = insoluble in aqueous solution
– = compound does not form
***s* = slightly soluble in aqueous solution**
d = decomposes in water

Procedure

Part I: Observing Double Displacement Reactions

1. Using 10 clean, dry small test tubes, measure 20 drops of Solution #1 from Reaction Mixtures 1-5 in the first five test tubes, and then 20 drops of Solution #2 from Reaction Mixtures 1-5 in the second five test tubes. Be sure to clearly label all ten test tubes.

2. For Reaction Mixture 1, add Solution #2 to Solution #1 and shake. Note any precipitate or evolution of a gas (formation of small bubbles) in your data sheet. If a precipitate does form, note the color in your observations.

3. If you do *not* observe a precipitate or bubbles, you will need to check for temperature change. Place 60 drops of Solution #1 in a clean, dry large test tube and record the initial temperature. Place 60 drops of Solution #2 in a different clean, dry large test tube. Quickly add Solution #2 to Solution #1, shake, and measure the temperature of the mixture. Record the final temperature. Be sure to thoroughly rinse your thermometer with deionized water before using it again.

4. Based on your observations, determine whether or not a reaction occurred. If it did, write the balanced molecular (ME), complete ionic (CIE), and net ionic (NIE) equations. Write the states for all substances in the molecular equation. In the complete ionic and net ionic equations, you do not need to write the symbol *(aq)* to save time and space, but you must write the state for any solid, liquid, or gas. If there is no reaction, write "NO REACTION" for the equations.

5. Repeat Steps 2-4 for the remaining Reaction Mixtures 2-5.

6. Empty your test tubes in the appropriate waste container. Rinse them with deionized water. Dry the outside of the test tubes. You do not need to dry the inside of the test tube before proceeding.

7. Repeat Steps 1-6 for the solutions listed for Reaction Mixtures 6-10.

Reaction Mixture	Solution #1	Solution #2
1	1.0 M sodium carbonate	1.0 M hydrochloric acid
2	1.0 M potassium hydroxide	1.0 M hydrochloric acid
3	0.1 M sodium chloride	1.0 M sodium carbonate
4	0.1 M lead(II) nitrate	0.1 M sodium iodide
5	0.1 M sodium sulfate	0. 1 M barium chloride
6	1.0 M sodium carbonate	0.1 M calcium chloride
7	1.0 M potassium hydroxide	0.3 M magnesium nitrate
8	0.1 M sodium sulfate	0.1 M copper(II) nitrate
9	1.0 M hydrochloric acid	1.0 M potassium bicarbonate
10	0.3 M strontium nitrate	0.3 M potassium iodate

Part II: Writing Double Displacement Reactions

1. Write the balanced molecular (ME), complete ionic (CIE), and net ionic (NIE) equations for any reaction that occurs. Write the states for all substances in the molecular equation. In the complete ionic and net ionic equations, you do not need to write the symbol *(aq)* to save time and space, but you must write the state for any solid, liquid, or gas. If there is no reaction, write "NO REACTION" for the equations.

Experiment 7—Data Sheet

Name: ______________________________________

Part I: Observing Double Displacement Reactions

Write the ionic formulas for the chemicals you will be using today.

barium chloride ________________________

calcium chloride ________________________

copper(II) nitrate ________________________

hydrochloric acid ________________________

lead(II) nitrate ________________________

magnesium nitrate ________________________

potassium bicarbonate ________________________

potassium hydroxide ________________________

potassium iodate ________________________

sodium carbonate ________________________

sodium chloride ________________________

sodium iodide ________________________

sodium sulfate ________________________

strontium nitrate ________________________

1. Solution 1 ______________________ Solution 2 ________________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

2. Solution 1 ______________________ Solution 2 ________________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

3. Solution 1 ____________________ Solution 2 ______________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

4. Solution 1 ____________________ Solution 2 ______________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

5. Solution 1 ____________________ Solution 2 ______________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

6. Solution 1 ____________________ Solution 2 ______________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

7. Solution 1 ______________________ Solution 2 ________________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

8. Solution 1 ______________________ Solution 2 ________________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

9. Solution 1 ____________________ Solution 2 ______________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

10. Solution 1 ____________________ Solution 2 ______________________

Did a reaction occur? YES or NO. List your observations to support your conclusion.

____

____

ME: ____

CIE: ____

NIE: ____

Part II: Writing Double Displacement Reactions

1. ME: _____ $Al_2(SO_4)_3$*(aq)*+ _____ $BaCl_2$*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

2. ME: _____ $MgSO_4$*(aq)*+ _____ $Cu(NO_3)_2$*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

3. ME: _____ $AlCl_3$*(aq)*+ _____ NH_4OH*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

4. ME: _____ $Ca(HCO_3)_2$*(aq)*+ _____ HI*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

5. ME: _____ Na_2CO_3*(aq)*+ _____ $CuSO_4$*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

6. ME: _____ $CaCO_3$***(s)***+ _____ HCl*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

7. ME: _____ K_3PO_4*(aq)*+ _____ $AgNO_3$*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

8. ME: _____ HNO_3*(aq)*+ _____ $Ba(OH)_2$*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

9. ME: _____ NaOH*(aq)*+ _____ NH_4Cl*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

10. ME: _____ $MgSO_3$*(aq)*+ _____ HCl*(aq)* → ________________________________

CIE: ________________________________

NIE: ________________________________

11. ME: _____ $BaCl_2$*(aq)*+ _____ Na_3PO_4*(aq)* → ______________________________

CIE: ______________________________

NIE: ______________________________

12. ME: _____ $Fe_2(SO_4)_3$*(aq)*+ _____ NaOH*(aq)* → ______________________________

CIE: ______________________________

NIE: ______________________________

13. ME: _____ Na_3AsO_4*(aq)*+ _____ $FeCl_3$*(aq)* → ______________________________

CIE: ______________________________

NIE: ______________________________

14. ME: _____ $NaNO_3$*(aq)* + _____ $FeCl_3$*(aq)* → ______________________________

CIE: ______________________________

NIE: ______________________________

15. ME: _____ HCl*(aq)*+ _____ $KC_2H_3O_2$*(aq)* → ______________________________

CIE: ______________________________

NIE: ______________________________

16. ME: _____ $Mg(OH)_2$*(s)* + _____ H_2SO_4*(aq)* → ____

CIE: ____

NIE: ____

Experiment 7—Post-Lab Assignment

Name: ____

1. Scientists often use their knowledge of precipitation reactions to help them identify unknown liquids or to separate a particular ion out of a mixture. A scientist receives two test tubes, each of which contains a different aqueous solution. What is one solution from the list on page 5 that could be added to the test tubes and react in different ways or react with one solution but not the other? For each test tube, describe any observations the scientist should expect to see and write the molecular equations for any reaction that occurs.

a. Test tube #1: potassium nitrate and test tube #2: barium nitrate

Solution added to both test tubes: ____________________________

Observations for Test tube #1: ____

Observations for Test tube #2: ____

Molecular equation(s) for the reaction(s) that occur:

b. Test tube #1:sodium chloride and test tube #2: hydrochloric acid

Solution added to both test tubes: ____________________________

Observations for Test tube #1: ____

Observations for Test tube #2: ____

Molecular equation(s) for the reaction(s) that occur:

2. A student was given five known solutions and asked to observe their interactions in double displacement reactions. Based on your experiment, fill in the table below with the expected observations for each pair of solutions. Use "NR" to indicate no reaction, "ppt" for precipitate, and "gas" for any bubbles observed.

	NaCl	HCl	Na_2CO_3	Na_2SO_4	$Ba(NO_3)_2$
$Ba(NO_3)_2$					
Na_2SO_4					
Na_2CO_3					
HCl					
NaCl					

The student was then given a set of the same five solutions as the table above, but the labels for each had been replaced with "A, B, C, D, and E" and their order had been changed. When the five solutions were mixed, the student recorded the following observations.

	A	B	C	D	E
E	NR	NR	white ppt	gas	
D	NR	NR	NR		gas
C	white ppt	NR		NR	white ppt
B	NR		NR	NR	NR
A		NR	white ppt	NR	NR

Identify the solution in each test tube.

Solution A ____________________ Solution D ____________________

Solution B ____________________ Solution E ____________________

Solution C ____________________

Write the net ionic equation for each unique pair of solutions from the table above that resulted in a successful double displacement reaction.

Experiment 7—Pre-Lab Assignment

Name: ______________________________________

1. Classify the following mixtures as a clear solution, a colorless solution, both, or neither.

   a. The supernatant of a reaction mixture has no color and contains a blue precipitate.

   b. The supernatant of a reaction mixture is orange and contains a white precipitate.

   c. The supernatant of a reaction mixture has no color and contains no precipitate.

   d. The supernatant of a reaction mixture is blue and contains no precipitate.

2. When a blue copper(II) nitrate solution is mixed with a colorless sodium sulfide solution, a black precipitate is formed.

   a. What is the chemical formula of the black precipitate? ______________________

   b. Write the molecular equation for this reaction.

   c. Write the total ionic equation for this reaction.

   d. Write the net ionic equation for this reaction.

3. Will a successful double displacement reaction occur if a potassium hydroxide solution is mixed with lead(II) nitrate solution? Why or why not? If a reaction does occur, write the net ionic equation for the reaction.

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