EXPERIMENT 3: REACTIONS IN AQUEOUS SOLUTIONS  
(Read through this prior to beginning part 1) 
This experiment corresponds to chapter 3 in your text

Introduction
One of the most important characteristics of water is its ability to dissolve many compounds. Solutions in which water is the solvent are called aqueous solutions. Many important reactions take place in aqueous solutions. In fact, many of the reactions that take place throughout your body (from your organs down to individual cells) are aqueous reactions. Understanding the most common aqueous reactions and how to correctly write them is one of the most important skills you should master in Chemistry 1A. This skill will be used extensively throughout the remainder of the semester and in Chemistry 1B.

Before you begin, one must ask the question: What observations indicate that a chemical reaction has occurred? Some indications include: the formation of an insoluble solid (precipitate), color change, the evolution of a gas, or a temperature change. In this experiment, you will predict what will happen when two aqueous solutions are mixed, and then test your predictions in the laboratory. During the previous discussion period, your lab instructor lectured on the topic of reactions in aqueous solution with examples of the correct way to write a molecular equation, an ionic equation, and the overall net ionic equation for several types of aqueous reactions.

In metathesis or double displacement reactions, cations and anions exchange partners as in the following generic reaction:

\[ AX + BY \rightarrow AY + BX \]

There are three types of metathesis reactions—precipitation reactions, gas-forming reactions, and neutralization reactions. An example of each type is given below:

<table>
<thead>
<tr>
<th>Reaction Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>[ \text{Pb(NO}_3\text{)}_2 \text{(aq)} + 2 \text{KI (aq)} \rightarrow 2 \text{KNO}_3 \text{(aq)} + \text{PbI}_2 \text{(s)} ] precipitate</td>
</tr>
<tr>
<td>Gas-forming</td>
<td>[ 2 \text{HCl (aq)} + \text{Na}_2\text{S (aq)} \rightarrow \text{H}_2\text{S (g)} + 2 \text{NaCl (aq)} ]</td>
</tr>
<tr>
<td>Neutralization</td>
<td>[ \text{HNO}_3 \text{(aq)} + \text{KOH (aq)} \rightarrow \text{KNO}_3 \text{(aq)} + \text{H}_2\text{O (l)} ] acid base salt</td>
</tr>
</tbody>
</table>

A metathesis reaction will occur if (1) a precipitate forms from soluble reactants or (2) a stable molecule forms, such as water or an insoluble gas. Refer to the example on the next page and the sections on ionic equations and metathesis reactions in your textbook for information on writing chemical equations for metathesis reactions. Familiarity with the solubility rules tabulated on the next page is required to write these equations.

Objectives: Upon completion of this exercise and laboratory experiment, you should be able to:
1. Using the solubility rules, determine the species present in aqueous solutions of compounds.
2. Predict the type of reaction that will occur when two aqueous solutions are mixed.
3. Write the chemical equation, the ionic equation, and the net ionic equation for reactions taking place between aqueous solutions.
4. Experimentally identify the type of reaction occurring when two aqueous solutions are mixed through simple visual and temperature measurements.
EXPERIMENT 3: REACTIONS IN AQUEOUS SOLUTIONS

Solubility Rules: You should be familiar with these rules and be able to use them efficiently. You will be provided these rules on quizzes and exams.

<table>
<thead>
<tr>
<th>Soluble Compounds</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compounds containing NO₃⁻ and C₂H₃O₂⁻</td>
<td>None</td>
</tr>
<tr>
<td>Compounds containing Cl⁻, Br⁻, and I⁻</td>
<td>Compounds containing Pb²⁺⁰⁰, Ag⁺, Hg₂²⁺</td>
</tr>
<tr>
<td>Compounds containing SO₄²⁻</td>
<td>Compounds containing Ca²⁺⁰⁰, Hg₂²⁺⁰⁰, Ag⁺⁰⁰, Sr²⁺⁰⁰, Ba²⁺⁰⁰, and Pb²⁺⁰⁰</td>
</tr>
<tr>
<td>Compounds containing NH₄⁺</td>
<td>None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Insoluble Compounds</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compounds containing CO₃²⁻</td>
<td>Compounds containing NH₄⁺ and alkali metal cations</td>
</tr>
<tr>
<td>Compounds containing OH⁻</td>
<td>Compounds containing NH₄⁺, Ca²⁺⁰⁰, Sr²⁺⁰⁰, Ba²⁺⁰⁰, and alkali metal cations</td>
</tr>
<tr>
<td>Compounds containing S²⁻</td>
<td>Compounds containing NH₄⁺ and alkali metal cations</td>
</tr>
</tbody>
</table>

Writing the molecular, ionic, and net ionic equations for a chemical reaction in aqueous solution:

The steps for writing a net ionic equation for the metathesis reaction of aqueous K₂SO₄ and Pb(C₂H₃O₂)₂ are outlined below.

1. Write the balanced molecular equation which gives the complete chemical formula and the phase of the reactants and products. Switch the reactant cation/anion pair to form the products and use the solubility rules to determine the phase of the products.

   K₂SO₄ (aq) + Pb(C₂H₃O₂)₂ (aq) → PbSO₄ (s) + 2 KC₂H₃O₂ (aq)

2. Write the balanced complete ionic equation which shows all strong electrolytes as ions.

   2 K⁺ (aq) + SO₄²⁻ (aq) + Pb²⁺ (aq) + 2 C₂H₃O₂⁻ (aq) → PbSO₄ (s) + 2 K⁺ (aq) + 2 C₂H₃O₂⁻ (aq)

3. Cancel out the spectator ions, the ions that appear as both reactants and products in the complete ionic equation. What remains is the net ionic equation.

   2 K⁺ (aq) + SO₄²⁻ (aq) + Pb²⁺ (aq) + 2 C₂H₃O₂⁻ (aq) → PbSO₄ (s) + 2 K⁺ (aq) + 2 C₂H₃O₂⁻ (aq)

   Pb²⁺ (aq) + SO₄²⁻ (aq) → PbSO₄ (s)

Adapted from "Reactions in Aqueous Solutions" by David Reichgott and Mary O'Brien, Edmonds Community College, Lynnwood, Washington and "Reactions in Aqueous Solutions" Illinois State University, Normal, Illinois.
Experiment 3: Reactions in Aqueous Solutions – Part 1:

(You may begin this at home, part 1 must be completed prior to leaving lab on day 1)

Name: _______________________________

Section: ____________________________

1. Precipitation Reactions (You may begin this at home, it must be completed and turned into your instructor prior to leaving lab on day 1 of the exp.)

a. On the reverse side of this page or on a separate piece of paper, neatly write the balanced molecular equation, an ionic equation with spectator ions crossed out, and the balanced net ionic equation for the reaction of each pair of aqueous solutions. (Be sure to include all states, aq, l, s or g. Use the solubility rules as a guide.) Attach any extra pages with your work.

Example: lead nitrate and potassium iodide

Molecular equation: \( \text{Pb(NO}_3\text{)}_2 \text{ (aq)} + 2 \text{KI (aq)} \rightarrow \text{PbI}_2 \text{ (s)} + 2 \text{KNO}_3 \text{ (aq)} \)

Ionic equation: \( \text{Pb}^{2+} \text{ (aq)} + 2 \text{NO}_3^- \text{ (aq)} + 2 \text{K}^+ \text{ (aq)} \rightarrow \text{PbI}_2 \text{ (s)} + 2 \text{K}^+ \text{ (aq)} + 2 \text{NO}_3^- \text{ (aq)} \)

Net ionic equation: \( \text{Pb}^{2+} \text{ (aq)} + 2 \text{I}^- \text{ (aq)} \rightarrow \text{PbI}_2 \text{ (s)} \)

b. Tabulate your expected results in the chart below based on the solubility rules covered in you text and lecture.
Place a “P” in the box if you expect a precipitate to form and “NR” if you do not think a reaction will occur. Note “SS” as well if any of the reactions generate a slightly soluble product.

Predicted Results

<table>
<thead>
<tr>
<th></th>
<th>NH$_4$NO$_3$</th>
<th>AgNO$_3$</th>
<th>Ba(NO$_3$)$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na$_2$SO$_4$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaOH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na$_2$CO$_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Instructor Date and Sign: ________________________________

Adapted from "Reactions in Aqueous Solutions" by David Reichgott and Mary O'Brien, Edmonds Community College, Lynnwood, Washington and “Reactions in Aqueous Solutions” Illinois State University, Normal, Illinois.
Experiment 3: Reactions in Aqueous Solutions Part 2 (Day 2):

Experimental Procedure:

In this part of the experiment, you will compare your predictions of reactions in aqueous solutions against your observed results obtained when aqueous solutions are mixed in the laboratory.

1. Unless noted, the test tubes that you use do not need to be completely dry. However, rinse them with deionized water before use.

2. Select three small test tubes. Using a graduated cylinder, measure 1.0 mL of deionized water and transfer it to a test tube. Use a grease pencil to mark the water level in the test tube and then use the test tube as a guide to make a 1.0 mL mark on the other two test tubes. Repeat this step to make 2.0 mL marks on each test tube. Each of the three test tubes should have a 1.0 mL and a 2.0 mL mark when you are finished.

Precipitation Reactions:

3. Add 1 mL of 0.1 M NaCl to each of the three test tubes. Then, in order, add 1 mL of each of the solutions listed in the first row of the table in question 1 of your lab report. For example, the first test tube should contain NaCl and NH₄NO₃, the second should contain NaCl and AgNO₃, and the third should contain NaCl and Ba(NO₃)₂. Record your observations. Dispose of the silver and barium solutions in the appropriate waste container.

4. Repeat step 3 for all solution combinations in the table. Again, dispose of all solutions containing silver and barium in the appropriate waste container.

Gas-Forming Reactions:

5. To a dry test tube, add a sample of CaCO₃ that is about the size of a pencil eraser. Then add 1 mL of deionized water followed by 1 mL of 2 M HCl. Record your observations.

6. Repeat step 5 using Na₂SO₄ in place of CaCO₃.

Neutralization Reactions:

7. Weigh about 0.5 g of Mg(OH)₂ on the top loading balance. Transfer the sample to a 150 ml beaker. Use a graduated cylinder to measure 25.0 mL of deionized water. Pour the water into the beaker containing Mg(OH)₂. Swirl the mixture.

8. Use a graduated cylinder to measure 25.0 mL of 1.0 M HCl. Add the HCl to the beaker containing the Mg(OH)₂ mixture and thoroughly stir the solution. Observe what happens, upon mixing.
EXP 3: REACTIONS IN AQUEOUS SOLUTIONS

Part 2: EXPERIMENTAL RESULTS

1. Precipitation Reactions: Tabulate your observations in the chart below. Compare your results to your predictions. Use an asterisk (*) to mark any observations that do not agree with your predictions.

Results

<table>
<thead>
<tr>
<th></th>
<th>NH₄NO₃</th>
<th>AgNO₃</th>
<th>Ba(NO₃)₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na₂SO₄</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaOH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Gas-Forming Reactions:
   a. Describe what happened when you mixed HCl with CaCO₃.

   b. Describe what happened when you mixed HCl with Na₂SO₄.

3. Neutralization Reactions:

   What happened when you mixed the Mg(OH)₂ and HCl? Explain your observations.

Instructor Date and Sign: _______________________________

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Part 2 Predictions

1. **Precipitation Reactions**: Completed in part 1 of this assignment.

2. **Gas-Forming Reactions** *(refer to you text and notes)*

   Which of the following pairs of reactants will give off a gas when mixed?

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Will a gas evolve? (Y/N)</th>
<th>Formula of Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl and CaCO₃</td>
<td>________________________</td>
<td>_____________</td>
</tr>
<tr>
<td>HCl and Na₂SO₄</td>
<td>________________________</td>
<td>_____________</td>
</tr>
</tbody>
</table>

3. **Neutralization Reactions**

   Write the balanced molecular equation, an ionic equation with spectator ions crossed out, and the balanced net ionic equation for the reactions below. *(Be sure to include all states, aq, l, s or g)*

   (a) Solutions of sodium hydroxide and hydrochloric acid.

   (b) Solutions of hydrofluoric acid and calcium hydroxide.

   (c) Solutions of nitric acid and aqueous ammonia.

   (d) Solid magnesium hydroxide and aqueous perchloric acid.
EXP 3: REACTIONS IN AQUEOUS SOLUTIONS

Name: ________________________________

(Post-lab questions… what you might see on an exam…) Section: _________

1. Describe how you could experimentally differentiate between the following pairs of solutions using a common aqueous test solution:

Example: A student is presented with two clear and colorless solutions, sodium nitrate and sodium carbonate. The student adds a few drops of a nitric acid solution to each and observes bubbles in one. That solution must be the sodium carbonate solution since the other cannot form a gas via reaction with nitric acid.

   a. Pb(NO₃)₂ or KNO₃

   b. HCl or H₂SO₄

2. Write a balanced net ionic equation for each of the following aqueous metathesis reactions. (Be sure to include all states, aq, s, l or g) Refer to the example in the introduction of this experiment and the section on ionic equations in your textbook for assistance. Classify each reaction as a neutralization, precipitation, or gas-forming reaction. (Refer to ch. 3 section 10 in your text)

   a. Hydrobromic acid and cesium hydroxide

      Classification: __________________________

   b. Sulfuric acid and sodium carbonate

      Classification: __________________________

   c. Cadmium chloride and sodium sulfide

      Classification: __________________________

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