Experiment 6 - Exploring Double Displacement Reactions

Introduction

This week, we are going to try a different style of lab. Instead of following a strict procedure, I want you to have an opportunity to try things out and explore your own ideas. Please be safe and responsible, but feel free to play around!

Many reactions depend on **dissociation**, the splitting of substances into ions when they dissolve. Recall that substances that split into ions are called **electrolytes**. Most molecular substances, including water, are non-electrolytes, meaning they don't split into ions enough to conduct electricity. Most ionic compounds are strong or moderately strong electrolytes, meaning they split completely into ions, or at least mostly into ions. Strong acids and bases are strong electrolytes, and weak acids and bases are weak electrolytes.

When two electrolyte compounds are mixed together, the ions can in theory rearrange in a **double-displacement reaction**:

$$AB + CD \rightarrow AD + CB \qquad \text{Rxn 1}$$

However, if all the combinations are soluble strong electrolytes, then nothing actually happens:

$$AB + CD \rightarrow \text{no reaction} \qquad \text{Rxn 2}$$

The reason is that you had four kinds of ions separate in solution at the beginning, and they are still completely separate at the end; no new chemical bonds have formed. Interesting reactions happen when some combinations are weak or non-electrolytes, or when some combinations are insoluble. If an insoluble combination forms, it will **precipitate**, and you'll see either cloudiness or solid in the mix, such as:

$$AB(aq) + CD(aq) \rightarrow AD(aq) + CB(s) \qquad \text{Rxn 3}$$

If a soluble weak or non-electrolyte forms, you may notice a temperature or color change (or you may not be able to tell that anything happened at all, even though something did). If a gas forms, you may see bubbling. In this experiment, you'll observe reactions and look for combinations that produce gas, solid, and color and temperature changes. When something interesting happens, figure out what the reaction was! For example, you can try other combinations to isolate which ions produced the observed effect.

Record your observations by writing two types of equations when you believe a reaction happened. First, write a **molecular equation**, like Rxn 3, that shows what two compounds you mixed and what compounds were formed. Then, write a **net ionic equation**. Net ionic equations show only the part that really changed. For example, if AB, CD, and AD are soluble strong electrolytes, but CB is insoluble, Rxn 4 (the **complete ionic equation**) is actually a better description than Rxn 3:

$$A^+(aq) + B^-(aq) + C^+(aq) + D^-(aq) \rightarrow A^+(aq) + D^-(aq) + CB(s) \qquad \text{Rxn 4}$$

But, complete ionic equations are laborious to write out, and notice that nothing has happened to the A^+ and D^- ions, which are called **spectator ions**. We can cancel them out (cross off both sides), and that leaves the **net ionic equation**, which focuses on the only new interaction:

$$B^-(aq) + C^+(aq) \rightarrow CB(s) \qquad \text{Rxn 5}$$

How to write equations: keep the following very important points in mind:

- Identify the correct charges on each ion! Use the periodic table, or for the polyatomic ions like ammonium and sulfate, if you haven't memorized them (you should!) look them up or figure out the charge based on the formulas given.
- When writing ionic formulas, the ion with the positive charge is always written first
- Only cation/anion (+/- ion) combinations that are *neutral* overall will form. So it's essential to identify the correct charge on all the ions, then write a formula with balanced charges.
- Check that you have simplified the formulas: Na_2Cl_2 should be NaCl.
- Balance the equation.
- Make sure the *charges* balance on both sides of the equation! This is just as important as balancing the atoms. For example, in Rxn 5, the total charge on the left and on the right is zero.
- For net ionic equations, only show aqueous strong electrolytes as dissociated. Weak electrolytes, non-electrolytes, and anything that is solid or gas should not be written as ions, and therefore won't be cancelled out.

Acid-base reactions are a special type of double displacement reaction in which hydrogen ions (one or more) change partners. The simplest example of acid-base neutralization involves hydrogen and hydroxide ions combining to form water, a non-electrolyte. In this case, the salt ions are spectators.

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) \qquad \text{Rxn 6}$$

Acid-base reactions can be less obvious to write than some other types of double displacement reactions because you might not know how many hydrogen ions move if some of the compounds have more than one. In general, this will depend on the amounts of each compound used, and you might not be able to tell for sure. For example, carbonate ion is basic, as many anions are. It can react with one hydrogen ion to make bicarbonate (Rxn 7), and with a second to make carbonic acid (Rxn 8). The carbonic acid can undergo a reverse anhydride reaction and produce CO_2 and water.

$$Na_2CO_3 + HCl \rightarrow NaHCO_3 + NaCl \qquad \text{Rxn 7}$$

$$NaHCO_3 + HCl \rightarrow H_2CO_3 + NaCl \qquad \text{Rxn 8}$$

If you mix sodium carbonate and acid, you might get either bicarbonate or carbon dioxide as product. In this case, you would be able to identify the latter because it would produce bubbling, but in some similar situations you might not be sure what the ratios are. If so, don't worry, just write down one or both of the possibilities.

Usually if a strong acid or base is involved, it will react completely. If both acid and base are weak, it will be much harder to predict what happens. Because they are both weak electrolytes, the reaction can run in both directions. For example,

$$NH_3 + H_2O \leftrightarrows NH_4^+ + OH^- \qquad \text{Rxn 9}$$

This reaction will only happen a little bit, maybe to 1% of the total ammonia molecules, but you might still see some evidence that it occurs. If you mix an ammonium salt and a hydroxide salt, it can easily go back in the other direction; now you have a strong base present so the reaction will probably finish.

Safety Precautions:

- Wear your safety goggles at all times.
- Be careful with the strong acids and bases (HCl, $Ba(OH)_2$, NaOH, etc.)
- If a bottle is in the fume hood, leave it there!
- Make very small test mixes: don't use more than 15 drops of any solution
- Wear latex or nitrile gloves
- Close bottles as soon as you are done using them

Waste Disposal:

- Pour your solutions into the waste bottle in the hood when you're done. Use the water squirt bottles to rinse the glassware into the waste bottle.

Procedure

Use the spot plates and/or small test tubes. Try combining the solutions provided by adding about 5 drops each of two solutions to a well or test tube. A few solids are also provided; just add a tiny amount of solid. For each mix you make, record which solutions you used and what you observed. If you think a reaction happened, try to determine what the reaction was by comparing to other combinations! Once you have decided what the products were, if possible, write molecular and net ionic equations for the reaction.

In some cases, you may notice interesting effects that depend on how much of each substance you use. If you want to explore this, start with about 5 drops of one substance and gradually add up to 15 drops of another. Keep the quantities small!

In your notebook, record the balanced molecular and net ionic equations (with s/l/g/aq indicated for each reactant and product) for:

- at least 4 combinations that formed 4 different precipitates
- at least 1 combination that formed a gas
- at least 3 combinations that changed color dramatically, but stayed clear and formed no precipitate
- at least 1 combination that changed temperature (for this, use a test tube!)

Suggestions to get you started:

1. Combine a bit of silver nitrate solution with a bit of sodium chloride solution. What happens? If you aren't sure what the product is, try some other combinations to eliminate the possibilities.
2. Combine a bit of barium hydroxide solution and a bit of sulfuric acid solution. What are the products? Can you make this product by other combinations?
3. Combine a concentrated acid solution with a concentrated base solution. Does the temperature change? Try a different combination of acid and base. Does the concentration matter? (Acids include hydrochloric acid, nitric acid, and sulfuric acid; bases include hydroxide compounds, ammonia, and carbonate compounds.)
4. Add a solution of a base to a solution with transition metal cations (iron, copper, or silver). What is the product? Do you get the same product no matter which base you use? Can you tell?

5. Add ammonia dropwise to a bit of copper(II) chloride. What do you observe? How can you explain this? Does anything happen if you add dropwise hydrochloric acid to the mixture, or to plain copper(II) chloride solution?
6. Add a drop of potassium thiocyanate to a bit of iron(III) nitrate solution. What could explain this? What is the phase of the product? What happens when you add a bit of potassium thiocyanate to other solutions, like copper(II) chloride or calcium chloride?

Name: Section:

Experiment 6 Pre-Lab Sheet

1. (3 pts) Identify the following compounds as acids (A), bases (B), or neutral salts (N):
H_2SO_4, $NaOH$, $AgCl$, NH_3, HNO_3, $FeCl_3$, Na_2CO_3, HCl, $NaCl$

2. (3 pts) Identify each of the following as strong (S), weak (W) or non-electrolytes (N):
H_2O, NH_3, HCl, $NaCl$, H_2SO_4, $NaOH$, KNO_3, H_2CO_3, $HC_2H_3O_2$

3. (1 pt) How much of any solution should you use for test mixes, at maximum?

4. (1 pt) Write the net ionic equation for this reaction, assuming CD and AD are strong electrolytes and all ions have single charges:

$$AB(s) + CD(aq) \rightarrow AD(aq) + CB(s).$$

5. (2 pts) What new compounds can form from the following mixes? Write balanced molecular equations for double displacement reactions.

$KCl + Hg(NO_3)_2 \rightarrow$

$H_2SO_4 + Na_2CO_3 \rightarrow$