IONIC REACTIONS in AQUEOUS SOLUTIONS: NET IONIC EQUATIONS

Double replacements are among the most common of the simple chemical reactions. Consider the hypothetical reaction:

\[ \text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB} \]

where AB exists as A\(^+\) and B\(^-\) ions in solution and CD exists as C\(^+\) and D\(^-\) ions in solution. As the ions come in contact with each other, there are six possible combinations that might conceivably cause a chemical reaction. Two of these combinations are the meeting of ions of like charge; that is, A\(^+\) with C\(^+\) and B\(^-\) with D\(^-\). Since particles with like electrical charges repel each other, no reaction will occur. Two other possible combinations are those of the original two compounds; that is A\(^+\) with B\(^-\) and C\(^+\) with D\(^-\). This combination would lead to no change. Thus the only possibilities for chemical reaction are the combination of each of the positive ions with the negative ion of the other compound; that is, A\(^+\) with D\(^-\) and C\(^+\) with B\(^-\).

**Example 1:** When solutions of sodium chloride and silver(I) nitrate are mixed, the combination of silver(I) cations and chloride anions form silver(I) chloride, which precipitates and settles to the bottom of the container. Note that the states of matter are included: (aq) substance is soluble in water; (s) substance is insoluble in water (solid precipitate)

\[ \text{NaCl}(\text{aq}) + \text{AgNO}_3(\text{aq}) \rightarrow \text{NaNO}_3(\text{aq}) + \text{AgCl}(\text{s}) \]

This combination of chemicals is referred to as a precipitation reaction since an insoluble solid, AgCl, is present as a product.

**Example 2:** When solutions of potassium chloride and sodium nitrate are mixed, the equation for the hypothetical double replacement reaction is:

\[ \text{KCl}(\text{aq}) + \text{NaNO}_3(\text{aq}) \rightarrow \text{KNO}_3 + \text{NaCl} \]

But has there been a reaction? Double replacement reactions occur when one of the following is formed as a product of the reaction:

- **a. an insoluble solid** (precipitate) - check the solubility table in this lab report. If a solid has formed, this is called a precipitation reaction.
- **b. a gas** - for example, CO\(_2\) (from H\(_2\)CO\(_3\)), SO\(_2\) (from H\(_2\)SO\(_3\)), or NH\(_3\) (from NH\(_4\)OH). If a gas has formed, this is called a gas forming reaction.
- **c. water** from an acid (source of H\(^+\)) and a base (source of OH\(^-\)). If water forms from an acid and a base (along with an ionic "salt"), this is called an acid-base reaction.

Using the solubility table (see below) we find both KNO\(_3\) and NaCl are water soluble products. There is no precipitate, gas or water from an acid and base combination. Thus in Example 2, we conclude that even though we can write an equation for a double replacement reaction, no reaction occurs. We simply end up with a solution containing four kinds of ions - Na\(^+\), K\(^+\), Cl\(^-\), and NO\(_3^-\).
Thus the equation is more properly written:

\[ \text{KCl}_{(aq)} + \text{NaNO}_3_{(aq)} \rightarrow \text{No Reaction} \]

Aqueous solutions of sodium chloride and silver(I) nitrate will undergo double replacement reaction to produce a white precipitate of silver(I) chloride and aqueous sodium nitrate. What would happen if we just mixed solid silver(I) nitrate and solid sodium chloride together? No apparent reaction occurs. Thus the water performs some necessary function that allows the reaction to proceed. When ionic compounds are dissolved in water, the ions separate and become surrounded by water molecules. This frees the ions from the crystal lattice, allowing them to move throughout the solution and react with appropriate ions of opposite charge.

To clarify what reaction occurs between ions in electrolyte solutions, we write \textbf{total ionic equations}. In this type of equation, compounds are written in the form in which they are predominately present in water. Most notably, soluble compounds (aq) are written as ions in solution. Others (s, l, g) are written in their molecular form.

For example, if we write the total ionic equation for the double replacement precipitation reaction (See Example 1) we get the following:

\[ \text{Total Ionic Equation: } \text{Na}^+_{(aq)} + \text{Cl}^-_{(aq)} + \text{Ag}^+_{(aq)} + \text{NO}_3^-_{(aq)} \rightarrow \text{Na}^+_{(aq)} + \text{NO}_3^-_{(aq)} + \text{AgCl}_{(s)} \]

Note that during the course of reaction, there has been no change in the Na\(^+\) and NO\(_3^-\) ions. These unreacted ions (spectator ions) can be left out of the total ionic equation to yield the \textbf{net ionic equation}. Net ionic equations tell us only what is actually changing during reaction.

\[ \text{Net Ionic Equation: } \text{Cl}^-_{(aq)} + \text{Ag}^+_{(aq)} \rightarrow \text{AgCl}_{(s)} \]

Another example is illustrated below for the reaction of nitric acid and a dilute aqueous solution of barium hydroxide (an \textbf{acid-base reaction}):\n
\[ \text{"Molecular" Equation: } 2 \text{HNO}_3_{(aq)} + \text{Ba(OH)}_2_{(aq)} \rightarrow 2 \text{H}_2\text{O}_{(l)} + \text{Ba(NO}_3\text{)}_2_{(aq)} \]

\[ \text{Total Ionic Equation: } 2 \text{H}^+_{(aq)} + 2 \text{NO}_3^-_{(aq)} + \text{Ba}^{2+}_{(aq)} + 2 \text{OH}^-_{(aq)} \rightarrow 2 \text{H}_2\text{O}_{(l)} + \text{Ba}^{2+}_{(aq)} + 2 \text{NO}_3^-_{(aq)} \]

\[ \text{Net Ionic Equation: } 2 \text{H}^+_{(aq)} + 2 \text{OH}^-_{(aq)} \rightarrow 2 \text{H}_2\text{O}_{(l)} \]

reduced to simplest form: \[ \text{H}^+_{(aq)} + \text{OH}^-_{(aq)} \rightarrow \text{H}_2\text{O}_{(l)} \]

This is an example of an \textbf{acid-base reaction}.

We will use the following solubility table in CH 221:
### CH 221 Solubility Table for Ionic Compounds

#### Soluble Compounds

- Almost all salts of Na⁺, K⁺, NH₄⁺
- Salts of nitrate, NO₃⁻
  - chlorate, ClO₃⁻
  - perchlorate, ClO₄⁻
  - acetate, CH₃CO₂⁻

#### Exceptions

- Almost all salts of Cl⁻, Br⁻, I⁻
- Compounds containing F⁻
- Salts of sulfate, SO₄²⁻

#### Insoluble Compounds

- Most salts of carbonate, CO₃²⁻
  - phosphate, PO₄³⁻
  - oxalate, C₂O₄²⁻
  - chromate, CrO₄²⁻
- Most metal sulfides, S²⁻
- Most metal hydroxides and oxides

#### Exceptions

- Halides of Ag⁺, Hg₂²⁺, Pb²⁺
- Fluorides of Mg²⁺, Ca²⁺, Sr²⁺, Ba²⁺, Pb²⁺
- Sulfates of Ca²⁺, Sr²⁺, Ba²⁺, Pb²⁺

- Salts of NH₄⁺ and the alkali metal cations
PROCEDURE and LAB REPORT:

Use the attached sheets to complete this week's lab. The purpose, conclusion, etc. can be omitted this week. For each reaction,

- **Mix** 1.0 mL (20 drops) of each of the two indicated solutions (below) in a clean (but not necessarily dry) small test tube and record observations that might indicate a chemical change has occurred (color, precipitate, bubbles of a gas, or heat released.) *Note* that there are two concentrations of sodium hydroxide present (0.1 M and 3 M), so only use the 3 M sodium hydroxide when asked.

- Write the **balanced molecular equation** (double displacement or exchange reaction) for each reaction. Show states of matter (use the solubility table in this lab report) and ionic charges for all species.

- Write the **total ionic equation** and the **net ionic equation** for each reaction. Be sure to include all states of matter and ionic charges. If all the products are aqueous, no reaction has occurred, and you should write no reaction in place of the net ionic equation. Note that even if no reaction occurs, you will still be required to write a balanced molecular equation and the total ionic equation.

- Finally, classify each reaction as **precipitation, acid-base** or **gas forming**. Remember that gas forming reactions often create unstable precursors (such as $\text{H}_2\text{CO}_3$ (which creates $\text{CO}_2(g)$ and $\text{H}_2\text{O}(l)$) and $\text{NH}_4\text{OH}$ (which creates $\text{NH}_3(g)$ and $\text{H}_2\text{O}(l)$.).)

The reactions:

1. Barium Nitrate + Magnesium Sulfate
2. Barium Nitrate + Hydrochloric Acid
3. Barium Nitrate + (0.1 M) Sodium Hydroxide
4. Barium Nitrate + Sodium Carbonate
5. Iron(III) Chloride + (3 M) Sodium Hydroxide
6. Iron(III) Chloride + Potassium Nitrate
7. Iron(III) Chloride + Magnesium Sulfate
8. Magnesium Sulfate + (0.1 M) Sodium Hydroxide
9. Magnesium Sulfate + Sodium Carbonate
10. Hydrochloric Acid + Potassium Nitrate
11. Hydrochloric Acid + (3 M) Sodium Hydroxide
12. Hydrochloric Acid + Sodium Carbonate
13. Potassium Nitrate + Sodium Carbonate
14. Silver(I) Nitrate + Sodium Sulfate
15. Silver(I) Nitrate + Iron(III) Chloride
16. (3 M) Sodium Hydroxide + Ammonium Chloride
17. Copper(II) Sulfate + Zinc(II) Nitrate
18. Acetic Acid + Sodium Carbonate
Complete the following worksheet using the instructions provided. Remember to show states of matter and charges where appropriate. **M** = Molecular Equation, **T** = Total Ionic Equation, and **N** = Net Ionic Equation.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Observations</th>
<th>Molecular Equation</th>
<th>Total Ionic Equation</th>
<th>Net Ionic Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Barium Nitrate + Magnesium Sulfate</td>
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<tr>
<td>2. Barium Nitrate + Hydrochloric Acid</td>
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<td></td>
</tr>
<tr>
<td>3. Barium Nitrate + (0.1 M) Sodium Hydroxide</td>
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<tr>
<td>4. Barium Nitrate + Sodium Carbonate</td>
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</tr>
</tbody>
</table>
5. Iron(III) Chloride + (3 M) Sodium Hydroxide  
   Observations: ________________________________
   M: ____________________________________________
   T: ____________________________________________
   N: ____________________________________________
   Type of reaction (if appropriate): __________________

6. Iron(III) Chloride + Potassium Nitrate  
   Observations: ________________________________
   M: ____________________________________________
   T: ____________________________________________
   N: ____________________________________________
   Type of reaction (if appropriate): __________________

7. Iron(III) Chloride + Magnesium Sulfate  
   Observations: ________________________________
   M: ____________________________________________
   T: ____________________________________________
   N: ____________________________________________
   Type of reaction (if appropriate): __________________

8. Magnesium Sulfate + (0.1 M) Sodium Hydroxide  
   Observations: ________________________________
   M: ____________________________________________
   T: ____________________________________________
   N: ____________________________________________
   Type of reaction (if appropriate): __________________

9. Magnesium Sulfate + Sodium Carbonate  
   Observations: ________________________________
   M: ____________________________________________
   T: ____________________________________________
   N: ____________________________________________
   Type of reaction (if appropriate): __________________
10. Hydrochloric Acid + Potassium Nitrate  
Observations: ______________________________________

M: _____________________________________________________________________________________

T: _____________________________________________________________________________________

N: ________________________________________________

Type of reaction (if appropriate): ______________________

11. Hydrochloric Acid + (3 M) Sodium Hydroxide  
Observations: ______________________________________

M: _____________________________________________________________________________________

T: _____________________________________________________________________________________

N: ________________________________________________

Type of reaction (if appropriate): ______________________

12. Hydrochloric Acid + Sodium Carbonate  
Observations: ______________________________________

M: _____________________________________________________________________________________

T: _____________________________________________________________________________________

N: ________________________________________________

Type of reaction (if appropriate): ______________________

13. Potassium Nitrate + Sodium Carbonate  
Observations: ______________________________________

M: _____________________________________________________________________________________

T: _____________________________________________________________________________________

N: ________________________________________________

Type of reaction (if appropriate): ______________________

14. Silver(I) Nitrate + Sodium Sulfate  
Observations: ______________________________________

M: _____________________________________________________________________________________

T: _____________________________________________________________________________________

N: ________________________________________________

Type of reaction (if appropriate): ______________________
15. Silver(I) Nitrate + Iron(III) Chloride  
Observations: _______________________________________
M: _____________________________________________________________________________________
T: _____________________________________________________________________________________
N: _____________________________________________________________________________________
Type of reaction (if appropriate): ________________

16. (3 M) Sodium Hydroxide + Ammonium Chloride  
Observations: ________________________
M: _____________________________________________________________________________________
T: _____________________________________________________________________________________
N: ___________________________________________________
Type of reaction (if appropriate): ______________________

17. Copper(II) Sulfate + Zinc(II) Nitrate  
Observations: _______________________________
M: _____________________________________________________________________________________
T: _____________________________________________________________________________________
N: _____________________________________________________________________________________
Type of reaction (if appropriate): ________________

18. Acetic Acid + Sodium Carbonate  
Observations: _______________________________
M: _____________________________________________________________________________________
T: _____________________________________________________________________________________
N: _____________________________________________________________________________________
Type of reaction (if appropriate): ________________

**Bonus!** Add an original poem for extra credit… content will not be criticized, but the poem must be original!