IONIC REACTIONS in AQUEOUS SOLUTIONS: NET IONIC EQUATIONS

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

$$\mathbf{AB + CD \rightarrow AD + CB}$$

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)

$$\mathbf{NaCl_{(aq)} + AgNO_{3(aq)} \rightarrow NaNO_{3(aq)} + AgCl_{(s)}}$$

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:

$$\mathbf{KCl_{(aq)} + NaNO_{3(aq)} \rightarrow KNO_3 + NaCl}$$

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_2CO_3), SO_2 (from H_2SO_3), or NH_3 (from NH_4OH). 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^{-1}). 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:

$$\mathbf{KCl_{(aq)} + NaNO_{3(aq)} \rightarrow \text{No Reaction}}$$

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 **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 <u>total ionic equation</u> for the double replacement precipitation reaction (See Example 1) we get the following:

<u>Total Ionic Equation:</u> $Na^+_{(aq)} + Cl^-_{(aq)} + Ag^+_{(aq)} + NO_3^-{}_{(aq)} \rightarrow Na^+_{(aq)} + NO_3^-{}_{(aq)} + AgCl_{(s)}$

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 **net ionic equation**. <u>Net ionic equations</u> tell us only what is actually changing during reaction.

<u>Net Ionic Equation</u>: $Cl^-_{(aq)} + Ag^+_{(aq)} \rightarrow AgCl_{(s)}$

Another example is illustrated below for the reaction of nitric acid and a dilute aqueous solution of barium hydroxide (an **acid-base reaction**):

"<u>Molecular" Equation</u>: $2\ HNO_{3(aq)} + Ba(OH)_{2(aq)} \rightarrow 2\ H_2O_{(l)} + Ba(NO_3)_{2(aq)}$

<u>Total Ionic Equation</u>: $2\ H^+_{(aq)} + 2\ NO_3^-{}_{(aq)} + Ba^{2+}_{(aq)} + 2\ OH^-_{(aq)} \rightarrow 2\ H_2O_{(l)} + Ba^{2+}_{(aq)} + 2\ NO_3^-{}_{(aq)}$

<u>Net Ionic Equation:</u> $2\ H^+_{(aq)} + 2\ OH^-_{(aq)} \rightarrow 2\ H_2O_{(l)}$

reduced to simplest form: $\mathbf{H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}}$

This is an example of an **acid-base reaction**.

We will use the following solubility table in CH 221:

CH 221 Solubility Table for Ionic Compounds

SOLUBLE COMPOUNDS	EXCEPTIONS
Almost all salts of Na^+, K^+, NH_4^+	
Salts of nitrate, NO_3^- chlorate, ClO_3^- perchlorate, ClO_4^- acetate, $CH_3CO_2^-$	
Almost all salts of Cl^-, Br^-, I^-	Halides of Ag^+, Hg_2^{2+}, Pb^{2+}
Compounds containing F^-	Fluorides of Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}
Salts of sulfate, SO_4^{2-}	Sulfates of Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}

INSOLUBLE COMPOUNDS	EXCEPTIONS
Most salts of carbonate, CO_3^{2-} phosphate, PO_4^{3-} oxalate, $C_2O_4^{2-}$ chromate, CrO_4^{2-}	Salts of NH_4^+ and the alkali metal cations
Most metal sulfides, S^{2-}	
Most metal hydroxides and oxides	

Note: **Use this table for *all* CH 221 solubility questions!**

PROCEDURE and LAB REPORT:

Use the attached sheets to complete this week's lab. The purpose, conclusion, etc. can be omitted this week, and typing is not required as long as your handwriting is legible. 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 for your answers**) 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 $\mathbf{H_2CO_3}$ (which creates CO_2(g) and H_2O(l)) and $\mathbf{NH_4OH}$ (which creates NH_3(g) and H_2O(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

IONIC REACTIONS: Net Ionic Equations *Worksheet* **Name:**

Lab Partner(s):

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**.

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1. Barium Nitrate + Magnesium Sulfate Observations: _____

M: _____

T: _____

N: _____

Type of reaction (if appropriate): _____

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2. Barium Nitrate + Hydrochloric Acid Observations: _____

M: _____

T: _____

N: _____

Type of reaction (if appropriate): _____

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3. Barium Nitrate + (0.1 M) Sodium Hydroxide Observations: _____

M: _____

T: _____

N: _____

Type of reaction (if appropriate): _____

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4. Barium Nitrate + Sodium Carbonate Observations: _____

M: _____

T: _____

N: _____

Type of reaction (if appropriate): _____

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! On a *separate piece of paper*, add an original poem or short story of at least 50 words in length for extra credit… content will not be criticized, but the poem must be original, and short haikus written at the bottom of this page will not count (although the instructor will find them fun to read! ☺)