Net Ionic Reactions in Aqueous Solutions

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 nitrate are mixed, the combination of silver cations and chloride anions form silver 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 – the **molecular equation** - 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 (aqueous, or *aq* for short) products. There is no precipitate, gas or water from this 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 **molecular equation** is more properly written:

$$\mathbf{KCl(aq) + NaNO_3(aq) \rightarrow KNO_3(aq) + NaCl(aq)}$$

but in terms of "if something happens", we should write:

$$\mathbf{KCl(aq) + NaNO_3(aq) \rightarrow No\ Reaction}$$

Aqueous solutions of sodium chloride and silver nitrate will undergo double replacement reaction to produce a white precipitate of silver chloride and aqueous sodium nitrate. What would happen if we just mixed solid silver 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 total ionic equation for the double replacement precipitation reaction (See Example 1) we get the following:

Total Ionic Equation: $Na^+(aq) + Cl^-(aq) + Ag^+(aq) + NO_3^-(aq) \rightarrow Na^+(aq) + NO_3^-(aq) + AgCl(s)$

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**. Net ionic equations tell us only what is actually changing during reaction.

Net Ionic Equation: $Cl^-(aq) + Ag^+(aq) \rightarrow AgCl(s)$

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

Molecular Equation: $2\ HNO_3(aq) + Ba(OH)_2(aq) \rightarrow 2\ H_2O(l) + Ba(NO_3)_2(aq)$

Total Ionic Equation: $2\ H^+(aq) + 2\ NO_3^-(aq) + Ba^{2+}(aq) + 2\ OH^-(aq) \rightarrow 2\ H_2O(l) + Ba^{2+}(aq) + 2\ NO_3^-(aq)$

Net Ionic Equation: $2\ H^+(aq) + 2\ OH^-(aq) \rightarrow 2\ H_2O(l)$

or, 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	$Ba(OH)_2$ is soluble

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

The following examples should help you understand how the solubility table works and also how to complete the written part of this assignment.

Example: Is $PbSO_4$ soluble in water? What species are present in a water solution?

Answer: To solve, notice how $PbSO_4$ has a sulfate ion (SO_4^{2-}). Most salts of sulfate are soluble (i.e. they dissolve in water, or are (aq)), but salts of sulfate with a Pb^{2+} ion are an exception to this rule. Hence, $PbSO_4$ is insoluble (it does not dissolve in water), and we would write $PbSO_4$ in water as $PbSO_4$(s). Indeed, $PbSO_4$(s) is the only species present in a water solution.

Example: Is Li_2S soluble in water? What species are present in a water solution?

Answer: To solve, notice how Li_2S has a sulfide ion (S^{2-}). Most salts of sulfide are insoluble (i.e. they do not dissolve in water, or are (s)), but salts of alkali metals (which includes Li^+) are an exception to this rule. Hence, Li_2S is soluble (it *does* dissolve in water), and we would write Li_2S in water as Li_2S(aq).

Further, because Li_2S dissolves in water, we should really write it as the dissociation ions – i.e. the molecular Li_2S dissociates into lithium and sulfide ions. The species which are present in a water solution of Li_2S(aq) are 2 Li^+(aq) and S^{-2}(aq) (molecular Li_2S does not exist in water.)

Example: Describe $CaCO_3$, $RbMnO_4$ and $TiCrO_4$ in terms of their solubility in water.

Answer: Use the solubility table to answer these types of questions:

$CaCO_3$ has a carbonate ion, and calcium is not an alkali metal or ammonium, so CaCO3 is insoluble in water. We would write it as $CaCO_3$(s).

$RbMnO_4$ has an alkali metal ion (rubidium), so by default, all alkali metals are water soluble (no exceptions, at least in CH 221!) So we would write this species as $RbMnO_4$(aq) or, as dissolve ions, we would write it as Rb^+(aq) and MnO_4^-(aq).

$TiCrO_4$ has a chromate ion, and titanium is not an alkali metal or ammonium, so $TiCrO_4$ is insoluble in water. We would write it as $TiCrO_4$(s).

Example: Write the balanced molecular equation and net ionic reaction that occurs between potassium nitrate and calcium chloride in water. Classify this reaction type.

Answer: First, we need the chemical equations for potassium nitrate and lithium chloride. They are KNO_3 and $CaCl_2$. Notice the ionic charges on the cations and anions: K^+, NO_3^{-1}, Ca^{2+}, Cl^{-1}.

All of the reactions in this lab are "double displacement" – the reactant cations will switch places, forming new products. *The ionic charges will not change upon going from reactant to product.* Potassium and chloride will come together as KCl (only one Cl^{-1} for every one K^{+1}), and calcium and nitrate will come together as $Ca(NO_3)_2$ (two nitrates being needed for every calcium +2 ion.) Initially, the equation looks like this:

$$KNO_3 + CaCl_2 \rightarrow KCl + Ca(NO_3)_2$$

Notice the parentheses used for more than one polyatomic ion ($Ca(NO_3)_2$) but parentheses are not used when only one polyatomic ion is used (KNO_3).

We need to balance this reaction and add states of matter. Every compound with potassium (an alkali metal) or nitrate will dissolve in water; $CaCl_2$ is also soluble in water (Ca is not Ag, Pb or Hg), leading to:

$$\mathbf{2\ KNO_3(aq) + CaCl_2(aq) \rightarrow 2\ KCl(aq) + Ca(NO_3)_2(aq)}$$

To *classify* this reaction, our options include: precipitate, acid-base, gas forming, or no reaction. Since no solids have formed, it is not a precipitation reaction. Water has not formed from an acid or base, so this is excluded; and H_2CO_3 and NH_4OH have not formed (see next example), so gas forming is excluded. Indeed, all the reactants and products are (aq), so nothing really happens; classify this reaction as "**no reaction**." Nothing needs to be written for a net ionic reaction because nothing happens!

Example: Write the balanced molecular equation and net ionic reaction that occurs between potassium carbonate and hydrobromic acid in water. Classify this reaction type.

Answer: First, we need the chemical equations for the reactants. They are K_2CO_3 and HBr, and they make K^+, CO_3^{-2}, H^{1+}, Br^{-1}.

Performing a "double displacement" on these reactants – the reactant cations will switch places – we get:

$$K_2CO_3 + HBr \rightarrow KBr + H_2CO_3$$

Balancing this reaction and adding states of matter, we get:

$$\mathbf{K_2CO_3(aq) + 2\ HBr(aq) \rightarrow 2\ KBr(aq) + H_2CO_3(aq)}$$

At first, it looks like this is a "no reaction" classification – all states are aqueous – but **make sure you check for H_2CO_3 and NH_4OH** – these two species are the hallmarks of the **gas forming reaction** since both are unstable compounds and further decompose to new products. ***Be watchful for H_2CO_3 and NH_4OH!***

Carbonic acid (H_2CO_3 breaks down into water and carbon dioxide, so really you should write:

$$H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$$

and ammonium hydroxide (NH_4OH), which breaks down into water and ammonia, should be written:

$$NH_4OH(aq) \rightarrow H_2O(l) + NH_3(g)$$

So in this **gas forming** example,

$$\mathbf{K_2CO_3(aq) + 2\ HBr(aq) \rightarrow 2\ KBr(aq) + H_2CO_3(aq)}$$

should be written as a net ionic equation in the following manner:

$$\mathbf{CO_3^{2-}(aq) + 2\ H^+(aq) \rightarrow H_2O(l) + CO_2(g)}$$

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.)**

- 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 (on ions, *not* molecules)** 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, gas forming or** (if nothing happened) **no reaction**. 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 + Sodium Carbonate

4. Iron(III) Chloride + Sodium Hydroxide
5. Iron(III) Chloride + Sodium Phosphate
6. Iron(III) Chloride + Magnesium Sulfate

7. Magnesium Sulfate + Sodium Hydroxide
8. Magnesium Sulfate + Sodium Carbonate
9. Ammonium Oxalate + Barium Nitrate

10. Hydrochloric Acid + Sodium Hydroxide
11. Hydrochloric Acid + Sodium Carbonate
12. Silver Nitrate + Potassium Chromate

13. Silver Nitrate + Iron(III) Chloride
14. Sodium Hydroxide + Ammonium Chloride
15. Sodium Hydroxide + Sulfuric Acid

16. Copper(II) Sulfate + Iron(III) Chloride
17. Copper(II) Sulfate + Sodium Phosphate
18. Acetic Acid + Sodium Carbonate

Net Ionic Reactions *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 (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

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2. Barium Nitrate + Hydrochloric Acid Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

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3. Barium Nitrate + Sodium Carbonate Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

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4. Iron(III) Chloride + Sodium Hydroxide Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

5. Iron(III) Chloride + Sodium Phosphate Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

6. Iron(III) Chloride + Magnesium Sulfate Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

7. Magnesium Sulfate + Sodium Hydroxide Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

8. Magnesium Sulfate + Sodium Carbonate Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

9. Ammonium Oxalate + Barium Nitrate Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

10. Hydrochloric Acid + Sodium Hydroxide Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

11. Hydrochloric Acid + Sodium Carbonate Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

12. Silver Nitrate + Potassium Chromate Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

13. Silver Nitrate + Iron(III) Chloride Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

14. Sodium Hydroxide + Ammonium Chloride Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

15. Sodium Hydroxide + Sulfuric Acid Observations: ______________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

16. Copper(II) Sulfate + Iron(III) Chloride Observations: ________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

17. Copper(II) Sulfate + Sodium Phosphate Observations: ________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

18. Acetic Acid + Sodium Carbonate Observations: ________________________

M: ____

T: ____

N: ____

***Type** of reaction (circle **one**):* **precipitation** **acid-base** **gas forming** **no reaction**

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! ☺)