CHM 130LL: Chemical Reactions

Introduction

We often study chemistry to understand how and why chemicals (reactants) can be transformed into different chemicals (products) via a chemical reaction:

Reactants	$\rightarrow$	**Products**
the starting materials		new substances that are formed

Many aspects of our lives actually involve chemical reactions—from batteries that power our cars and radios to the thousands of processes occurring within our bodies. For now, it will be sufficient for us to focus on the following six types of chemical reactions: **combination reactions**, **decomposition reactions**, **single-replacement reactions, double-replacement/precipitation reactions, acid-base neutralization reactions**, and **combustion reactions**.

General Information

Diatomic Elements

Seven elements exist naturally as ***diatomic molecules***. These are **H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2**. Thus, in a chemical equation hydrogen is written as H_2, not simply as H.

Solubility Rules

Many reactions occur in an aqueous environment. When a reactant or product has the physical state "aq" that substance is dissolved in water. For example, NaCl dissolves in water, so we write this as NaCl*(aq)*. An ionic compound in aqueous solution exists as individual ions in water; for example, NaCl*(aq)* exists as Na^+ and Cl^- ions moving around in water. To determine if an ionic compound is soluble—i.e., will dissolve—in water, we use the Solubility Rules on your Periodic Table. The Solubility Rules allow us to determine which compounds are **soluble**, and we represent these compounds as aqueous: e.g., KI*(aq)*, NaOH*(aq)*, etc. The Solubility Rules also tell us which compounds are **insoluble**— do not dissolve in water and remain mostly as solids: e.g. $BaSO_4$*(s)*, AgCl*(s)*, $CaCO_3$*(s)*, etc.

Types of Reactions

1. Combination Reactions: A + Z $\rightarrow$ AZ

In a combination reaction, two or more reactants combine to form a single product. For example, sodium metal reacts with chlorine gas to produce solid sodium chloride: $Na(s) + Cl_2(g) \rightarrow NaCl(s)$

To **balance the equation**, we get the same number of Cl atoms by putting a coefficient of 2 in front of NaCl*(s)*, then we put a 2 in front of the Na*(s)* to balance Na: $2\ Na(s) + Cl_2(g) \rightarrow 2\ NaCl(s)$

If you were carrying out this reaction in a laboratory, you will observe shiny sodium metal reacting with yellow chlorine gas to produce a white solid.

2. Decomposition Reactions: AB $\rightarrow$ A + B

In a decomposition reaction, a single compound breaks down into two or more substances. In general, decomposition reactions occur when a solid compound is heated. This type of reaction almost always produces a gas. For example, heating sodium hydrogen carbonate produces sodium carbonate, carbon dioxide gas, and steam, H_2O (g). The unbalanced reaction for this is

$$NaHCO_3\ (s) \rightarrow Na_2CO_3\ (s) + CO_2\ (g) + H_2O\ (g)$$

We balance this equation by placing a 2 in front of the $NaHCO_3$, and now we have 2 Na's, 2 H's, 2 C's and 6 O's on both sides of the equation:

$$2NaHCO_3\ (s) \rightarrow Na_2CO_3\ (s) + CO_2\ (g) + H_2O\ (g)$$

3. *Single-Replacement Reactions:* A + BZ $\rightarrow$ AZ + B

In a single-replacement reaction, a more reactive metal element displaces another element from a compound, and a new element and compound are formed as the products.

One type of single replacement reaction involves a metal reacting with an aqueous solution of a compound. Consider the reaction between aluminum metal in an aqueous solution of copper (II) chloride. The equation for this reaction is

$$Al(s) + CuCl_2(aq) \rightarrow Cu(s) + AlCl_3(aq)$$

To balance chlorine we place a 3 in front of $CuCl_2$ and a 2 in front of $AlCl_3$, and then we need to place a 2 in front of Al to balance aluminum and a 3 in front of Cu to balance copper. The balance equation is:

$$2\ Al(s) + 3\ CuCl_2(aq) \rightarrow 3\ Cu(s) + 2\ AlCl_3(aq)$$

If we carry out this reaction by placing a piece of aluminum metal in blue copper (II) chloride solution, we will see dark granules of copper forming at the bottom of the beaker.

Another type of single replacement reaction is that of a metal with an aqueous acid. Consider the reaction between cadmium metal and hydrochloric acid in which cadmium chloride and hydrogen gas are produced. The unbalanced equation for the reaction is

$$Cd(s) + HCl(aq) \rightarrow CdCl_2(aq) + H_2(g)$$

We then balance the reaction by placing a 2 in front of HCl to balance hydrogen and chlorine:

$$Cd(s) + 2\ HCl(aq) \rightarrow CdCl_2(aq) + H_2(g)$$

If we carry out this reaction by placing a piece of cadmium metal in colorless hydrochloric acid, we will see bubbles of hydrogen gas forming from the cadmium sitting in the solution.

4. *Double-Replacement/Precipitation Reactions*: AX + BZ $\rightarrow$ AZ + BX

In a double-replacement/precipitation reaction, two ionic compounds in aqueous solution swap metals to form a ***precipitate***, a solid formed when two ionic solutions are mixed.

Let us consider the following reaction between aqueous lead (II) nitrate with aqueous potassium bromide.
We can represent this reaction as follows:

$$Pb(NO_3)_2(aq) + KBr(aq) \rightarrow PbBr_2 + KNO_3$$

Next, we refer to the Solubility Rules to determine if $PbBr_2$ and KNO_3 are aqueous or solid. Based on Rule #4, $PbBr_2$ is insoluble, so we indicate it as $PbBr_2(s)$. Based on Rule #1, any compound with K^+ is soluble, so we represent potassium nitrate as $KNO_3(aq)$. Thus, the unbalanced equation is:

$$Pb(NO_3)_2(aq) + KBr(aq) \rightarrow PbBr_2(s) + KNO_3(aq)$$

We then balance the equation by placing a 2 in front of KNO_3 to balance the nitrate ions and a 2 in front of KBr to balance bromine. The balanced equation is:

$$Pb(NO_3)_2(aq) + 2\ KBr(aq) \rightarrow PbBr_2(s) + 2\ KNO_3(aq)$$

The lead (II) nitrate and potassium bromide solutions are both clear and colorless. When they are combined in the lab, the resulting mixture is cloudy, indicating a solid is present and small particles of the solid are suspended in the solution. When enough solid has formed, it will begin to settle at the bottom of the beaker. Thus, a clear solution becoming cloudy when another solution is added is often taken as experimental evidence of a precipitate forming.

5. Acid-Base Neutralization Reactions: $HX(aq) + MOH(aq) \rightarrow H_2O(l) + MX(aq)$

Acids are compounds that ***release hydrogen ions (H^+),*** also called ***protons***, when dissolved in water. The chemical formulas for acids are often given with the H's at the beginning, so acids are usually easy to recognize. A few common acids are hydrochloric acid, $HCl(aq)$, nitric acid, $HNO_3(aq)$, and sulfuric acid, $H_2SO_4(aq)$.

Bases are compounds that ***release hydroxide ions, OH^-,*** when dissolved in water. A few common bases are sodium hydroxide, NaOH*(aq)*, potassium hydroxide, KOH*(aq)*, and calcium hydroxide, $Ca(OH)_2$.

In an acid-base neutralization reaction, an acid reacts with a base to produce water and a salt:

$$\underset{\text{acid}}{HX(aq)} + \underset{\text{base}}{MOH(aq)} \rightarrow H_2O(l) + \underset{\text{salt}}{MX(aq)}$$

The ***hydrogen ion (H^+)*** from the acid reacts with the ***hydroxide ions (OH^-)*** from the base to form the water. The **salt** forms from the ***cation from the base*** and the ***anion from the acid***.

Let us consider the following unbalanced reaction between phosphoric acid and potassium hydroxide:

$$H_3PO_{4(aq)} + KOH(aq) \rightarrow H_2O(l) + K_3PO_4(aq)$$

We balance the equation by placing a 3 in front of KOH to balance potassium and a 3 in front of H_2O since 3 H^+'s and 3 OH^-'s will make 3 H_2O molecules. Thus, the balanced chemical equation is:

$$H_3PO_{4(aq)} + 3\ KOH(aq) \rightarrow 3\ H_2O(l) + K_3PO_4(aq)$$

When carrying out an acid-base neutralization reaction in the laboratory, one observes that most acid solutions and base solutions are colorless, and the resulting water and soluble salt solutions are also colorless. Thus, it is impossible to determine if a reaction has occurred. To help us monitor acid-base reactions, we use an ***acid-base indicator***, a solution that changes color depending on the pH (or acid-content) of the solution. One commonly used indicator is *phenolphthalein*, which is colorless in acidic and neutral solutions and pink in basic (or alkaline) solution. Thus, one can determine whether a solution is acidic or basic using phenolphthalein.

One can also use litmus paper to determine if a solution is acidic or basic. Blue litmus paper turns red in acidic solution, and red litmus paper turns blue in basic solution.

6. Combustion Reactions: $C_xH_y + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

In a combustion reaction, a **hydrocarbon, C_xH_y** (a compound containing only carbon and hydrogen atoms), or a **hydrocarbon derivative, $C_xH_yO_z$** (a compound containing carbon, hydrogen, and oxygen atoms), burns in oxygen to produce carbon dioxide gas, $CO_2(g)$, and steam, $H_2O(g)$. (Steam is formed rather than water because the reactions occur at high temperatures.)

For example, when butanol, $C_4H_9OH(l)$, burns in oxygen present in air, the products are carbon dioxide gas and steam:

$$C_4H_9OH(l) + O_2(g) \xrightarrow{\Delta} CO_2(g) + H_2O(g)$$

To balance the equation, first balance carbons, then hydrogens, and finally the oxygens. Thus, the balanced equation is:

$$C_4H_9OH(l) + 6\ O_2(g) \xrightarrow{\Delta} 4\ CO_2(g) + 5\ H_2O(g)$$

If we carry out this reaction in the laboratory, we see when lit with a flaming splint, liquid butanol burns and appears to completely disappear as the products are both colorless gases.

Balancing Chemical Equations

Chemical equations are written to represent chemical reactions, and these equations must be balanced to show that atoms are never created or destroyed in a chemical reaction but simply rearranged. Thus, a balanced equation has the same number of atoms of each element on both the reactant and product sides of the equation. In general, using the following order when balancing equations will make the process as easy as possible:

- Metals
- Polyatomic ions (balance as a whole unit, not as individual atoms)
- Carbon
- All other elements

After recording your observations, you will balance the corresponding chemical reactions. Additional chemical equations are given in Part VII. For these reactions, you will balance the equations and you will also identify the reaction type as one of the following:

- Combination reaction (C)
- Decomposition reaction (D)
- Single-Replacement reaction (SR)
- Double-Replacement/Precipitation reaction (DR)
- Acid-Base Neutralization reaction (N)
- Combustion reaction (B)

PROCEDURE

Note: All waste for this experiment should go into the appropriate waste containers in the hood. *Do not dispose of any solids in the sink!*

Note – When balancing the reactions, if there is a one coefficient, you MUST write the one in the blank or it will be counted wrong. Thanks.

I. Combination Reactions

a. Obtain a piece of copper wire, Cu*(s)*. Holding the copper metal with your crucible tongs, heat it in a Bunsen burner flame for about 30 seconds. Record your observations on your Lab Report form.

CAUTION: The burning of Magnesium metal results in an extremely bright light. Hold the magnesium away from you, and do not look directly at the piece when heating the magnesium.

b. Repeat step a with a small ribbon of magnesium metal, Mg*(s)*. Record your observations on your Lab Report form.

Waste disposal: Place used Cu and Mg in the waste container in the hood, NOT in the trash.

II. Decomposition Reactions

a. Place approximately a pea-size amount of copper(II) carbonate, $CuCO_3$*(s)*, in a dry test tube. Observe the color of the sample. Using a test tube clamp, heat the test tube over a Bunsen burner until you notice a color change. **DO NOT** *return the hot test tube to the plastic test tube rack, or it will melt the plastic.* Instead, place the test tube in an empty beaker to cool. Record the color of the solid sample after heating.

Waste disposal: When cool, dispose of used copper(II) carbonate into the waste container in the hood, NOT in the trash.

III. Single-Replacement Reactions

a. Place about 10 drops of 0.1 M copper (II) nitrate, $Cu(NO_3)_2$*(aq)*, in a clean small test tube. Note the color of the solution on your Lab Report. Now add a few pieces of zinc mesh (or granules), and let the solution sit for a few minutes. Note any changes in the color of the solution and the formation of any solid. Record your observations.

Caution: Silver nitrate solution, $AgNO_3(aq)$, stains skin and clothing. Wash any spilled silver nitrate immediately with plenty of water.

b. Clean a short (4-5 cm) piece of Cu wire with sandpaper. Coil the Cu wire and place it into a clean small test tube. Add enough 0.1 M silver nitrate, $AgNO_3$*(aq)*, to completely cover the copper wire, and allow the mixture to sit for 5-10 minutes. Record the appearance of the copper wire and the silver nitrate solution *before* any reaction. Record the appearance of the copper wire after sitting in the silver nitrate solution for 5-10 minutes, and record the appearance of the solution.

Caution: Hydrochloric acid, HCl(aq), is corrosive and can cause chemical burns as well as damage clothing. Any hydrochloric acid spilled on skin must be rinsed immediately with water for 15 minutes. Any acid spilled on your work area must be neutralized, then the entire area should be washed and dried.

c. Drop 2-3 pieces of magnesium turnings in a test tube. Add enough 0.1 M hydrochloric acid, HCl*(aq)* to completely cover the magnesium. Record your observations on your Data Sheet.

IV. Double-Replacment/Precipitation Reactions

Caution: Lead (II) nitrate solutions are toxic. Avoid contact with skin, eyes, and clothing. If the solution contacts your skin, rinse with water immediately.

a. Add ~10 drops of 0.1 M lead (II) nitrate, $Pb(NO_3)_2$*(aq)*, to a clean small test tube. Add an equal amount of 0.1 M potassium iodide, KI*(aq)*. Mix the solutions, and record your observation.

b. Silver nitrate, $AgNO_3$, is very sensitive to the presence of chloride ions and is used to detect chloride ions, Cl^-, in aqueous solution. Add ~10 drops of 0.1 M sodium chloride, NaCl*(aq)*, in a clean small test tube. Next add a few drops of 0.1 M $AgNO_3$, and record your observation on your Data Sheet.

Caution: See hydrochloric acid caution given in Part III.

V. Acid-Base Neutralization Reactions

a. Blue litmus paper turns red in an acidic solution, so it is used to identify acidic substances. Place a piece of blue litmus paper on a watch glass. Add 1 drop of 0.1 M hydrochloric acid, HCl*(aq)*, and record your observations.

Caution: Sodium hydroxide (NaOH) can easily damage eyes. It is corrosive and can cause chemical burns and damage clothing. Any NaOH splashed into eyes or spilled on skin must be rinsed immediately with water for 15 minutes. Any base spilled on your work area must be neutralized, then the entire area should be washed and dried.

b. Red litmus paper turns blue in a basic solution, so it is used to identify basic substances. Place a piece of red litmus paper on a watch glass. Add 1 drop of 0.1 M sodium hydroxide, NaOH*(aq)*, and record your observations.

c. Phenolphthalein is an acid-base indicator that is colorless in acidic and neutral solutions and pink in basic (or alkaline) solution. Fill a small clean test tube about 1/5 full with deionized water. Add a drop of phenolphthalein indicator. Next add 1-2 drops of 0.1 M hydrochloric acid, HCl*(aq)*, stir with a glass stirring rod, and record your observations.

d. Fill a small clean test tube about 1/5 full with deionized water. Add a drop of phenolphthalein indicator. Next add 1-2 drops of 0.1 M sodium hydroxide, NaOH*(aq)*, stir with a stirring rod, and record your observations.

e. Fill a small clean test tube about 1/5 full with deionized water. Add 5 drops of 0.1 M hydrochloric acid, HCl*(aq)*. Add 1 drop of phenolphthalein, and stir with a stirring rod. Add 0.1 M sodium hydroxide, NaOH*(aq)*, to this mixture one drop at a time, *mixing the solution with your glass stirring rod between additions*. Count how many drops of sodium hydroxide are needed for a permanent color change. Record your observations.

Caution: Sulfuric acid is corrosive and can cause chemical burns and damage clothing. Any sulfuric acid spilled on skin must be rinsed immediately with water for 15 minutes. Any acid spilled on your work area must be neutralized, then the entire area should be washed and dried.

f. Repeat step e, substituting 0.1 M sulfuric acid, H_2SO_4*(aq)* for 0.1 M hydrochloric acid, HCl*(aq)*. Again, count how many drops of sodium hydroxide are needed for a permanent color change. How many drops of NaOH*(aq)* were required to neutralize the sulfuric acid? Record your observations.

VI. Combustion Reactions

Note: Carefully extinguish all burning or smoldering splints in a beaker of water, then place in the waste container in the hood.

a. Add 15 drops of ethanol into a clean ceramic evaporating dish. Use your Bunsen burner to light a wood splint, then light the ethanol with the splint. Allow the ethanol to burn completely. Record your observations, including how the evaporating dish appears after the ethanol burns. Wash and dry the evaporating dish.

b. Add 15 drops of isopropyl alcohol into the clean evaporating dish. Light the isopropyl alcohol with the splint, and allow it to burn completely. Record your observations, including how the evaporating dish appears after the isopropyl alcohol burns.

Note: Wash your entire work area with a wet paper towel, then dry. Wash your hands completely with soap and water before you leave.

VII. Balance and identify the reaction type for the equations in part VII.

Cleanup: **Empty all your test tubes into the waste container. Then rinse them all in the sink with tap water. Give them a final rinse with DI water and put them back upside down in your test tube rack. If the test tube is still dirty gently use the small brush to clean it out. Only if a test tube cannot be cleaned even with the brush should you give it to your instructor to put with dirty test tubes. Now wash your bench off with a wet paper towel and wash your hands with soap and water.**

CHM 130LL: Chemical Reactions

Name: ________________________

Partner: ________________________

Section Number: _______________

I. Combination Reactions If there is a one coefficient, you MUST write the one in the blank or it will be counted wrong. Thanks.

	Observations
a. Copper metal, Cu(s), is heated.	
b. Magnesium metal, Mg(s), is heated.	

Balance the following equations representing the reactions observed:

a. _____ $Cu(s)$ + _____ $O_2(g) \xrightarrow{\Delta}$ _____ $CuO(s)$

b. _____ $Mg(s)$ + _____ $O_2(g) \xrightarrow{\Delta}$ _____ $MgO(s)$

Note: The reaction arrow with a triangle ($\xrightarrow{\Delta}$) indicates reactants were heated. Include all 1 coefficients. Leaving a blank without a number will be counted incorrect.

II. Decomposition Reactions

	Observations
a. Copper (II) Carbonate, $CuCO_3(s)$, is heated.	

Balance the following equation representing the reaction observed:

a. _____ $CuCO_3(s) \xrightarrow{\Delta}$ _____ $CuO(s)$ + _____ $CO_2(g)$

III. Single-Replacement Reactions

	Observations
a. Zinc (Zn) metal in $Cu(NO_3)_2(aq)$	Original color of **$Cu(NO_3)_2(aq)$.**: ____________________ Zinc metal before reaction: __________________________ Color of **solution** after reaction: _____________________ Zinc metal after reaction: ___________________________
b. Copper (Cu) metal in $AgNO_3(aq)$	Original color of **$AgNO_3(aq)$**: _______________________ Copper wire before reaction: _________________________ Color of **solution** after reaction: _____________________ Copper wire after reaction: __________________________
c. Magnesium (Mg) metal in HCl*(aq)*	

Balance the following equations representing the reactions observed:

a. _____ $Zn(s)$ + _____ $Cu(NO_3)_2(aq)$ $\rightarrow$ _____ $Cu(s)$ + _____ $Zn(NO_3)_2(aq)$

b. _____ $Cu(s)$ + _____ $AgNO_3(aq)$ $\rightarrow$ _____ $Ag(s)$ + _____ $Cu(NO_3)_2(aq)$

c. _____ $Mg(s)$ + _____ $HCl(aq)$ $\rightarrow$ _____ $H_2(g)$ + _____ $MgCl_2(aq)$

IV. Double-Replacement/Precipitation Reactions

	Observations
a. $Pb(NO_3)_2(aq) + KI(aq)$	
b. $NaCl(aq) + AgNO_3(aq)$	

Balance the following equations representing the reactions observed:

a. _____ $Pb(NO_3)_{2(aq)}$ + _____ $KI(aq)$ $\rightarrow$ _____ $PbI_2(s)$ + _____ $KNO_3(aq)$

b. _____ $NaCl(aq)$ + _____ $AgNO_3(aq)$ $\rightarrow$ _____ $AgCl(s)$ + _____ $NaNO_3(aq)$

V. Acid-Base Neutralization Reactions

	Observations
a. Blue litmus paper + $HCl(aq)$	
b. Red litmus paper + $NaOH(aq)$	
c. $HCl(aq)$ + phenolphthalein	Color of the solution: ________________________
d. $NaOH(aq)$ + phenolphthalein	Color of the solution: ________________________
e. $HCl(aq)$ + phenolphthalein + $NaOH(aq)$	Number of drops of NaOH required for permanent color change: ___________
f. $H_2SO_4(aq)$ + phenolphthalein + $NaOH(aq)$	Number of drops of NaOH required for permanent color change: ___________

Balance the following equations representing the reactions observed:

e. _____ $HCl(aq)$ + _____ $NaOH(aq)$ $\rightarrow$ _____ $H_2O(l)$ + _____ $NaCl(aq)$

f. _____ $H_2SO_4(aq)$ + _____ $NaOH(aq)$ $\rightarrow$ _____ $H_2O(l)$ + _____ $Na_2SO_4(aq)$

VI. Combustion Reactions

	Observations
a. Burning ethanol, $C_2H_5OH(l)$	
b. Burning isopropyl alcohol, $C_3H_7OH(l)$	

Balance the following equation representing the burning ethanol reaction:

a. _____ $C_2H_6O(l)$ + _____ $O_2(g)$ $\xrightarrow{\Delta}$ _____ $CO_2(g)$ + _____ $H_2O(g)$

VII. Balancing Equations and Classifying Chemical Reactions

Balance each of the chemical equations given, and identify each as one of the following:

- Combination reaction (C)
- Decomposition reaction (D)
- Single-Replacement reaction (SR)
- Double-Replacement/Precipitation reaction (DR)
- Acid-Base Neutralization reaction (N)
- Combustion reaction (B)

TYPE

_______ 1. _____ $Al(s)$ + _____ $O_2(g)$ $\xrightarrow{\Delta}$ _____ $Al_2O_3(s)$

_______ 2. _____ $HNO_3(aq)$ + _____ $Ba(OH)_2(aq)$ $\rightarrow$ _____ $H_2O(l)$ + _____ $Ba(NO_3)_2(aq)$

_______ 3. _____ $Mg(s)$ + _____ $Al(NO_3)_3(aq)$ $\rightarrow$ _____ $Al(s)$ + _____ $Mg(NO_3)_2(aq)$

_______ 4. _____ $C_3H_6O(l)$ + _____ $O_2(g)$ $\xrightarrow{\Delta}$ _____ $CO_2(g)$ + _____ $H_2O(g)$

_______ 5. _____ $H_3PO_4(aq)$ + _____ $KOH(aq)$ $\rightarrow$ _____ $H_2O(l)$ + _____ $K_3PO_4(aq)$

_______ 6. _____ $Al(s)$ + _____ $HBr(aq)$ $\rightarrow$ _____ $H_2(g)$ + _____ $AlBr_3(aq)$

_______ 7. _____ $CaCl_2(aq)$ + _____ $K_3PO_4(aq)$ $\rightarrow$ _____ $Ca_3(PO_4)_2(s)$ + _____ $KCl(aq)$

_______ 8. _____ $KHCO_3(s)$ $\xrightarrow{\Delta}$ _____ $K_2CO_3(s)$ + _____ $H_2O(g)$ + _____ $CO_2(g)$

_______ 9. _____ $C_3H_8(g)$ + _____ $O_2(g)$ $\xrightarrow{\Delta}$ _____ $CO_2(g)$ + _____ $H_2O(g)$

_______ 10. _____ $NaOH(aq)$ + _____ $AlCl_3(aq)$ $\rightarrow$ _____ $NaCl(aq)$ + _____ $Al(OH)_3(s)$