Classifying Chemical Reactions

Chemical reactions can be classified into one of five types: synthesis, combustion, decomposition, single-replacement, and double-replacement.

Synthesis Reactions

In the previous lesson, we examined the reaction that occurs between iron and chlorine gas to produce iron(III) chloride. In this reaction, two elements (*A* and *B*) combine to produce one new compound (*AB*).

$$A + B \rightarrow AB$$

$$2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(s)$$

The reaction between iron and chlorine gas is an example of a **synthesis reaction**. When two elements react, the reaction is always a synthesis reaction. Another example of a synthesis reaction is shown below.

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

Just as two elements can combine, two compounds can also combine to form one compound. For example,

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$$

Another type of synthesis reaction may involve a reaction between a compound and an element, as shown below.

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

Combustion Reactions

In a **combustion reaction**, oxygen combines with a substance and releases energy in the form of heat and light. Oxygen can combine in this way with many different substances.

A combustion reaction occurs between hydrogen and oxygen when heat is applied. Water is formed during the reaction and a large amount of energy is released.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

Another important combustion reaction occurs when coal is burned to produce energy. Coal is composed primarily of the element carbon.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

Note that the combustion reactions above are also synthesis reactions. However, not all combustion reactions are synthesis reactions. For example, the reaction involving methane gas and oxygen illustrates a combustion reaction in which one substance replaces another in the formation of products.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

Decomposition Reactions

Some chemical reactions are essentially the opposite of synthesis reactions. These reactions are classified as decomposition reactions. A **decomposition reaction** is one in which a single compound (*AB*) breaks down into two or more elements or new compounds (*A* and *B*).

$$AB \rightarrow A + B$$

Decomposition reactions often require an energy source, such as heat, light, or electricity, to occur. For example, ammonium nitrate breaks down into dinitrogen monoxide and water when the reactant is heated to high temperatures.

$$NH_4NO_3(s) \rightarrow N_2O(g) + 2H_2O(g)$$

Automobile safety air bags inflate rapidly as sodium azide pellets decompose. A device that can provide an electric signal to start the reaction is packaged inside the air bags along with the sodium azide pellets. When the device is activated, sodium azide decomposes, producing nitrogen gas that quickly inflates the safety bag.

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

Single–Replacement Reactions

Consider the reaction between lithium and water that is shown below.

$$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$$

In this reaction, lithium replaces a hydrogen atom in water. A reaction in which the atoms of one element replace the atoms of another element in a compound is called a **single–replacement reaction**.

$$A + BX \rightarrow AX + B$$

The reaction between lithium and water is one type of single–replacement reaction in which a metal replaces a hydrogen in a water molecule. Another type occurs when one metal replaces another metal in a compound dissolved in water. For example, when a copper wire is placed in aqueous silver nitrate, shiny crystals are seen to form on the wire. These shiny crystals are the silver atoms that the copper atoms replaced.

$$Cu(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Cu(NO_3)_2(aq)$$

Metals
Lithium
Rubidium
Potassium
Calcium
Sodium
Magnesium
Aluminum
Manganese
Zinc
Iron
Nickel
Tin
Lead
Copper
Silver
Platinum
Gold

Halogens
Fluorine
Chlorine
Bromine
Iodine

It should be noted that a metal will not always replace another metal in a compound. This is because metals differ in their reactivity. To predict whether or not a metal can replace another metal, we use an activity series, such as the one shown to the right.

A specific metal can replace any metal that is below it on the series. It cannot replace a metal that is above it. For example, if you place silver into aqueous copper(II) nitrate, the silver will not replace the copper.

$$Ag(s) + Cu(NO_3)_2(aq) \rightarrow NR$$

The letters NR stand for no reaction, and indicate that a reaction will not occur.

A third type of single–replacement reaction involves the replacement of a nonmetal in a compound by another nonmetal. Halogens are frequently involved in this type of reaction. Like metals, halogens will only replace other halogens that are below them in the activity series on the right.

For example, fluorine replaces bromine in a water containing dissolved sodium bromide. However, bromine does not replace fluorine in water containing dissolved sodium fluoride.

$$F_2(g) + 2NaBr(aq) \rightarrow 2NaF(aq) + Br_2(l)$$

$$Br_2(g) + 2NaF(aq) \rightarrow NR$$

Example
Predict the products that will occur when these reactants combine and write a balanced chemical equation for each reaction.

$Fe(s) + CuSO_4(aq) \rightarrow$

$Br_2(l) + MgCl_2(aq) \rightarrow$

$Mg(s) + AlCl_3(aq) \rightarrow$

Double–Replacement Reactions

The final type of reaction involves an exchange of ions between two compounds, and is called a **double–replacement reaction**.

$$AX + BY \rightarrow AY + BX$$

The reaction between calcium hydroxide and hydrochloric acid is a double–replacement reaction.

$$Ca(OH)_2(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + 2H_2O(l)$$

The ionic components of the reaction are Ca^{2+}, OH^-, H^+, and Cl^-. Knowing this, you can see the two replacements in the reaction.

The reaction between sodium hydroxide and copper(II) chloride in solution is also a double–replacement reaction.

$$2NaOH(aq) + CuCl_2(aq) \rightarrow 2NaCl(aq) + Cu(OH)_2(s)$$

Notice that the copper(II) hydroxide that is formed is a solid. A solid produced during a chemical reaction in a solution is called a **precipitate**.

One of the key characteristics of double–replacement reaction is the type of product formed. All double–replacement reactions produce either a precipitate, a gas, or water. An example of a double–replacement reaction that produces a gas is that of potassium cyanide and hydrobromic acid.

$$KCN(aq) + HBr(aq) \rightarrow KBr(aq) + HCN(g)$$

Reaction Types

Write chemical equation for the following reactions. Classify each reaction into as many categories as possible.

1. The solids aluminum and sulfur react to produce aluminum sulfide.

2. Water and dinitrogen pentoxide gas react to produce aqueous hydrogen nitrate.

3. The gases nitrogen dioxide and oxygen react to produce dinitrogen pentoxide gas.

4. Ethane gas (C_2H_6) burns in air, producing carbon dioxide gas and water vapor.

Write chemical equations for the following decomposition reactions.

5. Solid aluminum oxide decomposes when electricity is passed through it.

6. Solid nickel(II) hydroxide decomposes to produce solid nickel(II) oxide and water.

7. Heating solid sodium hydrogen carbonate produces aqueous sodium carbonate, carbon dioxide gas, and water.

Predict if the following single–replacement reactions will occur. If a reaction occurs, write a balanced equation for the reaction.

8. $K(s) + ZnCl_2(aq) \rightarrow$

9. $Cl_2(g) + HF(aq) \rightarrow$

10. $Fe(s) + Na_3PO_4(aq) \rightarrow$

Write the balanced chemical equations for the following double–replacement reactions.

11. Aqueous lithium iodide and aqueous silver nitrate react to produce solid silver iodide and aqueous lithium nitrate.

12. Aqueous barium chloride and aqueous potassium carbonate react to produce solid barium carbonate and aqueous potassium chloride.

13. Aqueous sodium oxalate and aqueous lead(II) nitrate react to produce solid lead(II) oxalate and aqueous sodium nitrate.