Chemical Reactions

In order to make sense of the huge array of chemical reactions observed, chemists classify them into a few basic categories. The biggest categories are “organic” and “inorganic” reactions. Organic reactions involve the millions of compounds of carbon, and there are thousands of “named” reactions, as well as every biochemical reaction. The scope of this course only includes the most basic organic chemistry, and really only one kind of classified reaction.

Inorganic reactions include all the other compounds, including some of carbon. Typical compounds include mineral acids, bases, salts, and other compounds with metals or ionic bonds.

All chemical reactions involve chemical changes. They start with some reactant chemicals, which change to become some product chemicals. We show them by listing the reactants on the left side and the products on the right, and we use an arrow (“ —> “) to indicate that a change is taking place. We do not use an equals sign, because the point of a chemical change is that you end up with new compounds with new properties. Here is the general form for writing a chemical reaction as a chemical equation.

Reactant A + Reactant B —> Product C + Product D

We will classify reactions into five types for now. This classification scheme is different than the one that is preferred by your text. However, I think that this scheme is easier to understand and to recognize, and says more about what is going on. This is the classification scheme we talked about in class.

1. **Combination (Synthesis) Reactions** are reactions in which two or more reactants combine to form a single new product.

   Reactant A + Reactant B —> Product AB
   A + B —> AB
   $N_2 + 3\ H_2 \longrightarrow 2\ NH_3$

   In the second reaction, with the actual chemicals, the numbers in front of the hydrogen and ammonia are called coefficients. They are necessary to account for all the mass present at the start and finish of a chemical reaction. According to the Law of Conservation of Mass, “matter cannot be created nor destroyed in ordinary chemical reactions” (this is not entirely true in nuclear reactions, but they are not “ordinary” chemical reactions either).

   As you have learned, **balancing chemical equations** means finding the coefficients so that the total number of each kind of atom on each side of the chemical equation is the same. The most common way to do this at first is by the "trial and error" method: See if the first atom you see is the same on both sides, and adjust coefficients as needed. Then check the second atom you see, and so on. This may take several repetitions to complete. Time can be saved if you recognize that, in many cases, polyatomic ions do not change during the reaction (remember Table 4.4!). So if you have $NaNO_3$ involved, right after you balance Na^+, you can balance NO_3^- all at once. Remember: Coefficients distribute to everything in the molecule or formula unit. Subscripts only apply to whatever they immediately follow.

2. **Decomposition Reactions** are the opposite of combination reactions: A single reactant breaks down into one or more simpler products. These reactions often fit a few patterns, which are described briefly here.

Reactant A —> Product B + Product C + …
A —> B + C + D + ...
$2\ NH_3 \longrightarrow 3\ H_2 + N_2$
$2\ H_2O_2 \longrightarrow 2\ H_2O + O_2$
$N_2O_4 \longrightarrow 2\ NO_2$
$CaCO_3 \longrightarrow CaO + CO_2$

Three specific decomposition reactions that you should know because they will show up later in other reactions:
$H_2CO_3 \longrightarrow CO_2 + H_2O$
$NH_4OH \longrightarrow NH_3 + H_2O$
$H_2SO_3 \longrightarrow SO_2 + H_2O$

3. **Single Replacement Reactions** are one in which an element replaces another in a compound. These are also sometimes called "Single Displacement" or plain "Replacement" or "Displacement" reactions. These reactions can be predicted by using the Activity Series of Metals (and Hydrogen) or, as we discussed, looking at the halogen group for some of the non-metals.

Element A + Reactant —> Element B + Product
A + BC —> B + AC
$Mg + 2\ HCl \longrightarrow H_2 + MgCl_2$
$MgCl_2 + Br_2 \longrightarrow MgBr_2 + Cl_2$

4. **Double Replacement** reactions are ones in which parts of two compounds trade places. These are also known as “Double Displacement” or “Metathesis” reactions. An easy way to think about these is that they occur with the exchange of positive ions between two reactants to form two new products.

Reactant A + Reactant B —> Product C + Product D
WX + YZ—> WZ + YX
$2\ AgNO_3 + ZnCl_2 \longrightarrow 2\ AgCl + Zn(NO_3)_2$
NaOH + HCl —> NaCl + HOH

The last reaction above is a special category of double replacement reaction, because it involves an acid (HCl) and a base (NaOH). This can also be called a "neutralization" or “**acid-base reaction,**” because the products are generally neither acid nor base. However, one product is almost always water (either as HOH or H_2O). We will concentrate on neutralization reactions when we study acids and bases, but it is necessary at this point to recognize these double replacement reactions that produce water as one of the products.

It is important to note that these double replacement reactions can be identified because they will produce a solid ("precipitate"), a gas (bubbles), or water as a result of the reaction. When a precipitate or water is formed it can be predicted by using a Solubility Table to predict whether a precipitate will be formed and which possible product it will be.

Sometimes the gas that is formed occurs as the result of a decomposition reaction that follows the double replacement reaction. The following reaction only produces carbon dioxide because the double replacement reaction to produce the H_2CO_3 occurred first and this then spontaneously decomposes.

$$Na_2CO_3 + 2\ HCl \longrightarrow 2\ NaCl + H_2CO_3 \longrightarrow 2\ NaCl + CO_2 + H_2O$$

5. The fifth type of reaction we will be concerned with is called a **Combustion Reaction**. All combustion reactions are burning reactions, and all combustion reactions involve molecular oxygen, O_2. Combustion reactions are almost always exothermic (they give off heat).

   When organic compounds that contain carbon and hydrogen ("hydrocarbons") or carbon, hydrogen and oxygen ("carbohydrates") combust the reaction products are carbon dioxide and water (and heat).

   Hydrocarbon + Oxygen —> Water + Carbon dioxide
   $C_xH_y + O_2 \longrightarrow H_2O + CO_2$ or $C_xH_yO_z + O_2 \longrightarrow H_2O + CO_2$
   $CH_4 + 2\ O_2 \longrightarrow 2\ H_2O + CO_2$
   $C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ H_2O + 6\ CO_2$

   Not all combustion reactions release carbon dioxide and water. Consider the combustion of metals to form the metal oxides (these can also be considered as Combination Reactions) or the case of carbon itself or hydrogen or sulfur burning (also a Combination Reaction). The products of these latter reaction can be predicted from the oxidations states of the elements.

   $2\ Mg + O_2 \longrightarrow 2\ MgO$
   $C + O_2 \longrightarrow CO_2$

   Some people do not consider these latter reactions to be combustion, and that combustion only occurs with organic compounds (contain carbon). Further, there are some specific reactions involving hydrocarbons which do not result in carbon dioxide and water. These may produce carbon monoxide and water. These are often referred to as "INCOMPLETE" combustion reactions. In our course we will mostly be considering complete combustion reactions.

   $2\ CH_4 + 3\ O_2 \longrightarrow 4\ H_2O + 2\ CO$
   $2\ C + O_2 \longrightarrow CO$

6. Some people say there is a sixth reaction type in this method. For reactions that do not fit any of the patterns above the type is **Other**.

So, What does this do for us? How does all this classification stuff help us figure out what is going on?

Well, for one thing it helps us to sort through all sorts of information and to see trends in what we see occurring. We do not have to memorize each individual reaction and can start to predict things we have never seen before.

Understand: No one can say that this or any method is foolproof, and that we always "know" but it (and any other scheme) is a start.

HANDY CHECKLIST

Here is a handy checklist for figuring out what type of reaction is taking place.
Follow this series of questions when you are practicing learning the reaction types. When you can answer "yes" to a question, then stop!

1. Does your reaction have oxygen as one of its reactants, and carbon dioxide and water as products? If yes, then it is a combustion reaction for hydrocarbons.

2. Does your reaction have two (or more) chemicals combining to form one chemical? If yes, then it is a combination reaction.

   [If one of the reactants is oxygen and the reactants combine to form one chemical, then this is also a combination reaction but it could also be called a combustion reaction with things other than organic molecules.]

3. Does your reaction have a large compound falling apart to make several small ones? If yes, then it is a decomposition reaction.

4. Does your reaction have any components that contain only one element? If yes, then it is a single replacement reaction.

5. Does your reaction have water as one of the products? If yes, then it is a double replacement reaction involving acids and bases (aka, and acid-base reaction).

   [This could also be a double replacement reaction where one of the products decomposes into a smaller compound and water.]

6. If you have not answered "yes" to any of these questions, then you have a double replacement reaction that has probably produced a precipitate as one of the products.

As noted several time above, some reactions can possibly be considered under more than one of these reaction types. Part of this may depend upon how one looks at the reaction or what one is interested. Other reactions, however, can simple be called only one of the reaction types.

The other common reaction scheme describes reactions in terms of other characteristics. There are three principle classifications of reactions in this scheme. It is this second scheme that your text prefers to use.

A. **Oxidation-Reduction Reactions** ("redox") are all reactions that involve the transfer of electrons, that is specifically, they have their oxidation numbers changed. Atoms that lose electrons are said to be "oxidized" and those that gain electrons are "reduced." This classification came from the fact that the first observed reactions of this type involved oxygen. However, though sufficient for many purposes, these descriptions are not precisely correct. Oxidation and reduction properly refer to a change in oxidation number — the actual transfer of electrons may never occur. Thus, oxidation is better defined as an increase in oxidation number, and reduction as a decrease in oxidation number. In order for the reaction to take place there have to be both an oxidation and a reduction occurring.

Hence, the following is an oxidation-reduction reaction.

$2\ Na + Cl_2 \longrightarrow 2\ NaCl$

(The Na is oxidized to form Na^+, while the Cl is reduced to form the Cl^-.)

$C + O_2 \longrightarrow CO_2$

$C + 2\ H_2 \longrightarrow CH_4$

These can also be an involved process such as the oxidation of sugar in the body by a series of complex processes.

In this classification scheme, combustion reactions are considered a kind of oxidation-reduction reaction. In the case of organic molecules, like the combustion of CH_4, carbon changes from having a -4 oxidation number to being a +4.

$2\ CH_4 + 3\ O_2 \longrightarrow 4\ H_2O + 2\ CO$

B. **Precipitation Reactions** are reactions in which soluble ions in separate solutions are mixed together to form an insoluble compound that settles out of solution as a solid. That insoluble compound is called a **precipitate**. The solutions are most often in water.

$2\ AgNO_3 + ZnCl_2 \longrightarrow 2\ AgCl + Zn(NO_3)_2$ (AgCl is insoluble in water)

Solubility rules and tables are useful **summaries of information** about which ionic compounds (or combinations of ions) are soluble in water and which are not. They are also important tools for **making predictions** about whether certain ions will react with one another to form a precipitate. In addition, they are useful for **figuring out** what ions might be involved when a precipitation reaction has been observed.

C. The nature of **Acid-Base Reactions** can be viewed in different ways, but each view holds in common that acids and bases are opposite in their chemical nature and because of this, acids and bases react with one another. Most often these reactions form water as one of the products, the H^+ ion in the acid reacts with the OH^- ion in the base. Remember that H_2O and HOH are both ways to write water.

$$NaOH + HCl \longrightarrow NaCl + HOH$$
$$H_2SO_4 + 2\ KOH \longrightarrow K_2SO_4 + 2\ H_2O$$

However, it should be noted that there are some acid-base reactions where the base does not contain the OH^- ion. These are still called acid-base reactions because an acid is reacting with a base.