Chemical Equations and Stoichiometry

Chemical Equations

A **chemical equation** is a shorthand way of indicating what is going on in a chemical reaction. We could do it the long way…

Two molecules of Hydrogen gas react with one molecule of Oxygen gas to produce two molecule of liquid water.

Or we can use the shorthand…

$2\ H_{2\,(g)} + O_{2\,(g)} \rightarrow 2\ H_2O_{(l)}$

The second way is easier to read and keep track of everything going on. The equation above uses **phase symbols**. Phase symbols are used to denote the phase of substances in an equation.

(*g*)	gas
(*s*)	solid
(*l*)	liquid
(*aq*)	aqueous (water solution)

The chemical equation must represent reality. The symbol, Δ, is sometimes used to denote a reaction that is heated and is written above the arrow. Catalyst symbols or formulas are also placed above the arrow.

Balancing equations

An equation is balanced when the number of atoms of each type present is the same on both sides of the equation. The chemical formulas CANNOT be changed in the process of balancing an equation. The process of balancing an equation can sometimes seem to be trial and error. In reality, there is a method to the madness. When we balance a chemical equation we are looking at the relationships between the elements on both sides of the equation. This relationship helps us to figure out what needs to be done. Some basic rules for balancing chemical equations are…

1. Start with the most complicated chemical first and start with the element that appears the most number of times in that compound.

2. Save "free" elements for last.

Example:

$$CH_{4\,(g)} + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{(l)}$$

Here CH_4 is the most complicated and Hydrogen appears the most number of times so we will start with that element. O_2 is a “free” element (not combined with other elements) so we will leave that for last.

There are 4 hydrogens on the reactant side and 2 on the product side. Therefore, we multiply the water on the product side by 2 and the hydrogens balance.

$$CH_{4\,(g)} + O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2\ H_2O_{(l)}$$

The carbons are already balanced. Now we can balance the oxygen atoms. There are 2 on the reactant side and 4 on the product side. If we multiply the O_2 by 2 we balance the oxygen.

$$CH_{4\,(g)} + 2\ O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2\ H_2O_{(l)}$$

Now the equation is balanced.

A Mathematical Method of Balancing Equations

This can also be done mathematically. We start by assigning generic coefficients to the equation. If we are using the same equation as before, we would get:

$$a\ CH_{4\,(g)} + b\ O_{2\,(g)} \rightarrow c\ CO_{2\,(g)} + d\ H_2O_{(l)}$$

From this we can then derive a set of mathematical equations for each element. We know that the number of each element should be the same on both sides of the equation. For example, with carbon we can see that there is one carbon atom in CH_4 times the coefficient a on the left side. On the right side we have one carbon atom in CO_2 times c. These two numbers have to be equal. This gives us:

$$a = c$$

For the other elements we get:

$$4a = 2d$$
$$2b = 2c + d$$

Note that we have only three equations but four unknowns. This means that we have an infinite number of solutions to this system of equations. This is fine because there are an infinite number of ways of balancing a chemical equation. All we need to do at this point is to pick one of those solutions. If we choose the solution where a =1 we then get that c = 1 also. If a = 1 then, by the second equation, we get that d is equal to 2. If c =1 and d = 2, then, by the last equation, b = 2. This give us the balanced chemical equation:

$$CH_{4\,(g)} + 2\ O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2\ H_2O_{(l)}$$

Molar interpretation vs. Molecular interpretation of a chemical reaction

The balanced chemical reaction gives you a series of conversion factors to use in problem solving.

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

The conversion factors are obtained from the coefficients in the balanced chemical reaction. These conversion factors can be used to relate the amounts of reactant to other reactants or to amounts of products. It is this reason that, in order to solve a chemical problem, you first need to have a balanced chemical equation.

Example:

How many grams of solid Barium Sulfate can be produced from the reaction of 154.6 g of Barium Nitrate with Sodium Sulfate? The other product of the reaction is Sodium Nitrate.

First we need to write the balanced chemical equation:

$$Ba(NO_3)_2 + Na_2SO_4 \rightarrow BaSO_4 + 2\ NaNO_3$$

Now we can proceed with the calculation.

$$154.6\text{ g Ba(NO}_3)_2 \times \frac{1\text{ mol Ba(NO}_3)_2}{261.337\text{ g Ba(NO}_3)_2} \times \frac{1\text{ mol BaSO}_4}{1\text{ mol Ba(NO}_3)_2} \times \frac{233.391\text{ g BaSO}_4}{1\text{ mol BaSO}_4} = 138.1\text{ g BaSO}_4$$

Limiting Reactants

The **Limiting Reactant** is the reactant that is completely consumed during the course of a reaction. If the reactant is not completely consumed it is known as an **excess reactant**.

The limiting reactant is what determines the amount of product(s). When all of the limiting reactant is consumed, no more product(s) can be produced.

Determining the limiting reactant

1. Calculate the amount of product that would result from each of the reactants.

2. The reactant that corresponds to whichever amount of product is smallest is the limiting reactant. All other reactants are excess reactants.

Theoretical Yield is the maximum amount of product that can be produced from a reaction mixture. It is the amount of product determined from the limiting reactant.

Actual Yield is the amount of product that results when the reaction is carried out in the lab.

Percent yield is the ratio of actual yield to theoretical yield multiplied by 100.

$$\%\text{ yield}=\frac{\text{actual yield}}{\text{theoretical yield}}\times 100\%$$

Why determine the % yield? When a chemist reports his results from a reaction, he/she does so by using the percent yield. This is done because the percent yield should be the same for the same reaction regardless of how much reactant is initially used.

Example:

17.56 g of Ethanol (C_2H_6O) reacts with 102.5 g of Oxygen to produce Carbon Dioxide and water. How many grams of Carbon Dioxide are produced in this reaction? What is the limiting reactant? If only 30.00 g of Carbon Dioxide are produced, what is the percent yield?

Balanced Chemical Equation:

$$C_2H_6O + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$$

Calculations:

$$17.56\text{ g }C_2H_6O\times\frac{1\text{ mol }C_2H_6O}{46.07\text{ g }C_2H_6O}\times\frac{2\text{ mol }CO_2}{1\text{ mol }C_2H_6O}\times\frac{44.01\text{ g }CO_2}{1\text{ mol }CO_2}=33.54\text{ g }CO_2$$

$$102.5\text{ g }O_2\times\frac{1\text{ mol }O_2}{32.00\text{ g }O_2}\times\frac{2\text{ mol }CO_2}{3\text{ mol }O_2}\times\frac{44.01\text{ g }CO_2}{1\text{ mol }CO_2}=93.98\text{ g }CO_2$$

$$\frac{30.00\text{ g }CO_2}{33.54\text{ g }CO_2}\times 100=89.45\%$$

The limiting reactant is the reactant that gives the smallest amount of product. In this case, that is Ethanol. The theoretical yield is that amount of product, 33.54 g CO_2. The percent yield is 89.45%.