Balancing Chemical Equations

Chemical equations do not come already balanced. This must be done before the equation can be used in a chemically meaningful way.

All chemical calculations to come must be done with a balanced equation.

A balanced equation has equal numbers of each type of atom on each side of the equation.

The **Law of Conservation of Mass** is the rationale for balancing a chemical equation. The law was discovered by Antoine Laurent Lavoisier (1743-94) and this is his formulation of it, translated into English in 1790 from the *Traité élémentaire de Chimie* (which was published in 1789):

> "We may lay it down as an incontestible axiom, that, in all the operations of art and nature, nothing is created; an equal quantity of matter exists both before and after the experiment; the quality and quantity of the elements remain precisely the same; and nothing takes place beyond changes and modifications in the combination of these elements."

A less wordy way to say it might be:

"Matter is neither created nor destroyed."

Therefore, we must finish our chemical reaction with as many atoms of each element as when we started.

Here is the example equation for this lesson:

$$H_2 + O_2 \text{ ---> } H_2O$$

It is an unbalanced equation (sometimes also called a skeleton equation). This means that there are UNEQUAL numbers at least one atom on each side of the arrow.

In the example equation, there are two atoms of hydrogen on each side, BUT there are two atoms of oxygen on the left side and only one on the right side.

Remember this: A balanced equation MUST have EQUAL numbers of EACH type of atom on BOTH sides of the arrow.

An equation is balanced by changing coefficients in a somewhat trial-and-error fashion. It is important to note that only the coefficients can be changed, NEVER a subscript.

The coefficient times the subscript gives the total number of atoms.

Three quick examples before balancing the equation.

(a) 2 H_2 - there are 2 x 2 atoms of hydrogen (a total of 4).

(b) 2 H_2O - there are 2 x 2 atoms of hydrogen (a total of 4) and 2 x 1 atoms of oxygen (a total of 2).

(c) 2 $(NH_4)_2S$ - there are 2 x 1 x 2 atoms of nitrogen (a total of 4), there are 2 x 4 x 2 atoms of hydrogen (a total of 16), and 2 x 1 atoms of sulfur (a total of 2).

So, now to balancing the example equation:

$$H_2 + O_2 \text{ ---> } H_2O$$

The hydrogen are balanced, but the oxygens are not. We have to get both balanced. We put a two in front of the water and this balances the oxygen.

$$H_2 + O_2 \text{ ---> } 2\ H_2O$$

However, this causes the hydrogen to become unbalanced. To fix this, we place a two in front of the hydrogen on the left side.

$$2\ H_2 + O_2 \text{ ---> } 2\ H_2O$$

This balances the equation.

Two things you CANNOT do when balancing an equation.

1) You cannot change a subscript.

You cannot change the oxygen's subscript in water from one to two, as in:

$$H_2 + O_2 \text{ ---> } H_2O_2$$

True, this balances the equation, but you have changed the substances in it. H_2O_2 is a completely different substance from H_2O.

2) You cannot place a coefficient in the middle of a formula.

The coefficient goes at the beginning of a formula, not in the middle, as in:

$$H_2 + O_2 \text{ ---> } H_22O$$

Water only comes as H_2O and you can only use whole formula units of it.

There is another thing you should avoid. Make sure that your final set of coefficients are all whole numbers with no common factors other than one. For example, this equation is balanced:

$$4\ H_2 + 2\ O_2 \text{ ---> } 4\ H_2O$$

However, all the coefficients have the common factor of two. Divide through to eliminate common factors like this.

The equation just above is correctly balanced, but it is not the BEST answer. The best answer has all common factors greater than one removed.

Balance this equation: $H_2 + Cl_2$ ---> HCl

Remember that the rule is: A balanced equation MUST have EQUAL numbers of EACH type of atom on BOTH sides of the arrow.

The correctly balanced equation is:

$$H_2 + Cl_2 \text{ ---> } 2\ HCl$$

Placement of a two in front of the HCl balances the hydrogen and chlorine at the same time.

Balance this equation: O_2 ---> O_3

Hint: think about what the least common multiple is between 2 and 3. That's right - six.

The LCM tells you how many of each atom will be needed. Your job is to pick coefficients that get you to the LCM.

The correctly balanced equation is:

$$3\ O_2 \text{ ---> } 2\ O_3$$

Practice Problems

How many oxygens are indicated: $3\ Ca(NO_3)_2$

Balance these equations:

$Zn + HCl$ ---> $ZnCl_2 + H_2$

$KClO_3$ ---> $KCl + O_2$

$S_8 + F_2$ ---> SF_6

$Fe + O_2$ ---> Fe_2O_3

$C_2H_6 + O_2$ ---> $CO_2 + H_2O$

The last problem above involved the use of fractional coefficients. Balance these three equations using ONLY fractional coefficients:

$S_8 + F_2$ ---> SF_6

$C_4H_{10} + O_2$ ---> $CO_2 + H_2O$

$S_8 + O_3$ ---> SO_2

Be careful on using fractions. For example, 1/2 H_2O is not a correct use of fractions. Why not?

1/2 H_2 = one H atom, but 1/2 O = one half of one atom. You cannot split atoms in chemical reactions.

Generally speaking, fractions are mostly used with diatomics (with O_2 is the most common). However, know that you do not have to use fractions in balancing equations. The “official” method for balancing says that you should go back to the beginning and change the coefficient of the first compound to the next number (a “1" becomes a “2,” etc.) and then go through the entire equation again with this new starting point. So, fractions or starting over – both methods will give the same answer. I usually use the fraction approach when it occurs because it is easier for me. Find what works best for you.

Want more balancing practice? Try Balancing Worksheet #1 with 50 problems and answers.

Want still more? Try Balancing Worksheet #2 with 60 more problems and answers.

Have fun!

ANSWERS TO THE PRACTICE PROBLEMS

How many oxygens are indicated: 18

Balance these equations:

Equation 1) Zn + HCl ---> $ZnCl_2$ + H_2

Upon examining this equation, you see that there is already one Zn on each side of the equation. We will attempt to leave it alone, if at all possible, since it is already balanced.

One the right side, we see two chlorines and two hydrogens, with only one of each on the left. Putting a two in front of the HCl doubles the number of chlorine and hydrogen on the left side.

This now leaves us with two chlorines and two hydrogens on each side of the arrow, making them both balanced.

Since the zinc was already balanced, the entire equation is now balanced.

Equation 2) $KClO_3$ ---> KCl + O_2

Start by noticing the the K and the Cl are ALREADY balanced in the skeleton equation. However, the oxygen is out of balance with three on the left and two on the right.

It is important to emphasize that the oxygen on the left will increase only in steps of three, while the oxygen on the right will increase only in steps of two. The question to ask yourself is "What is the least common multiple between 2 and 3?" The answer of course is six. We need six oxygens on each side of the equation. We use a two on the left side since 2 x 3 = 6 and we use a three on the right side since 3 x 2 = 6.

This causes the K and the Cl to become unbalanced, but putting a two in front of the KCl on the right side fixes that.

This problem is interesting because you focused on the oxygens first. Normally, oxygen is the last (or next-to-last) element to be balanced.

Equation 3) S_8 + F_2 ---> SF_6

An eight in front of the SF_6 will balance the sulfurs.

This now gives us 48 fluorines on the right-hand side, since 8 x 6 = 48. Use a 24 in front of F_2 since 24 x 2 also equals 48.

Equation 4) Fe + O_2 ---> Fe_2O_3

In the unbalanced equation, there was only one Fe on the left and two on the right. Putting a two in front of the Fe on the left brings the irons into balance.

The situation balancing the oxygen is quite common. You saw it in a previous example. This time, I'll try to lay it out in steps.

1. The oxygen on the left ONLY comes in twos, while the right-hand side oxygen comes only in threes.
2. We have to get an equal number of oxygens. (Remember, we can only adjust the value of the coefficient. We cannot change the subscript.)
3. The least common multiple between two and three is six. This means we will need six oxygens on each side of the equation.
4. To get this, we put a three in front of the O_2 since 3 x 2 = 6 and we put a two in front of the Fe_2O_3 since 2 x 3 = 6.

The Fe was balanced, but has become unbalanced as a consequence of our work with the oxygen. Putting a four in front of the Fe on the left solves this.

Equation 5) $C_2H_6 + O_2 \text{ ---> } CO_2 + H_2O$

First, balance the carbons with a two in front of the CO_2. Then balance the hydrogens with a three in front of the H_2O. This leaves the following equation:

$$C_2H_6 + O_2 \text{ ---> } 2\ CO_2 + 3\ H_2O$$

Only the oxygens remain to be balanced, but there is a problem. On the right side of the equation, there are seven oxygen atoms, BUT oxygen only comes in a group of two atoms on the left side. Another way to say it - with O_2 it is impossible to generate an ODD number of oxygen atoms.

However, that is true only if you were using whole number coefficients. It is allowable to use **FRACTIONAL** coefficients in the balancing process. That means I can use seven-halves as a coefficient to balance this equation, like this:

$$C_2H_6 + (7/2)\ O_2 \text{ ---> } 2\ CO_2 + 3\ H_2O$$

Generally, the fractional coefficient is not retained in the final answer. Multiplying the coefficients through by two gets rid of the fraction. here is the final answer:

$$2\ C_2H_6 + 7\ O_2 \text{ ---> } 4\ CO_2 + 6\ H_2O$$

Also, improper fractions like 7/2 should be used rather than a mixed number like 3 1/2.

FOR THE FRACTIONAL COEFFICIENT PROBLEMS:

Equation 1) $(1/8)\ S_8 + 3\ F_2 \text{ ---> } SF_6$ ===> $S_8 + 24\ F_2 \text{ ---> } 8\ SF_6$

Equations 2) $C_4H_{10} + (13/2)\ O_2 \text{ ---> } 4\ CO_2 + 5\ H_2O$ ===> $2\ C_4H_{10} + 13\ O_2 \text{ ---> } 8\ CO_2 + 10\ H_2O$

Equation 3) $(1/8)\ S_8 + (2/3)\ O_3 \text{ ---> } SO_2$ ===> [see below for the final balanced equation]

Equation 3 alternate) $(3/8)\ S_8 + 2\ O_3 \text{ ---> } 3\ SO_2$ ===> $3\ S_8 + 16\ O_3 \text{ ---> } 24\ SO_2$