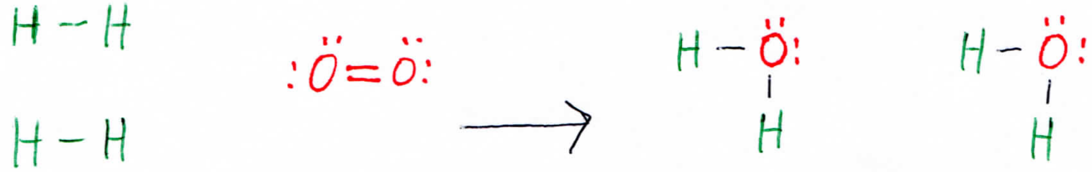
Chemistry Lecture #44: Balancing Chemical Equations

Substances react with other substances to make new substances. For example, gaseous hydrogen molecules will react with gaseous oxygen molecules to make water vapor.

Below are Lewis structures of hydrogen, oxygen, and water molecules. We start with hydrogen and oxygen. The atoms then rearrange themselves to form H_2O.



Instead of drawing Lewis structures to show a chemical reaction, we can write a chemical equation. In the reaction, two hydrogen molecules react with one oxygen molecule to produce two H_2O molecules. The equation for this reaction is

$$\underbrace{2\,H_2\,(g) + O_2\,(g)}_{\text{Reactants}} \rightarrow \underbrace{2\,H_2O\,(g)}_{\text{Products}}$$

Hydrogen gas and oxygen gas are the reactants. Reactants are the substances you have before the reaction occurs. The H_2O molecules are the products of the reaction. Products are the substances you end up with after the reaction has occurred.

The (g) next to each substance indicates that the substance is a gas. Different physical states have different notations. Below is a list of the notations used for the different states of matter.

(g) = gas
(l) = liquid
(cr) = crystal or solid
(s) = solid
(aq) = aqueous. This means the substance is dissolved in water.

Your textbook will include notations next to formulas, but I won't always include them in these lecture notes.

Look at this equation below and see if you can detect what is wrong with it.

$$C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$$

The problem with the above equation is that it is not balanced: there are an unequal number of atoms on each side. The law of conservation of mass states that the number of atoms that exist before a reaction has to equal the number of atoms that exist after a reaction.

If you count the number of atoms on each side, you'll find that there are 3 carbons on the left, but only one carbon on the right. There are 8 hydrogen atoms on the left, but only 2 hydrogens on the right. Finally, there are two oxygen atoms on the left, but three oxygens on the right. The equation is unbalanced.

Here are the guidelines for balancing a chemical equation:

1. Balance equations by putting the appropriate number *in front* of the chemical formula. The number in front of the formula is called the coefficient.

2. *Never* balance by changing or adding numbers to the lower part of the symbol.

For example, changing H_2O to H_2O_2 would be wrong. You can't just slap the subscript 2 on to the oxygen. Changing H_2O to H_3O would also be incorrect.

3. Try to balance the complicated molecules first. Balance uncombined elements last.

4. In general, we want the smallest whole numbers as coefficients in the equation.

There's no specific procedure for balancing equations. A lot of times you make a guess and hope that you are on the right track toward the correct solution.

Let's balance $C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$. We'll start with a guess and put a 3 in front of CO_2. This gives us

$$C_3H_8 + O_2 \longrightarrow 3CO_2 + H_2O$$

There are now 3 C's on each side. Next, we'll put a 4 in front of H_2O. This gives us

$$C_3H_8 + O_2 \longrightarrow 3CO_2 + 4H_2O$$

There are now 8 H's on each side since ($4 \times 2 = 8$). There are 2 O's on the left, and $3(2) + 4(1) = 6 + 4 = 10$ O's on the right. To balance the oxygens, we'll put a 5 in front of the O_2. This gives us

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

The equation is now balanced. There are 3 C's, 8 H's, and 10 O's on each side of the arrow.

Fractions such as ½ , 3/2, 5/2, and 7/2 can sometimes be used as an intermediate step in balancing uncombined elements. For example, let's balance

$$Na + H_2O \longrightarrow NaOH + H_2$$

There one Na on both sides, and there is also one O on each side. But there are 2 H's on the left, and three H's on the right. How can we balance the H's without messing up the Na and O atoms, which are already balanced?

If we put ½ in front of the H_2, we would then have $1 + (½ \times 2) = 1 + 1 = 2$ H's on the right. Now the H's are balanced on both sides. The balanced equation would be

$$Na + H_2O \longrightarrow NaOH + 1/2\ H_2$$

If we don't want fractions in our equation, we can get rid of them by multiplying the coefficients in front of each substance by 2. $2 \times ½ = 1$, so we'd end up with a 1 in front of the H_2. This gives us

$$2Na + 2H_2O \longrightarrow 2NaOH + 1\ H_2$$

Or

$$2Na + 2H_2O \longrightarrow 2NaOH + H_2$$

Each side has 2 Na's, 4 H's, and 2 O's.

Try balancing $C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$

Answer:

Balance C's by putting a 2 in front of CO_2.

$C_2H_6 + O_2 \longrightarrow 2CO_2 + H_2O$

Balance H's by putting a 3 in front of H_2O.

$C_2H_6 + O_2 \longrightarrow 2CO_2 + 3H_2O$

There are now 2 C's and 6 H's on each side. But the right side has 7 O's while the left has 2 O's. If we place 7/2 in front of the O_2, we'd have 7 O's on the left since $(7/2) \times 2 = 7$.

$C_2H_6 + 7/2\ O_2 \longrightarrow 2CO_2 + 3H_2O$

If we multiply each coefficient by 2, we get

$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$

Each side now has 4 C's, 12 H's, and 14 O's.

The least common multiple between coefficients can sometimes be used to balance equations. For example, try to balance the equation

$Ca + AlCl_3 \longrightarrow CaCl_2 + Al$

We have 3 Cl's on the left and 2 Cl's on the right. The least common multiple between the numbers 2 and 3 is 6. If we put a 2 in front of $AlCl_3$, and a 3 in front of $CaCl_2$, it would give us 6 Cl's on each side.

$Ca + 2AlCl_3 \longrightarrow 3CaCl_2 + Al$

We can now balance Ca and Al. The balanced equation is

$3Ca + 2AlCl_3 \longrightarrow 3CaCl_2 + 2Al$

If the equation has identical polyatomic ions in the reactants and products, treat the polyatomic ions as though they were elements. For example, try to balance

$$Al + Cu(NO_3)_2 \longrightarrow Al(NO_3)_3 + Cu$$

There are 2 NO_3 on the left, and 3 NO_3 on the right. The least common multiple between 2 and 3 is 6, so we'll put a 3 in front of $Cu(NO_3)_2$ and a 2 in front of $Al(NO_3)_3$.

$$Al + 3Cu(NO_3)_2 \longrightarrow 2Al(NO_3)_3 + Cu$$

There are now 6 NO_3 's on each side. We can balance the Al and Cu to get

$$2Al + 3Cu(NO_3)_2 \longrightarrow 2Al(NO_3)_3 + 3Cu$$

You could also say that there are 6 N's on each side, and 18 oxygens on each side.