

Balancing Equations

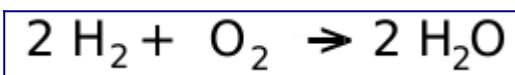
Balancing equations is one of those iconic subjects that is synonymous with chemistry. Even if you have no idea what it means, you know that you'll be balancing equations at some point during your chemical education.

Fortunately, balancing equations isn't all that hard to do. I mean, sure, there are numbers and formulas and stuff, but even with all of these complicated looking things, it's actually surprisingly easy. Let's learn more...

Parts of a chemical equation

Before you can learn to balance an equation, you need to learn what the parts of an equation are and what they mean. After all, you can't balance something if you don't know what you're looking at.

Let's take a look at a simple equation:



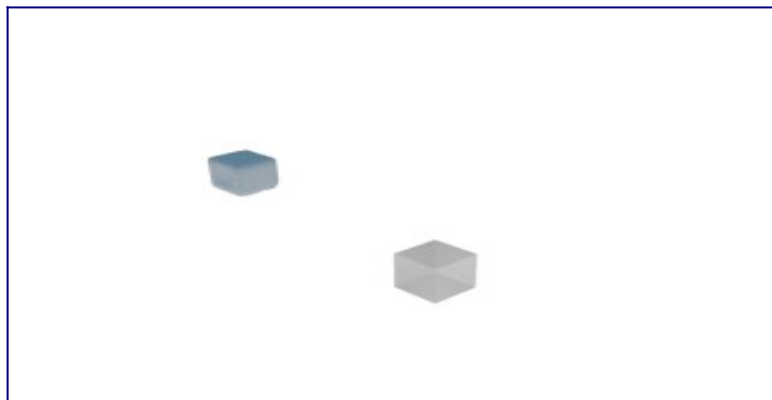
- The stuff on the left side of the equation (the 2H_2 and O_2 part) consist of the **reagents** (also called the *reactants*). These are the things that you're putting together in the reaction.
- The stuff on the right side of the equation (two water molecules) are the **products** of the reaction. This is what you're left with when the reaction is done.
- The arrow literally means "make", as in "the combined reagents make the products in this reaction."
- The numbers in front of each formula are called **coefficients**. In the case of this reaction, where you have 2 in front of H_2 and H_2O , the "2"s mean that the reaction involves two molecules of H_2 and two molecules of H_2O . Since there's no number in front of O_2 , we assume that the coefficient is 1 and that there's one molecule of it involved in this reaction.

Now that you understand the terms we'll be working with, let's balance some equations!

Why we balance equations

You didn't think I'd let you off that easy, did you? Before we can balance equations, we need to learn why we do this in the first place. After all, you don't need to do any balancing to know that if you react H_2 and O_2 with one another, you'll end up with water. It sounds like we're making life hard for ourselves.

But we're not. If you think back to earlier in your scientific learnings, you may recall something called the *law of conservation of mass*. For those of you who don't remember this, what it means is that when you do something, *anything*, the weight of the stuff you make will be equal to the weight of the stuff you started with. This is why adding 100 grams of water to 100 grams of cereal gives you a bowl of cereal weighing 200 grams.



This was the first Wikimedia image for “Conservation of Mass.” Insert your own joke here.

It’s important to write equations in a form that follows the law of conservation of mass because it saves us time and hassle. For example, if you use an equation that is balanced to perform some reaction, you’ll have enough knowledge to understand how much stuff you’ll start with and how much stuff you’ll make. If you don’t have a balanced equation, you’ll just have to hope that everything comes out OK.



How barbecue grills were lit prior to the era of balanced equations.

The way that we balance equations is to write coefficients in front of the chemical formulas in an equation. These coefficients multiply the number of atoms of each element in these formulas, so if you see a “2” in front of water, you’ll know you have four hydrogen atoms and two oxygen atoms. When both sides have the same number of atoms of each element, you’ve balanced the equation and written an equation according to the law of conservation of mass.

An aside: Doesn’t the equation $2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O}$ violate the law of conservation of mass? After all, you’ve got three molecules on the left side of the equation (2 H_2 molecules and 1 O_2 molecule) and two molecules on the right (2 H_2O molecules).

This doesn't violate the law of conservation of mass. Remember, to conserve mass, everything needs to weigh the same on both sides of the equation, which means the number of atoms of each element has to be identical. Though there are three reagent molecules and two product molecules in this equation, the number of atoms of each element is the same. Essentially, the two molecules on the right are just bigger than the ones on the left.

Let's finally balance equations!

If you follow these steps, you'll balance equations with ease. If you take shortcuts or ignore these rules, you may or may not have success. Since I'll guess you like both success and easy things, why not just follow these steps?

We'll start with the equation for the formation of water that we've already seen. Yes, I know that we already know the answer, but I'm going over it again so we know *how* to get this answer. Seriously, just go with me on this one.

Example: Balance this equation – $\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}$

Step 1: Make an inventory of the atoms in this unbalanced equation.

If our goal is to get the same number of atoms of each element on both sides of the reaction, we need to figure out how many we have to start with. Let's make a chart here:

Element	Reagent	Product
H		
O		

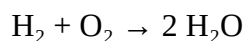
To use this chart, just figure out how many atoms of each element are on the reagent and product sides of this reaction.

In our case, H_2 indicates two atoms of hydrogen and O_2 indicates two atoms of oxygen on the reagent side of the reaction. H_2O indicates two atoms of hydrogen and one atom of oxygen on the product side. Let's fill out the chart.

Element	Reagent	Product
H	2	2
O	2	1

Step 2: Figure out what coefficient should be changed.

In this step, you merely look at your inventory and figure out how you can get the reagent and product sides to become the same. Because coefficients multiply the number of atoms in the formula, you have to do this via multiplication. In our case, hydrogen is balanced out and the oxygen is not. To get them to balance out, you need to turn the “1” into a “2”, and the only way to do this is to add a coefficient before water that will do this. Given that $1 \times 2 = 2$, let's try adding a “2”:



Did it work? Well, to find out, we need to move on to...

Step 3: Redo the inventory using the updated equation

Now that we've added a “2” before “H₂O”, we need to change our inventories for H and O on the product side of the equation. If both columns match up, the equation is balanced and we can rejoice. If not, then we need to keep balancing until we're finished.

In our case, the updated inventory should look like this:

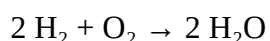
Element	Reagent	Product
H	2	4
O	2	2

Though the oxygen atoms are now equal, the hydrogen atoms have become unbalanced. This is not unusual when balancing equations, so if inventories seem to get a little screwed up from time to time, don't panic.

Because the reagent and product inventories aren't the same, we need to go back to step 2 and change another coefficient.

Step 2, again: Change a coefficient

In this revised equation, we can see that oxygen is fine but that there are two hydrogen atoms on the left and four as products. This problem can be solved by putting the coefficient “2” in front of the compound that contains hydrogen in this equation. Straightforwardly enough, this is simply H₂:



Of course, we can't be sure that this worked, so let's go back to...

Step 3 (again): Redo the inventory with the revised equation.

When we redo this inventory, it looks like this:

Element	Reagent	Product
H	4	4
O	2	2

Because the columns are the same, the equation is now totally balanced. Which, if you had looked at the example at the top, you knew already.

On the other hand, if the equation was not balanced, the right thing to do would be to go back to step 2 and continue the process until you get the right answer.

Tips, tricks, and cautions

When using this method (or any other, for that matter), there are some tips and tricks that can help you to navigate equation balancing and increase your odds of getting a quick answer. Here are some of them:

1. Do not EVER change the formulas of any of the chemical compounds!

In the example we did, the urge is strong for people to simply change H_2O to H_2O_2 to make the equation balance. Though this will, indeed, make the equation balance, the balanced equation won't be for the chemical reaction you were interested in. For example, $\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}_2$ is a balanced and valid equation, but it's for the synthesis of hydrogen peroxide and not water. Nice, but irrelevant. No matter what you do, imagine that there's a box drawn around each formula and that you can't change anything inside of it.

2. If it doesn't work, start over from scratch

You'll sometimes find that the two columns you're working with *never* balance. The most common reason for this is that you've made a mistake in your inventory somewhere and the error makes the equation unbalanceable. If this happens to you, starting over is the best thing to do.

3. Always do the inventory for every single step!

There will come a time when you will be able to visualize the answers and skip this whole method. This time has not come yet, so when you work on these problems, make sure that you actually write down each inventory instead of trying to keep it all in your brain. There are too many numbers to keep track of, and it takes practice to get it right. We chemists have a saying "If you don't write it down, it didn't happen", and in this case, it's true.



This girl was originally a boring loser. However, once she started doing equation balancing inventories, she became the sort of wacky person who points a pencil at people. Which is... good?

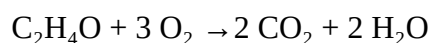
4. One step at a time

When balancing an equation, you may be thinking that you can put several coefficients into the equation at once to figure out the answer. Maybe this is true, and maybe not. However, I know from my own teaching experience that students are much more likely to get things wrong if they try this, because they quickly confuse themselves with all the numbers in the equation. Take it step-by-step, and only put in more than one coefficient at a time if you have no other options.

5. If the equation simply won't balance, just write a "2" in front of the most complicated-looking formula and start over.

Let's imagine the equation: $\text{C}_2\text{H}_4\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$

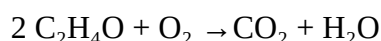
If you go through the process, you'll find that you end up with the following equation:



For which the inventory leaves oxygen unbalanced

Element	Reagent	Product
H	4	4
C	2	2
O	3	6

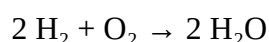
If this happens to you, just start over and write a “2” in front of the most complicated-looking molecule, then start over. In this case, we’d just go ahead and start with:



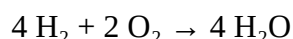
and take the process from there. I won’t go through all the steps, but doing so will lead to the answer $2 \text{C}_2\text{H}_4\text{O} + 5 \text{O}_2 \rightarrow 2 \text{CO}_2 + 4 \text{H}_2\text{O}$. Not a beautiful answer, but the correct one.

6. If you can reduce the coefficients, do it.

Let’s take a look at the equation for making water, which I’ve already gone over about a million times:

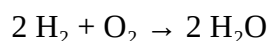


Now, let’s imagine that I doubled the coefficients to give us:



It balances, right? I mean, the numbers in the inventory are all doubled, but they still equal each other. Case closed!

Except the case isn’t closed. If you think of an equation as being a recipe, the coefficients tell you how much of each ingredient you’ll need and how much stuff you’ll make. Now, there’s nothing wrong with giving a recipe with large numbers, but it isn’t really useful to you. For example, if I were to give you a recipe for making 450,000 chocolate chip cookies at a time, it would probably be just a scaled-up version of a recipe for making 45 cookies. However, using huge numbers isn’t really convenient when making cookies in your own house, and it’s not particularly convenient when doing chemical reactions. As a result, if the coefficients can all be reduced by the same number, do it! In our case, we would divide all of the coefficients by 2 to give us our favorite:



There is one caution, though – you can only reduce things when all of the coefficients can be reduced. For example, with our favorite water equation, you can easily see that the 2 in front of hydrogen and 2 in front of water can both be divided by 2 to give 1s instead. However, since oxygen can’t reduce by 2, we can’t do this.



I just made 450,000 cookies and I approve of this message.

7. If you still can't balance the equation, give up (for a few minutes).

Yep, give up and move on. For a few minutes. Chances are good that if you've been working on a single equation for ten minutes you'll be burned out and making the same mistakes over and over again. If you wait a few minutes before returning, you'll forget the mistakes that you've made and have a better chance of finding the answer.



It is, however, possible to wait too long before finishing the problem.

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