balance_chem_eqn

How to Balance a Chemical Equation

$H_2 + O_2 = H_2O$

Three unknowns:

a = number of hydrogen molecules H_2 (2 hydrogen atoms per molecule)
b = number of oxygen molecules O_2 (2 oxygen atoms per molecule)
c = number of oxygen molecules H_2O (2 hydrogen atoms and one oxygen atom per molecule)

$aH_2 + bO_2 = cH_2O$

This equation is so simple that it can be solved just by looking at it $a = 1$, $b = 1/2$, $c = 1$ A purist would then multiply both sides of the equation by 2 and end up with $2H_2 + O_2 = 2H_2O$.

But ... most chemical processes are more complicated, and simple algebra is a much better bet.

Here's the trick - You learned in Algebra that if you have two unknowns, say x and y, you need two simultaneous equations to find a solution. Well, you learned wrong, sort of. If you want to know the exact number which x represents and the exact number which y represents, then yes, you need two independent equations. But, if you only need to know the ratio of x to y, then one equation works just fine.

If all you need to do is balance an equation, you do not need to know the exact number of Hydrogen atoms and the exact number of Oxygen atoms that you should combine in your process to make water. The exact numbers will come later, after you are given additional information, like the number of pounds of water that you want to produce. When you balance an equation, your only concern is to work out the ratios of atoms or molecules you supply, such that you'll get what you want, but you won't have anything left over.

Here's an example. How much stuff do you need to bake a bunch of cakes?

The box tells you that you need 3 eggs, 1-1/3 cups of water, and 1/2 cup of vegetable oil. It doesn't come right out and say so, but the implication is that you will end up with 1 cake. Let's write it in algebra.

3 eggs + 4/3 cups of water + 1/2 cup of oil + 1 box of mix = 1 cake

This is your balanced equation. It doesn't look pretty with the fractions, but it's the best when you're baking a bunch of cakes. If you want it to look nice for a chemistry test, get rid of the fractions by multiplying both sides of the equation by 6.

18 eggs + 8 cups water + 3 cups oil + 6 boxes of mix = 6 cakes

This is the cake version of $2H_2 + O_2 = 2H_2O$.

You have balanced the equation. Now, how would you use it. This is a separate question. You weren't asked about the ingredients for one cake, or for six cakes. You were asked about the ingredients for a bunch of cakes. If a bunch turns out to be one or six, then your work is done, but let's say you need to make fifty cakes. In that case, you go to the equation for one cake and multiply everything by fifty.

The important thing to keep in mind is that when you're asked to balance an equation, you are just being asked to work out the ingredients for one cake, although your answer will probably look much better if you get rid of the fractions and show what you need for two, or three, or some other number of cakes.

When you've balanced the equation for water, you won't know how many pounds of water come out. All you know, and all you need to show, is that for every four atoms of hydrogen and every two atoms of oxygen you will get two molecules of water.

How do balance an equation if you can't do it just by looking? As far as I know, there's only one simple and straightforward way that works every time. Algebra. Don't cringe - you had to go through all that trouble to learn it, now use it.

I'm always surprised that people, even those with years of training, hardly ever use math to solve little day to day problems. In fairness, most of the time they get along just fine without it, but every now and then math comes in handy.

When you balance an equation, you don't solve for x and y in the sense that you need to know how many pounds of mixed nuts you'll get if you want to sell them for ten bucks a pound.

Instead, you are just solving for the ratio of x/y, or the ratio of peanuts to cashews. It's easier to get a ratio than it is to get a total amount. In math-speak, this means that if you have three unknowns, you won't need three equations, you'll only need two. If you have five unknowns, you'll only need four equations, and so on. You're still using the rules of Algebra, you just don't need to use them as often. True, you'll end up with less information than what you were taught to expect, but you'll have all that you need.

Here's how to solve a simple equation step by step.

Step 1 - Write your equation. Let's use the little letters a, b, and c to represent the number of hydrogen molecules, oxygen molecules, and water molecules.

$aH_2 + bO_2 = cH_2O$

aH_2 means that we have 2a hydrogen atoms (a molecules, 2 atoms per molecule)

bO_2 means that we have 2b oxygen atoms (b molecules, 2 atoms per molecule)

cH_2O means that we have 2c hydrogen atoms and c oxygen atoms

Step 2 Write equations which relate a, b, and c, keeping in mind that the total number of hydrogen and oxygen atoms (not molecules) on the left must equal the total number of hydrogen and oxygen atoms (not molecules) on the right.

$2a = 2c$ (Hydrogen atoms)

$2b = c$ (Oxygen atoms)

Oops you say - three unknowns and only two equations. Not a problem, we have all we need.

Step 3 Let any of the variables (a, b, or c) equal 1 (we'll let c = 1). Instead of 1, you could use any number you want, but let's keep things simple this time, even if makes the solution a teeny bit harder.

c=1 (just because we say so) and so

$2a = 2$

$2b = 1$

That didn't take much work a = 1 and b = 1/2 and we already know c = 1

$H_2 + 1/2O_2 = H_2O$ and multiplying both sides by 2 to get rid of the fractions

$2H_2 + O_2 = 2H_2O$

Did we get the right answer?
4 hydrogen atoms plus 2 oxygen atoms = 4 hydrogen atoms plus 2 oxygen atoms. Looks good.

Let's do it again, but this time we'll make the solution even easier by letting a = 2. We start, as before, with

$aH_2 + bO_2 = cH_2O$

$2a = 2c$ (Hydrogen atoms)

$2b = c$ (Oxygen atoms)

Now when we let a = 2 we get

$4 = 2c$ (Hydrogen atoms)
so c = 2

$2b = c$ (Oxygen atoms)
so b = 1

And, just like the first time, we end up with $2H_2 + O_2 = 2H_2O$. Piece of cake.

Let's try one which is a little more complicated. Balance this.

$Ca_3(PO_4)_2 + SiO_2 + C = CaSiO_3 + P + CO$

Step 1 - Write your equation. Use the little letters a, b, c, d, e, and f to represent the reactants and the products of reaction.

$aCa_3(PO_4)_2 + bSiO_2 + cC = dCaSiO_3 + eP + fCO$

Step 2 Write equations which relate a, b, c, d, e, and f.

$3a = d$ (Calcium atoms, Ca)

$2a = e$ (Phosphorus atoms, P)

$8a + 2b = 3d + f$ (Oxygen atoms, O)

$b = d$ (Silicon atoms, Si)

$c = f$ (Carbon atoms, C)

Six unknowns and five equations. Just right.

We're going to say that one of the unknowns equals a number. We can pick any unknown, and assign any number we want to it. Here's the way to look at it.

The fact that 3a = d, b = d, and 2a = e says that if you assign a number to a, you've just taken care of four of the six variables a, d, b, and e. Say that a = 1.

Because a = 1, we know that d = 3, b = 3, and e = 6. Now our equation reads

$Ca_3(PO_4)_2 + 3SiO_2 + cC = 3CaSiO_3 + 6P + fCO$ and all that we're left with is c (Carbon) and f (Carbon Monoxide). This is a big improvement. Lets solve for c and f.

$Ca_3(PO_4)_2 + 3SiO_2 + cC = 3CaSiO_3 + 6P + fCO$

The easiest way to finish this is to count oxygen atoms on the left side and then on the right side. They must come out the same.

$8 + 6 = 9 + f$

$f = 5$ and because we already know that $c = f$ from above, $c = 5$

$Ca_3(PO_4)_2 + 3SiO_2 + 5C = 3CaSiO_3 + 6P + 5CO$

and when you count up all the individual atoms as a check on yourself, everything matches up.

We got our solution with a minimum amount of math. We could have gotten the same solution by solving the 5 simultaneous equations with any of the standard techniques of algebra. As it turns out this time, we don't need sophisticated tools (like determinants) to solve the equations. They are so easy to solve that a couple of taps with a hammer does the job.

This is a good point to pass along an analogy which a friend of mine and an excellent engineer, Vince Boliver, once shared with me. Vince had just taken a course on Electrostatic Field Analysis which had covered several different methods for solving Maxwell's Equations. His instructor had pointed out to the class that mathematical techniques were like wrenches in a tool box. You should carry around a couple adjustable wrenches, some open end wrenches, a good set of sockets, and a pair of pliers.

Adjustable wrenches work great for many jobs, but they aren't any good for changing spark plugs. You need a socket for that, but if there is a long pipe going through the middle of your nut, sockets won't work. Mathematical techniques act the same way. Some problems can be solved graphically, just by making a few freehand sketches. More complicated problems might require some algebra, some differential equations, a computer solution, or enen an analog solution using conductive paper or fluid.

The important thing is to use the right tool for the job, and thinking of mathematical techniques as tools is a very good tool itself.

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