

An Introduction to Matter and Measurement

An Introduction to Chemistry and the Scientific Method

An Introduction to Chemistry Page [1 of 2]

Let's do an experiment. Take a match, take a piece of paper and here we go. It's an experiment.

You probably, as a 21st Century person, can explain what just happened, but suppose it's back in the 18th Century, and let me tell you how scientists were thinking about what just happened. They were trying to explain their world, just like we try to explain our world, only they didn't have nearly what we have, didn't have the information that we have. And, in particular, we can make observations about this experiment that we just did. For instance, what's left over from burning the piece of paper is ashy and it doesn't have the strength that it had originally. It's gray, so we can make an observation about its color, and, in particular, we can take what's left over and we can try to burn it again.

Okay, take another match and take what's left over, and nothing's happening. So, somehow, whatever it is that allowed it to burn in the first place is gone. And we can formulate an hypothesis about what has happened to the piece of paper, and let me walk you through what we call the scientific method, or how we today and scientists then would have taken our observation from our experiment and tried to evolve from the observation to an explanation of what's going on.

So, we've already done the experiment and we made observations. And the observation I want to key on is the fact that it doesn't burn anymore. Once it's burned, it doesn't burn anymore. And if we had taken a bunch of different things, so let's do another experiment, where we took some tobacco, for instance, and we burned it. And we'd have gotten a pile of ash, just like this. And pretty soon we'd have gotten to a point where we had a pattern developing, or a trend. And what scientists do at that point is they formulate that observation of a pattern or a trend into what is called a scientific law. So a scientific law is a concise verbal statement that summarizes a broad variety of observations and, in particular, our observation is that once burned, doesn't burn anymore.

Now, from that, we can formulate and test a hypothesis. And a hypothesis is a tentative explanation for our observation. So here's a hypothesis, and this is the hypothesis that was the prevailing idea in the 18th Century, and that is that things, objects, matter, have flagiston. And flagiston, and I'm not joking, you've probably never heard of the word, but this is the real deal. Things like paper and wood have flagiston, and flagiston is driven off when you burn something. And, because it's driven off, there's no more flagiston in this wood, and so now it's something else. It's flagiston-less, if you will. And that explains why it doesn't burn anymore. We've driven off all the flagiston. Well, okay, so we can take that hypothesis and we can do more observations and see whether or not we can make our observation and our ideas all fit together in a totally consistent package. But here's an experiment that goes beyond this. So, we have this idea of flagiston, and now we're going to do another experiment and let's see what happens.

And the experiment I'm going to do is I'm going to take a piece of magnesium ribbon, instead of wood. So we'll take some magnesium ribbon and we'll burn the magnesium ribbon instead. Magnesium ribbon happens to burn with a very white-hot flame. And so, let's do that, and now let's make a different kind of observation. And the different kind of observation we're going to make, first of all, it burned, just like the wood seemed to burn, but the observation is let's weigh what's left over. Let's weight what's left over when we burn wood and compare it to weighing what's left over when we burn the magnesium ribbon. And, if we do that, we find out that the weight of the ash is less than the weight of the original piece of paper. And if we weigh the magnesium ash, we find out that the ash that's left over weighs more than the original magnesium ribbon.

Well now, we have a quandary. And quandary is if flagiston is something and something you can get your hands around, then if we drive it off in burning, and both of these things burn, so we've driven the flagiston off from both of these two objects, then how come the paper burning weighs less, which sort of fits with the idea that flagiston is stuff, but the magnesium ribbon, once it's burned, weighs more? So much for flagiston. Flagiston's out of here, because it doesn't fit with our observation. We have to go back to the drawing board and start all over again.

Well, around the end of the 18th Century, Antoine Lavoisier was doing experiments very carefully, in which he weighed not only the reactants or stuff that he started with, but every bit of the products, every bit of what came off from this chemical reaction. And what he discovered was what we call the Law of Conservation of Mass. So here's a law; a law again is a summary of observations. And his law says that in every chemical operation, an equal quantity of matter exists before and after the operation. Well, this leads to ultimately ... Okay, so that's a new law. And then we can test that law over and over again, burn a bunch of things, weigh how much we started with, weight everything that comes off as a result of the combustion and see whether or not that works out. And it turns out to work out beautifully.

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An Introduction to Chemistry Page [2 of 2]

Now, once you have a law that leads to a hypothesis, and what would the hypothesis be? The hypothesis would be that matter is somehow composed of building blocks that are indestructible. That building blocks are composed are, excuse me, that matter is composed of building blocks that don't really change. They're immutable in some level. And so that law leads to that hypothesis, and that hypothesis has been tested over and over and over again. But, at the time, it was tested enough where it evolved to the idea of a theory. And what a theory is, is it's a way to explain everything. In other words, it's a way to explain combustion. It's an all-encompassing idea that explains the observation. So it's the top of the heat in the evolution of the scientific method. And this is very different from the way normal people think about laws and theories.

For instance, people think about laws, you can't break a law. Well, a law just summarizes a bunch of observations. It's entirely possible you'd come up with an observation that didn't fit together with the law. Our burning magnesium ribbon didn't fit together with the idea that flagston was stuff that was driven off when things were burning, in particular, when the magnesium was burning. And so that law got broken. Law's get broken all the time. Some laws seem to be standing the test of time, but laws get broken. Hypothesis is the tentative explanation. This is the thing where scientists say, "Well, you know, we're not exactly sure, but this is what we think is going on." But by the time something has evolved all the way to a theory - that means that it's an all-encompassing explanation for what's going on. And this is very different from, say, what a criminologist thinks of as a theory. A criminologist would say, "Well, I think this bad guy did the robbery." He's not sure, but maybe. It's possible. The evidence seems to point that way, whereas, for a scientist, by the time something gets to a theory, we're pretty sure about it. It may still not explain everything, but it's on pretty firm ground, because it's been tested over and over again. The theory makes predictions and those predictions have to fit together with observations. And that's a key point of science, that a theory gives rise to observations. It gives rise to, not gives rise to, but it predicts observations. Scientists and science is about making predictions and then seeing whether or not our reality fits together with the prediction.

All right, so, where did Lawassier's idea of the Law of Conservation of Mass lead to? In 1801, John Dalton came up with his atomic theory. And there were five postulates in the atomic theory: 1) that matter consists of indivisible atoms; 2) that all the atoms of a given element are identical in mass and all other properties; 3) that different chemical elements have different kinds of atoms, in particular, the atoms have different masses; 4) that atoms are indestructible and retain their identities in chemical reactions; that's a thing that fits together with Lawassier's suggestion of the Law of Conservation of Mass; and 5) a compound forms from its elements through the combination of atoms of unlike elements in small, whole number ratios.

Well I'm not going to explain what 5) is. Really why I'm telling you all of this is I consider this sort of the birth of chemistry. Once chemistry started talking about atoms, then we were talking about the building blocks, and really that gave rise to the organization of matter that we call chemistry. It all builds on this idea of the scientific approach that you tie together observations, which lead to laws, which give rise to hypotheses, which get tested, and tested, and give more observations, until everything evolves to a theory. That's when we think we really know something, meaning that we can explain what's going on in the world around us. Ultimately, that's what chemistry is all about, is explaining what's going on in the world around us.