Teacher Tune-up

Quick Content Refresher for Busy Professionals

What evidence first led chemists to adopt the modern atomic theory of matter?

Modern atomic theory was initially founded not on any direct perception of the essential granularity of matter, but on reasoning about the proportions of reactants and products in chemical reactions.

Throughout the 1700s, scientists like Antoine Lavoisier busily identified elements. They figured out, for example, that water was not an element, because it could be separated into hydrogen and oxygen. Hydrogen and oxygen, however, cannot be broken down into other ingredients, so they *are* elements.

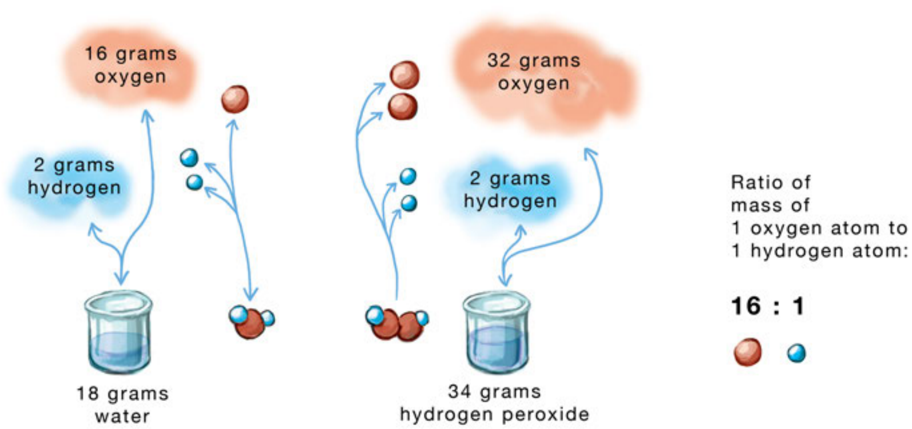
In addition to being combined to make water, hydrogen and oxygen can also be combined to make hydrogen peroxide. What's the difference? Proportion. It takes different proportions of hydrogen and oxygen to make water and hydrogen peroxide.

Consider these facts: any 18-gram sample of water is *always* made of 2 grams of hydrogen combined with 16 grams of oxygen. Also, 34 grams of hydrogen peroxide is *always* made of 2 grams of hydrogen combined with 32 grams of oxygen. Each of these chemical "recipes" demonstrates the **Law of Conservation of Matter** (the masses add up to the same amount whether the ingredients are separate or combined), and the **Law of Definite Proportions** (the chemicals always obey exact recipes).

There is a crucial third law lurking in this data. Notice that when we start with a fixed amount of hydrogen (2 g here), the amount of oxygen we need to make hydrogen peroxide (32 g) is *exactly double* the amount of oxygen needed to make water (16 g). Coincidence? Nope. This kind of small whole number ratio holds true for other elements and compounds, obeying a **Law of Multiple Proportions.** Whenever two elements can combine to form more than one compound, a *small whole number ratio* (like 2:1 in our example, or 3:4, or 2:5, but never something like 65,147:13 or π:1) tells you the different masses of one element that combine with a fixed mass of the other element.

This Law of Multiple Proportions was articulated by a British schoolteacher, John Dalton, in 1803. He argued that the best explanation for these three laws was an atomic model of matter.

As the illustration below shows, if each oxygen atom weighs 16 times as much as a hydrogen atom, and if water molecules are made of two hydrogen atoms and one oxygen atom, and hydrogen peroxide molecules are made of two hydrogen atoms and two oxygen atoms, the masses in the recipes make sense!



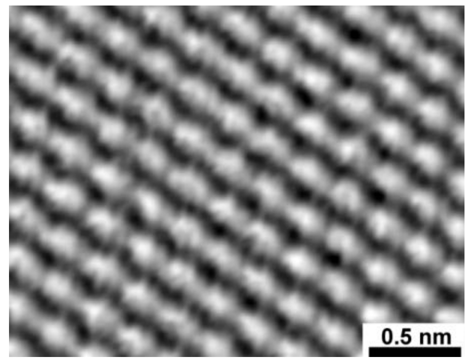
The atomic model makes sense of the experimentally determined masses of reactants and products in chemical reactions. This example of the Law of Multiple Proportions suggests that an oxygen atom has 16 times the mass of a hydrogen atom.

Dalton's atoms made their debut in modern chemistry as an accounting device. Many chemists throughout the nineteenth century used the atomic model to make sense of the proportions in which elements combined to make compounds, but denied that atoms really existed. They regarded the atomic model as a kind of useful fiction, an intellectual cheat that worked but shouldn't be taken too literally.

Over time, however, evidence mounted that atoms were as real as the macroscopic phenomena they explained. And gradually, scientists worked out the structure of atoms: they contained small negatively charged particles—electrons—and must also have an ambient positive charge component to cancel the charge of the electrons. Wait, no, that positive component was concentrated in a tiny central kernel, a nucleus. And look, there was more detail within that nucleus—neutrons with no charge alongside positively charged protons. The electrons were in planetary orbits. No, they were in probability clouds, their exact location unknowable. At least an element was an element, unchangeable—except, hold on, nuclear reactions, quite different from chemical reactions, could break apart or combine nuclei to form different elements.

The atomic model has come a long way since Dalton, both in complexity and in explanatory power. Nowadays, scanning tunneling microscopes give us tantalizing images of actual atoms. Say "cheese," atoms!

Such images give us a heightened impression of the reality of atoms. But it is a testament to human ingenuity that the atomic model arose long before such graphic confirmation. Scientists weighed things carefully, and by reasoning, detected atoms in the numbers.



STM image of graphite. Each big ("big"!) blob in this array is a ring of six smaller carbon atoms.

https://commons.wikimedia.org/wiki/File:Graphite_ambient_STM.jpg