Atomic Theory

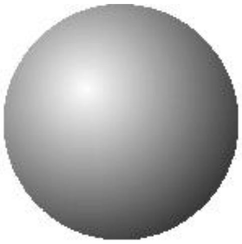
Democritus <u>(460 B.C.E.)</u> and the Greek Philosophers

Democritus was known as "The Laughing Philosopher."

Before we discuss the experiments and evidence that have convinced scientists matter is made up of atoms, it is only fair to credit the man who proposed the concept of the atom in the first place. About 2,500 years ago, early Greek philosophers believed the entire universe was a single, huge entity. In other words, "everything was one." They believed that all objects, all matter, and all substances were connected as a single, big, unchangeable "thing."

One of the first people to propose the existence of atoms was a man known as Democritus, pictured above. He suggested an alternative theory where **atomos –** tiny, indivisible, solid objects – made up all matter in the universe. Democritus then reasoned that changes occur when the many atomos in an object were reconnected or recombined in different ways. Democritus even extended his theory to suggest that there were different varieties of atomos with different shapes, sizes, and masses. He thought, however, that shape, size, and mass were the only properties differentiating the types of atomos. According to Democritus, other characteristics, like color and taste, did not reflect properties of the atomos themselves but from the different ways in which the atomos were combined and connected to one another.

So how could the Greek philosophers have known that Democritus had a good idea with his theory of atomos? The best way would have been to take some careful observation and conduct a few experiments. Recall, however, that the early Greek philosophers tried to understand the nature of the world through reason and logic, not through experimentation and observation. The Greek philosophers truly believed that, above all else, our understanding of the world should rely on logic. In fact, they argued that the world couldn't be understood using our senses at all because our senses could deceive us. Therefore, instead of relying on observation, Greek philosophers tried to understand the world using their minds and, more specifically, the power of reason.



Democritus's version of the atom

As a result, the early Greek philosophers developed some very interesting ideas, but they felt no need to justify their ideas. Aristotle concluded men had more teeth than women did. He concluded this without ever checking in anyone's mouth because his conclusion was the "logical" one. As a result, the Greek philosophers missed or rejected a lot of discoveries because they never performed any experiments. Democritus's theory would be one of these rejected theories. It would take over two millennia before the theory of atomos (or atoms, as they're known today) was fully appreciated.

Atomic Theory

Let's consider a simple but important experiment that suggested matter might be made up of atoms. In the late 1700s and early 1800s, scientists began noticing that when certain substances, like hydrogen and oxygen, were combined to produce a new substance, the reactants (hydrogen and oxygen) always reacted in the same proportions by mass. In other words, if 1 gram of hydrogen reacted with 8 grams of oxygen, then 2 grams of hydrogen would react with 16 grams of oxygen, and 3 grams of hydrogen would react with 24 grams of oxygen.

Strangely, the observation that hydrogen and oxygen always reacted in the "same proportions by mass" wasn't unique to hydrogen and oxygen. In fact, it turned out that the reactants in every chemical reaction for a given compound react in the same proportions by mass. Take, for example, nitrogen and hydrogen, which can react to produce ammonia (NH_3). In chemical reactions, 1 gram of hydrogen will react with 4.7 grams of nitrogen, and 2 grams of hydrogen will react with 9.4 grams of nitrogen. Can you guess how much nitrogen would react with 3 grams of hydrogen?

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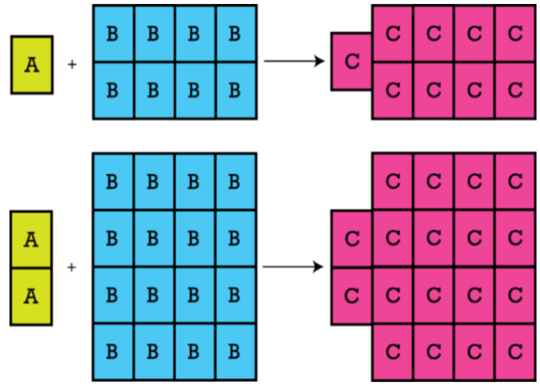
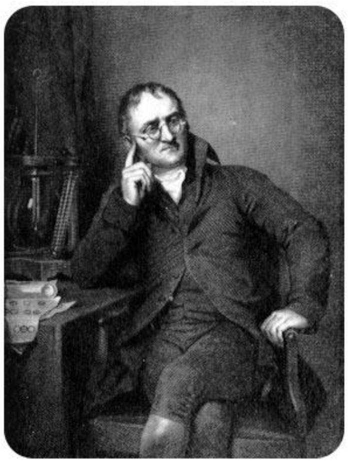


Scientists studied reaction after reaction, but every time the result was the same. The reactants always reacted in the same proportions by mass or in what we call "definite proportions," as illustrated in figure to the right. As a result, scientists proposed the **law of definite proportions**. This law states that:

In a given type of chemical substance, the elements always combine in the same proportions by mass

The law of definite proportions applies when the elements reacting together form the same product. Therefore, the law of definite proportions can be used to compare two experiments in which hydrogen and oxygen react to form water. The law, however, cannot be used to compare one experiment in which hydrogen and oxygen react to form water, H_2O, with another experiment in which hydrogen and oxygen react to form hydrogen peroxide, H_2O_2, (peroxide is another material that can be made from hydrogen and oxygen).



Dalton (1766-1844)

A man named John Dalton, (to the left) discovered this limitation in the law of definite proportions in some of his experiments. Dalton was experimenting with several reactions in which the reactant elements formed different products, depending on the experimental conditions he used. One common reaction that he studied was the reaction between carbon and oxygen. When carbon and oxygen react, they produce two different substances – we'll call these substances *A* and *B*. It turned out that, given the same amount of carbon, forming *B* always required exactly twice as much oxygen as forming *A*. In other words, if you could make *A* with 3 grams of carbon and 4 grams of oxygen, *B* could be made with the same 3 grams of carbon but with 8 grams of oxygen instead. Dalton asked himself – why does *B* require twice as much oxygen as *A* does? Why not 1.21 times as much oxygen, or 0.95 times as much oxygen? Why a whole number, like 2?

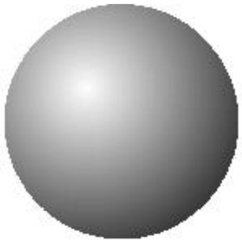
The situation became even stranger when Dalton tried similar experiments with different substances. For example, when he reacted nitrogen and oxygen, Dalton discovered that he could make three different substances – we'll call them *C*, *D*, and *E*. As it turned out, for the same amount of nitrogen, *D* always required twice as much oxygen as C does. Similarly, *E* always required exactly four times as much oxygen as *C* does. Once again, Dalton noticed that small whole numbers (2 and 4) seemed to be the rule. Dalton used his experimental results to propose the **law of multiple proportions**:

When two elements react to form more than one substance and the same amount of one element (like oxygen) is used in each substance, then the ratio of the masses used of the other element (like nitrogen) will be in small whole numbers.

This law summarized Dalton's findings, but it did not explain why the ratio was a small whole number. Dalton thought about his law of multiple proportions and tried to develop a theory that would explain it. Dalton also knew about the law of definite proportions and the law of conservation of mass, so what he really wanted was a theory that explained all three laws with a simple, plausible model. One way to explain the relationships that Dalton and others had observed was to suggest that materials like nitrogen, carbon, and oxygen were composed of small, indivisible quantities, which Dalton called "atoms" (in reference to Democritus's original idea). Dalton used this idea to generate what is now known as **Dalton's atomic theory**.

Atomic Theory

Dalton's Atomic Theory:



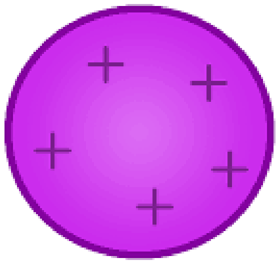
Dalton's version of the atom

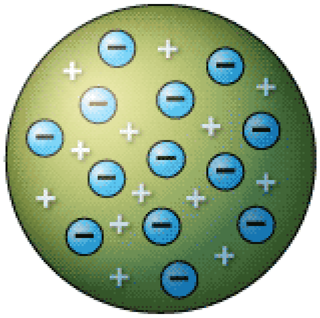
a. All elements are composed (made up) of atoms. It is impossible to divide or destroy an atom.
b. All atoms of the same elements are alike. (One atom of oxygen is like another atom of oxygen.)
c. Atoms of different elements are different. (An atom of oxygen is different from an atom of hydrogen.)
d. Atoms of different elements combine to form a compound. These atoms have to be in definite whole number ratios. For example, water is a compound made up of 2 atoms of hydrogen and 1 atom of oxygen (a ratio of 2:1). Three atoms of hydrogen and 2 atoms of oxygen cannot combine to make water.

Dalton's atomic theory explained a lot about matter, chemicals, and chemical reactions. Nevertheless, it wasn't entirely accurate because, contrary to what Dalton believed, atoms can in fact be broken apart into smaller subunits or subatomic particles. Also, we now know that atoms of a given element have different masses, called isotopes (we will discuss later in the chapter). With Dalton's Theory scientists were able to continue their research, later discovering the electron, proton, neutron and the structure of the atom.

Eugene Goldstein (1886)

Eugen Goldstein, a German physicist worked with cathode ray tubes. He discovered a positively charged particle (proton) while moving particles towards the anode (positive) side of the cathode ray tube. He noticed rays traveling in the opposite direction (towards the positive end) calling them canal; rays. Goldstein proved the existence of protons. He believed these protons were evenly distributed throughout the atom.





J. J. Thomson (1906):

J. J. Thompson was an English scientist. He discovered the electron when he was experimenting with gas discharge tubes. He noticed a movement in a tube. He called the movement cathode rays. The rays moved from the negative end of the tube to the positive end. He realized that the rays were made of negatively charged particles – electrons. Thompson's model of the atom, which he called the plum-pudding model after the English dessert, showed the protons and electrons evenly distributed throughout the entire atom.

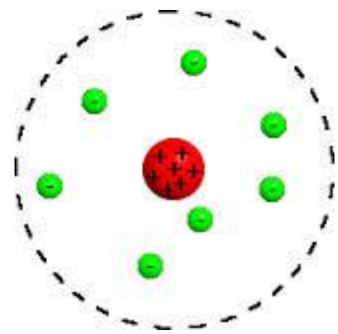
Atomic Theory

Max Planck (1918):

Max Planck was a German physicist who work with Einstein. Planck originated the Quantum Theory. Plank stated that electromagnetic energy would be omitted only in quantized form (a multiple of a unit). This is applied in chemistry to electrons; Planck's theory lead to mathematically describe the probable location of electrons in an atom. His ideas lead to the thought that electrons can be found in different "levels" in an atom.

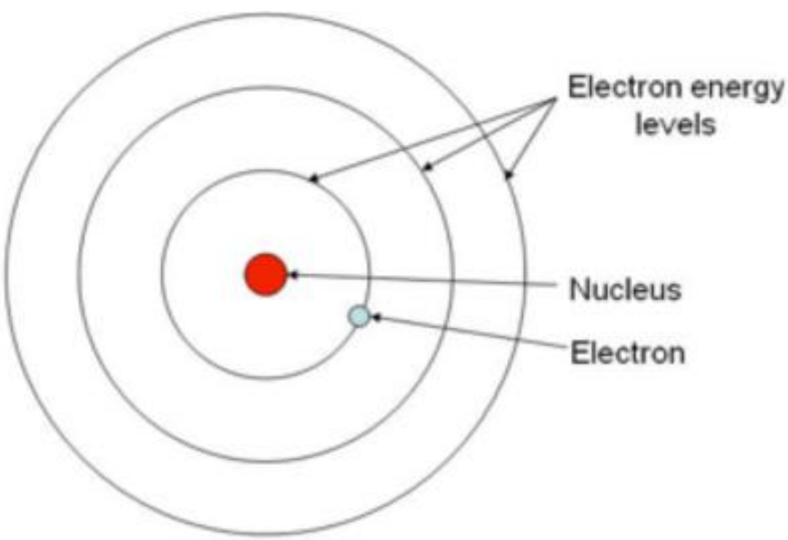
Lord Ernest Rutherford (1911):

Ernest Rutherford conducted a famous experiment called the gold foil experiment. He used a thin sheet of gold foil. He also used special equipment to shoot alpha particles (positively charged particles) at the gold foil. Most particles passed straight through the foil like the foil was not there. Some particles went straight back or were deflected (went in another direction) as if they had hit something. The experiment shows:



a. Atoms are made of a small positive nucleus; positive nucleus repels (pushes away) positive alpha particles
b. Atoms are mostly empty space

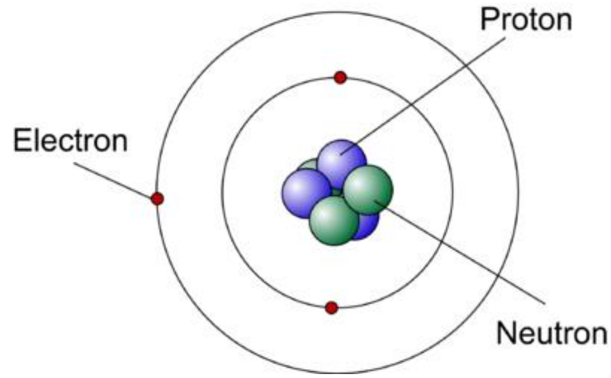
Niels Bohr (Early 1913):



Niels Bohr was a Danish physicist. He proposed a model of the atom that is similar to the model of the solar system. The electrons go around the nucleus like planets orbit around the sun. All electrons have their energy levels – a certain distance from the nucleus. Each energy level can hold a certain number of electrons. Level 1 can hold 2 electrons, Level 2 - 8 electrons, Level 3 - 18 electrons, and level 4 – 32 electrons. The energy of electrons goes up from level 1 to other levels. When electrons release (lose) energy they go down a level. When electrons absorb (gain) energy, they go to a higher level.

James Chadwick (1932):

James Chadwick was an English physicist who observed that when beryllium was bombarded with alpha (positively charged) particles, it emitted an unknown radiation that had approximately the same mass as a proton but with no electrical charge. Chadwick discovered the neutron.



Resources

Video: Dalton's Atomic Theory

https://www.youtube.com/watch?v=IdSUqsq1yY8