Atomic Theory:

# Democritus and Aristotle:

An atomic theory is a model developed to explain the properties and behaviors of atoms. As with any scientific theory, an atomic theory is based on scientific evidence available at any given time and serves to suggest future lines of research about atoms.

The concept of an atom can be traced to debates among Greek philosophers that took place around the sixth century B.C. One of the questions that interested these thinkers was the nature of matter. Is matter, they asked, continuous or discontinuous? That is, if you could break apart a piece of chalk as long as you wanted, would you ever reach some ultimate particle beyond which further division was impossible? Or could you keep up that process of division forever? A proponent of the ultimate particle concept was the philosopher Democritus (c. 470–c. 380 B.C. ), who named those particles *atomos.* In Greek, *atomos* means "indivisible."

The debate over ultimate particles was never resolved. Greek philosophers had no interest in testing their ideas with experiments. They preferred to choose those concepts that were most sound logically. Aristotle, for instance, believed that matter was continuous and was created from four basic substances, fire, air, water, and earth. Most people believed him and for more than 2,000 years, the Democritus concept of atoms languished as kind of a secondary interest among scientists.

# John Dalton

Then, in the first decade of the 1800s, the idea was revived. English chemist John Dalton (1766–1844) proposed the first modern atomic theory. Dalton's theory can be called modern because it contained statements about atoms that could be tested experimentally. Dalton's theory had five major parts. He said:

1. All matter is composed of very small particles called atoms.
2. All atoms of a given element are identical.
3. Atoms cannot be created, destroyed, or subdivided.
4. In chemical reactions, atoms combine with or separate from other atoms.
5. In chemical reactions, atoms combine with each other in simple, whole-number ratios to form combined atoms.

Dalton's atomic theory is important not because everything he said was correct. It wasn't. Instead, its value lies in the research ideas it contains. As you read through the list above, you'll see that every idea can be tested by experiment.

# J.J. Thomson

As each part of Dalton's theory was tested, new ideas about atoms were discovered. For example, in 1897, English physicist J. J. Thomson (1856–1940) discovered that atoms are not indivisible. When excited by means of an electrical current, atoms break down into two parts. One of those parts is a tiny particle carrying a negative electrical charge, the electron.

To explain what he had discovered, Thomson suggested a new model of the atom, a model widely known as the plum-pudding atom. The name comes from a comparison of the atom with a traditional English plum pudding, in which plums are embedded in pudding, as shown in the accompanying figure of the evolution of atomic theory. In Thomson's atomic model, the "plums" are negatively charged electrons, and the "pudding" is a mass of positive charge.

# Ernest Rutherford

**The nuclear atom.** Like the Dalton model before it, Thomson's plum pudding atom was soon put to the test. It did not survive very long. In the period between 1906 and 1908, English chemist and physicist Ernest Rutherford (1871–1937) studied the effects of bombarding thin gold foil with alpha particles. Alpha particles are helium atoms that have lost their electrons and that, therefore, are positively charged. Rutherford reasoned that the way alpha particles traveled through the gold foil would give him information about the structure of gold atoms in the foil.

Rutherford's experiments provided him with two important pieces of information. First, most of the alpha particles traveled right through the foil without being deflected at all. This result tells us, Rutherford concluded, that atoms consist mostly of empty space. Second, a few of the alpha particles were deflected at very sharp angles. In fact, some reflected completely backwards and were detected next to the gun from which they were first produced. Rutherford was enormously surprised. The result, he said, was something like shooting a cannon ball at a piece of tissue paper and having the ball bounce back at you.

According to Rutherford, the conclusion to be drawn from this result was that the positive charge in an atom must all be packed together in one small region of the atom. He called that region the nucleus of the atom. A sketch of Rutherford's nuclear atom is shown in the figure as well.

One part of Rutherford's model—the nucleus—has turned out to be correct. However, his placement of electrons created some problems, which he himself recognized. The peculiar difficulty is that electrons cannot remain stationary in an atom, as they appear to be in the figure. If they were stationary, they would be attracted to the nucleus and become part of it. (Remember that electrons are negatively charged and the nucleus is positively charged; opposite charges attract.)

But the electrons could not be spinning around the nucleus either. According to a well-known law of physics, charged particles (like electrons) that travel through space give off energy. Moving electrons would eventually lose energy, lose speed, and fall into the nucleus. Electrons in Rutherford's atom could neither be at rest nor in motion.

# Niels Bohr

**The planetary model -** The solution to this dilemma was proposed in a new and brilliant atomic theory in 1913. Suppose, said Danish physicist Niels Bohr (1885–1962) that places exist in the atom where electrons can travel without losing energy. Let's call those places "permitted orbits," something like the orbits that planets travel in their journey around the Sun. A sketch of Bohr's planetary atom is also shown in the figure. If we can accept that idea, Bohr said, the problem with electrons in Rutherford's atom would be solved.

Scientists were flabbergasted. Bohr was saying that the way to explain the structure of an atom was to ignore an accepted principle of physics—at least for certain small parts of the atom. The Bohr model sounded almost like cheating: inventing a model just because it might look right.

The test, of course, was to see if the Bohr model could survive experiments designed specifically to test it. And it did. Within a very short period of time, other scientists were able to report that the Bohr model met all the tests they were able to devise for it. By 1930, then, the accepted model of the atom consisted of two parts, a nucleus whose positive charge was known to be due to tiny particles called protons, and one or more electrons arranged in distinct orbits outside the nucleus.

# James Chadwick (Jimmy Neutron)

**The neutron.** One final problem remained. In the Bohr model, there must be an equal number of protons and electrons. This balance is the only way to be sure that an atom is electrically neutral, which we know to be the case for all atoms. But if one adds up the mass (total amount of matter) of all the protons and electrons in an atom, the total comes nowhere near the actual mass of an atom.

The solution to this problem was suggested by English physicist James Chadwick (1891–1974) in 1932. The reason for mass differences, Chadwick found, was that the nuclei of atoms contain a particle with no electric charge. He called this particle a neutron.

Chadwick's discovery resulted in a model of the atom that is fairly easy to understand. The core of the atom is the atomic nucleus, in which are found one or more protons and neutrons. Outside the nucleus are electrons traveling in discrete orbits.

# Modern Theories

This model of the atom can be used to explain many of the ideas in chemistry in which ordinary people are interested. But chemists themselves have not used the model for many decades. The reason for this difference is that revolutionary changes occurred in physics during the 1920s. These changes included the rise of relativity, quantum theory, and uncertainty that forced chemists to rethink the most basic concepts about atoms.

As an example, the principle of uncertainty says that it is impossible to describe with perfect accuracy both the position and the motion of an object. In other words, you might be able to say very accurately where an electron is located in an atom, but to do so reduces the accuracy with which you can describe its motion.

By the end of the 1920s, then, chemists had begun to look for new ways to describe the atom that would incorporate the new discoveries in physics. One step in this direction was to rely less on physical models and more on mathematical models. That is, chemists began to give up on the idea of an electron as a tiny particle carrying an electrical charge traveling in a certain direction with a certain speed in a certain part of an atom. Instead, they began to look for mathematical equations which, when solved, gave the correct answers for the charge, mass, speed, spin, and other properties of the electron.

Mathematical models of the atom are often very difficult to understand, but they are enormously useful and successful for professional chemists. The clues they have given about the ultimate structure of matter have led not only to a better understanding of atoms themselves, but also to the development of countless innovative new products in our daily lives.

## Do atoms exist?

One of the most remarkable features of atomic theory is that even today, after hundreds of years of research, no one has yet seen a single atom. Some of the very best microscopes have produced images of groups of atoms, but no actual picture of an atom yet exists. How, then, can scientists be so completely certain of the existence of atoms and of the models they have created for them? The answer is that models of the atom, like other scientific models, can be tested by experimentation. Those models that pass the test of experimentation survive, while those that do not are abandoned. The model of atoms that scientists use today has survived and been modified by untold numbers of experiments and will be subjected to other such tests in the future.

