

The Atomic Theory

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CONCEPT

1

The Atomic Theory

Lesson Objectives

The student will:

- give a short history of how the concept of the atom developed.
- describe the contributions of Democritus and Dalton to the atomic theory.
- summarize Dalton's atomic theory and explain its historical development.
- state the law of definite proportions.
- state the law of multiple proportions.

Vocabulary

- atomos
- Dalton's atomic theory
- law of definite proportions
- law of multiple proportions

Introduction

You learned earlier in the chapter “Matter and Energy” that all matter in the universe is made up of tiny building blocks called atoms. All modern scientists accept the concept of the atom, but when the concept of the atom was first proposed about 2,500 years ago, ancient philosophers laughed at the idea. After all, it is difficult to be convinced that something too small to be seen really exists. We will spend some time considering the evidence (observations) that convinced scientists of the existence of atoms.

Democritus and the Greek Philosophers

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.”

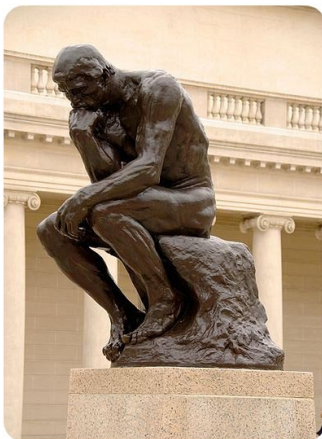
One of the first people to propose the existence of atoms was a man known as Democritus, pictured in **Figure 1.1**. He suggested an alternative theory where **atomos** – tiny, indivisible, solid objects – made up all matter in the universe. Democritus then reasoned that changes occur when the many atomos 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,

**FIGURE 1.1**

Democritus was known as "The Laughing Philosopher." It's a good thing he liked to laugh, because most other philosophers were laughing at his theories.

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 (see **Figure 1.2**).

**FIGURE 1.2**

This sculpture (named "The Thinker") reflects the value Greek philosophers placed on logic. Greek philosophers liked to think, but they didn't like to experiment all that much.

As a result, the early Greek philosophers developed some very interesting ideas, but they felt no need to justify their ideas. You may recall from the "Introduction to Chemistry" chapter that 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 that could have made otherwise 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.

Dalton's 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?

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 1.3**. 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.

This version of the law is a more modern version. Earlier, you learned that an element is a substance made up of only one type of atom, but when the law of definite proportions was first discovered, scientists did not know about atoms or elements and stated the law slightly differently. We'll stick with this modern version, though, since it is the easiest version to understand.

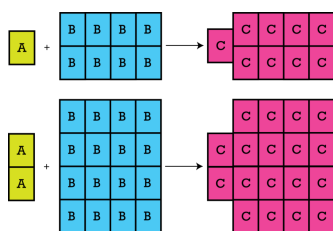


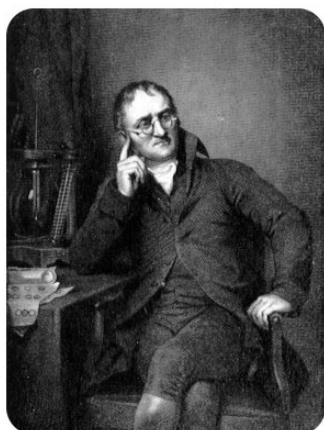
FIGURE 1.3

If 1 gram of A reacts with 8 grams of B, then by the law of definite proportions, 2 grams of A must react with 16 grams of B. If 1 gram of A reacts with 8 grams of B, then by the law of conservation of mass, they must produce 9 grams of C.

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 with another experiment in which hydrogen and oxygen react to form hydrogen peroxide (peroxide is another material that can be made from hydrogen and oxygen).

A man named John Dalton (**Figure 1.4**) 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

**FIGURE 1.4**

Unlike the early Greek philosophers, John Dalton was both a thinker and an experimenter. He would help develop the modern conception of an atom based on his experimental results.

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**.

Dalton's atomic theory:

1. Matter is made of tiny particles called atoms.
2. Atoms are indivisible. During a chemical reaction, atoms are rearranged, but they do not break apart, nor are they created or destroyed.
3. All atoms of a given element are identical in mass and other properties.
4. The atoms of different elements differ in mass and other properties.
5. Atoms of one element can combine with atoms of another element to form compounds. In a given compound, however, the different types of atoms are always present in the same relative numbers.

Historical note: Some people think that Dalton developed his atomic theory before stating the law of multiple proportions, while others argue that the law of multiple proportions, though not formally stated, was actually discovered first. In reality, Dalton was probably contemplating both concepts at the same time, although it is hard to say conclusively from looking at the laboratory notes he left behind.

Lesson Summary

- 2,500 years ago, Democritus suggested that all matter in the universe was made up of tiny, indivisible, solid objects he called atomos.
- Other Greek philosophers disliked Democritus's atomos theory because they felt it was illogical.
- The law of definite proportions states that in a given chemical substance, the elements are always combined in the same proportions by mass.
- The law of multiple proportions states that when two elements react to form more than one substance and the same amount of one element is used in each substance, then the ratio of the masses used of the other element will be in small whole numbers.
- Dalton used the law of definite proportions, the law of multiple proportions, and the law of conservation of mass to propose his atomic theory.
- Dalton's atomic theory states:
 1. Matter is made of tiny particles called atoms.
 2. Atoms are indivisible. During a chemical reaction, atoms are rearranged, but they do not break apart, nor are they created or destroyed.
 3. All atoms of a given element are identical in mass and other properties.
 4. The atoms of different elements differ in mass and other properties.
 5. Atoms of one element can combine with atoms of another element to form compounds. In a given compound, however, the different types of atoms are always present in the same relative numbers.

Review Questions

1. It turns out that a few of the ideas in Dalton's atomic theory aren't entirely correct. Are inaccurate theories an indication that science is a waste of time?
2. Suppose you are trying to decide whether to wear a sweater or a T-shirt. To make your decision, you phone two friends. The first friend says, "Wear a sweater, because I've already been outside today, and it's cold." The second friend, however, says, "Wear a T-shirt. It isn't logical to wear a sweater in July." Would you decide to go with your first friend and wear a sweater or with your second friend and wear a T-shirt? Why?
3. Decide whether each of the following statements is true or false.
 - a. Democritus believed that all matter was made of atomos.
 - b. Democritus also believed that there was only one kind of atomos.
 - c. Most early Greek scholars thought that the world was "ever-changing."
 - d. If the early Greek philosophers hadn't been so interested in making gold, they probably would have liked the idea of the atomos.
4. Match the person, or group of people, with their role in the development of chemistry in the table below.

Person/Group of People	Role in Chemistry
(a) early Greek philosophers	(i) first suggested that all matter was made up of tiny, indivisible, solid objects
(b) alchemists	(ii) tried to apply logic to the world around them
(c) John Dalton	(iii) proposed the first scientific theory relating chemical changes to the structure, properties, and behavior of atoms
(d) Democritus	(iv) were primarily concerned with finding ways to turn common metals into gold

- Early Greek philosophers felt that Democritus's atomos theory was illogical because:
 - no matter how hard they tried, they could never break matter into smaller pieces.
 - it didn't help them to make gold.
 - sulfur is yellow and carbon is black, so clearly atomos must be colored.
 - empty space is illogical because it implies that nothing is actually something.
- Identify the law that explains the following observation: Carbon monoxide can be formed by reacting 12 grams of carbon with 16 grams of oxygen. To form carbon dioxide, however, 12 grams of carbon must react with 32 grams of oxygen.
- Identify the law that explains the following observation: Carbon monoxide can be formed by reacting 12 grams of carbon with 16 grams of oxygen. It can also be formed by reacting 24 grams of carbon with 32 grams of oxygen.
- Identify the law that explains the following observation: 28 grams of carbon monoxide are formed when 12 grams of carbon reacts with 16 grams of oxygen.
- Identify the law that explains the following observations: When 12 grams of carbon react with 4 grams of hydrogen, they produce methane, and there is no carbon or hydrogen left over at the end of the reaction. If, however, 11 grams of carbon react with 4 grams of hydrogen, there is hydrogen left over at the end of the reaction.
- Which of the following is *not* part of Dalton's atomic theory?
 - Matter is made of tiny particles called atoms.
 - During a chemical reaction, atoms are rearranged.
 - During a nuclear reaction, atoms are split apart.
 - All atoms of a specific element are the same.
- Consider the following data: 3.6 grams of boron react with 1.0 grams of hydrogen to give 4.6 grams of BH_3 . How many grams of boron would react with 2.0 grams of hydrogen?
- Consider the following data: 12 grams of carbon and 4 grams of hydrogen react to give 16 grams of compound A. 24 grams of carbon and 6 grams of hydrogen react to give 30 grams of compound B. Are compound A and compound B the same? Why or why not?

References

- Hendrick ter Brugghen. [Democritus](#). Public domain
- Sculpture by Auguste Rodin, photograph by Karora. [The Thinker](#). Public domain
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