Theories of the Atom

If you were to take a gold bar and cut it into smaller and smaller pieces, what is the smallest piece of gold that you could get? Would the piece of gold ever become so small that, if you were to cut it further, it would no longer be gold?

These are the questions that occupied Greek philosophers thousands of years ago. Their answers, and those of many curious minds, have shaped our theories about the structure of matter. Let's trace this journey with a brief history of atomic theory.

Theories Evolve

A scientific theory is not a guess. It is not even an educated guess. A scientific theory is an expression of our best understandings of a phenomenon, based on scientific evidence or reasoning. As technologies are improved and new observations are gathered, or when old observations are reinterpreted, old theories may need to be modified. Sometimes old theories need to be discarded, and new theories need to be created.

Theories are constantly evolving as we gather more information and gain a wider perspective. When we begin to "connect the dots" of all the separate pieces of data, we are able to expand and refine our scientific theory. This is certainly true of our model of the structure of the atom.

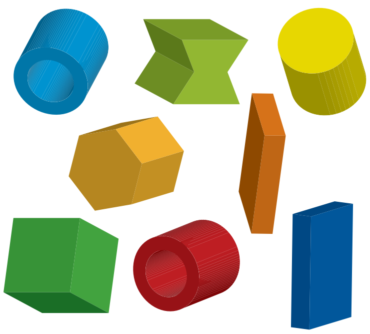

Figure 1 Democritus thought that the atom was indivisible.

atom the smallest unit of an element

The Evolution of Atomic Theory

AN INDIVISIBLE PARTICLE—THE ATOM

Around 400 BCE, the Greek philosopher Democritus proposed that all matter can be divided into smaller and smaller pieces until a single indivisible particle is reached. He named this particle the **atom**, which means "cannot be cut" (Figure 1). Without any experimental evidence, he proposed that atoms are

- of different sizes
- in constant motion
- separated by empty spaces (the void)

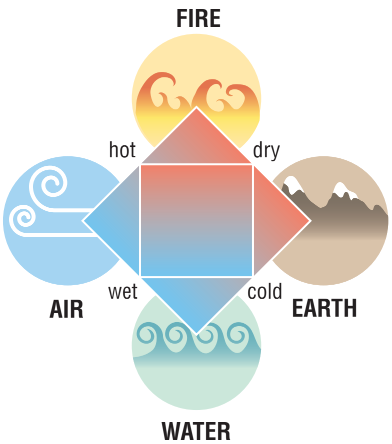

Figure 2 According to Aristotle, everything is made of earth, water, air, and fire.

EARTH, WATER, AIR, AND FIRE: ARISTOTLE (AROUND 450 BCE)

Another famous Greek philosopher, Aristotle, rejected the idea of the atom. He supported an earlier theory that all matter is made up of four basic substances: earth, water, air, and fire (Figure 2). These substances were thought to have four specific qualities: dry, wet, cold, and hot, respectively. Aristotle's theory of the structure of matter was accepted for almost 2000 years.

THE BILLIARD BALL MODEL

In 1807, John Dalton, an English scientist and teacher, revived Democritus' theory of the indivisible atom. Dalton proposed that

- all matter is made up of tiny, indivisible particles called atoms
- all atoms of an element are identical
- atoms of different elements are different
- atoms are rearranged to form new substances in chemical reactions, but they are never created or destroyed

Dalton's model is known as the billiard ball model (Figure 3). This model was useful because it could explain many properties of matter. For example, Dalton believed that pure gold samples from different locations had identical properties because the samples contained identical atoms. However, the billiard ball model could not explain why some objects attract each other, while other objects repel each other. For example, rubbing a balloon in your hair causes your hair to be attracted to the balloon (Figure 4). The explanation came almost 100 years later!

Figure 3 In Dalton's model, the atom resembles a billiard ball.

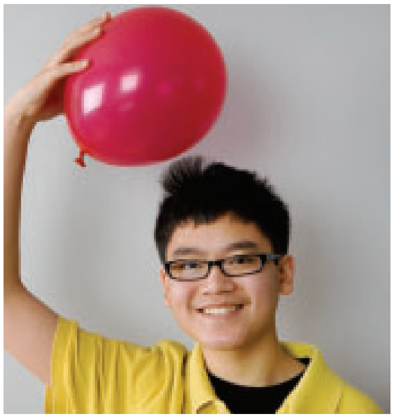

Figure 4 Dalton's model could not explain attractions between objects.

THOMSON'S EXPERIMENTS—THE ELECTRON

In 1897, J.J. Thomson discovered that extremely small negatively charged particles could be emitted by very hot materials. These particles were attracted to the positive end of a circuit (Figure 5). Positive charges and negative charges were known to attract each other, so Thomson concluded that the particles must be negatively charged. These particles were later called **electrons**. Thomson theorized that

- atoms contain negatively charged electrons
- since atoms are neutral, the rest of the atom is a positively charged sphere
- negatively charged electrons are evenly distributed throughout the atom

electron a negatively charged particle in an atom

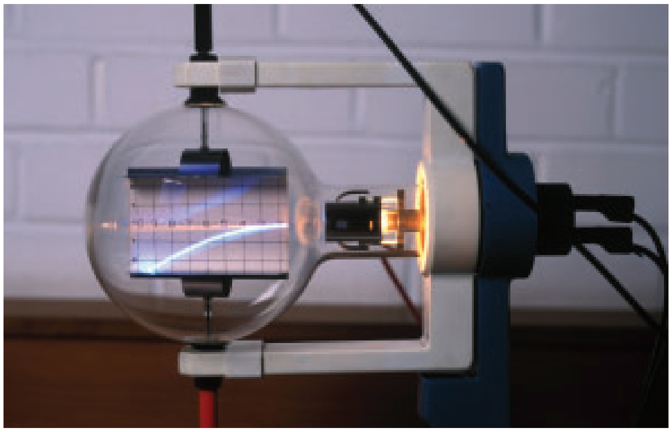

Figure 5 Thomson used a device called a cathode ray tube to conduct his experiments. The particles he detected were attracted to the positive end of the circuit, so they had to be negatively charged.

Thompson's model was called the "plum pudding" model because the electrons embedded in an atom resembled the raisins in a plum pudding (Figure 6). If Thomson had lived in more modern times, he may have called it a "chocolate chip muffin" model.

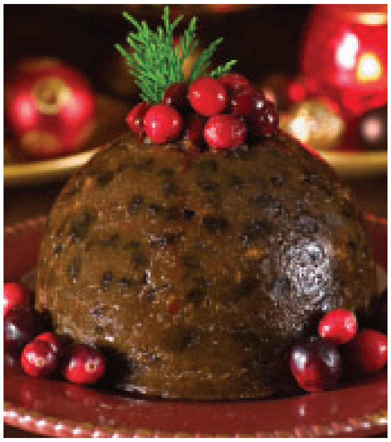

Figure 6 Thomson's model of the atom resembles a plum pudding.

READING TIP

Look for Context Clues

Look for context clues such as key words, examples, or explanations to help you make inferences. For example, in the explanation of Rutherford's experiment, you notice the word "reasoned." This tells you that Rutherford did not observe the nucleus of the atom directly, but rather inferred it from the results of the experiment.

THE GOLD FOIL EXPERIMENT—THE NUCLEUS AND THE PROTON

In 1909, Ernest Rutherford supervised an experiment to test Thomson's model of the atom. He predicted that if positive and negative charges were uniformly distributed throughout atoms, then tiny positively charged particles shot at a thin piece of gold foil would pass through the foil. Some of the particles might be slowed down or deflected at very small angles (Figure 7(a)). When the experiment was performed, most of the particles passed through the foil unaffected. Also, a small number of particles were deflected at very large angles, as though something very massive but very small was repelling them (Figure 7(b)). This result was shocking! Rutherford then reasoned that these large angles of deflection were caused by a collision with a small, concentrated, positively charged central mass inside the atom. In Rutherford's revised model,

- the centre of the atom has a positive charge. This centre is called the nucleus. It contains most of the atom's mass but occupies a very small space. The nucleus is what made some particles bounce back during the experiment.
- the nucleus is surrounded by a cloud of negatively charged electrons
- most of the atom is empty space

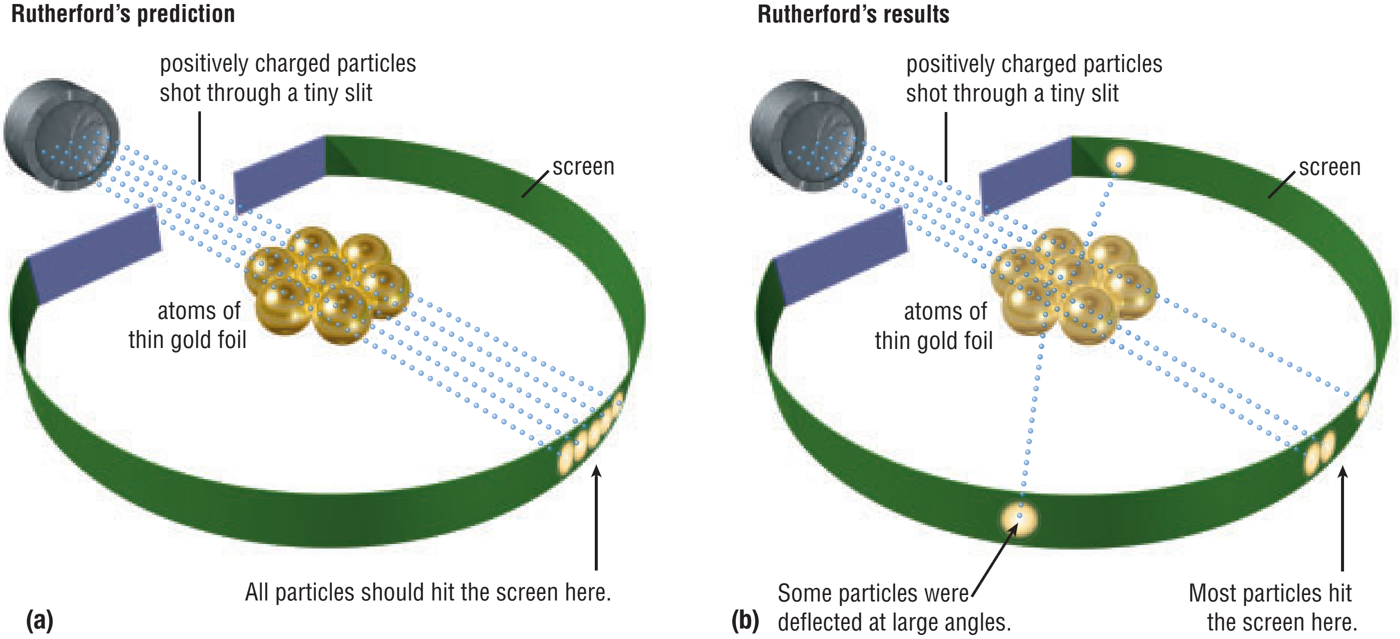

Figure 7 (a) Rutherford's prediction: Particles should pass directly through the gold foil, with very little deflection. (b) Rutherford's results: Most of the particles passed through the gold foil, but a few were deflected at very large angles.

proton a positively charged particle in the atom's nucleus

Rutherford is also credited with discovering the proton in 1920. A **proton** is a positively charged particle that is found in the atom's nucleus. Measurements of atomic mass showed that protons alone could not account for the total mass of a nucleus, given the amount of their charge. Rutherford predicted that there must be a third particle in the nucleus that had about the same mass as the proton but that was neutral in charge.

TRY THIS SIMULATING RUTHERFORD'S BLACK BOX

SKILLS: Performing, Observing, Analyzing, Evaluating, Communicating

In this simulation of Rutherford's gold foil experiment, you will shoot marbles at unidentified objects that are hidden under a large board. The paths that the marbles take as they travel under the board—straight through or deflected—will allow you to deduce the shape of the contents of this "black box."

Equipment and Materials: large board such as bristol board, foam board, or cardboard presentation board; small objects of similar height such as hockey pucks, small boxes, or Petri dishes; several marbles; large sheet of paper such as newspaper; markers; masking tape

1. Tape one or more objects under a large board. Make sure you perform this step while hidden from view of the participants, all of whom are named "Rutherford."
2. Tape a large sheet of paper to cover the top surface of the board.
3. Bring in the "Rutherfords" but do not allow them to look under the board. Give them marbles and markers. Allow them to roll marbles under the board and trace the paths of the marbles on the paper above the board (Figure 8).
4. After a sufficient number of rolls, ask the "Rutherfords" to draw the shape and size of the objects hidden in the "black box."

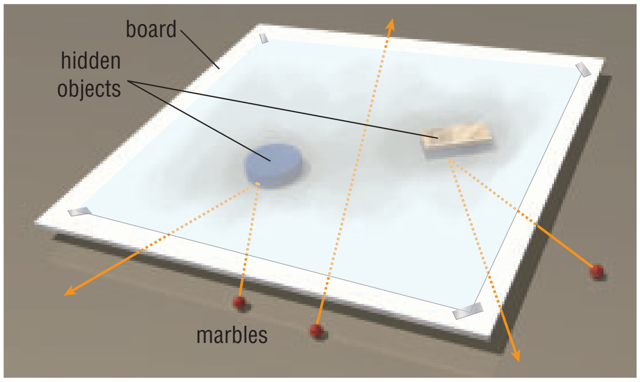

Figure 8 Experimental setup

5. Remove the board and the hidden objects, but do not reveal the objects to the "Rutherfords," just as the actual structure of the atom was never revealed to Ernest Rutherford.

A. In what way is this activity similar to Rutherford's gold foil experiment? A

B. In what way is not revealing the contents of the black box similar to scientists trying to discover what is inside the atom? A

C. Suggest other items that may be used instead of marbles to produce more informative clues about the hidden objects. A

CHADWICK'S EXPERIMENTS—THE NEUTRON

In 1932, James Chadwick, Rutherford's student, found a particle that could penetrate and disintegrate atoms with extraordinary power. Unlike positively charged protons, these particles have zero charge. Therefore, there must be other undetected particles in the atom. These particles must be neutral. Based on this discovery, Chadwick proposed that

- an atom must be an empty sphere with a tiny dense central nucleus
- this nucleus contains positively charged protons and neutral particles called **neutrons**
- the mass of a neutron is about the same as that of a proton (Table 1)
- negatively charged electrons circle rapidly through the empty space around the nucleus (Figure 9)
- a neutral atom has the same number of protons as electrons

This model of the atom is called the planetary model.

neutron a neutral particle in the atom's nucleus

Table 1 Types of Subatomic Particles

	Proton	Neutron	Electron
charge	+	0	–
location	in nucleus	in nucleus	orbiting nucleus
relative mass	1	1	$\frac{1}{2000}$
symbol	p^+	n^0	e^-

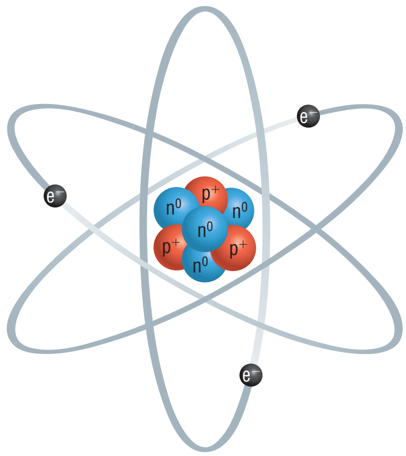

Figure 9 In the planetary model of the atom, electrons orbit the nucleus the way planets orbit the Sun in our solar system.

ELECTRON ORBITS

Niels Bohr, a Danish scientist, studied the hydrogen atom and the light that it produces when it is excited by thermal energy or electricity. When white light is shone through a prism, a full rainbow of colours is seen (Figure 10(a)). When light produced by hydrogen is examined in the same way, only a few lines of colour are seen. Most colours are missing (Figure 10(b)).

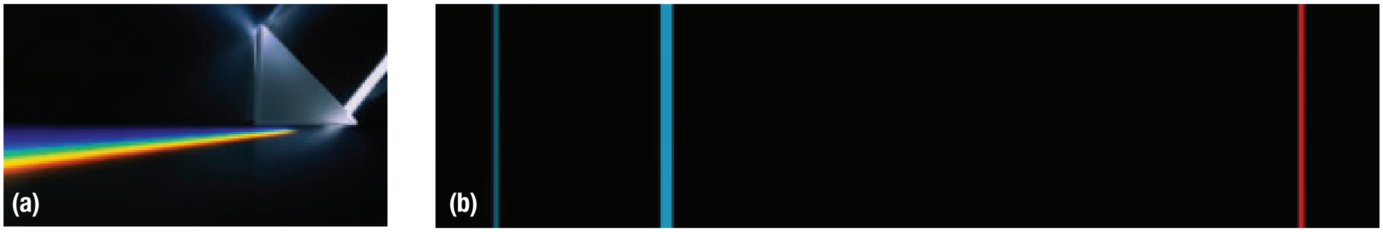

Figure 10 (a) A prism separates white light into a rainbow of colours. (b) Lines of only certain colours of light are emitted by a hydrogen atom. This observation led Bohr to propose a new theory of the atom.

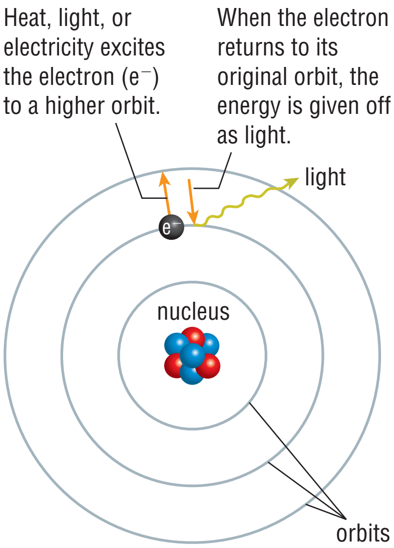

Figure 11 The Bohr–Rutherford model of the atom

In 1913, Bohr used this evidence to propose the following theory:

- Electrons orbit the nucleus of the atom much like the planets orbit the Sun.
- Each electron in an orbit has a definite amount of energy.
- The farther the electron is from the nucleus, the greater its energy.
- Electrons cannot be between orbits, but they can jump to and from different orbits (Figure 11). They release energy as light when they jump from higher to lower orbits, as shown in Figure 11. This energy is the light Bohr observed in his experiments.
- Each orbit can hold a certain maximum number of electrons. The maximum number of electrons in the first, second, and third orbits is 2, 8, and 8, respectively.

This model of the atom (shown in Figure 11) is known as the Bohr–Rutherford model because it is the product of the ideas of these two scientists. This model is useful for explaining the properties of the first 20 elements. However, it does not work as well for explaining the properties of the remaining elements on the periodic table.

TRY THIS LINES OF LIGHT

SKILLS: Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK 3.B.6.

In this activity, you will use a device called a spectroscope to analyze the light emitted by two different sources of light. Niels Bohr used evidence from an experiment similar to this one to develop his model of the atom.

Equipment and Materials: fluorescent light source; spectroscope; power supply; hydrogen gas discharge tube; other gas discharge tubes

1. Use the spectroscope to observe the light emitted by the fluorescent lights in the classroom.
2. Your teacher will insert a hydrogen discharge tube into the power supply. Use the spectroscope to observe the light emitted by hydrogen.
3. Use the spectroscope to observe the light emitted by other elements.

A. Compare the appearance of fluorescent light and light from elements as seen through a spectroscope. T/I

B. Why are the lines of light emitted by an element sometimes described as being a "fingerprint" of the element? T/I

The Bohr–Rutherford model completely explained the observations of the light emitted by a hydrogen atom. It is a useful model because of its simplicity. The Bohr–Rutherford model of a central nucleus and orbiting electrons at different electron orbits serves well in explaining and predicting many physical and chemical properties of matter.

IN SUMMARY

- A scientific theory is an expression of our best understandings of a phenomenon, always based on scientific evidence or reasoning.
- John Dalton proposed that matter is made of tiny, indivisible particles called atoms.
- J. J. Thomson proposed that the atom contains negatively charged electrons. If the atom is neutral, the rest of the atom must be a positively charged sphere. The electrons are evenly distributed in the atom, like the raisins in plum pudding.
- Ernest Rutherford's gold foil experiment led him to propose that atoms are mostly empty space. A positively charged centre is surrounded by negatively charged electrons.
- Niels Bohr studied light produced by hydrogen atoms and proposed that electrons occupy fixed orbits around the nucleus.
- The Bohr–Rutherford model of the atom consists of positively charged protons and neutral neutrons in the nucleus of an atom. Negatively charged electrons orbit the nucleus.

CHECK YOUR LEARNING

1. Dalton theorized that matter is made of tiny, indivisible particles called atoms. In what way did the theories of each of these scientists support or differ from Dalton's theory? K/U
   (a) J. J. Thomson
   (b) Ernest Rutherford
   (c) James Chadwick
2. In his experiments, J. J. Thomson discovered a tiny stream of particles. K/U
   (a) Why did he conclude that these particles were negatively charged?
   (b) What were these particles eventually called?
   (c) According to Thomson, where are these particles located in the atom?
   (d) Why did Thomson conclude that atoms also contain a positive charge?
   (e) According to Thomson, where are the positive charges located in the atom?
3. If a neutral atom has three electrons, how many protons does it have? K/U
4. In what ways is Bohr's model of the atom similar to and different from Thomson's model? K/U
5. Rutherford's experiment consisted of beaming positively charged particles at thin gold foil. K/U
   (a) What did he expect to happen to the particles?
   (b) Why did the results surprise him?
   (c) From his results, which particles were proposed as part of an atom?
   (d) According to Rutherford, where in an atom are these particles located?
6. Is it reasonable to expect that these models will change again in time? Explain. K/U
7. Copy and complete Table 2 in your notebook. K/U

Table 2

Scientist	Date	Discovery/idea	Model (diagram)
Democritus			
Aristotle			
Dalton			
Thomson			
Rutherford			
Chadwick			
Bohr			