Chapter 9

Understanding the Atom

THE BIG IDEA **What are atoms, and what are they made of?**

Inquiry All This to Study Tiny Particles?

This huge machine is called the Large Hadron Collider (LHC). It's like a circular racetrack for particles and is about 27 km long. The LHC accelerates particle beams to high speeds and then smashes them into each other. The longer the tunnel, the faster the beams move and the harder they smash together. Scientists study the tiny particles produced in the crash.

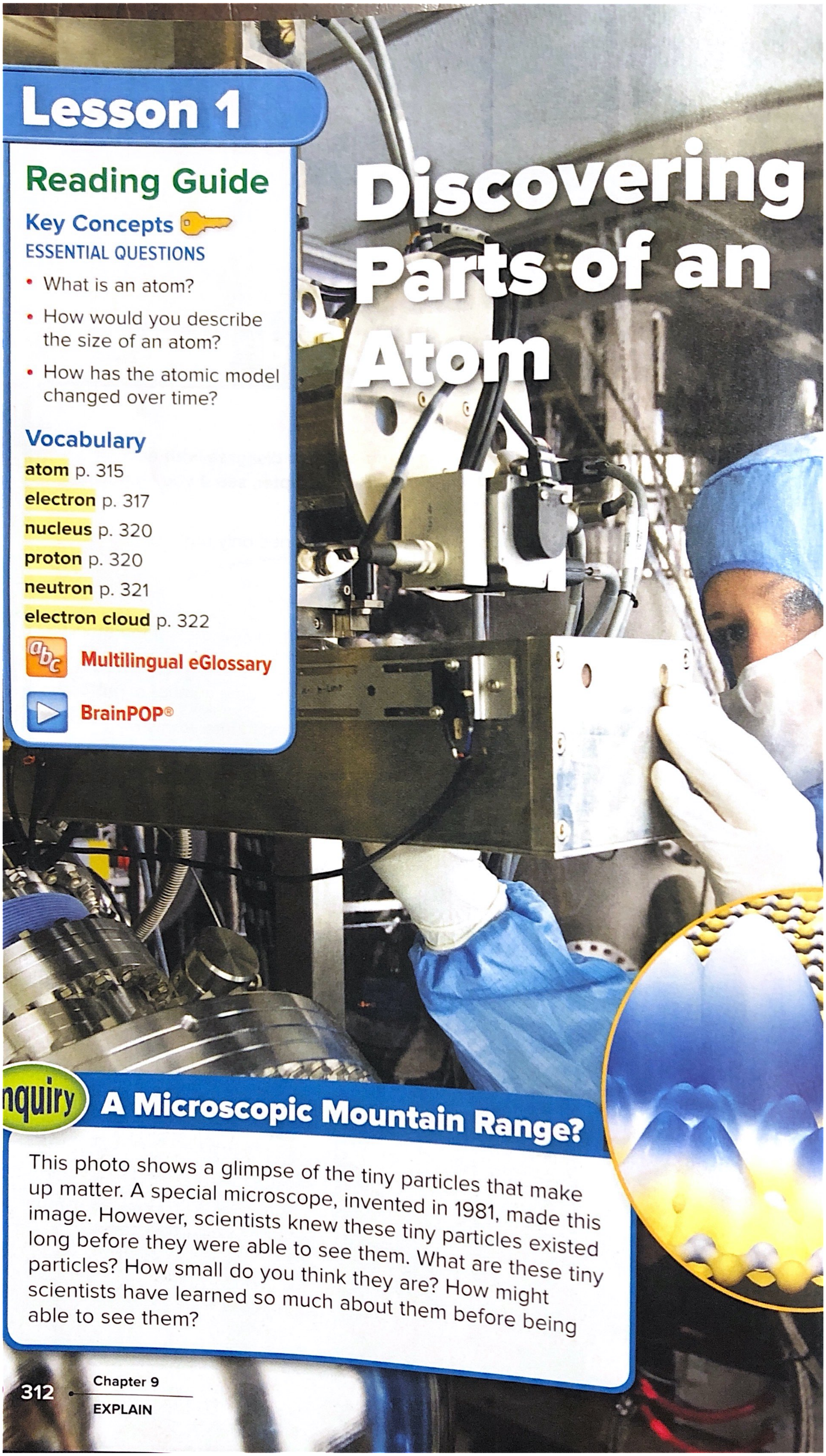
- How might scientists have studied matter before colliders were invented?
- What do you think are the smallest parts of matter?
- What are atoms, and what are they made of?

Get Ready to Read

What do you think?

Before you read, decide if you agree or disagree with each of these statements. As you read this chapter, see if you change your mind about any of the statements.

1. The earliest model of an atom contained only protons and electrons.
2. Air fills most of an atom.
3. In the present-day model of the atom, the nucleus of the atom is at the center of an electron cloud.
4. All atoms of the same element have the same number of protons.
5. Atoms of one element cannot be changed into atoms of another element.
6. Ions form when atoms lose or gain electrons.



Lesson 1

Discovering Parts of an Atom

Reading Guide

Key Concepts

ESSENTIAL QUESTIONS

- What is an atom?
- How would you describe the size of an atom?
- How has the atomic model changed over time?

Vocabulary

atom p. 315
electron p. 317
nucleus p. 320
proton p. 320
neutron p. 321
electron cloud p. 322

Multilingual eGlossary

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Inquiry A Microscopic Mountain Range?

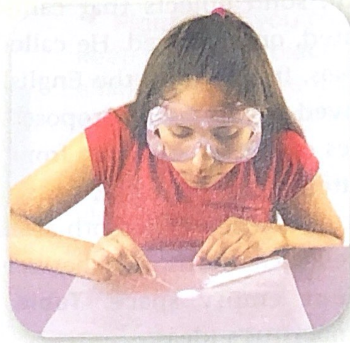
This photo shows a glimpse of the tiny particles that make up matter. A special microscope, invented in 1981, made this image. However, scientists knew these tiny particles existed long before they were able to see them. What are these tiny particles? How small do you think they are? How might scientists have learned so much about them before being able to see them?

Launch Lab

10 minutes

What's in there?

When you look at a sandy beach from far away, it looks like a solid surface. You can't see the individual grains of sand. What would you see if you zoomed in on one grain of sand?



1. Read and complete a lab safety form.
2. Have your partner hold a **test tube** of **a substance,** filled to a height of 2–3 cm.
3. Observe the test tube from a distance of at least 2 m. Write a description of what you see in your Science Journal.
4. Pour about 1 cm of the substance onto a piece of **waxed paper.** Record your observations.
5. Use a **toothpick** to separate out one particle of the substance. Suppose you could zoom in. What do you think you would see? Record your ideas in your Science Journal.

Think About This

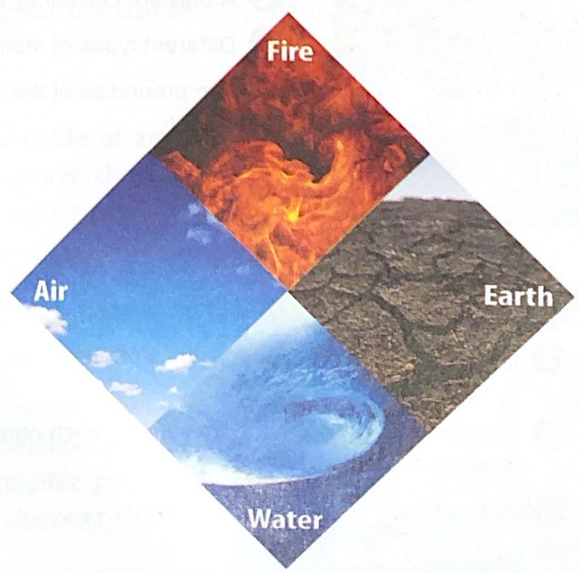
1. Do you think one particle of the substance is made of smaller particles? Why or why not?
2. **Key Concept** Do you think you could use a microscope to see what the particles are made of? Why or why not?

Early Ideas About Matter

Look at your hands. What are they made of? You might answer that your hands are made of things such as skin, bone, muscle, and blood. You might recall that each of these is made of even smaller structures called cells. Are cells made of even smaller parts? Imagine dividing something into smaller and smaller parts. What would you end up with?

Greek philosophers discussed and debated questions such as these more than 2,000 years ago. At the time, many thought that all matter is made of only four elements–fire, water, air, and earth, as shown in **Figure 1**. However, they weren't able to test their ideas because scientific tools and methods, such as experimentation, did not exist yet. The ideas proposed by the most influential philosophers usually were accepted over the ideas of less influential philosophers. One philosopher, Democritus (460-370 B.C.), challenged the popular idea of matter.

Figure 1 Most Greek philosophers believed that all matter is made of only four elements—fire, water, air, and earth.



(t)Hutchings Photography/Digital Light Source, (l to r, t to b)CL Clarke/Corbis, (2)©Arthur Tilley/Creatas/PunchStock, (3)©Marshall Myrman/Corbis, (4)DAJ/Getty Images

Democritus

Democritus believed that matter is made of small, solid objects that cannot be divided, created, or destroyed. He called these objects *atomos*, from which the English word *atom* is derived. Democritus proposed that different types of matter are made from different types of atoms. For example, he said that smooth matter is made of smooth atoms. He also proposed that nothing is between these atoms except empty space. **Table 1** summarizes Democritus's ideas.

Although Democritus had no way to test his ideas, many of his ideas are similar to the way scientists describe the atom today. Because Democritus's ideas did not conform to the popular opinion and because they could not be tested scientifically, they were open for debate. One philosopher who challenged Democritus's ideas was Aristotle.

Reading Check According to Democritus, what might atoms of gold look like?

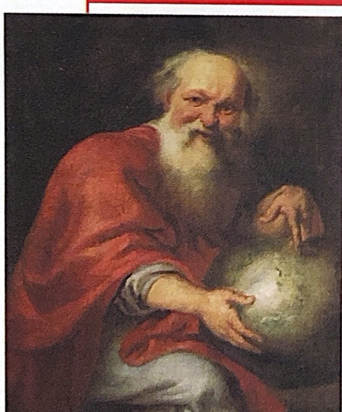
Aristotle

Aristotle (384–322 B.C.) did not believe that empty space exists. Instead, he favored the more popular idea–that all matter is made of fire, water, air, and earth. Because Aristotle was so influential, his ideas were accepted. Democritus's ideas about atoms were not studied again for more than 2,000 years.

Dalton's Atomic Model

In the late 1700s, English schoolteacher and scientist John Dalton (1766–1844) revisited the idea of atoms. Since Democritus's time, advancements had been made in technology and scientific methods. Dalton made careful observations and measurements of chemical reactions. He combined data from his own scientific research with data from the research of other scientists to propose the atomic theory. **Table 1** lists ways that Dalton's atomic theory supported some of the ideas of Democritus.

Table 1 Similarities Between Democritus's and Dalton's Ideas

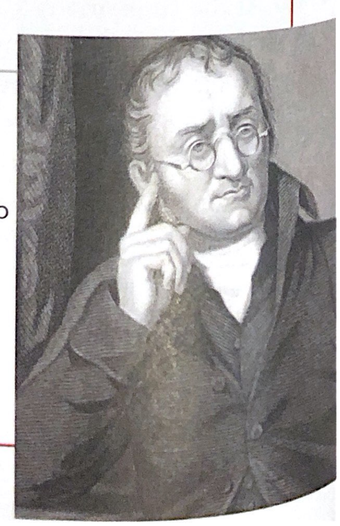


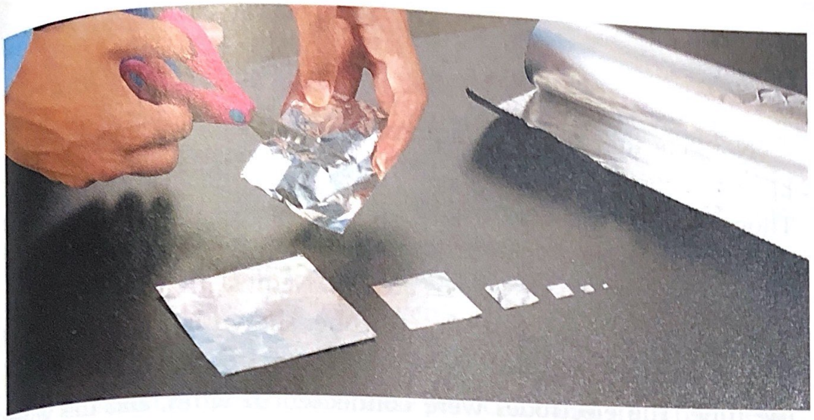
Democritus

1. Atoms are small solid objects that cannot be divided, created, or destroyed.
2. Atoms are constantly moving in empty space.
3. Different types of matter are made of different types of atoms.
4. The properties of the atoms determine the properties of matter.

John Dalton

1. All matter is made of atoms that cannot be divided, created, or destroyed.
2. During a chemical reaction, atoms of one element cannot be converted into atoms of another element.
3. Atoms of one element are identical to each other but different from atoms of another element.
4. Atoms combine in specific ratios.





◀ **Figure 2** If you could keep dividing a piece of aluminum, you eventually would have the smallest possible piece of aluminum—an aluminum atom.

The Atom

Today, scientists agree that matter is made of atoms with empty space between and within them. What is an atom? Imagine dividing the piece of aluminum shown in **Figure 2** into smaller and smaller pieces. At first you would be able to cut the pieces with scissors. But eventually you would have a piece that is too small to see–much smaller than the smallest piece you could cut with scissors. This small piece is an aluminum atom. An aluminum atom cannot be divided into smaller aluminum pieces. *An* **atom** *is the smallest piece of an element that still represents that element.*

Key Concept Check What is a copper atom?

The Size of Atoms

Just how small is an atom? Atoms of different elements are different sizes, but all are very, very small. You cannot see atoms with just your eyes or even with most microscopes. Atoms are so small that about 7.5 trillion carbon atoms could fit into the period at the end of this sentence.

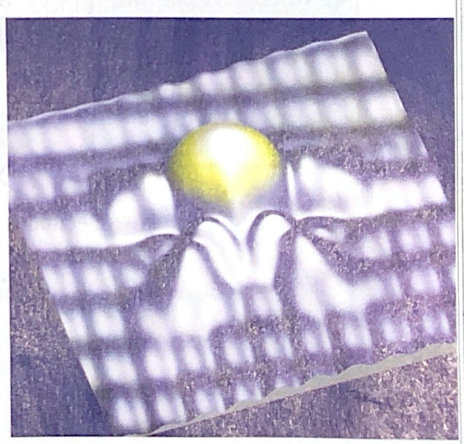
Key Concept Check How would you describe the size of an atom?

Seeing Atoms

Scientific experiments verified that matter is made of atoms long before scientists were able to see atoms. However, the 1981 invention of a high-powered microscope, called a scanning tunneling microscope (STM), enabled scientists to see individual atoms for the first time. **Figure 3** shows an STM image. An STM uses a tiny, metal tip to trace the surface of a piece of matter. The result is an image of atoms on the surface.

Even today, scientists still cannot see inside an atom. However, scientists have learned that atoms are not the smallest particles of matter. In fact, atoms are made of much smaller particles. What are these particles, and how did scientists discover them if they could not see them?

Figure 3 A scanning tunneling microscope created this image. The yellow sphere is a manganese atom on the surface of gallium arsenide. ▼



Thomson—Discovering Electrons

Not long after Dalton's findings, another English scientist, named J.J. Thomson (1856-1940), made some important discoveries. Thomson and other scientists of that time worked with cathode ray tubes. Cube-shaped computer monitors and television screens are cathode ray tubes. Flat screens are not. Neon signs are also cathode ray tubes. Thomson's cathode ray tube, shown in **Figure 4**, was a glass tube with pieces of metal, called electrodes, attached inside the tube. The electrodes were connected to wires, and the wires were connected to a battery. Thomson discovered that if most of the air was removed from the tube and electricity was passed through the wires, greenish-colored rays traveled from one electrode to the other end of the tube. What were these rays made of?

Negative Particles

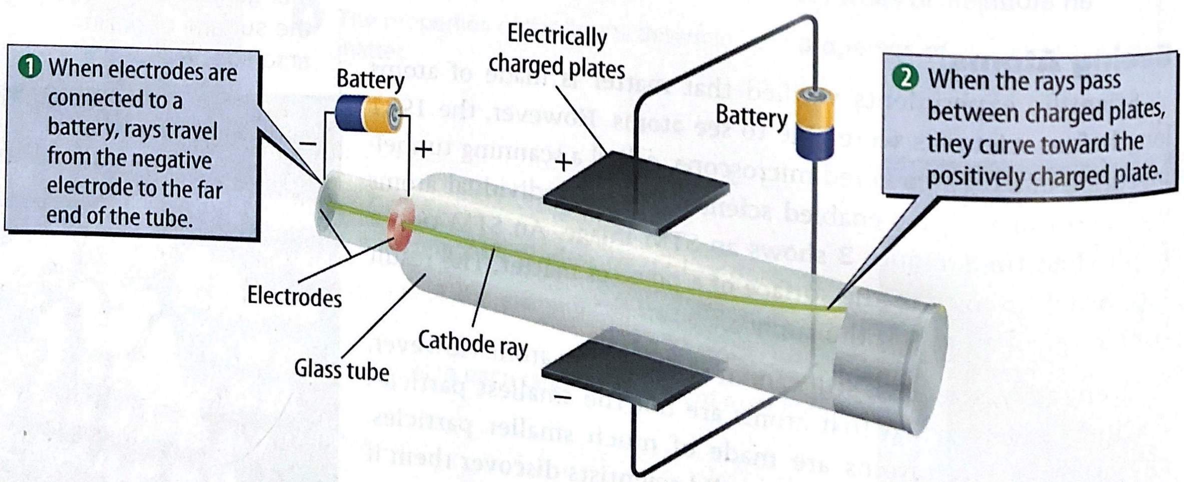
Scientists called these rays cathode rays. Thomson wanted to know if these rays had an electric charge. To find out, he placed two plates on opposite sides of the tube. One plate was positively charged, and the other plate was negatively charged, as shown in **Figure 4**. Thomson discovered that these rays bent toward the positively charged plate and away from the negatively charged plate. Recall that opposite charges attract each other, and like charges repel each other. Thomson concluded that cathode rays are negatively charged.

Reading Check If the rays were positively charged, what would Thomson have observed as they passed between the plates?

Figure 4 As the cathode rays passed between the plates, they were bent toward the positive plate. Because opposite charges attract, the rays must be negatively charged.

Thomson's Cathode Ray Tube Experiment

Animation



Parts of Atoms

Through more experiments, Thomson learned that these rays were made of particles that had mass. The mass of one of these particles was much smaller than the mass of the smallest atoms. This was surprising information to Thomson. Until then, scientists understood that the smallest particle of matter is an atom. But these rays were made of particles that were even smaller than atoms.

Where did these small, negatively charged particles come from? Thomson proposed that these particles came from the metal atoms in the electrode. Thomson discovered that identical rays were produced regardless of the kind of metal used to make the electrode. Putting these clues together, Thomson concluded that cathode rays were made of small, negatively charged particles. He called these particles electrons. *An* **electron** *is a particle with one negative charge (1−).* Because atoms are neutral, or not electrically charged, Thomson proposed that atoms also must contain a positive charge that balances the negatively charged electrons.

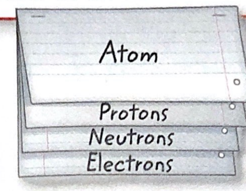
Thomson's Atomic Model

Thomson used this information to propose a new model of the atom. Instead of a solid, neutral sphere that was the same throughout, Thomson's model of the atom contained both positive and negative charges. He proposed that an atom was a sphere with a positive charge evenly spread throughout. Negatively charged electrons were mixed through the positive charge, similar to the way chocolate chips are mixed in cookie dough. **Figure 5** shows this model.

Reading Check How did Thomson's atomic model differ from Dalton's atomic model?

FOLDABLES®

Use two sheets of paper to make a layered book. Label it as shown. Use it to organize your notes and diagrams on the parts of an atom.



WORD ORIGIN

electron
from Greek *elektron,* means "amber," from *electricity,* the physical force so called because it first was generated by rubbing amber. Amber is a fossilized substance produced by trees.

Thomson's Atomic Model

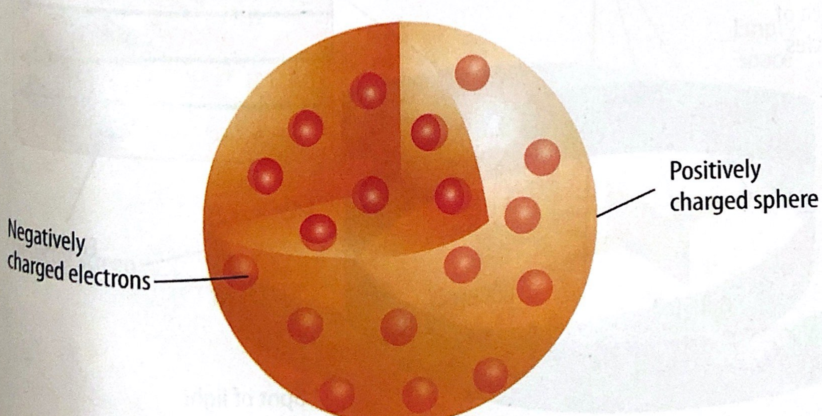


Figure 5 Thomson's model of the atom contained a positively charged sphere with negatively charged electrons within it.

Rutherford—Discovering the Nucleus

The discovery of electrons stunned scientists. Ernest Rutherford (1871–1937) was a student of Thomson's who eventually had students of his own. Rutherford's students set up experiments to test Thomson's atomic model and to learn more about what atoms contain. They discovered another surprise.

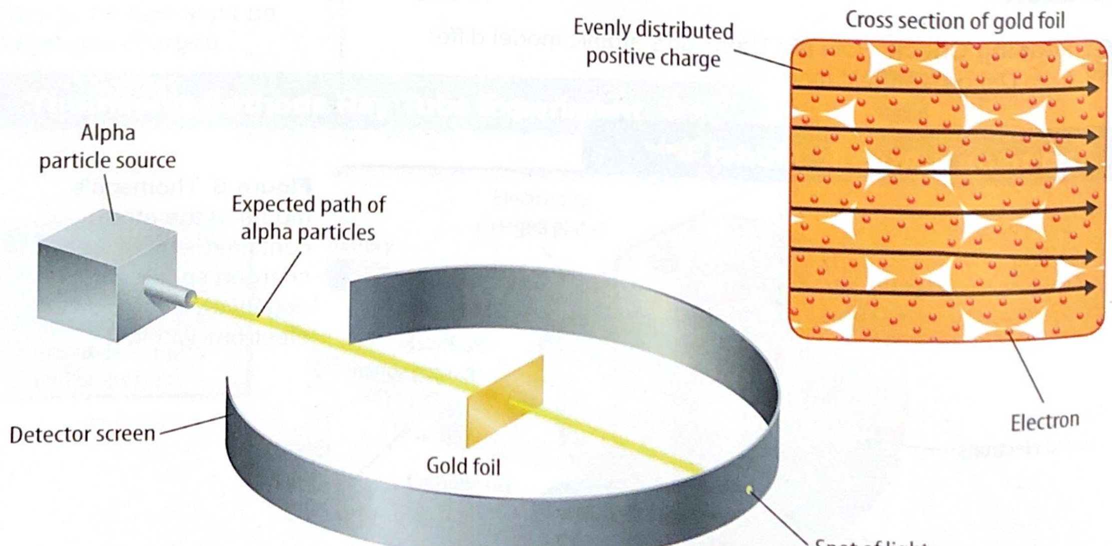
Rutherford's Predicted Result

Imagine throwing a baseball into a pile of table tennis balls. The baseball likely would knock the table tennis balls out of the way and continue moving in a relatively straight line. This is similar to what Rutherford's students expected to see when they shot alpha particles into atoms. Alpha particles are dense and positively charged. Because they are so dense, only another dense particle could deflect the path of an alpha particle. According to Thomson's model, the positive charge of the atom was too spread out and not dense enough to change the path of an alpha particle. Electrons wouldn't affect the path of an alpha particle because electrons didn't have enough mass. The result that Rutherford's students expected is shown in **Figure 6.**

Reading Check Explain why Rutherford's students did not think an atom could change the path of an alpha particle.

Figure 6 The Thomson model of the atom did not contain a charge that was dense enough to change the path of an alpha particle. Rutherford expected the positive alpha particles to travel straight through the foil with only small deflections.

Rutherford's Predicted Result



The Gold Foil Experiment

Rutherford's students went to work. They placed a source of alpha particles near a very thin piece of gold foil. Recall that all matter is made of atoms. Therefore, the gold foil was made of gold atoms. A screen surrounded the gold foil. When an alpha particle struck the screen, it created a spot of light. Rutherford's students could determine the path of the alpha particles by observing the spots of light on the screen.

The Surprising Result

Figure 7 shows what the students observed. Most of the particles did indeed travel through the foil in a straight path. However, a few particles struck the foil and bounced off to the side. And one particle in 10,000 bounced straight back! Rutherford later described this surprising result, saying it was almost as incredible as if you had fired a 38-cm shell at a piece of tissue paper and it came back and hit you. The alpha particles must have struck something dense and positively charged inside the nucleus. Thomson's model had to be refined.

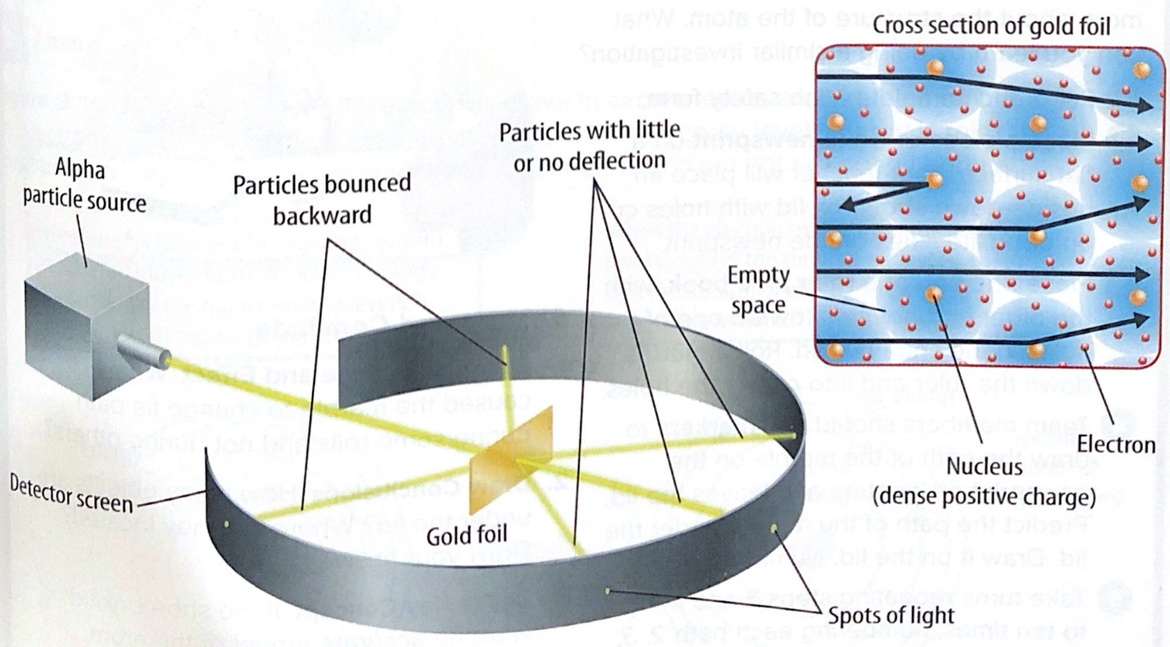
Key Concept Check Given the results of the gold foil experiment, how do you think an actual atom differs from Thomson's model?

Animation

Figure 7 Some alpha particles traveled in a straight path, as expected. But some changed direction, and some bounced straight back.

Visual Check What do the dots on the screen indicate?

The Surprising Result



Rutherford's Atomic Model

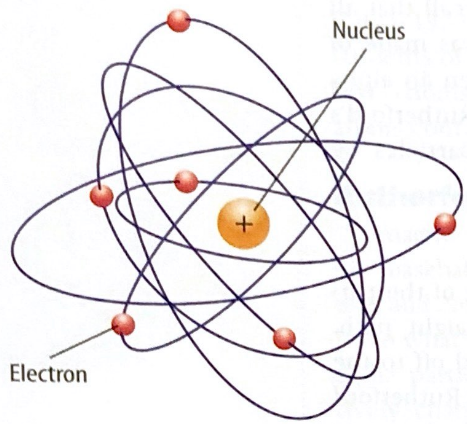


Figure 8 Rutherford's model contains a small, dense, positive nucleus. Tiny, negatively charged electrons travel in empty space around the nucleus.

Rutherford's Atomic Model

Because most alpha particles traveled through the foil in a straight path, Rutherford concluded that atoms are made mostly of empty space. The alpha particles that bounced backward must have hit a dense, positive mass. Rutherford concluded that *most of an atom's mass and positive charge is concentrated in a small area in the center of the atom called the* **nucleus.** **Figure 8** shows Rutherford's atomic model. Additional research showed that the positive charge in the nucleus was made of positively charged particles called protons. *A* **proton** *is an atomic particle that has one positive charge (1+).* Negatively charged electrons move in the empty space surrounding the nucleus.

Reading Check How did Rutherford explain the observation that some of the alpha particles bounced directly backward?

MiniLab

20–30 minutes

How can you gather information about what you can't see?

Rutherford did his gold foil experiment to learn more about the structure of the atom. What can you learn by doing a similar investigation?

1. Read and complete a lab safety form.
2. Place a piece of white **newsprint** on a flat surface. Your teacher will place an upside-down **shoe box lid** with holes cut on opposite sides on the newsprint.
3. Place one end of a **ruler** on a **book,** with the other end pointing toward one of the holes in the shoe box lid. Roll a **marble** down the ruler and into one of the holes.
4. Team members should use **markers** to draw the path of the marble on the newsprint as it enters and leaves the lid. Predict the path of the marble under the lid. Draw it on the lid. Number the path *1.*
5. Take turns repeating steps 3 and 4 eight to ten times, numbering each path *2, 3, 4,* etc. Move the ruler and aim it in a slightly different direction each time.

Analyze and Conclude

1. **Recognize Cause and Effect** What caused the marble to change its path during some rolls and not during others?
2. **Draw Conclusions** How many objects are under the lid? Where are they located? Draw your answer.
3. **Key Concept** If the shoe box lid were an accurate model of the atom, what hypothesis would you make about the atom's structure?

Discovering Neutrons

The modern model of the atom was beginning to take shape. Rutherford's colleague, James Chadwick (1891–1974), also researched atoms and discovered that, in addition to protons, the nucleus also contained neutrons. *A* **neutron** *is a neutral particle that exists in the nucleus of an atom.*

Bohr's Atomic Model

Rutherford's model explained much of his students' experimental evidence. However, there were several observations that the model could not explain. For example, scientists noticed that if certain elements were heated in a flame, they gave off specific colors of light. Each color of light had a specific amount of energy. Where did this light come from? Niels Bohr (1885–1962), another student of Rutherford's, proposed an answer. Bohr studied hydrogen atoms because they contain only one electron. He experimented with adding electric energy to hydrogen and studying the energy that was released. His experiments led to a revised atomic model.

Electrons in the Bohr Model

Bohr's model is shown in **Figure 9.** Bohr proposed that electrons move in circular orbits, or energy levels, around the nucleus. Electrons in an energy level have a specific amount of energy. Electrons closer to the nucleus have less energy than electrons farther away from the nucleus. When energy is added to an atom, electrons gain energy and move from a lower energy level to a higher energy level. When the electrons return to the lower energy level, they release a specific amount of energy as light. This is the light that is seen when elements are heated.

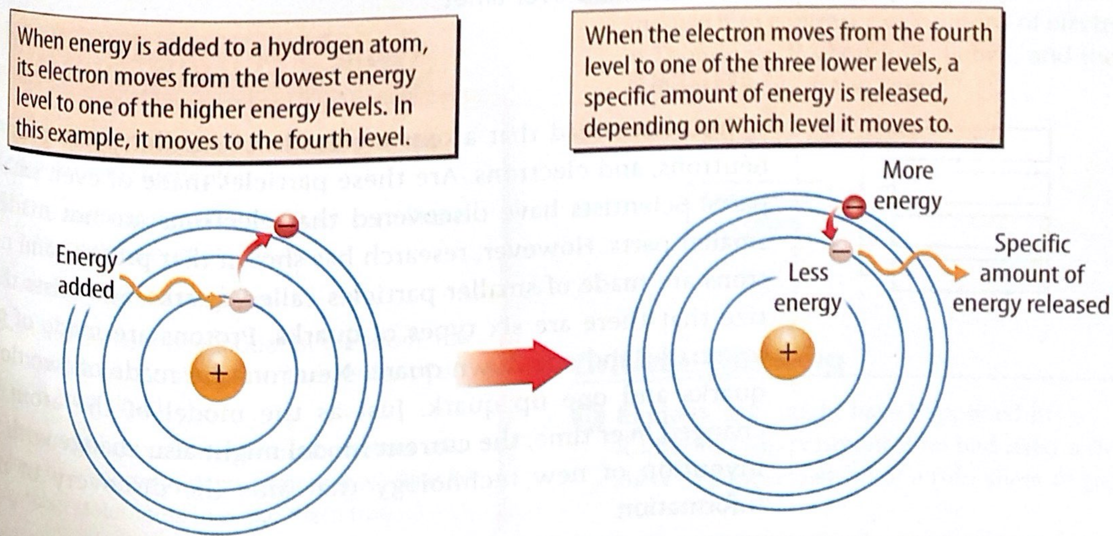
Limitations of the Bohr Model

Bohr reasoned that if his model were accurate for atoms with one electron, it would be accurate for atoms with more than one electron. However, this was not the case. More research showed that, although electrons have specific amounts of energy, energy levels are not arranged in circular orbits. How do electrons move in an atom?

Key Concept Check How did Bohr's atomic model differ from Rutherford's?

Animation

Figure 9 In Bohr's atomic model, electrons move in circular orbits around the atom. When an electron moves from a higher energy level to a lower energy level, energy is released—sometimes as light. Further research showed that electrons are not arranged in orbits.



The Modern Atomic Model

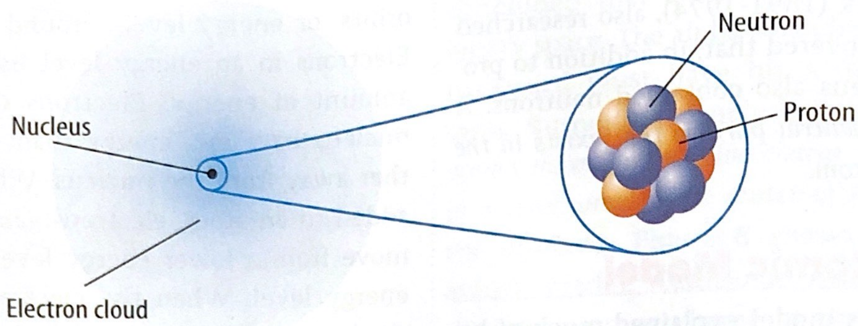


Figure 10 In this model, electrons are more likely to be found closer to the nucleus than farther away.

Visual Check Why do you think this model of the atom doesn't show the electrons?

The Modern Atomic Model

In the modern atomic model, electrons form an electron cloud. *An* **electron cloud** *is an area around an atomic nucleus where an electron is most likely to be located.* Imagine taking a time-lapse photograph of bees around a hive. You might see a blurry cloud. The cloud might be denser near the hive than farther away because the bees spend more time near the hive.

In a similar way, electrons constantly move around the nucleus. It is impossible to know both the speed and exact location of an electron at a given moment in time. Instead, scientists only can predict the likelihood that an electron is in a particular location. The electron cloud shown in **Figure 10** is mostly empty space but represents the likelihood of finding an electron in a given area. The darker areas represent areas where electrons are more likely to be.

Key Concept Check How has the model of the atom changed over time?

Quarks

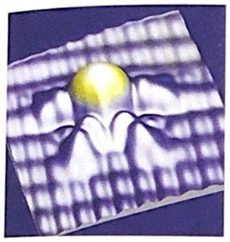
You have read that atoms are made of smaller parts–protons, neutrons, and electrons. Are these particles made of even smaller parts? Scientists have discovered that electrons are not made of smaller parts. However, research has shown that protons and neutrons are made of smaller particles called quarks. Scientists theorize that there are six types of quarks. Protons are made of two up quarks and one down quark. Neutrons are made of two down quarks and one up quark. Just as the model of the atom has changed over time, the current model might also change with the invention of new technology that aids the discovery of new information.

Lesson 1 Review

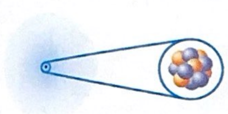
Online Quiz

Visual Summary

If you were to divide an element into smaller and smaller pieces, the smallest piece would be an atom.



Atoms are so small that they can be seen only by using very powerful microscopes.



Scientists now know that atoms contain a dense, positive nucleus surrounded by an electron cloud.

FOLDABLES®

Use your lesson Foldable to review the lesson. Save your Foldable for the project at the end of the chapter.

What do you think NOW?

You first read the statements below at the beginning of the chapter.

1. The earliest model of an atom contained only protons and electrons.
2. Air fills most of an atom.
3. In the present-day model of the atom, the nucleus of the atom is at the center of an electron cloud.

Did you change your mind about whether you agree or disagree with the statements? Rewrite any false statements to make them true.

Use Vocabulary

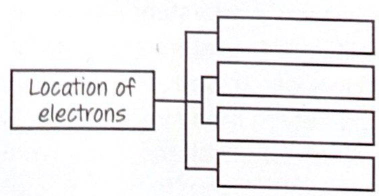
1. The smallest piece of the element gold is a gold ________.
2. **Write** a sentence that describes the nucleus of an atom.
3. **Define** *electron cloud* in your own words.

Understand Key Concepts

4. What is an atom mostly made of?
   - A. air
   - B. empty space
   - C. neutrons
   - D. protons
5. Why have scientists only recently been able to see atoms?
   - A. Atoms are too small to see with ordinary microscopes.
   - B. Early experiments disproved the idea of atoms.
   - C. Scientists didn't know atoms existed.
   - D. Scientists were not looking for atoms.
6. **Draw** Thomson's model of the atom, and label the parts of the drawing.
7. **Explain** how Rutherford's students knew that Thomson's model of the atom needed to change.

Interpret Graphics

8. **Contrast** Copy the graphic organizer below and use it to contrast the locations of electrons in Thomson's, Rutherford's, Bohr's, and the modern models of the atom.



Critical Thinking

9. **Explain** what might have happened in Rutherford's experiment if he had used a thin sheet of copper instead of a thin sheet of gold.

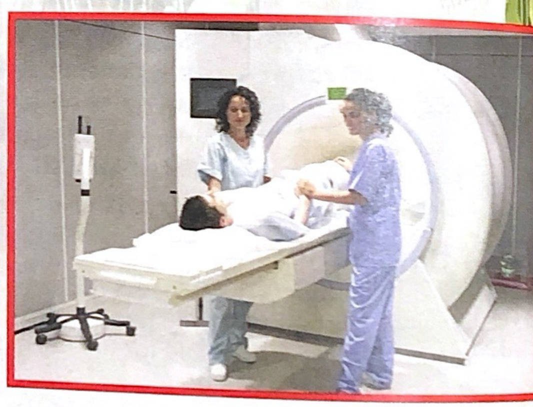
SCIENCE & SOCIETY

Subatomic Particles

Much has changed since Democritus and Aristotle studied atoms.

When Democritus and Aristotle developed ideas about matter, they probably never imagined the kinds of research being performed today! From the discovery of electrons, protons, and neutrons to the exploration of quarks and other particles, the atomic model continues to change.

You've learned about quarks, which make up protons and neutrons. But quarks are not the only kind of particles! In fact, some scientists call the collection of particles that have been discovered the particle zoo, because different types of particles have unique characteristics, just like the different kinds of animals in a zoo.



▲ **MRIs are just one way in which particle physics technology is applied.**

Javier Larrea/Pixtal/age fotostock

In addition to quarks, scientists have discovered a group of particles called leptons, which includes the electron. Gluons and photons are examples of bosons—particles that carry forces. Some particles, such as the Higgs Boson, have been predicted to exist but have yet to be observed in experiments.

Identifying and understanding the particles that make up matter is important work. However, it might be difficult to understand why time and money are spent to learn more about tiny subatomic particles. How can this research possibly affect everyday life? Research on subatomic particles has changed society in many ways. For example, magnetic resonance imaging (MRI), a tool used to diagnose medical problems, uses technology that was developed to study subatomic particles. Cancer treatments using protons, neutrons, and X-rays are all based on particle physics technology. And, in the 1990s, the need for particle physicists to share information with one another led to the development of the World Wide Web!

It's Your Turn

RESEARCH AND REPORT Learn more about research on subatomic particles. Find out about one recent discovery. Make a poster to share what you learn with your classmates.