1 FOCUS

Objectives

4.1.1 **Describe** ancient Greek models of matter.

4.1.2 **List** the main points of Dalton's atomic theory and **describe** his evidence for the existence of atoms.

4.1.3 **Explain** how Thomson and Rutherford used data from experiments to produce their atomic models.

Reading Focus

Build Vocabulary L2

Latin Plural Forms Explain that the word *nucleus* comes from a Latin word meaning "kernel." Explain that a kernel is a grain or seed. Ask students to discuss how the definition of the term *nucleus* relates to its Latin origin. *(Like the kernel of a nut, the nucleus is a small, massive center of the atom.)* Remind students that the plural of the word *nucleus* is *nuclei.*

Reading Strategy L2

a. Dalton **b.** Indivisible, solid spheres **c.** Thomson **d.** Negative charges evenly scattered through a positively charged mass of matter (plum pudding model) **e.** Deflection of alpha particles passing through gold foil

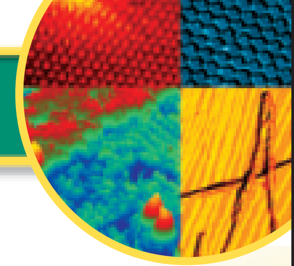
2 INSTRUCT

Ancient Greek Models of Atoms

Use Visuals L1

Figure 1 Have students examine the diagram in Figure 1 that lists the qualities of each of Aristotle's four elements. Ask, **What qualities did Aristotle use to describe air?** *(Air is a combination of hot and wet.)* **What element was a combination of dry and cold?** *(Earth)* **Is "wet and cold" an accurate description of water?** *(Wet describes water, but water isn't always cold.)*
Visual

4.1 Studying Atoms



Reading Focus

Key Concepts

- What was Dalton's theory of the structure of matter?
- What contributions did Thomson and Rutherford make to the development of atomic theory?

Vocabulary

- nucleus

Reading Strategy

Summarizing Copy the table. As you read, complete the table about atomic models.

Scientist	Evidence	Model
a. ___?___	Ratio of masses in compounds	b. ___?___
c. ___?___	Deflected beam	d. ___?___
Rutherford	e. ___?___	Positive, dense nucleus

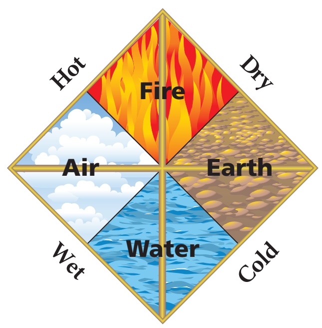


Figure 1 Aristotle thought that all substances were built up from only four elements—earth, air, fire, and water. These elements were a combination of four qualities—hot, cold, dry, and wet. Fire was a combination of hot and dry. Water was a combination of cold and wet.

Studying the structure of atoms is a little like studying wind. Because you cannot see air, you must use indirect evidence to tell the direction of the wind. You might notice which way fallen leaves move as they are pushed by the wind, and infer that the leaves and wind are moving in the same direction.

Atoms pose a similar problem because they are extremely small. Even with a microscope, scientists cannot see the structure of an atom. In this chapter, you will find out how John Dalton, J. J. Thomson, Ernest Rutherford, Niels Bohr, and other scientists used evidence from experiments to develop models of atoms.

Ancient Greek Models of Atoms

If you cut a piece of aluminum foil in half, you have two smaller pieces of the same shiny, flexible substance. You could cut the pieces again and again. Can you keep dividing the aluminum into smaller pieces? Greek philosophers debated a similar question about 2500 years ago.

The philosopher Democritus believed that all matter consisted of extremely small particles that could not be divided. He called these particles *atoms* from the Greek word *atomos,* which means "uncut" or "indivisible." He thought there were different types of atoms with specific sets of properties. The atoms in liquids, for example, were round and smooth, but the atoms in solids were rough and prickly.

Aristotle did not think there was a limit to the number of times matter could be divided. Figure 1 shows the model Aristotle used to describe matter. For many centuries, most people accepted Aristotle's views on the structure of matter. But by the 1800s, scientists had enough data from experiments to support an atomic model of matter.

Section Resources

Print

- ***Reading and Study Workbook With Math Support,*** Section 4.1
- ***Transparencies,*** Chapter Pretest and Section 4.1

Technology

- ***Interactive Textbook,*** Section 4.1
- ***Presentation Pro CD-ROM,*** Chapter Pretest and Section 4.1
- ***Go Online,*** NSTA SciLinks, Atomic theory

Dalton's Atomic Theory

John Dalton was born in England in 1766. He was a teacher who spent his spare time doing scientific experiments. Because of his interest in predicting the weather, Dalton studied the behavior of gases in air. Based on the way gases exert pressure, Dalton correctly concluded that a gas consists of individual particles.

Evidence for Atoms Dalton gathered evidence for the existence of atoms by measuring the masses of elements that combine when compounds form. He noticed that all compounds have something in common. No matter how large or small the sample, the ratio of the masses of the elements in the compound is always the same. In other words, compounds have a fixed composition.

For example, when magnesium burns, as shown in Figure 2, it combines with oxygen. The product of this change is a white solid called magnesium oxide. A 100-gram sample of magnesium combines with 65.8 grams of oxygen. A 10-gram sample of magnesium combines with 6.58 grams of oxygen. The ratio of the mass of magnesium to the mass of oxygen is constant in magnesium oxide.

Dalton's Theory Dalton developed a theory to explain why the elements in a compound always join in the same way. **Dalton proposed the theory that all matter is made up of individual particles called atoms, which cannot be divided.** The main points of Dalton's theory are as follows.

- All elements are composed of atoms.
- All atoms of the same element have the same mass, and atoms of different elements have different masses.
- Compounds contain atoms of more than one element.
- In a particular compound, atoms of different elements always combine in the same way.

In the model of atoms based on Dalton's theory, the elements are pictured as solid spheres like those in Figure 3. Each type of atom is represented by a tiny, solid sphere with a different mass.

Recall that a theory must explain the data from many experiments. Because Dalton's atomic theory met that goal, the theory became widely accepted. Over time, scientists found that not all of Dalton's ideas about atoms were completely correct. But this did not cause later scientists to discard the atomic theory. Instead, they revised the theory to take into account new discoveries.

Reading Checkpoint ***What did Dalton notice that all compounds have in common?***

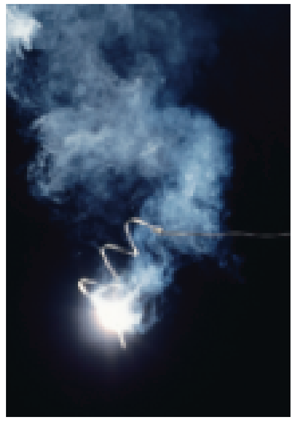


Figure 2 Magnesium reacts with oxygen to form the compound magnesium oxide. The ratio of magnesium to oxygen, by mass, in magnesium oxide is always about 3 : 2. **Observing** ***What color is magnesium oxide?***

Figure 3 Dalton made these wooden spheres to represent the atoms of different elements.

Dalton's Atomic Theory

Build Science Skills L2

Evaluating As students read Chapter 4, have them evaluate what portions of Dalton's model were accurate and what portions needed to be revised. *(Dalton did not discuss subatomic particles, which are smaller components of atoms. Atoms of the same element can have different masses.)*
Logical

Address Misconceptions L2

Many students have trouble differentiating compounds from mixtures. Remind students that Dalton noticed that the ratio of masses of elements in a compound is always the same. Compounds are distinguished from mixtures and solutions by their fixed compositions. Have students recall examples of mixtures and describe how their compositions can vary.
Verbal

Use Visuals L1

Figure 3 Have students examine the wooden spheres shown in Figure 3. Ask, **Why do you think there are holes in Dalton's wooden spheres?** *(One acceptable answer is that Dalton used the holes in the spheres to connect spheres together to construct models of compounds.)*
Visual, Logical

FYI

Not every scientist was convinced that Dalton had the physical evidence to support the assumption that elements are composed of indivisible particles called atoms. William Whewell (1784–1868) argued that particles could combine in fixed proportions in compounds, but still not be indivisible.

Customize for English Language Learners

Using Visual Aids
Have students draw simple illustrations for the models of atoms according to Dalton, Thompson, and Rutherford. Have them describe each model to a partner using the illustrations as a visual aid. Then, have each pair of students discuss the similarities and differences among the three models.

Answer to . . .

Figure 2 *White*

Reading Checkpoint *Dalton noticed that the ratio of masses of elements in a compound is always the same.*

Thomson's Model of the Atom

Quick Lab

Investigating Charged Objects

L2

Objective
After completing this activity, students will be able to
- explain that like charges repel and unlike charges attract.

Skills Focus Observing, Drawing Conclusions, Formulating Hypotheses

Prep Time 5 minutes

Class Time 10 minutes

Expected Outcome Students will discover that the two pieces of tape are attracted to one another after they are pulled apart and then brought near one another.

Analyze and Conclude
1. The two pieces of tape have opposite charges because they attract when brought close together.
2. Possible answers include clothes that cling together when removed from a dryer, and the charge that builds up when a person walks across a carpet (which is demonstrated by the spark that occurs when the person touches a doorknob).

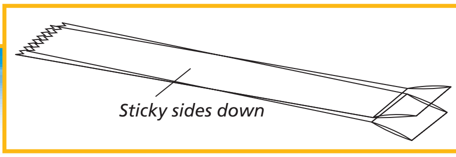
Kinesthetic, Logical

FYI

If you do not want to present all the experimental evidence for the atomic theory, be sure students understand attraction and repulsion of charged particles and Rutherford's nucleus model of the atom.

Quick Lab

Investigating Charged Objects



Materials

transparent tape, metric ruler, scissors

Procedure

1. Cut two 10-cm pieces of tape. Fold over 1 cm of tape at one end of each piece of tape to form a "handle."
2. Hold the pieces of tape by their folded ends so that they are hanging straight down. Then, without letting the pieces of tape touch, slowly bring their sticky sides close together. Record your observations.
3. Place one piece of tape on a clean surface with the sticky side facing down.
4. Place the second piece, sticky side down, directly over the first piece, as shown. Press down firmly so the pieces stick together.
5. Remove the joined strips from the table. Slowly peel the strips apart.
6. Bring the separated strips close together without touching. Record your observations.

Analyze and Conclude

1. **Drawing Conclusions** What can you conclude about the charges on the two pieces of tape after they are separated?
2. **Inferring** What other objects have you observed that became charged?

Figure 4 Amber is the hardened form of a sticky, viscous liquid that protects trees from insects and disease. If amber is rubbed with wool, it becomes charged and can attract a feather. **Predicting** ***What will happen to the feather if the amber loses its charge?***

Thomson's Model of the Atom

When some materials are rubbed, they gain the ability to attract or repel other materials. Glass and the amber in Figure 4 have this property. Based on their behavior, such materials are said to have either a positive or a negative electric charge. Objects with like charges repel, or push apart. Objects with opposite charges attract, or pull together.

Some charged particles can flow from one location to another. A flow of charged particles is called an electric current. When you turn on an appliance such as a hair dryer, a current flows from the wall socket through the appliance. Joseph John Thomson (1856–1940), better known as J. J. Thomson, used an electric current to learn more about atoms.

Thomson's Experiments Thomson used a device like the one shown in Figure 5A. At the center of the device is a sealed glass tube from which most of the air has been removed. There is a metal disk at each end of the tube. Wires connect the metal disks to a source of electric current. When the current is turned on, one disk becomes negatively charged and the other disk becomes positively charged. A glowing beam appears in the space between the disks.

Thomson hypothesized that the beam was a stream of charged particles that interacted with the air in the tube and caused the air to glow. In one experiment Thomson did to test his hypothesis, he placed a pair of charged metal plates on either side of the glass tube, as shown in Figure 5B. The plates caused the beam to deflect, or bend, from its straight path. Thomson observed that the beam was repelled by the negatively charged plate and attracted by the positively charged plate.

Facts and Figures

Charge People have known for thousands of years that amber can attract other materials after it has been rubbed with fur. Plato even refers to these attractive powers of amber in one of his dialogues.

The labels *positive* and *negative* were arbitrarily assigned by Benjamin Franklin during his studies of electric charge and electric current. (He also was the first to use the terms *battery* and *conductor*.)

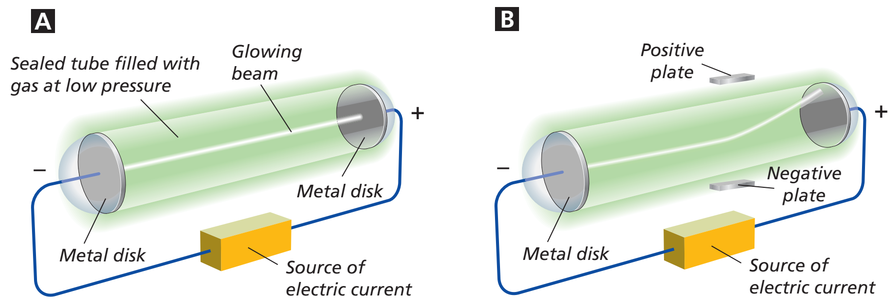


Figure 5 Thomson used a sealed tube of gas in his experiments. **A** When the current was on, the disks became charged and a glowing beam appeared in the tube. **B** The beam bent toward a positively charged plate placed outside the tube.
Inferring ***What was the charge on the particles in the beam?***

Evidence for Subatomic Particles Thomson concluded that the particles in the beam had a negative charge because they were attracted to the positive plate. He hypothesized that the particles came from inside atoms. He had two pieces of evidence to support his hypothesis. No matter what metal Thomson used for the disk, the particles produced were identical. The particles had about $\frac{1}{2000}$ the mass of a hydrogen atom, the lightest atom.

Thomson's discovery changed how scientists thought about atoms. Before his experiments, the accepted model of the atom was a solid ball of matter that could not be divided into smaller parts. **Thomson's experiments provided the first evidence that atoms are made of even smaller particles.** Thomson revised Dalton's model to account for these subatomic particles.

Thomson's Model An atom is neutral, meaning it has neither a negative nor a positive charge. How can an atom contain negative particles and still be neutral? There must be some positive charge in the atom. In Thomson's model of the atom, the negative charges were evenly scattered throughout an atom filled with a positively charged mass of matter. The model is called the "plum pudding" model, after a traditional English dessert.

You might prefer to think of Thomson's model as the "chocolate chip ice cream" model. Think of the chocolate chips in Figure 6 as the negative particles and the vanilla ice cream as the positively charged mass of matter. When the chocolate chips are spread evenly throughout the ice cream, their "negative charges" balance out the "positive charge" of the vanilla ice cream.

Reading Checkpoint ***How do objects with the same charge behave when they come close to one another?***

Figure 6 A scoop of chocolate chip ice cream can represent Thomson's model of the atom. The chips represent negatively charged particles, which are spread evenly through a mass of positively charged matter—the vanilla ice cream.

FYI

Thomson used the speed of an electron, its angle of deflection, and the strength of the current to determine the charge-to-mass ratio of an electron. Robert Milliken determined the actual mass of an electron through his oil-drop experiment.

The current that flows through an appliance is an alternating current. The current Thomson used in his experiment was a direct current. Not all movement of charge is a current. Charge can flow to or from a balloon (or between a hand and a doorknob). With a current, charge must flow continuously (at least until the circuit is interrupted). The concepts of electric charge and current are addressed in depth in Chapter 20.

Use Community Resources L2

Have a physics or chemistry professor visit the class and demonstrate Thomson's experiment using a cathode ray tube. Encourage students to think of questions to ask about how the experiment demonstrates the properties of electrons.
Interpersonal, Visual

Build Reading Literacy L1

Compare and Contrast Refer to page **226D** in **Chapter 8**, which provides the guidelines for comparing and contrasting.

Have students read about the different atomic models described in Section 4.1. Then, have students create a chart that compares and contrasts each model.
Logical

Answer to . . .

Figure 4 *The feather will no longer be attracted to the amber and will drop to the ground.*

Figure 5 *Negative*

Reading Checkpoint *Objects with the same charge repel.*

Atomic Structure 103

Rutherford's Atomic Theory

FYI

Based on Figure 7, students might conclude that Marsden used a circular screen. The screen in the diagram represents multiple positions of a smaller screen that was moved from one position to another while data was collected. Alpha particles will be identified as helium nuclei in Chapter 10.

Teacher Demo

Comparing Atomic Models L2

Purpose Students will compare different atomic models.

Materials 3 clear, round bowls; flavored gelatin mix; canned blueberries; maraschino cherries

Procedure The day before, prepare the flavored gelatin mix. Divide the liquid gelatin evenly into the three bowls. Chill slightly. Drain the blueberries and add them to one of the bowls so that they are distributed as evenly as possible in the nearly gelled mix. Return the bowls to the refrigerator. Right before class, place a cherry in the center of the third bowl. Have students discuss which atomic models are represented by each bowl of gelatin.

Expected Outcome The gelatin alone represents Dalton's atomic model. The gelatin with blueberries represents Thomson's "plum-pudding" atomic model, with the berries representing electrons. The gelatin with the cherry represents Rutherford's atomic model.
Visual, Logical

Go Online NSTA SCILINKS

Download a worksheet on atomic theory for students to complete, and find additional teacher support from NSTA SciLinks.

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For: Links on atomic theory
Visit: www.SciLinks.org
Web Code: ccn-1041

Rutherford's Atomic Theory

When you try something new, you may have expectations about the outcome. Does the outcome always meet your expectations or are you sometimes surprised? Scientists can also be surprised by the results of their experiments, but unexpected results can lead to important discoveries. This is what happened to Ernest Rutherford (1871–1937).

Rutherford's Hypothesis In 1899, Ernest Rutherford discovered that uranium emits fast-moving particles that have a positive charge. He named them alpha particles. In 1909, Rutherford asked one of his students, Ernest Marsden, to find out what happens to alpha particles when they pass through a thin sheet of gold.

Recall that in Thomson's model of the atom, the mass and positive charge are evenly spread throughout an atom. Based on this model, Rutherford hypothesized that the mass and charge at any location in the gold would be too small to change the path of an alpha particle. He predicted that most particles would travel in a straight path from their source to a screen that lit up when struck. Those few that did not pass straight through would be deflected only slightly.

The Gold Foil Experiment Marsden used the equipment shown in Figure 7. He aimed a narrow beam of alpha particles at the gold. The screen around the gold was made of a material that produced a flash of light when struck by a fast-moving alpha particle. By observing the flash, Marsden could figure out the path of an alpha particle after it passed through the gold.

Some of the locations of the flashes on the screen did not support Rutherford's prediction. More particles were deflected than he expected. About one out of every 20,000 was deflected by more than 90 degrees. Some of the alpha particles behaved as though they had struck an object and bounced straight back.

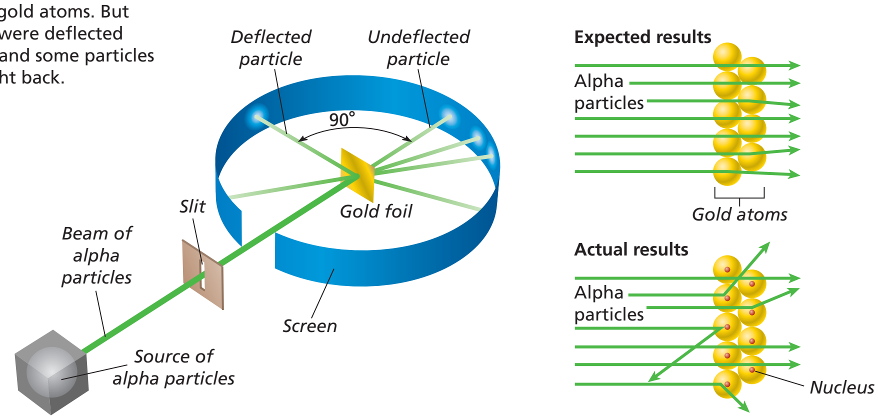

Figure 7 The path of an alpha particle can be detected by the location of a flash on a screen. Rutherford expected the paths of the positively charged alpha particles that were aimed at the thin gold foil to be affected only slightly by the gold atoms. But more particles were deflected than expected and some particles bounced straight back.

Facts and Figures

In His Own Words In a lecture Rutherford gave at Cambridge in 1936, he recalled his reaction when Geiger told him about alpha particles being scattered backward by the gold foil. Rutherford described his reaction. "It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

Discovery of the Nucleus The alpha particles whose paths were deflected must have come close to another charged object. The closer they came, the greater the deflection was. But many alpha particles passed through the gold without being deflected. From these results, Rutherford concluded that the positive charge of an atom is not evenly spread throughout the atom. It is concentrated in a very small, central area that Rutherford called the nucleus. The **nucleus** is a dense, positively charged mass located in the center of the atom. (The plural of *nucleus* is *nuclei.*)

Because Thomson's model no longer explained all the evidence, Rutherford proposed a new model. **According to Rutherford's model, all of an atom's positive charge is concentrated in its nucleus.** The alpha particles whose paths were deflected by more than 90 degrees came very close to a nucleus. The alpha particles whose paths were not bent moved through the space surrounding the nuclei without coming very close to any nucleus.

Figure 8 shows the inside of the Astrodome, a domed stadium in Houston, Texas. The roof of the stadium rises to a height of 202 feet above the center of the field. If an atom had the same volume as the stadium, its nucleus would have the volume of a marble. The total volume of an atom is about a trillion (10^{12}) times the volume of its nucleus.

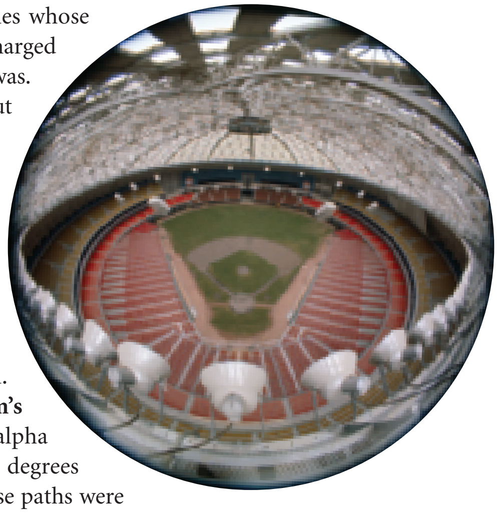

Figure 8 The Houston Astrodome occupies more than nine acres and seats 60,000 people. If the stadium were a model for an atom, a marble could represent its nucleus. **Using Analogies** ***In the model, where would the marble have to be located in the stadium to represent the nucleus?***

Section 4.1 Assessment

Reviewing Concepts

1. What theory did Dalton propose about the structure of matter?
2. What evidence did J. J. Thomson provide about the structure of an atom?
3. What did Rutherford discover about the structure of an atom?
4. What evidence did Thomson have that his glowing beam contained negative particles?
5. Why was Dalton's model of the atom changed after Thomson's experiment?

Critical Thinking

6. **Comparing and Contrasting** Explain why scientists accepted Dalton's atomic theory but not the idea of an atom proposed by the Greek philosophers.
7. **Drawing Conclusions** If you observed a beam of particles being bent toward a negatively charged plate, what might you conclude?
8. **Relating Cause and Effect** In the Rutherford experiment, why weren't all the alpha particles deflected?

Writing in Science

Writing to Persuade Imagine you live in ancient Greece. Assume all you know about matter is what you can observe with your five senses. You have heard the views of both Democritus and Aristotle about matter. Write a paragraph supporting one of their views.

Section 4.1 Assessment

1. All matter is composed of individual particles called atoms, which cannot be divided.
2. Thomson provided the first evidence that atoms are made from even smaller particles.
3. All of the positive charge of an atom is concentrated in its nucleus.
4. The beam was attracted to a positively charged plate and repelled by a negatively charged plate.
5. Dalton assumed atoms were solid, indivisible particles. Thomson had evidence that smaller particles existed inside atoms.
6. Dalton had data from experiments to support his theory, whereas the Greeks did not have data.
7. The particles have a positive charge.
8. The nucleus is small compared with the atom as a whole. Very few of the alpha particles came close enough to a gold nucleus to be deflected.

Build Science Skills L2

Using Models Have students model the gold foil experiment by shooting marbles across the floor at an arrangement of widely spaced, small objects—such as beads that are glued to a flat surface—and recording the angle of the marbles that are deflected. Discuss the results of their experiment in light of Marsden's findings.
Kinesthetic, Interpersonal

Integrate Biology L2

Cells in most living organisms have a central structure called a nucleus. This organelle contains the cell's genetic, or hereditary, material. Ask, **How are an atom's nucleus and a cell's nucleus similar?** *(They are both central structures of a basic unit.)*
Logical

3 ASSESS

Evaluate Understanding L2

Ask groups of students to summarize Dalton's, Thompson's, and Rutherford's atomic theories. Have them come up with simple word phrases or mnemonic devices to help them easily distinguish among the three theories. For example, Dogs Sort Socks = Dalton's Solid Sphere; Turtles Play Ping-pong = Thomson's Plum Pudding; and Rats Poke Noodles = Rutherford's Positive Nucleus.

Reteach L1

Use the Science and History time line on p. 114 to present and discuss a summary of the three models.

Writing in Science

Students might argue that the properties Democritus assigned to atoms match observed properties of matter, such as smoothness and roughness. Students might argue that the properties Aristotle assigned to elements serve a similar purpose, and his system also seems to account for changes between types of matter.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 4.1.

Answer to . . .

Figure 8 *The marble would have to be located in the center of the stadium.*