

**1 FOCUS****Objectives**

- 4.2.1 Identify** three types of subatomic particles.
- 4.2.2 Describe** the structure of atoms according to the Rutherford atomic model.

**Guide for Reading****Build Vocabulary** **L2**

**Word Parts** Have students think of words that start with the same word parts as the three subatomic particles described in this section: neutron, electron, and proton. (*Sample answer: neutral, electric, protein*) Point out that using words that students already know may help them remember the meaning of new terms.

**Reading Strategy** **L2**

**Outline** Suggest that students use the headings in this section to write an outline. They should include the most important points under each heading.

**2 INSTRUCT****Connecting to Your World**

Ask students to describe characteristics of the modern cathode-ray tube (CRT)—a television picture tube. (*It has a source of rays at one end. A receiving area at the other end creates a display. Students may know it's a vacuum tube.*)

**Subatomic Particles****Relate** **L2**

Mass spectrometers operate like cathode ray tubes. A vaporized sample is bombarded by high-energy electrons. A magnetic field separates the positively charged products based on their mass/charge ratios.

**Guide for Reading****Key Concepts**

- What are three kinds of subatomic particles?
- How can you describe the structure of the nuclear atom?

**Vocabulary**

electrons  
cathode ray  
protons  
neutrons  
nucleus

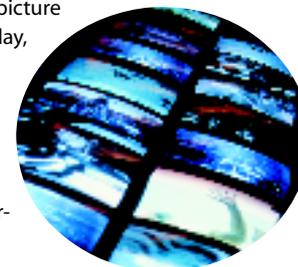
**Reading Strategy****Comparing and Contrasting**

When you compare and contrast things, you examine how they are alike and different. As you read, compare different subatomic particles by listing similarities and differences.

**Connecting to Your World**

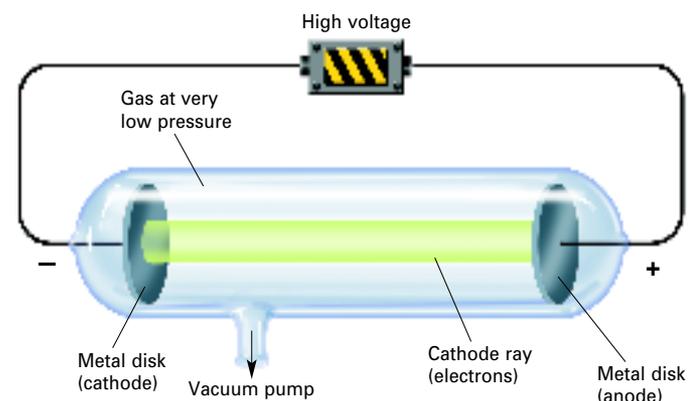
first used by scientists in the late nineteenth century, the cathode-ray tube would achieve its greatest fame as the picture tube of the common television set. Today, cathode-ray tubes are found in TVs, computer monitors, and many other devices with electronic displays. But more than 100 years ago, scientists were the only ones staring into the glow of a cathode-ray tube. Their observations provided important evidence about the structure of atoms.

A simple but important device

**Subatomic Particles**

Much of Dalton's atomic theory is accepted today. One important change, however, is that atoms are now known to be divisible. They can be broken down into even smaller, more fundamental particles, called subatomic particles. **Three kinds of subatomic particles are electrons, protons, and neutrons.**

**Electrons** In 1897, the English physicist J. J. Thomson (1856–1940) discovered the electron. **Electrons** are negatively charged subatomic particles. Thomson performed experiments that involved passing electric current through gases at low pressure. He sealed the gases in glass tubes fitted at both ends with metal disks called electrodes. The electrodes were connected to a source of electricity, as shown in Figure 4.4. One electrode, the anode, became positively charged. The other electrode, the cathode, became negatively charged. The result was a glowing beam, or **cathode ray**, that traveled from the cathode to the anode.



**Figure 4.4** In a cathode-ray tube, electrons travel as a ray from the cathode (–) to the anode (+). A television tube is a specialized type of cathode-ray tube.

104 Chapter 4

**Section Resources****Print**

- **Guided Reading and Study Workbook**, Section 4.2
- **Core Teaching Resources**, Section 4.2 Review
- **Transparencies**, T45–T47
- **Laboratory Manual**, Lab 5

**Technology**

- **Interactive Textbook with ChemASAP**, Animation 4, Assessment 4.2
- **Go Online**, Section 4.2



**Figure 4.5** Thomson examined two ways that a cathode ray can be deflected: **a** by using a magnet, and **b** by using electrically charged plates.

**Inferring** If a cathode ray is attracted to a positively charged plate, what can you infer about the charge of the particles that make up the cathode ray?

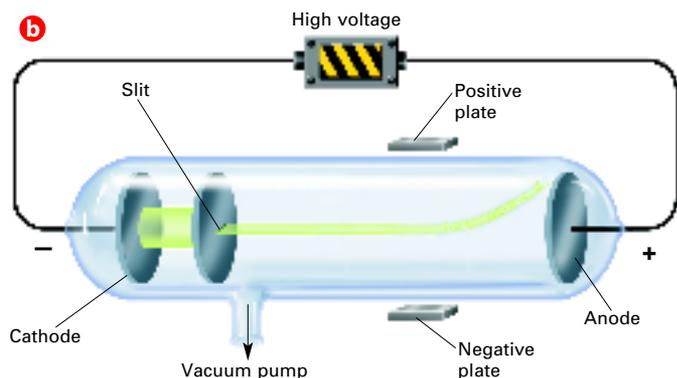


Figure 4.5a shows how a cathode ray is deflected by a magnet. A cathode ray is also deflected by electrically charged metal plates, as shown in Figure 4.5b. A positively charged plate attracts the cathode ray, while a negatively charged plate repels it. Thomson knew that opposite charges attract and like charges repel, so he hypothesized that a cathode ray is a stream of tiny negatively charged particles moving at high speed. Thomson called these particles corpuscles; later they were named electrons.

To test his hypothesis, Thomson set up an experiment to measure the ratio of the charge of an electron to its mass. He found this ratio to be constant. In addition, the charge-to-mass ratio of electrons did not depend on the kind of gas in the cathode-ray tube or the type of metal used for the electrodes. Thomson concluded that electrons must be parts of the atoms of all elements.

The U.S. physicist Robert A. Millikan (1868–1953) carried out experiments to find the quantity of charge carried by an electron. Using this value and the charge-to-mass ratio of an electron measured by Thomson, Millikan calculated the mass of the electron. Millikan's values for electron charge and mass, reported in 1916, are very similar to those accepted today. An electron carries exactly one unit of negative charge, and its mass is 1/1840 the mass of a hydrogen atom.

**Checkpoint** How do negatively charged plates affect the path of cathode rays?

**Go Online**  
 NSTA SciLinks  
 For: Links on J.J. Thomson  
 Visit: [www.SciLinks.org](http://www.SciLinks.org)  
 Web Code: cdn-1042

## Facts and Figures

### Piecing Together Atomic Structure

It took another eighty years after the Dalton model for scientists to begin gathering clues about the structure of atoms. By 1887, the British scientist William Crookes knew that metal atoms contained negatively charged particles. In a cathode ray tube containing hydrogen gas at low pressure, he found that

hydrogen contains positive charges. Scientists knew that the mass of the atom was greater than its proton content. They inferred that this extra mass was due to neutral particles, which were called neutrons. James Chadwick provided evidence for neutrons in 1932.

## TEACHER Demo

### Observing Cathode Rays

L2

**Purpose** To demonstrate a cathode-ray tube and observe properties of cathode rays

**Materials** cathode-ray tube, magnet

**Procedure** Demonstrate a cathode-ray tube in class. Use a magnet to deflect the beam of particles. Review the components of a cathode-ray tube, and discuss the connection to television picture tubes and computer monitors.

**Expected Outcome** Students should be able to explain how the CRT works and see how the cathode ray is deflected by a magnetic field.

### FYI

Based on his experiments with cathode rays, J.J. Thomson calculated the charge-to-mass ratio of the electron ( $e/m_e$ ) to be  $1.8 \times 10^8$  C/g. (The modern accepted value of  $e/m_e$  is  $1.758820 \times 10^8$  C/g.) This ratio is constant regardless of the gas or the cathode material used in the cathode-ray tube. In 1909, Robert Millikan and his co-workers began a series of experiments in which they studied the motion of charged oil droplets in an electric field. The experiments yielded values for the charge of an electron ( $e$ ) that were very close to the modern accepted value of  $1.602177 \times 10^{-19}$  C. Based on the values of  $e/m_e$  and  $e$ , Millikan was able to determine  $m_e$ , the mass of an electron. The modern accepted value of  $m_e$  is  $9.109381 \times 10^{-28}$  g

**Go Online**  
 NSTA SciLinks

Download a worksheet on **J.J. Thomson** for students to complete, and find additional teacher support from NSTA SciLinks.

### Answers to...

**Figure 4.5** The particles are negative.

**Checkpoint** A negatively charged plate repels a cathode ray.

## The Atomic Nucleus

### Use Visuals

L1

**Table 4.1** Have students compare the masses and charges of the three elementary particles shown in Table 4.1. Ask, **What particles make up most of the mass of an atom?** (*protons and neutrons*) **Why are relative charges and mass useful in talking about subatomic particles?** (*The actual values are unwieldy numbers.*)

### CLASS Activity

#### Atomic Model Timeline

L2

**Purpose** To trace the history of atomic models, and examine the role of the scientific method in the development of such models

**Materials** Library or Internet access

**Procedure** Have students create a timeline that traces the development of the atomic model. Have them note the data that led to an existing model being changed.

**Expected Outcome** Students' timelines should list at least some of the atomic models shown in Figure 5.2 on pages 110 and 111. Students should be able to explain how certain scientific discoveries (e.g., Rutherford's gold foil experiment) resulted in the revision of the prevailing atomic model at the time.

**Figure 4.6** Born in New Zealand, Ernest Rutherford was awarded the Nobel Prize for Chemistry in 1908. His portrait appears on the New Zealand \$100 bill.



106 Chapter 4

Table 4.1

Properties of Subatomic Particles

Particle	Symbol	Relative charge	Relative mass (mass of proton = 1)	Actual mass (g)
Electron	$e^-$	1-	1/1840	$9.11 \times 10^{-28}$
Proton	$p^+$	1+	1	$1.67 \times 10^{-24}$
Neutron	$n^0$	0	1	$1.67 \times 10^{-24}$

**Protons and Neutrons** If cathode rays are electrons given off by atoms, what remains of the atoms that have lost the electrons? For example, after a hydrogen atom (the lightest kind of atom) loses an electron, what is left? You can think through this problem using four simple ideas about matter and electric charges. First, atoms have no net electric charge; they are electrically neutral. (One important piece of evidence for electrical neutrality is that you do not receive an electric shock every time you touch something!) Second, electric charges are carried by particles of matter. Third, electric charges always exist in whole-number multiples of a single basic unit; that is, there are no fractions of charges. Fourth, when a given number of negatively charged particles combines with an equal number of positively charged particles, an electrically neutral particle is formed.

Considering all of this information, it follows that a particle with one unit of positive charge should remain when a typical hydrogen atom loses an electron. Evidence for such a positively charged particle was found in 1886, when Eugen Goldstein (1850–1930) observed a cathode-ray tube and found rays traveling in the direction opposite to that of the cathode rays. He called these rays canal rays and concluded that they were composed of positive particles. Such positively charged subatomic particles are called **protons**. Each proton has a mass about 1840 times that of an electron.

In 1932, the English physicist James Chadwick (1891–1974) confirmed the existence of yet another subatomic particle: the neutron. **Neutrons** are subatomic particles with no charge but with a mass nearly equal to that of a proton. Table 4.1 summarizes the properties of these subatomic particles.

**Checkpoint** What is the charge of a neutron?

## The Atomic Nucleus

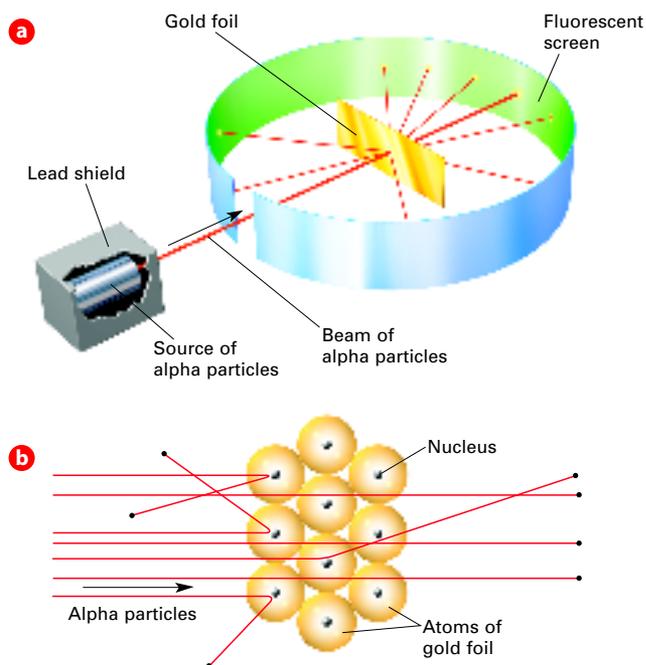
When subatomic particles were discovered, scientists wondered how these particles were put together in an atom. This was a difficult question to answer, given how tiny atoms are. Most scientists—including J.J. Thomson, the discoverer of the electron—thought it likely that the electrons were evenly distributed throughout an atom filled uniformly with positively charged material. In Thomson's atomic model, known as the "plum-pudding model," electrons were stuck into a lump of positive charge, similar to raisins stuck in dough. This model of the atom turned out to be short-lived, however, due to the groundbreaking work of Ernest Rutherford (1871–1937), a former student of Thomson.

### Differentiated Instruction

#### Gifted and Talented

L3

Have students use the Internet or library to find the original papers for the discoveries described in this chapter and write a report on what they have learned.



**Figure 4.7** Rutherford's gold-foil experiment yielded evidence of the atomic nucleus. **a** Rutherford and his coworkers aimed a beam of alpha particles at a sheet of gold foil surrounded by a fluorescent screen. Most of the particles passed through the foil with no deflection at all. A few particles were greatly deflected. **b** Rutherford concluded that most of the alpha particles pass through the gold foil because the atom is mostly empty space. The mass and positive charge are concentrated in a small region of the atom. Rutherford called this region the nucleus. Particles that approach the nucleus closely are greatly deflected.

**Rutherford's Gold-Foil Experiment** In 1911, Rutherford and his coworkers at the University of Manchester, England, decided to test what was then the current theory of atomic structure. Their test used relatively massive alpha particles, which are helium atoms that have lost their two electrons and have a double positive charge because of the two remaining protons. In the experiment, illustrated in Figure 4.7, a narrow beam of alpha particles was directed at a very thin sheet of gold foil. According to the prevailing theory, the alpha particles should have passed easily through the gold, with only a slight deflection due to the positive charge thought to be spread out in the gold atoms.

To everyone's surprise, the great majority of alpha particles passed straight through the gold atoms, without deflection. Even more surprisingly, a small fraction of the alpha particles bounced off the gold foil at very large angles. Some even bounced straight back toward the source. Rutherford later recollected, "This is almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

**The Rutherford Atomic Model** Based on his experimental results, Rutherford suggested a new theory of the atom. He proposed that the atom is mostly empty space, thus explaining the lack of deflection of most of the alpha particles. He concluded that all the positive charge and almost all the mass are concentrated in a small region that has enough positive charge to account for the great deflection of some of the alpha particles. He called this region the nucleus. The **nucleus** is the tiny central core of an atom and is composed of protons and neutrons.

**Interactive Textbook**

**Animation 4** Take a look at Rutherford's gold-foil experiment, its results, and its conclusions.

with ChemASAP

**Discuss**

**L2**

The ratio of the size of the nucleus to the size of an atom is about  $10^{-5}$ . Discuss how small the nucleus is compared to the entire atom. Explain that if a housefly sitting on second base in a baseball stadium represented the nucleus of an atom, the rest of the atom would be the size of the stadium.

**Quick LAB**

**Using Inference: The Black Box**

**L2**

**Objective** After completing this activity, students will be able to:

- determine the shape of the hidden object by analyzing the rebound paths of a marble rolled at the object.

**Skills Focus** Observing, inferring

**Prep Time** 5 minutes

**Materials** box containing a regularly shaped object fixed in place and a loose marble

**Advance Prep** Cut geometric shapes—such as a triangle, circle, or L, from a sheet of 1-inch plastic foam.

**Class Time** 10 minutes

**Expected Outcome** Students' inferences may or may not be different for the same object.

**Analyze and Conclude**

1. See Expected Outcome.
2. The activity simulates the strategy that Rutherford used to probe the structure of metal atoms. Like the students, Rutherford and his coworkers were also faced with the problem of identifying properties of an object not visible to the eye.

**For Enrichment**

**L3**

Make a more challenging black box for students who have an easy time with the simple boxes. Put two single objects in one box, or a single object with a complex shape.

**Answers to...**



**Checkpoint** A neutron has a relative charge of 0.

## Section 4.2 (continued)

### 3 ASSESS

#### Evaluate Understanding L2

Have students describe the discoveries of Thomson, Millikan, and Rutherford, and relate how those discoveries led to the current understanding of atomic structure.

#### Reteach L1

Have students review Table 4.1. Ask them to compare electrons, protons, and neutrons, using a table or a diagram.

#### Writing Activity

In Rutherford's gold-foil experiment, a narrow beam of alpha particles was directed at a very thin sheet of gold foil. Most of the alpha particles passed straight through the gold atoms without being deflected, but a small fraction bounced off the foil at very large angles. To explain his results, Rutherford proposed that an atom is mostly empty space, and that the positive charge and most of the mass of the atom are concentrated in a very small region. Rutherford's experiment yielded evidence of the nucleus, and led to an improved atomic model known as the nuclear atom.

#### Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 4.2.

with ChemASAP

### Quick LAB

#### Using Inference: The Black Box

##### Purpose

To determine the shape of a fixed object inside a sealed box without opening the box.

##### Materials

- box containing a regularly shaped object fixed in place and a loose marble

##### Procedure

1. Do not open the box.
2. Manipulate the box so that the marble moves around the fixed object.
3. Gather data (clues) that describe the movement of the marble.
4. Sketch a picture of the object in the box, showing its shape, size, and location within the box.
5. Repeat this activity with a different box containing a different object.



##### Analysis and Conclusions

1. Find a classmate who had the same lettered box that you had, and compare your findings.
2. What experiment that contributed to a better understanding of the atom does this activity remind you of?

The Rutherford atomic model is known as the nuclear atom. **In the nuclear atom, the protons and neutrons are located in the nucleus. The electrons are distributed around the nucleus and occupy almost all the volume of the atom.** According to this model, the nucleus is tiny compared with the atom as a whole. If an atom were the size of a football stadium, the nucleus would be about the size of a marble.

Although it was an improvement over Thomson's model of the atom, Rutherford's model turned out to be incomplete. In Chapter 5, you will learn how the Rutherford atomic model had to be revised in order to explain the chemical properties of elements.

## 4.2 Section Assessment

8. **Key Concept** What are three types of subatomic particles?
9. **Key Concept** How does the Rutherford model describe the structure of atoms?
10. What are the charges and relative masses of the three main subatomic particles?
11. Describe Thomson's and Millikan's contributions to atomic theory.
12. Compare Rutherford's expected outcome of the gold-foil experiment with the actual outcome.
13. What experimental evidence led Rutherford to conclude that an atom is mostly empty space?
14. How did Rutherford's model of the atom differ from Thomson's?

#### Writing Activity

**Explanatory Paragraph** Write a paragraph explaining how Rutherford's gold-foil experiment yielded new evidence about atomic structure. *Hint:* First describe the setup of the experiment. Then explain how Rutherford interpreted his experimental data.

#### Interactive Textbook

**Assessment 4.2** Test yourself on the concepts in Section 4.2.

with ChemASAP

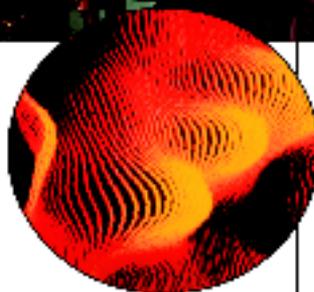
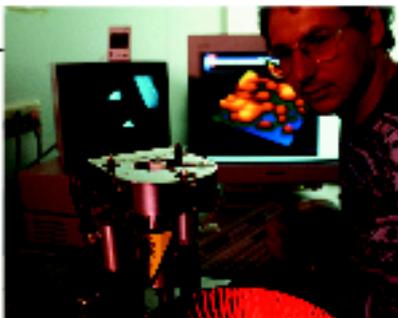
108 Chapter 4

## Section 4.2 Assessment

8. protons, neutrons, and electrons
9. A positively charged nucleus surrounded by electrons, which occupy most of the volume.
10. proton, positive charge, relative mass = 1; electron, negative charge, relative mass = 1/1840; neutron, no charge, relative mass = 1
11. Thomson passed an electric current through sealed glass tubes filled with gases. The resulting glowing beam consisted of tiny negatively charged particles moving at high speed. Thomson concluded that electrons must be parts of the atoms of all elements. Millikan determined the charge and mass of the electron.

## Electron Microscopy

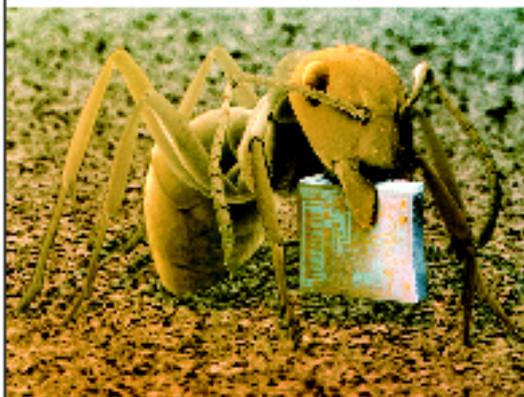
Within 30 years of J.J. Thomson's discovery of the electron, scientists were studying how to produce images of objects by using an electron beam. In 1931, German scientists Ernst Ruska and Max Knoll built the first electron microscope. While an ordinary light microscope uses a beam of light and lenses to magnify objects, an electron microscope uses an electron beam and "lenses" consisting of magnetic or electric fields. A typical light microscope is capable of magnifying an object 1000 times. An electron microscope can magnify an object over 100,000 times. **Interpreting Photographs** What characteristics of the images below provide the viewer with a sense of scale?



**Biochemistry** A scientist uses an electron microscope to look at the surface of DNA molecules.



**Microelectronics** In the colorized electron micrograph below, a wood ant (*Formica fusca*), about 5 mm long, holds a microchip in its jaws. Microelectronics engineers use electron microscopes to measure and analyze the characteristics of microcircuits.



**Biology** A dust mite (*Dermatophagoides pteronyssinus*), smaller than the period at the end of this sentence, sits on the point of a sewing needle.

## Electron Microscopy

Point out how a person sees an image made by the electron microscope; the scientist in the photo is not looking into a tube, but sees a projection. Have students research the different types of electron microscopy, what their limitations are, and how specimens are prepared for viewing.

12. Rutherford expected all the alpha particles to pass straight through with little deflection. He found that most alpha particles passed straight through, but some particles were deflected at very large angles—and some even bounced straight back.
13. The great majority of the alpha particles passed straight through the gold foil.

14. Rutherford's atomic model described the atom as having a positively charged, dense nucleus that is tiny compared to the atom as a whole. In Thomson's plum-pudding model, electrons were stuck in a chunk of positive charge.

### Answers to...

**Interpreting Photographs** In both images, a small, familiar object is shown so that the viewer can make a size comparison. In the image of the dust mite, showing the tip of the sewing needle provides a sense of scale; in the image of the microchip, showing the ant provides a sense of scale.