4.2 Structure of the Nuclear Atom

Guide for Reading

Key Concepts

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

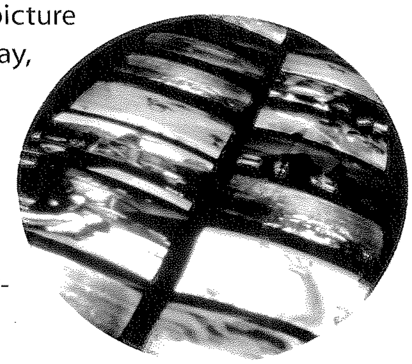
Vocabulary

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 A simple but important device 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.



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.

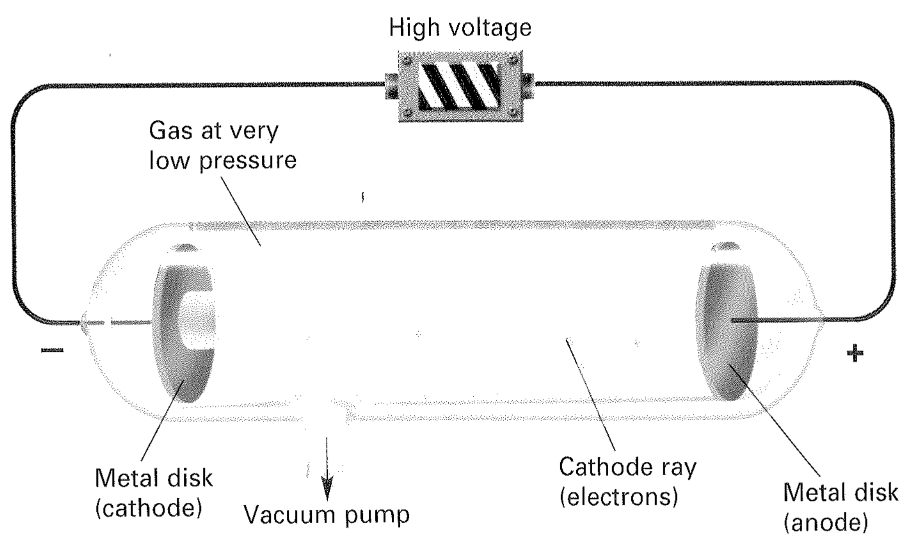
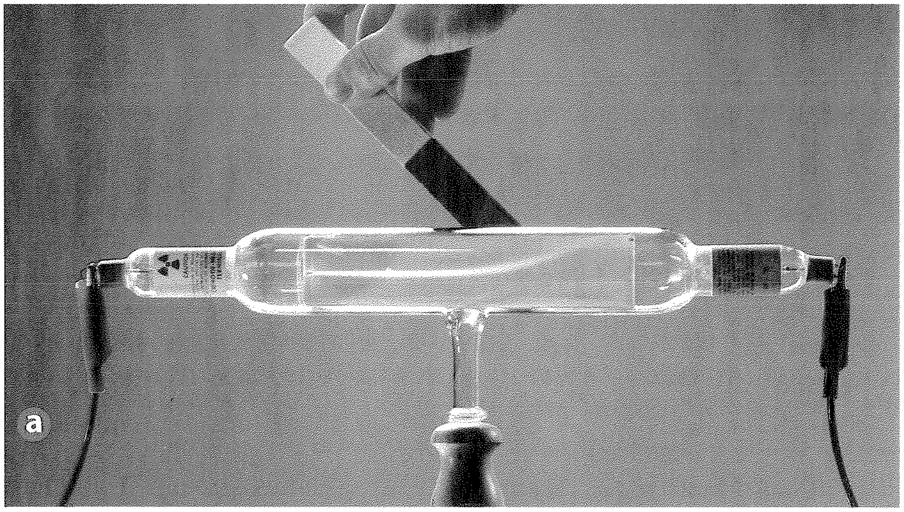


Figure 4.4 In a cathode-ray tube, electrons travel as a ray from the cathode (−) to the anode (+). A television tube is a specialized type of cathode-ray tube.



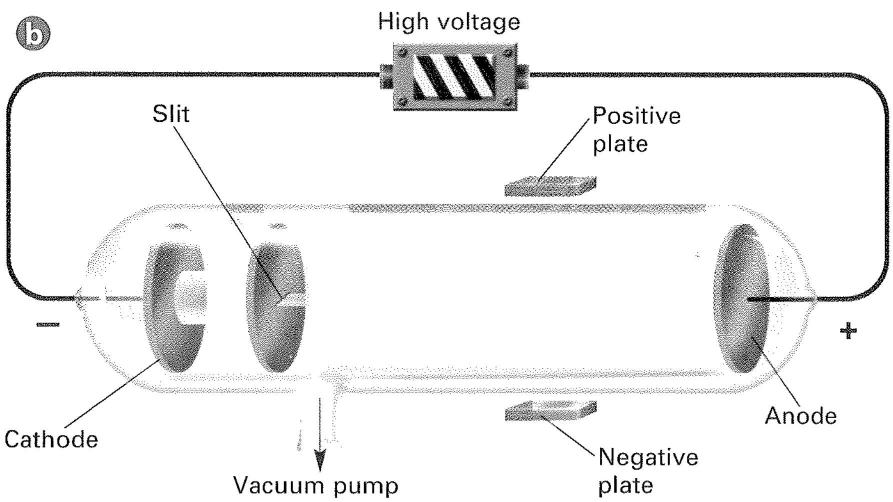


Figure 4.5 Thomson examined two ways that a cathode ray can be deflected: ⓐ by using a magnet, and ⓑ by using electrically charged plates. **Inferring** ***If a cathode ray is attracted to a positively charged plate, what can you infer about the charge of the particles that make up the cathode ray?***

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.

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

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	9.11×10^{-28}
Proton	p^+	1+	1	1.67×10^{-24}
Neutron	n^0	0	1	1.67×10^{-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. Although protons and neutrons are exceedingly small, theoretical physicists believe that they are composed of yet smaller subnuclear particles called *quarks*.

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.

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.

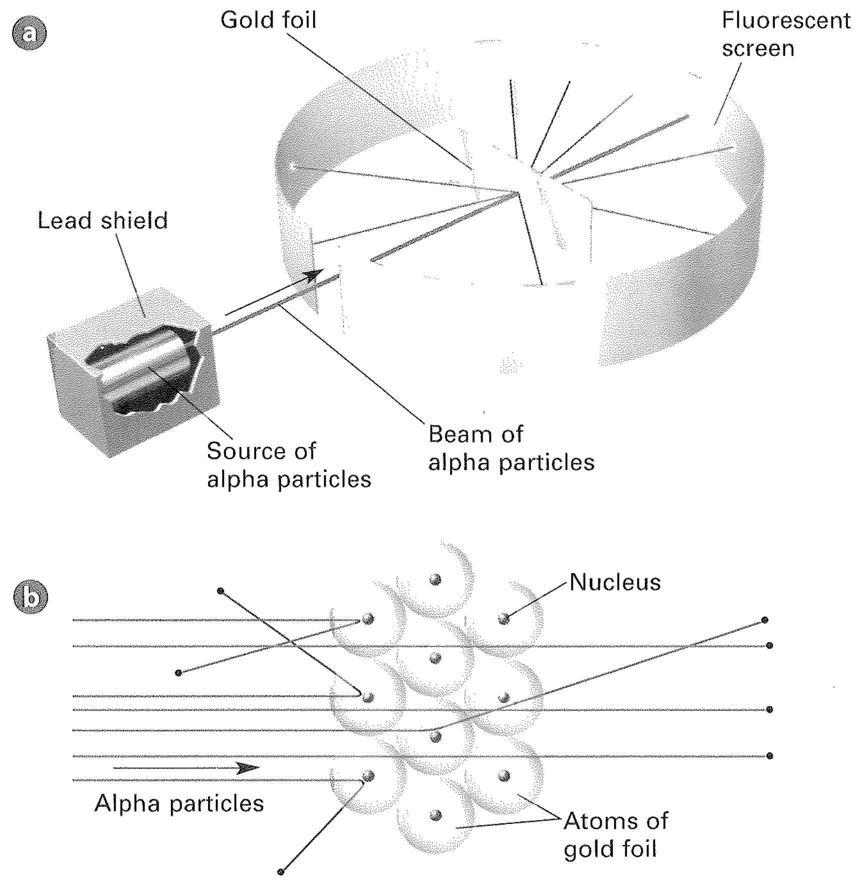

Figure 4.7 Rutherford's gold-foil experiment yielded evidence of the atomic nucleus. (a) Rutherford and his coworkers aimed a beam of alpha particles at a sheet of gold foil surrounded by a fluorescent screen. Most of the particles passed through the foil with no deflection at all. A few particles were 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.

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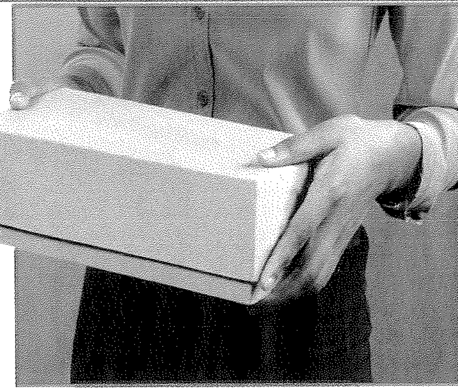
Quick LAB

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.

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