

Introduction to Atoms

Reading Preview

Key Concepts

- How did atomic theory develop and change?
- What is the modern model of the atom?

Key Terms

- atom • electron • nucleus
- proton • energy level
- neutron • atomic number
- isotope • mass number

Target Reading Skill

Previewing Visuals Before you read, preview Figure 7. Then write two questions you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

Structure of an Atom

Q. What particles are in the center of an atom?

A.

Q.

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Discover Activity

What's in the Box?

1. Your teacher will give you a sealed box that contains an object. Without opening the box, move the box around to find out as much as you can about the object.
2. Make a list of your observations about the object. For example, does the object slide or roll? Is it heavy or light? Is it soft or hard? Is the object round or flat?
3. Think about familiar objects that could give you clues about what's inside the box.

Think It Over

Inferring Make a sketch showing what you think the object looks like. Tell how you inferred the properties of the object from indirect observations.

Glance at the painting below and you see people enjoying an afternoon in the park. Now look closely at the circled detail of the painting. There you'll discover that the artist used thousands of small spots of color to create these images of people and the park.

Are you surprised that such a rich painting can be created from lots of small spots? Matter is like that, too. The properties of matter that you can observe result from the properties of tiny objects that you cannot see. As you learned earlier, the tiny objects that make up all matter are atoms.



FIGURE 1

Sunday Afternoon on the Island of La Grande Jatte

This painting by artist Georges Seurat, which is made from tiny dots of paint, gives you a simple model for thinking about how matter is made of atoms.

Development of Atomic Models

If you could look into an atom, what might you see? Figuring out what atoms are made of hasn't been easy. Because atoms are so small, studying them is a bit like trying to solve the mystery of the sealed box in the Discover activity. Ideas about the shape and structure of atoms have changed many times.

The first people to think about the nature of matter were the ancient Greeks. Around the year 430 B.C., a Greek philosopher named Democritus proposed the idea that matter is formed of small pieces that could not be cut into smaller parts. He used the word *atomos*, which means "uncuttable," for these smallest possible pieces. In modern terms, an **atom** is the smallest particle of an element.

The ancient Greeks did not prove the existence of atoms because they did not do experiments. In science, ideas are just ideas unless they can be tested. The idea of atoms began to develop again in the 1600s. This time, however, people did do experiments. As a result, atomic theory began to take shape. **Atomic theory grew as a series of models that developed from experimental evidence. As more evidence was collected, the theory and models were revised.**

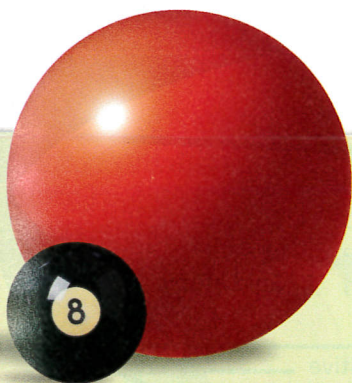
Dalton's Atomic Theory Using evidence from many experiments, John Dalton, an English chemist, inferred that atoms had certain characteristics. He began to propose an atomic theory and model for atoms. The main ideas of Dalton's theory are summarized in Figure 2. With only a few changes, Dalton's atomic theory is still accepted today.

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FIGURE 2 Dalton Model

Dalton thought that atoms were like smooth, hard balls that could not be broken into smaller pieces.



Summary of Dalton's Ideas

- All elements are composed of atoms that cannot be divided.
- All atoms of the same element are exactly alike and have the same mass. Atoms of different elements are different and have different masses.
- An atom of one element cannot be changed into an atom of a different element. Atoms cannot be created or destroyed in any chemical change, only rearranged.
- Every compound is composed of atoms of different elements, combined in a specific ratio.

FIGURE 3

Thomson Model

Thomson suggested that atoms had negatively charged electrons embedded in a positive sphere.



Thomson and Smaller Parts of Atoms Through a series of experiments around the start of the twentieth century, scientists discovered that atoms are made of even smaller parts. In 1897, another British scientist, J. J. Thomson, found that atoms contain negatively charged particles. Yet, scientists knew that atoms themselves had no electrical charge. So, Thomson reasoned, atoms must also contain some sort of positive charge.

Thomson proposed a model like the one in Figure 3. He described an atom that consisted of negative charges scattered throughout a ball of positive charge—something like raisins or berries in a muffin. The negatively charged particles later became known as **electrons**.

Rutherford and the Nucleus In 1911, one of Thomson's students, Ernest Rutherford, found evidence that countered Thomson's model. In an experiment diagrammed in Figure 4, Rutherford's research team aimed a beam of positively charged particles at a thin sheet of gold foil. They predicted that, if Thomson's model were correct, the charged particles would pass right through the foil in a straight line. The gold atoms would not have enough positive charge in any one region to strongly repel the charged particles.

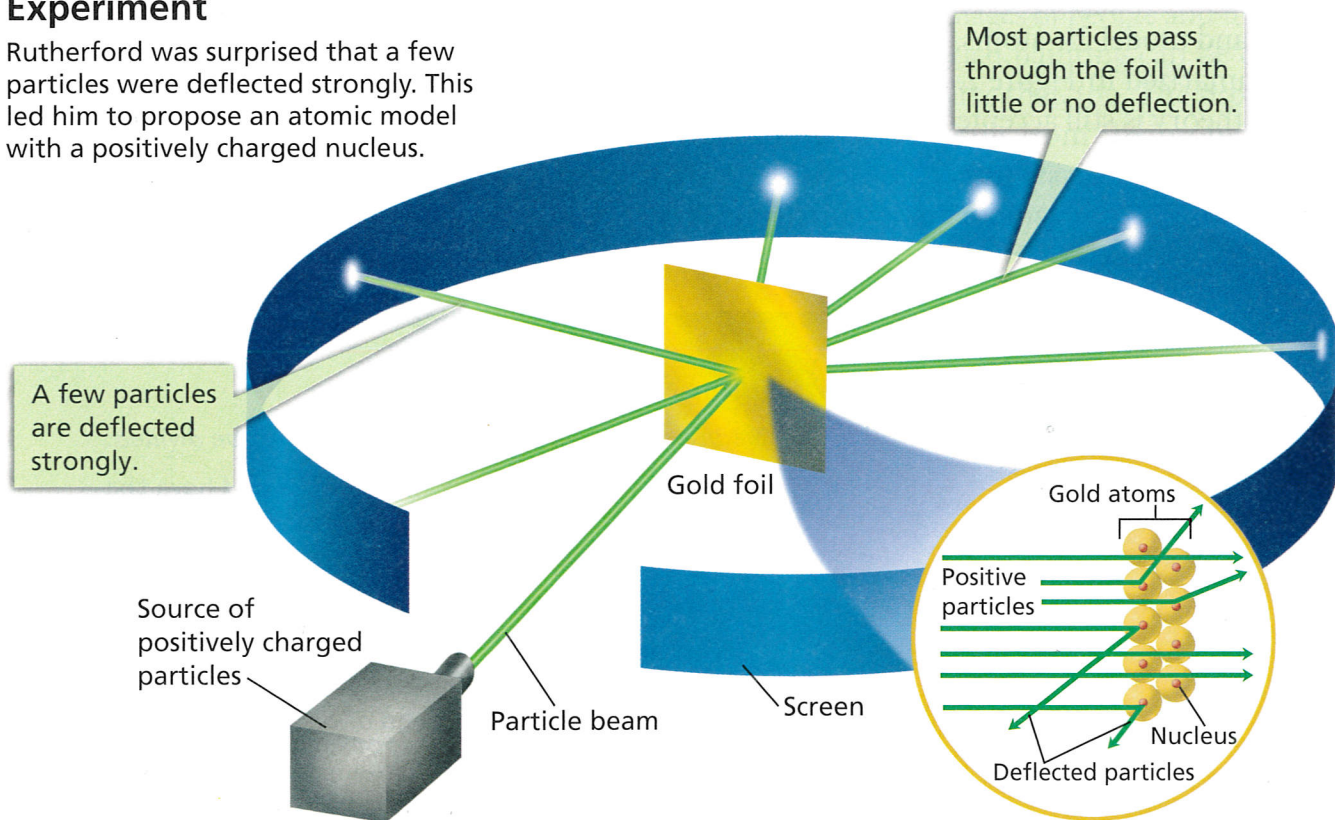
FIGURE 4

Rutherford's Gold Foil Experiment

Rutherford was surprised that a few particles were deflected strongly. This led him to propose an atomic model with a positively charged nucleus.



Where were the electrons located in Thomson's model of an atom?



Rutherford's team observed that most of the particles passed through the foil undisturbed, as expected. But, to their surprise, a few particles were deflected strongly. Since like charges repel each other, Rutherford inferred that an atom's positive charge must be clustered in a tiny region in its center, called the **nucleus** (NOO klee us). Any particle that was deflected strongly had been repelled by a gold atom's nucleus.

Scientists knew from other experiments that electrons had almost no mass. Therefore, they reasoned that nearly all of an atom's mass must also be located in the tiny, positively charged nucleus. In Rutherford's model of the atom, the atom was mostly empty space with electrons moving around the nucleus in that space. Work by other scientists later suggested that the nucleus was made of one or more positively charged particles. Rutherford named these positively charged particles in the nucleus of an atom **protons**.

Bohr's Model In 1913, Niels Bohr, a Danish scientist and a student of both Thomson and Rutherford, revised the atomic model again. Bohr showed that electrons could have only specific amounts of energy, leading them to move in certain orbits. The series of orbits in Bohr's model resemble planets orbiting the sun or the layers of an onion, as shown in Figure 6.

A Cloud of Electrons In the 1920s, the atomic model changed again. Scientists determined that electrons do not orbit the nucleus like planets. Instead, electrons can be anywhere in a cloudlike region around the nucleus. The "cloud" is a visual model. It symbolizes where electrons are likely to be found. An electron's movement is related to its **energy level**, or the specific amount of energy it has. Electrons of different energy levels are likely to be found in different places.

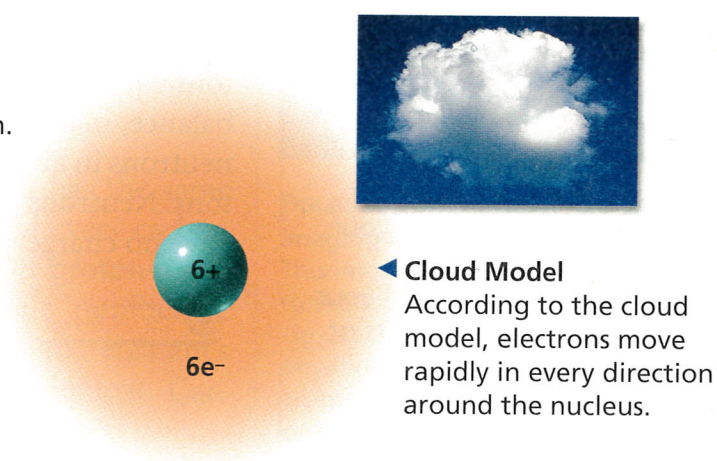
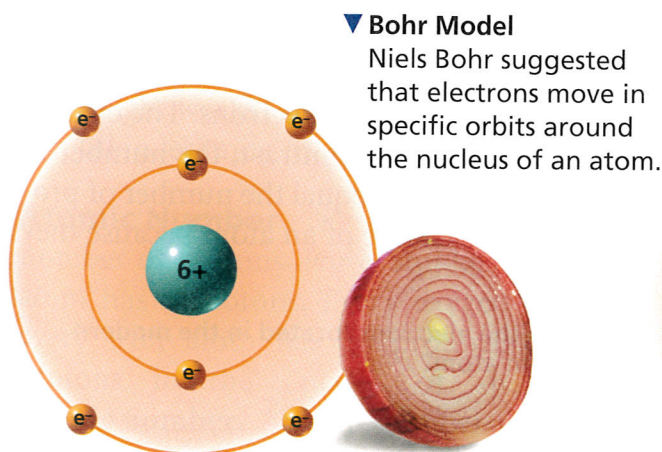


FIGURE 5

Rutherford Model

According to Rutherford's model, an atom was mostly empty space.

Making Models How is a fruit with a pit at its center a simple model for Rutherford's idea?

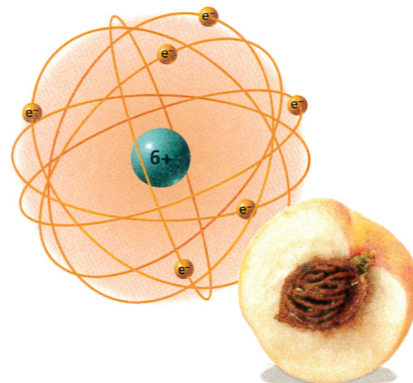


FIGURE 6

Later Atomic Models

Through the first part of the twentieth century, atomic models continued to change.

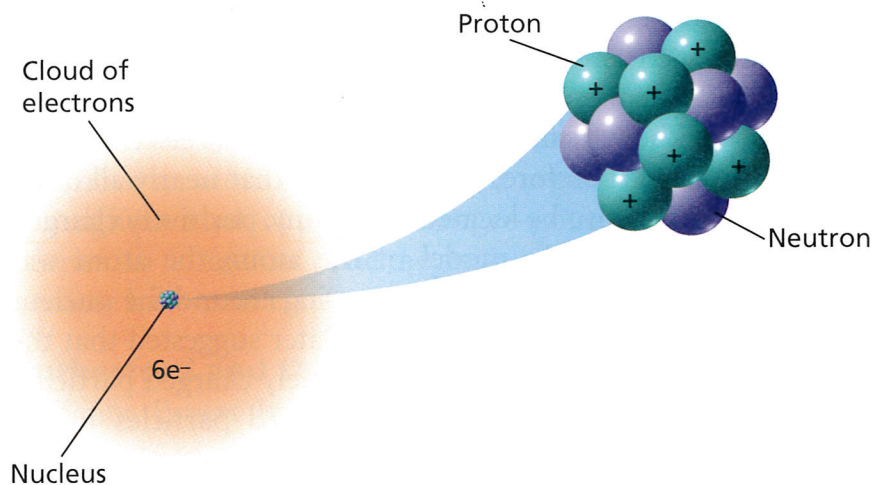


FIGURE 7

Modern Model of an Atom

This model of a carbon atom consists of protons and neutrons in a nucleus that is surrounded by a cloud of electrons.

Relating Cause and Effect *What effect do the neutrons in the nucleus have on the atom's electric charge? Explain.*



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Try This Activity

How Far Away?

1. On a piece of paper, make a small circle no bigger than a dime. The circle represents the nucleus of an atom.
2. Measure the diameter of the circle in centimeters.
3. Now predict where the outer edge of this model atom would be. For example, would the outer edge be within the edges of the paper? Your desk? The classroom? The school building?

Calculating The diameter of an actual atom can be 100,000 times that of its nucleus. Calculate the diameter of your model atom. How close was your prediction in Step 3 to your calculation? (*Hint:* To understand the scale of your answer, change the units of measurement from centimeters to meters.)

The Modern Atomic Model

In 1932, British scientist James Chadwick discovered another particle in the nucleus of atoms. This new particle was hard to detect because it has nearly the same mass as a proton. Since it was electrically neutral, the particle was called a **neutron**.

Chadwick's discovery led to an adjustment in the atomic model. This model, pictured in Figure 7, has not changed much since the 1930s. **The modern model describes an atom as consisting of a nucleus that contains protons and neutrons, surrounded by a cloudlike region of moving electrons.** New research continues to provide data that support this model.

Particle Charges Look closely at the model of the carbon atom in Figure 7. Protons are shown in the diagram by a plus sign (+), and electrons are shown by the symbol e^- . If you count the number of protons and electrons, you'll see there are six of each. In an atom, the number of protons equals the number of electrons. As a result, the positive charge from the protons equals the negative charge from the electrons. The charges balance, making the atom neutral. In contrast, the number of neutrons in an atom does not have to equal the number of protons. Neutrons don't affect the charge of an atom because they have no charge.



Where are the electrons located in the modern model of an atom?




| Particles in an Atom | | | | |
|----------------------|----------------|--------|---------------------|---|
| Particle | Symbol | Charge | Relative Mass (amu) | Model |
| Proton | p ⁺ | 1+ | 1 |  |
| Neutron | n | 0 | 1 |  |
| Electron | e ⁻ | 1- | $\frac{1}{1,836}$ |  |

FIGURE 8

Each particle in an atom has a unique symbol. In this book, protons, neutrons, and electrons may also be represented by the colored models shown in the table.

Comparing Particle Masses Although electrons may balance protons charge-for-charge, they can't compare when it comes to mass. It takes almost 2,000 electrons to equal the mass of just one proton. On the other hand, a proton and a neutron are about equal in mass. Together, the protons and neutrons make up nearly all the mass of an atom.

Figure 8 compares the charges and masses of the three atomic particles. Atoms are too small to be described easily by everyday units of mass, such as grams or kilograms. Sometimes scientists use units known as atomic mass units (amu). A proton or a neutron has a mass equal to about one amu.

Scale and Size of Atoms Looking back at the modern model (Figure 7), you may see that most of an atom's volume is the space in which the electrons move. In contrast, the nucleus seems tiny. But no image can be drawn in a book that would show how small the nucleus really is compared to an entire atom. To picture the scale of an atom, imagine that the nucleus were the size of an eraser on a pencil. If you put this "nucleus" on the pitcher's mound of a baseball stadium, the electrons could be as far away as the top row of seats!

In reality, atoms themselves are amazingly small. The tiniest visible speck of dust may contain 10 million billion atoms. Because they are so small, atoms are hard to study. Today's powerful microscopes can give a glimpse of atoms, as shown in Figure 9. But they do not show the structure of atoms or how they might work. Models, such as those shown in this book, are helpful in learning more about atoms.

Atomic Number Every atom of an element has the same number of protons. For example, the nucleus of every carbon atom has 6 protons. Every oxygen atom has 8 protons, and every iron atom has 26 protons. This unique number of protons in the nucleus of an atom is an element's **atomic number**. Atomic number identifies an element. Carbon's atomic number is 6, oxygen's is 8, and iron's is 26.

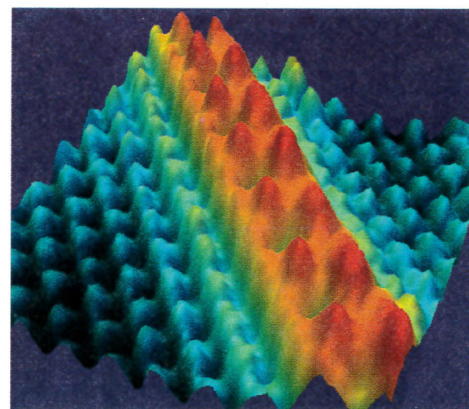


FIGURE 9

Imaging Atoms

This image was made by a scanning tunneling microscope. It shows a zigzag chain of cesium atoms (red) on a background of gallium and arsenic atoms (blue). The colors were added to the image.

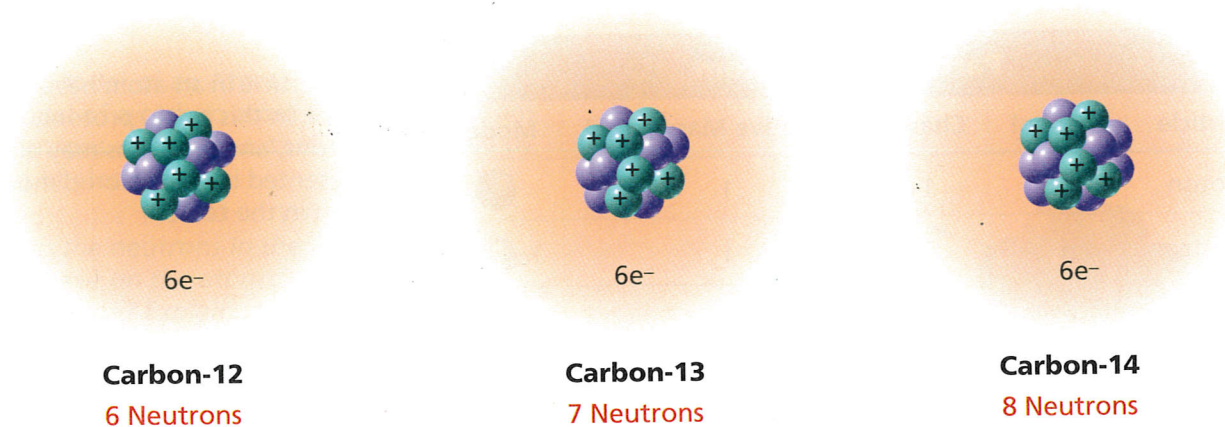


FIGURE 10 Isotopes

Atoms of all isotopes of carbon contain 6 protons and 6 electrons, but they differ in their number of neutrons. Carbon-12 is the most common isotope.

Interpreting Diagrams Which isotope of carbon has the largest mass number?

Isotopes and Mass Number Although all atoms of an element have the same number of protons, their number of neutrons can vary. Atoms with the same number of protons and a different number of neutrons are called **isotopes** (EYE suh tohps). Three isotopes of carbon are illustrated in Figure 10. Each carbon atom has 6 protons and 6 electrons. But the number of neutrons is 6, 7, or 8.

An isotope is identified by its **mass number**, which is the sum of the protons and neutrons in the nucleus of an atom. The most common isotope of carbon has a mass number of 12 (6 protons + 6 neutrons) and may be written as “carbon-12.” Two other isotopes are carbon-13 and carbon-14. Although these carbon atoms have different mass numbers, all carbon atoms react the same way chemically.

Section 1 Assessment

Target Reading Skill Previewing Visuals Compare your questions and answers about Figure 7 with those of a partner.

Reviewing Key Concepts

1. a. **Reviewing** In general, why did atomic theory change with time?
- b. **Describing** Describe Bohr’s model of the atom. What specific information did Bohr contribute to scientists’ understanding of the atom?
- c. **Comparing and Contrasting** How is the modern atomic model different from Bohr’s model?
2. a. **Reviewing** What are the three main particles in the modern model of an atom?
- b. **Relating Cause and Effect** Why do atoms have no electric charge even though most of their particles have charges?

- c. **Explaining** What is atomic number, and how is it used to distinguish one element from another?
- d. **Applying Concepts** The atomic number of the isotope nitrogen-15 is 7. How many protons, neutrons, and electrons make up an atom of nitrogen-15?

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At-Home Activity

Modeling Atoms Build a three-dimensional model of an atom to show to your family. Use beads, cotton, small candies, clay, and other simple materials. Describe the parts of your model, and explain what makes atoms of different elements different from one another.