

Terms to Learn

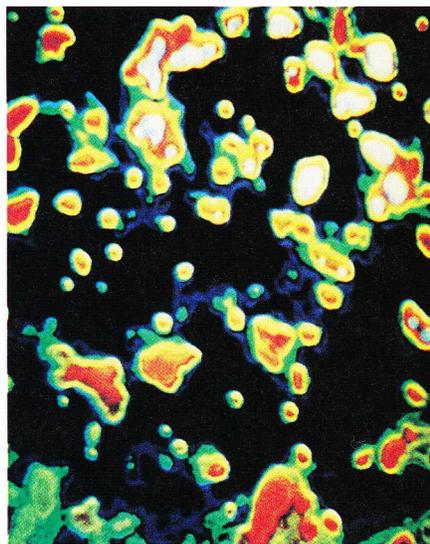
atom	model
theory	nucleus
electrons	electron clouds

What You'll Do

- ◆ Describe some of the experiments that led to the current atomic theory.
- ◆ Compare the different models of the atom.
- ◆ Explain how the atomic theory has changed as scientists have discovered new information about the atom.

Development of the Atomic Theory

The photo at right shows uranium atoms magnified 3.5 million times by a scanning tunneling microscope. An **atom** is the smallest particle into which an element can be divided and still be the same substance. Atoms make up elements; elements combine to form compounds. Because all matter is made of elements or compounds, atoms are often called the building blocks of matter.



Before the scanning tunneling microscope was invented, in 1981, no one had ever seen an atom. But the existence of atoms is not a new idea. In fact, atomic theory has been around for more than 2,000 years. A **theory** is a unifying explanation for a broad range of hypotheses and observations that have been supported by testing. In this section, you will travel through history to see how our understanding of atoms has developed. Your first stop—ancient Greece.

Democritus Proposes the Atom

Imagine that you cut the silver coin shown in **Figure 1** in half, then cut those halves in half, and so on. Could you keep cutting the pieces in half forever? Around 440 B.C., a Greek philosopher named Democritus (di MAHK ruh tuhs) proposed that you would eventually end up with an “uncuttable” particle. He called this particle an *atom* (from the Greek word *atomos*, meaning “indivisible”). Democritus proposed that all atoms are small, hard particles made of a single material formed into different shapes and sizes. He also claimed that atoms are always moving and that they form different materials by joining together.

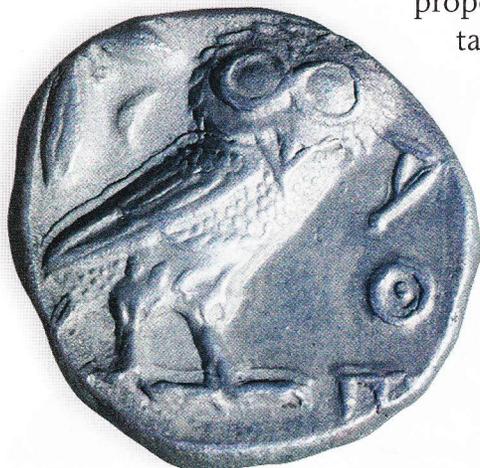


Figure 1 This coin was in use during Democritus's time. Democritus thought the smallest particle in an object like this silver coin was an atom.

Aristotle Disagrees Aristotle (ER is TAHT uhl), a Greek philosopher who lived from 384 to 322 B.C., disagreed with Democritus's ideas. He believed that you would never end up with an indivisible particle. Although Aristotle's ideas were eventually proved incorrect, he had such a strong influence on popular belief that Democritus's ideas were largely ignored for centuries.

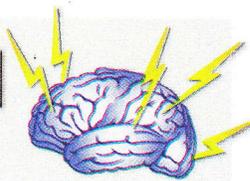
Dalton Creates an Atomic Theory Based on Experiments

By the late 1700s, scientists had learned that elements combine in specific proportions based on mass to form compounds. For example, hydrogen and oxygen always combine in the same proportion to form water. John Dalton, a British chemist and school teacher, wanted to know why. He performed experiments with different substances. His results demonstrated that elements combine in specific proportions because they are made of individual atoms. Dalton, shown in **Figure 2**, published his own atomic theory in 1803. His theory stated the following:

- All substances are made of atoms. Atoms are small particles that cannot be created, divided, or destroyed.
- Atoms of the same element are exactly alike, and atoms of different elements are different.
- Atoms join with other atoms to make new substances.

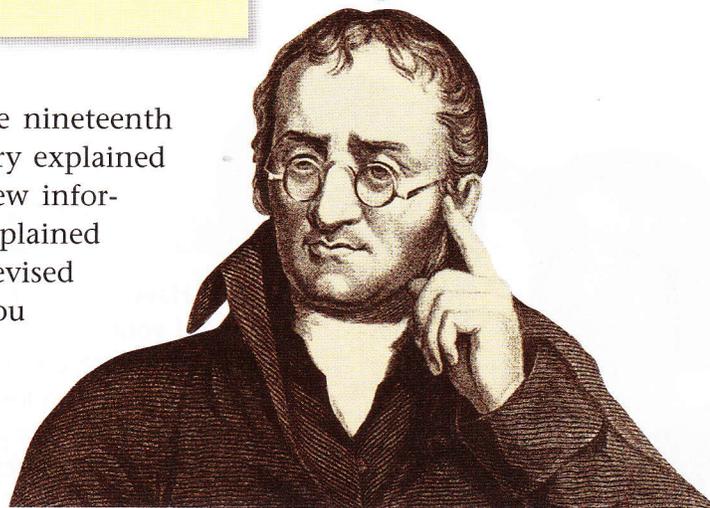
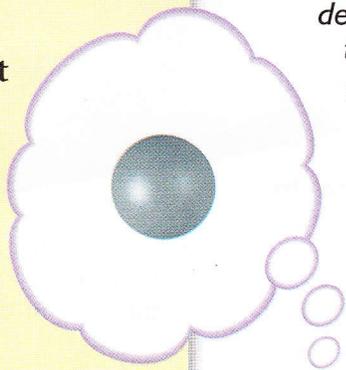
Not Quite Correct Toward the end of the nineteenth century scientists agreed that Dalton's theory explained many of their observations. However, as new information was discovered that could not be explained by Dalton's ideas, the atomic theory was revised to more correctly describe the atom. As you read on, you will learn how Dalton's theory has changed, step by step, into the current atomic theory.

BRAIN FOOD



In 342 or 343 B.C., King Phillip II of Macedon appointed Aristotle to be a tutor for his son, Alexander. Alexander later conquered Greece and the Persian Empire (in what is now Iran) and became known as Alexander the Great.

Figure 2 John Dalton developed his atomic theory from observations gathered from many experiments.

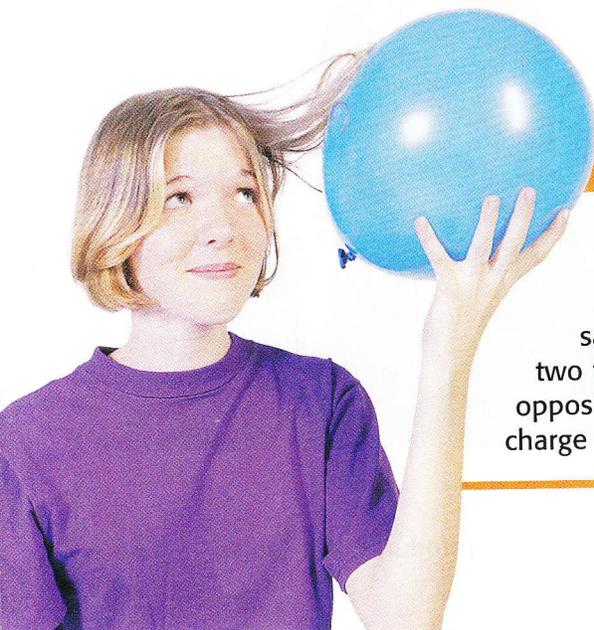
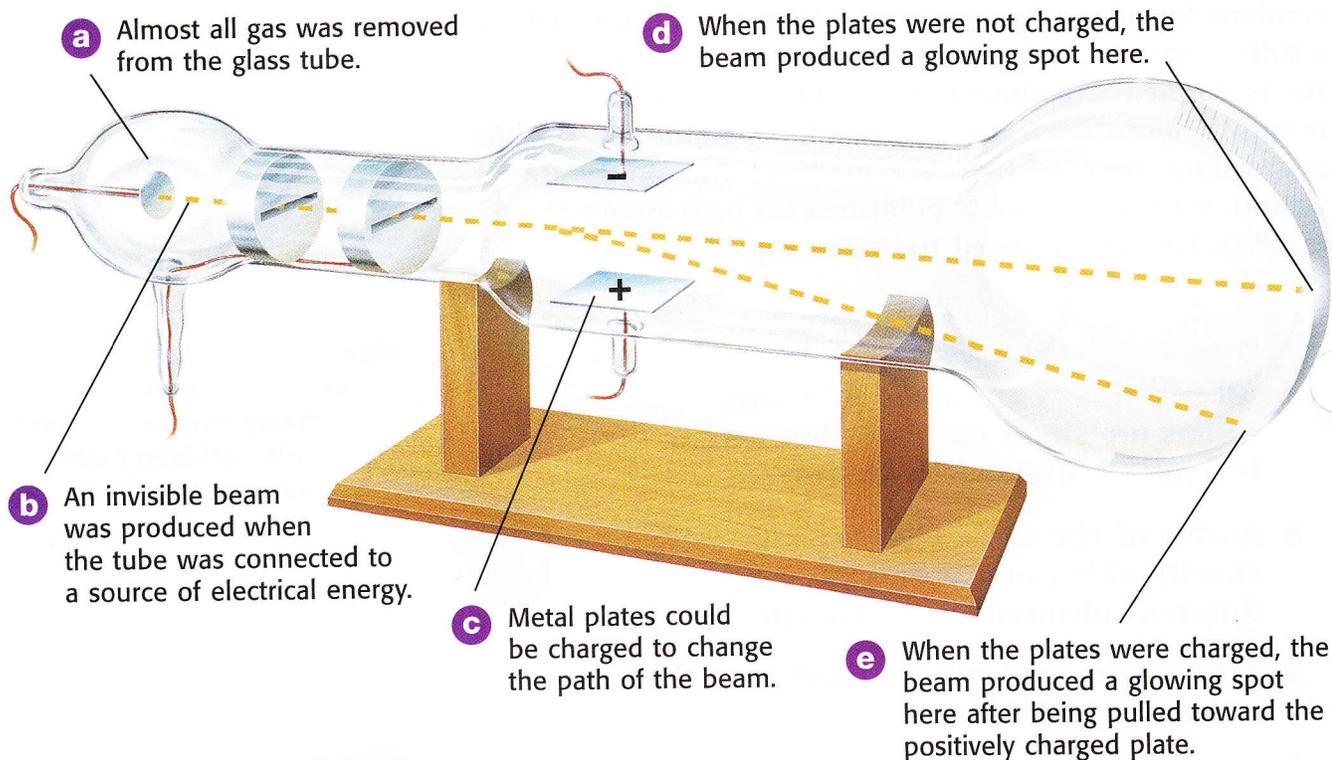


Thomson Finds Electrons in the Atom

In 1897, a British scientist named J. J. Thomson made a discovery that identified an error in Dalton's theory. Using simple equipment (compared with modern equipment), Thomson discovered that there are small particles *inside* the atom. Therefore, atoms *can* be divided into even smaller parts.

Thomson experimented with a cathode-ray tube, as shown in **Figure 3**. He discovered that a positively charged plate (marked with a positive sign in the illustration) attracts the beam. Thomson concluded that the beam was made of particles with a negative electric charge.

Figure 3 Thomson's Cathode-Ray Tube Experiment



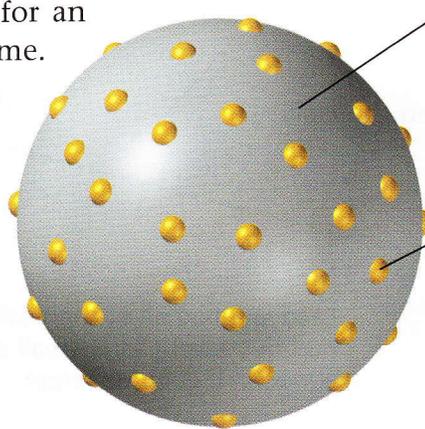
Just What Is Electric Charge?

Have you ever rubbed a balloon on your hair? The properties of your hair and the balloon seem to change, making them attract one another. To describe these observations, scientists say that the balloon and your hair become "charged." There are two types of electric charges—positive and negative. Objects with opposite charges attract each other, while objects with the same charge push each other away.

Negative Corpuscles Thomson repeated his experiment several times and found that the particle beam behaved in exactly the same way each time. He called the particles in the beam corpuscles (KOR PUHS uhls). His results led him to conclude that corpuscles are present in every type of atom and that all corpuscles are identical. The negatively charged particles found in all atoms are now called **electrons**.

Like Plums in a Pudding Thomson revised the atomic theory to account for the presence of electrons. Because Thomson knew that atoms have no overall charge, he realized that positive charges must be present to balance the negative charges of the electrons. But Thomson didn't know the location of the electrons or of the positive charges. So he proposed a model to describe a possible structure of the atom. A **model** is a representation of an object or system. A model is different from a theory in that a model presents a picture of what the theory explains.

Thomson's model, illustrated in **Figure 4**, came to be known as the plum-pudding model, named for an English dessert that was popular at the time. Today you might call Thomson's model the chocolate-chip-ice-cream model; electrons in the atom could be compared to the chocolate chips found throughout the ice cream!



The atom is mostly positively charged material.

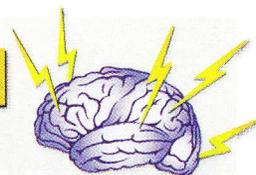
Electrons are small, negatively charged particles located throughout the positive material.

Figure 4 Thomson's plum-pudding model of the atom is shown above. A modern version of Thomson's model might be chocolate-chip ice cream.

REVIEW

1. What discovery demonstrated that atoms are not the smallest particles?
2. What did Dalton do in developing his theory that Democritus did not do?
3. **Analyzing Methods** Why was it important for Thomson to repeat his experiment?

BRAIN FOOD



The word *electron* comes from a Greek word meaning "amber." A piece of amber (the solidified sap from ancient trees) attracts small bits of paper after being rubbed with cloth.

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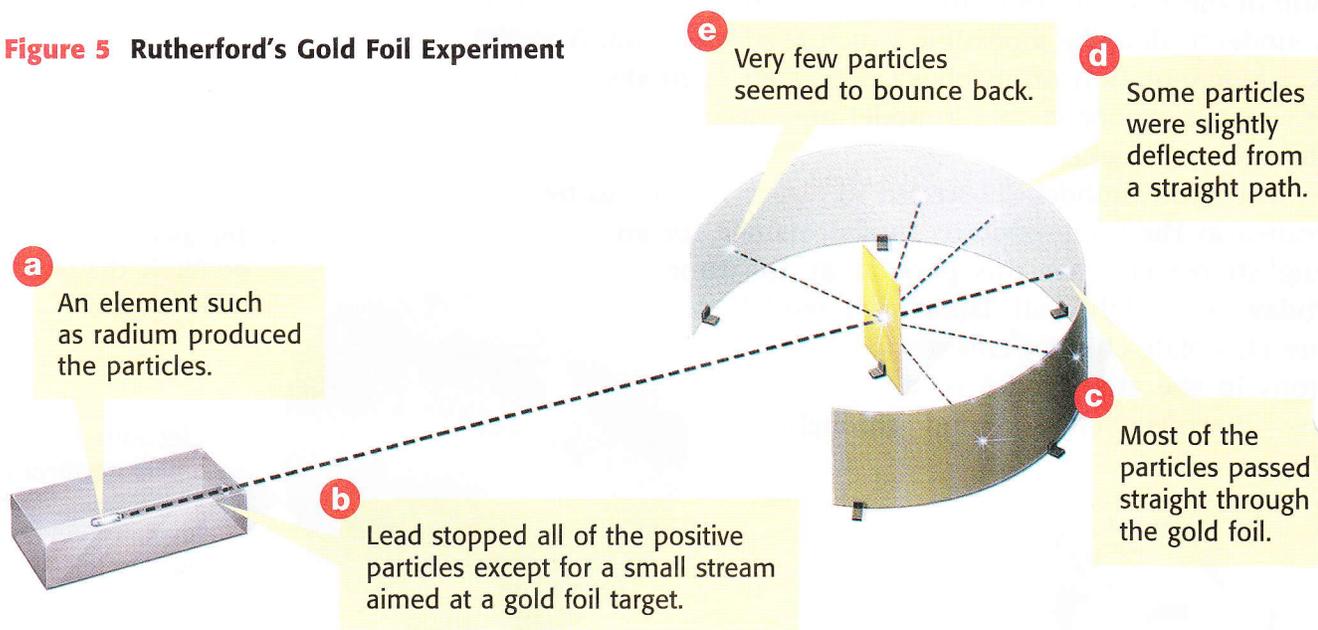
Rutherford Opens an Atomic “Shooting Gallery”



Find out about Melissa Franklin, a modern atom explorer, on page 299.

In 1909, a former student of Thomson’s named Ernest Rutherford decided to test Thomson’s theory. He designed an experiment to investigate the structure of the atom. He aimed a beam of small, positively charged particles at a thin sheet of gold foil. These particles were larger than *protons*, even smaller positive particles identified in 1902. **Figure 5** shows a diagram of Rutherford’s experiment. To find out where the particles went after being “shot” at the gold foil, Rutherford surrounded the foil with a screen coated with zinc sulfide, a substance that glowed when struck by the particles.

Figure 5 Rutherford’s Gold Foil Experiment



Rutherford Gets Surprising Results Rutherford thought that if atoms were soft “blobs” of material, as suggested by Thomson, then the particles would pass through the gold and continue in a straight line. Most of the particles did just that. But to Rutherford’s great surprise, some of the particles were deflected (turned to one side) a little, some were deflected a great deal, and some particles seemed to bounce back. Rutherford reportedly said,

“It was quite the most incredible event that has ever happened to me in my life. It was almost as if you fired a fifteen-inch shell into a piece of tissue paper and it came back and hit you.”

Rutherford Presents a New Atomic Model Rutherford realized that the plum-pudding model of the atom did not explain his results. In 1911, he revised the atomic theory and developed a new model of the atom, as shown in **Figure 6**. To explain the deflection of the particles, Rutherford proposed that in the center of the atom is a tiny, extremely dense, positively charged region called the **nucleus** (NOO klee uhs). Most of the atom's mass is concentrated here. Rutherford reasoned that positively charged particles that passed close by the nucleus were pushed away by the positive charges in the nucleus. A particle that headed straight for a nucleus would be pushed almost straight back in the direction from which it came. From his results, Rutherford calculated that the diameter of the nucleus was 100,000 times smaller than the diameter of the gold atom. To imagine how small this is, look at **Figure 7**.

Figure 6
Rutherford's Model of the Atom

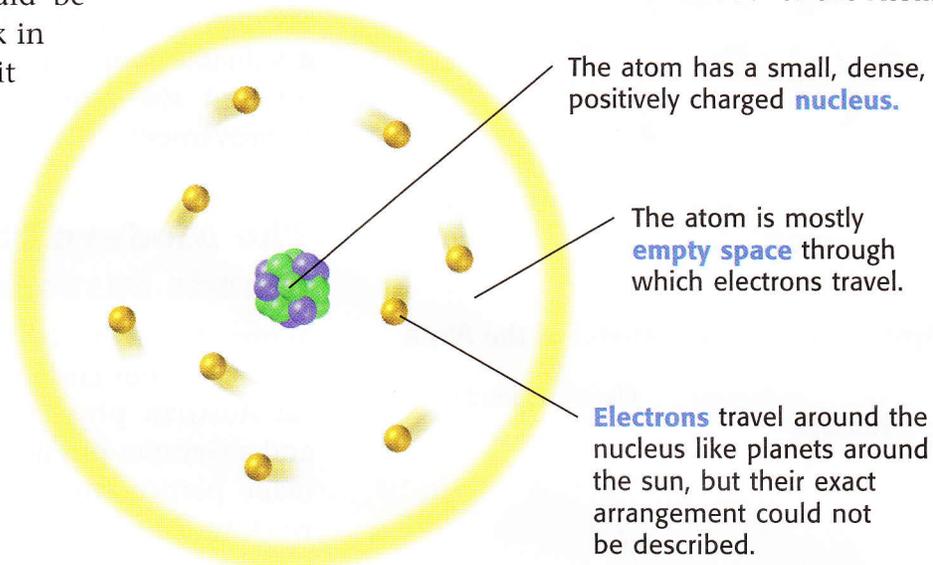


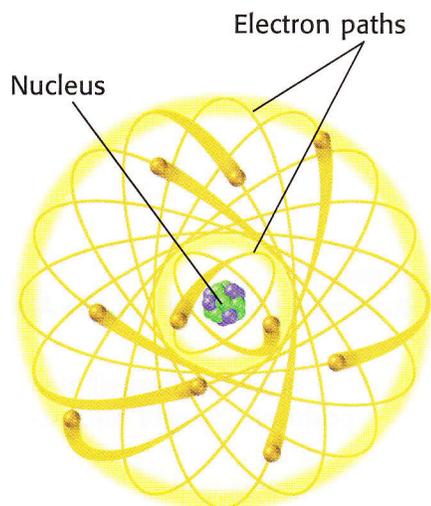
Figure 7 The diameter of this pinhead is 100,000 times smaller than the diameter of the stadium.



Self-Check

Why did Thomson think the atom contains positive charges? (See page 724 to check your answer.)

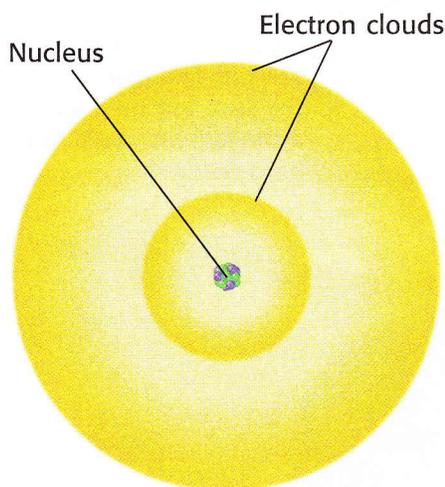
Figure 8 Bohr's Model of the Atom



Bohr States That Electrons Can Jump Between Levels

In 1913, Niels Bohr, a Danish scientist who worked with Rutherford, suggested that electrons travel around the nucleus in definite paths. These paths are located in levels at certain distances from the nucleus, as illustrated in **Figure 8**. Bohr proposed that no paths are located between the levels, but electrons can jump from a path in one level to a path in another level. Think of the levels as rungs on a ladder. You can stand *on* the rungs of a ladder but not *between* the rungs. Bohr's model was a valuable tool in predicting some atomic behavior, but the atomic theory still had room for improvement.

Figure 9 The Current Model of the Atom



The Modern Theory: Electron Clouds Surround the Nucleus

Many twentieth-century scientists have contributed to our current understanding of the atom. An Austrian physicist named Erwin Schrödinger and a German physicist named Werner Heisenberg made particularly important contributions. Their work further explained the nature of electrons in the atom. For example, electrons do not travel in definite paths as Bohr suggested. In fact, the exact path of a moving electron cannot be predicted. According to the current theory, there are regions inside the atom where electrons are *likely* to be found—these regions are called **electron clouds**. Electron clouds are related to the paths described in Bohr's model. The electron-cloud model of the atom is illustrated in **Figure 9**.

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REVIEW

1. In what part of an atom is most of its mass located?
2. What are two differences between the atomic theory described by Thomson and that described by Rutherford?
3. **Comparing Concepts** Identify the difference in how Bohr's theory and the modern theory describe the location of electrons.

Terms to Learn

protons
atomic mass unit
neutrons
atomic number
isotopes
mass number
atomic mass

What You'll Do

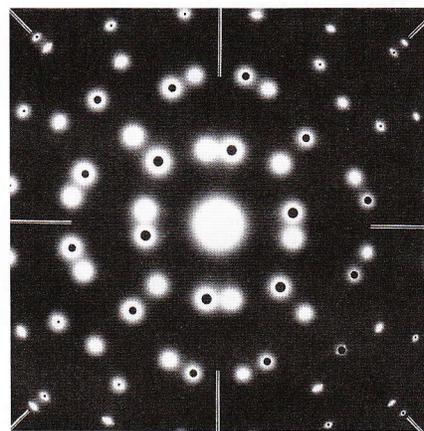
- ◆ Compare the charge, location, and relative mass of protons, neutrons, and electrons.
- ◆ Calculate the number of particles in an atom using the atomic number, mass number, and overall charge.
- ◆ Calculate the atomic mass of elements.

The Atom

In the last section, you learned how the atomic theory developed through centuries of observation and experimentation. Now it's time to learn about the atom itself. In this section, you'll learn about the particles inside the atom, and you'll learn about the forces that act on those particles. But first you'll find out just how small an atom really is.

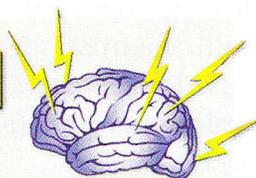
How Small Is an Atom?

The photograph below shows the pattern that forms when a beam of electrons is directed at a sample of aluminum. By analyzing this pattern, scientists can determine the size of an atom. Analysis of similar patterns for many elements has shown that aluminum atoms, which are average-sized atoms, have a diameter of about 0.00000003 cm. That's three hundred-millionths of a centimeter. That is so small that it would take a stack of 50,000 aluminum atoms to equal the thickness of a sheet of aluminum foil from your kitchen!



As another example, consider an ordinary penny. Believe it or not, a penny contains about 2×10^{22} atoms, which can be written as 20,000,000,000,000,000,000 atoms, of copper and zinc. That's twenty thousand billion billion atoms—over 3,000,000,000,000 times more atoms than there are people on Earth! So if there are that many atoms in a penny, each atom must be very small. You can get a better idea of just how small an atom is in **Figure 10**.

BRAIN FOOD



The size of atoms varies widely. Helium atoms have the smallest diameter, and francium atoms have the largest diameter. In fact, about 600 atoms of helium would fit in the space occupied by a single francium atom!

Figure 10 If you could enlarge a penny until it was as wide as the continental United States, each of its atoms would be only about 3 cm in diameter—about the size of this table-tennis ball.



What's Inside an Atom?

As tiny as an atom is, it consists of even smaller particles—protons, neutrons, and electrons—as shown in the model in **Figure 11**. (The particles represented in the figures are not shown in their correct proportions because the electrons would be too small to see.)

Figure 11 Parts of an Atom

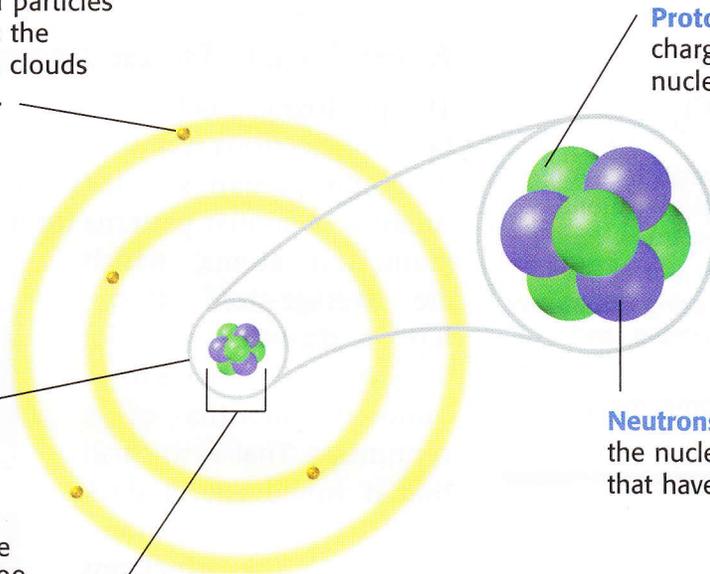
Electrons are negatively charged particles found in electron clouds outside the nucleus. The size of the electron clouds determines the size of the atom.

The **nucleus** is the small, dense, positively charged center of the atom. It contains most of the atom's mass.

The diameter of the nucleus is $1/100,000$ the diameter of the atom.

Protons are positively charged particles in the nucleus of an atom.

Neutrons are particles in the nucleus of an atom that have no charge.



The Nucleus **Protons** are the positively charged particles of the nucleus. It was these particles that repelled Rutherford's "bullets." All protons are identical. The mass of a proton is approximately 1.7×10^{-24} g, which can also be written as 0.0000000000000000000000017 g. Because the masses of particles in atoms are so small, scientists developed a new unit for them. The SI unit used to express the masses of particles in atoms is the **atomic mass unit (amu)**. Scientists assign each proton a mass of 1 amu.

Neutrons are the particles of the nucleus that have no charge. All neutrons are identical. Neutrons are slightly more massive than protons, but the difference in mass is so small that neutrons are also given a mass of 1 amu.

Protons and neutrons are the most massive particles in an atom, yet the nucleus has a very small volume. So the nucleus is very dense. If it were possible to have a nucleus the volume of an average grape, that nucleus would have mass greater than 9 million metric tons!



Proton Profile

Charge: positive

Mass: 1 amu

Location: nucleus



Neutron Profile

Charge: none

Mass: 1 amu

Location: nucleus

Outside of the Nucleus Electrons are the negatively charged particles in atoms. Electrons are likely to be found around the nucleus within electron clouds. The charges of protons and electrons are opposite but equal in size. An atom is neutral (has no overall charge) because there are equal numbers of protons and electrons, so their charges cancel out. If the numbers of electrons and protons are not equal, the atom becomes a charged particle called an *ion* (IE ahn). Ions are positively charged if the protons outnumber the electrons, and they are negatively charged if the electrons outnumber the protons.

Electrons are very small in mass compared with protons and neutrons. It takes more than 1,800 electrons to equal the mass of 1 proton. In fact, the mass of an electron is so small that it is usually considered to be zero.

Electron Profile

Charge: negative

Mass: almost zero

Location: electron clouds

REVIEW

1. What particles form the nucleus?
2. Explain why atoms are neutral.
3. **Summarizing Data** Why do scientists say that most of the mass of an atom is located in the nucleus?



Help wanted! Elements-4-U needs qualified nucleus builders. Report to page 676 of the LabBook.

How Do Atoms of Different Elements Differ?

There are over 110 different elements, each of which is made of different atoms. What makes atoms different from each other? To find out, imagine that it's possible to "build" an atom by putting together protons, neutrons, and electrons.

Starting Simply It's easiest to start with the simplest atom. Protons and electrons are found in all atoms, and the simplest atom consists of just one of each. It's so simple it doesn't even have a neutron. Put just one proton in the center of the atom for the nucleus. Then put one electron in the electron cloud, as shown in the model in **Figure 12**. Congratulations! You have just made the simplest atom—a hydrogen atom.

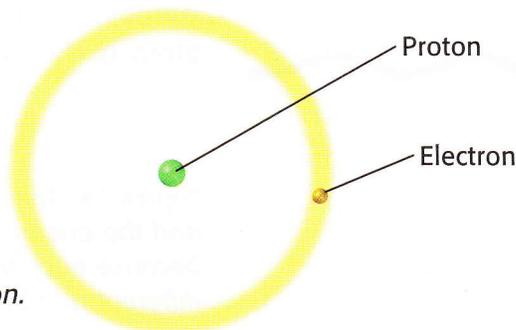
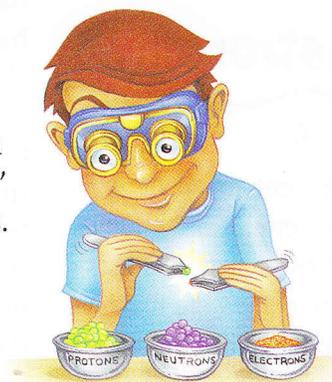
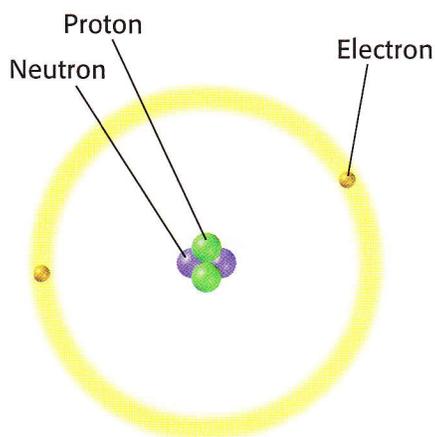


Figure 12 The simplest atom has one proton and one electron.

Figure 13 A helium nucleus must have neutrons in it to keep the protons from moving apart.



Now for Some Neutrons Now build an atom containing two protons. Both of the protons are positively charged, so they repel one another. You cannot form a nucleus with them unless you add some neutrons. For this atom, two neutrons will do. Your new atom will also need two electrons outside the nucleus, as shown in the model in **Figure 13**. This is an atom of the element helium.

Building Bigger Atoms You could build a carbon atom using 6 protons, 6 neutrons, and 6 electrons; or you could build an oxygen atom using 8 protons, 9 neutrons, and 8 electrons. You could even build a gold atom with 79 protons, 118 neutrons, and 79 electrons! As you can see, an atom does not have to have equal numbers of protons and neutrons.

The Number of Protons Determines the Element How can you tell which elements these atoms represent? The key is the number of protons. The number of protons in the nucleus of an atom is the **atomic number** of that atom. All atoms of an element have the same atomic number. Every hydrogen atom has only one proton in its nucleus, so hydrogen has an atomic number of 1. Every carbon atom has six protons in its nucleus, so carbon has an atomic number of 6.

Are All Atoms of an Element the Same?

Back in the atom-building workshop, you make an atom that has one proton, one electron, and one neutron, as shown in **Figure 14**. The atomic number of this new atom is 1, so the atom is hydrogen. However, this hydrogen atom's nucleus has two particles; therefore, this atom has a greater mass than the first hydrogen atom you made. What you have is another isotope (IE suh TOHP) of hydrogen. **Isotopes** are atoms that have the same number of protons but have different numbers of neutrons. Atoms that are isotopes of each other are always the same element because the number of protons in each atom is the same.

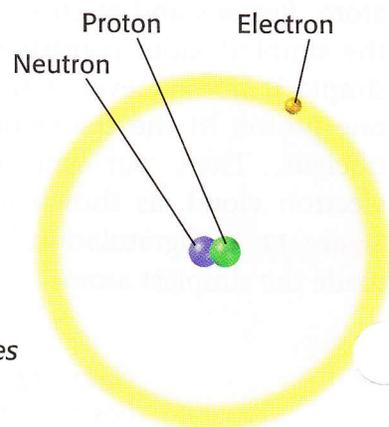


Figure 14 The atom in this model and the one in Figure 12 are isotopes because each has one proton but a different number of neutrons.

Astronomy CONNECTION

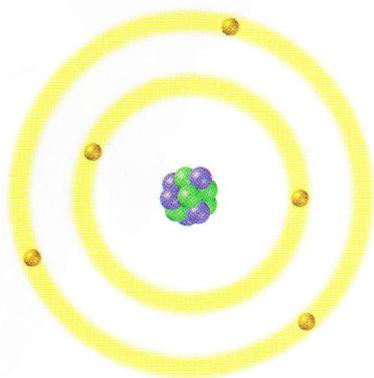
Hydrogen is the most abundant element in the universe. It is the fuel for the sun and other stars. It is currently believed that there are roughly 2,000 times more hydrogen atoms than oxygen atoms and 10,000 times more hydrogen atoms than carbon atoms.

Properties of Isotopes Each element has a limited number of isotopes that occur naturally. Some isotopes of an element have unique properties because they are unstable. An unstable atom is an atom whose nucleus can change its composition. This type of isotope is *radioactive*. However, isotopes of an element share most of the same chemical and physical properties. For example, the most common oxygen isotope has 8 neutrons in the nucleus, but other isotopes have 9 or 10 neutrons. All three isotopes are colorless, odorless gases at room temperature. Each isotope has the chemical property of combining with a substance as it burns and even behaves the same in chemical changes in your body.

How Can You Tell One Isotope from Another?

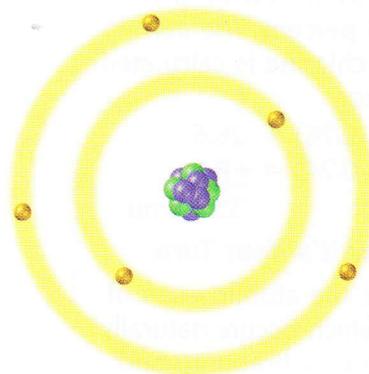
You can identify each isotope of an element by its mass number. The **mass number** is the sum of the protons and neutrons in an atom. Electrons are not included in an atom's mass number because their mass is so small that they have very little effect on the atom's total mass. Look at the boron isotope models shown in **Figure 15** to see how to calculate an atom's mass number.

Figure 15 Each of these boron isotopes has five protons. But because each has a different number of neutrons, each has a different mass number.



Protons: 5
Neutrons: 5
Electrons: 5

Mass number = protons + neutrons = 10



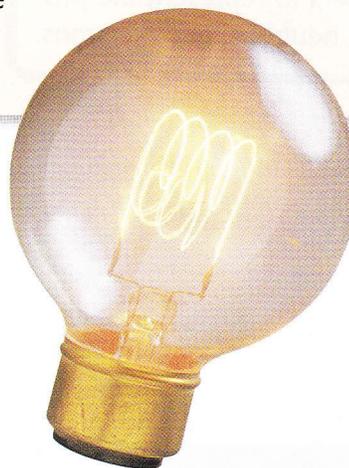
Protons: 5
Neutrons: 6
Electrons: 5

Mass number = protons + neutrons = 11

APPLY

Isotopes and Light Bulbs

Oxygen reacts, or undergoes a chemical change, with the hot filament in a light bulb, quickly burning out the bulb. Argon does not react with the filament, so a light bulb filled with argon burns out more slowly than one filled with oxygen. Do all three naturally-occurring isotopes of argon have the same effect in light bulbs? Explain your reasoning.



Activity

Draw diagrams of hydrogen-2, helium-3, and carbon-14. Show the correct number and location of each type of particle. For the electrons, simply write the total number of electrons in the electron cloud. Use colored pencils or markers to represent the protons, neutrons, and electrons.

TRY at HOME

Naming Isotopes To identify a specific isotope of an element, write the name of the element followed by a hyphen and the mass number of the isotope. A hydrogen atom with one proton and no neutrons has a mass number of 1. Its name is hydrogen-1. Hydrogen-2 has one proton and one neutron. The carbon isotope with a mass number of 12 is called carbon-12. If you know that the atomic number for carbon is 6, you can calculate the number of neutrons in carbon-12 by subtracting the atomic number from the mass number. For carbon-12, the number of neutrons is $12 - 6$, or 6.

12	Mass number
-6	Number of protons (atomic number)
6	Number of neutrons

Calculating the Mass of an Element

Most elements found in nature contain a mixture of two or more stable (nonradioactive) isotopes. For example, all copper is composed of copper-63 atoms and copper-65 atoms. The term *atomic mass* describes the mass of a mixture of isotopes.

Atomic mass is the weighted average of the masses of all the naturally occurring isotopes of an element. A weighted average accounts for the percentages of each isotope that are present. Copper, including the copper in the Statue of Liberty (shown in **Figure 16**), is 69 percent copper-63 and 31 percent copper-65. The atomic mass of copper is 63.6 amu. You can try your hand at calculating atomic mass by doing the MathBreak at left.



Figure 16 The copper used to make the Statue of Liberty includes both copper-63 and copper-65. Copper's atomic mass is 63.6 amu.

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MATH BREAK

Atomic Mass

To calculate the atomic mass of an element, multiply the mass number of each isotope by its percentage abundance in decimal form. Then add these amounts together to find the atomic mass. For example, chlorine-35 makes up 76 percent (its percentage abundance) of all the chlorine in nature, and chlorine-37 makes up the other 24 percent. The atomic mass of chlorine is calculated as follows:

$$\begin{aligned}(35 \times 0.76) &= 26.6 \\ (37 \times 0.24) &= +8.9 \\ &35.5 \text{ amu}\end{aligned}$$

Now It's Your Turn

Calculate the atomic mass of boron, which occurs naturally as 20 percent boron-10 and 80 percent boron-11.

What Forces Are at Work in Atoms?

You have seen how atoms are composed of protons, neutrons, and electrons. But what are the *forces* (the pushes or pulls between two objects) acting between these particles? Four basic forces are at work everywhere, including within the atom—gravity, the electromagnetic force, the strong force, and the weak force. These forces are discussed below.

Forces in the Atom

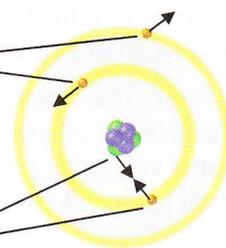
Gravity Probably the most familiar of the four forces is *gravity*. Gravity acts between all objects all the time. The amount of gravity between objects depends on their masses and the distance between them. Gravity pulls objects, such as the sun, Earth, cars, and books, toward one another. However, because the masses of particles in atoms are so small, the force of gravity within atoms is very small.



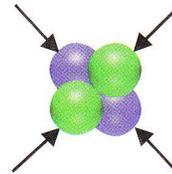
Electromagnetic Force As mentioned earlier, objects that have the same charge repel each other, while objects with opposite charge attract each other. This is due to the *electromagnetic force*. Protons and electrons are attracted to each other because they have opposite charges. The electromagnetic force holds the electrons around the nucleus.

Particles with the same charges repel each other.

Particles with opposite charges attract each other.



Strong Force Protons push away from one another because of the electromagnetic force. A nucleus containing two or more protons would fly apart if it were not for the *strong force*. At the close distances between protons in the nucleus, the strong force is greater than the electromagnetic force, so the nucleus stays together.



Weak Force The *weak force* is an important force in radioactive atoms. In certain unstable atoms, a neutron can change into a proton and an electron. The weak force plays a key role in this change.



REVIEW

1. List the charge, location, and mass of a proton, a neutron, and an electron.
2. Determine the number of protons, neutrons, and electrons in an atom of aluminum-27.
3. **Doing Calculations** The metal thallium occurs naturally as 30 percent thallium-203 and 70 percent thallium-205. Calculate the atomic mass of thallium.

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Chapter Highlights

SECTION 1

Vocabulary

atom (p. 280)

theory (p. 280)

electrons (p. 283)

model (p. 283)

nucleus (p. 285)

electron clouds (p. 286)

Section Notes

- Atoms are the smallest particles of an element that retain the properties of the element
- In ancient Greece, Democritus argued that atoms were the smallest particles in all matter.

- Dalton proposed an atomic theory that stated the following: Atoms are small particles that make up all matter; atoms cannot be created, divided, or destroyed; atoms of an element are exactly alike; atoms of different elements are different; and atoms join together to make new substances.



- Thomson discovered electrons. His plum-pudding model described the atom as a lump of positively charged material with negative electrons scattered throughout.
- Rutherford discovered that atoms contain a small, dense, positively charged center called the nucleus.
- Bohr suggested that electrons move around the nucleus at only certain distances.
- According to the current atomic theory, electron clouds are where electrons are most likely to be in the space around the nucleus.

Skills Check

Math Concepts

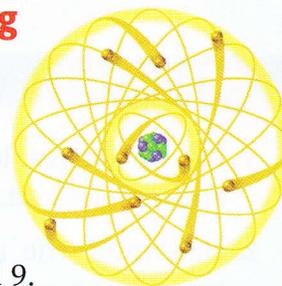
ATOMIC MASS The atomic mass of an element takes into account the mass of each isotope and the percentage of the element that exists as that isotope. For example, magnesium occurs naturally as 79 percent magnesium-24, 10 percent magnesium-25, and 11 percent magnesium-26. The atomic mass is calculated as follows:

$$\begin{array}{r} (24 \times 0.79) = 19.0 \\ (25 \times 0.10) = 2.5 \\ (26 \times 0.11) = + 2.8 \\ \hline 24.3 \text{ amu} \end{array}$$

Visual Understanding

ATOMIC MODELS

The atomic theory has changed over the past several hundred years. To understand the different models of the atom, look over Figures 2, 4, 6, 8, and 9.



PARTS OF THE ATOM Atoms are composed of protons, neutrons, and electrons. To review the particles and their placement in the atom, study Figure 11 on page 288.

SECTION 2

Vocabulary

protons (p. 288)

atomic mass unit (p. 288)

neutrons (p. 288)

atomic number (p. 290)

isotopes (p. 290)

mass number (p. 291)

atomic mass (p. 292)

Section Notes

- A proton is a positively charged particle with a mass of 1 amu.
- A neutron is a particle with no charge that has a mass of 1 amu.
- An electron is a negatively charged particle with an extremely small mass.

- Protons and neutrons make up the nucleus. Electrons are found in electron clouds outside the nucleus.
- The number of protons in the nucleus of an atom is the atomic number. The atomic number identifies the atoms of a particular element.
- Isotopes of an atom have the same number of protons but have different numbers of neutrons. Isotopes share most of the same chemical and physical properties.
- The mass number of an atom is the sum of the atom's neutrons and protons.
- The atomic mass is an average of the masses of all naturally occurring isotopes of an element.
- The four forces at work in an atom are gravity, the electromagnetic force, the strong force, and the weak force.

Labs

Made to Order (p. 676)



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Visit the **HRW** Web site for a variety of learning tools related to this chapter. Just type in the keyword:

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TOPIC: Development of the Atomic Theory

TOPIC: Modern Atomic Theory

TOPIC: Inside the Atom

TOPIC: Isotopes

sciLINKS NUMBER: HSTP255

sciLINKS NUMBER: HSTP260

sciLINKS NUMBER: HSTP265

sciLINKS NUMBER: HSTP270

Chapter Review

USING VOCABULARY

The statements below are false. For each statement, replace the underlined word to make a true statement.

1. Electrons are found in the nucleus of an atom.
2. All atoms of the same element contain the same number of neutrons.
3. Protons have no electric charge.
4. The atomic number of an element is the number of protons and neutrons in the nucleus.
5. The mass number is an average of the masses of all naturally occurring isotopes of an element.

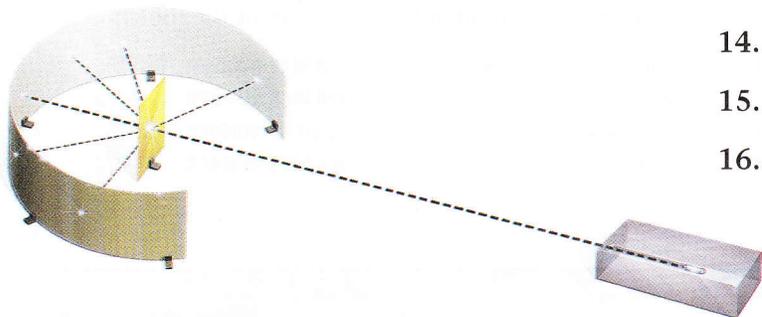
UNDERSTANDING CONCEPTS

Multiple Choice

6. The discovery of which particle proved that the atom is not indivisible?
a. proton c. electron
b. neutron d. nucleus
7. In his gold foil experiment, Rutherford concluded that the atom is mostly empty space with a small, massive, positively charged center because
a. most of the particles passed straight through the foil.
b. some particles were slightly deflected.
c. a few particles bounced back.
d. All of the above
8. How many protons does an atom with an atomic number of 23 and a mass number of 51 have?
a. 23 c. 51
b. 28 d. 74
9. An atom has no overall charge if it contains equal numbers of
a. electrons and protons.
b. neutrons and protons.
c. neutrons and electrons.
d. None of the above
10. Which statement about protons is true?
a. Protons have a mass of 1/1,840 amu.
b. Protons have no charge.
c. Protons are part of the nucleus of an atom.
d. Protons circle the nucleus of an atom.
11. Which statement about neutrons is true?
a. Neutrons have a mass of 1 amu.
b. Neutrons circle the nucleus of an atom.
c. Neutrons are the only particles that make up the nucleus.
d. Neutrons have a negative charge.
12. Which of the following determines the identity of an element?
a. atomic number c. atomic mass
b. mass number d. overall charge
13. Isotopes exist because atoms of the same element can have different numbers of
a. protons. c. electrons.
b. neutrons. d. None of the above

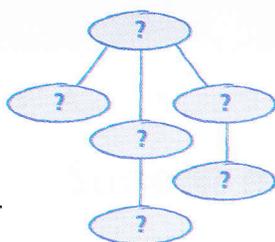
Short Answer

14. Why do scientific theories change?
15. What force holds electrons in atoms?
16. In two or three sentences, describe the plum-pudding model of the atom.



Concept Mapping

17. Use the following terms to create a concept map: atom, nucleus, protons, neutrons, electrons, isotopes, atomic number, mass number.



CRITICAL THINKING AND PROBLEM SOLVING

18. Particle accelerators, like the one shown below, are devices that speed up charged particles in order to smash them together. Sometimes the result of the collision is a new nucleus. How can scientists determine whether the nucleus formed is that of a new element or that of a new isotope of a known element?



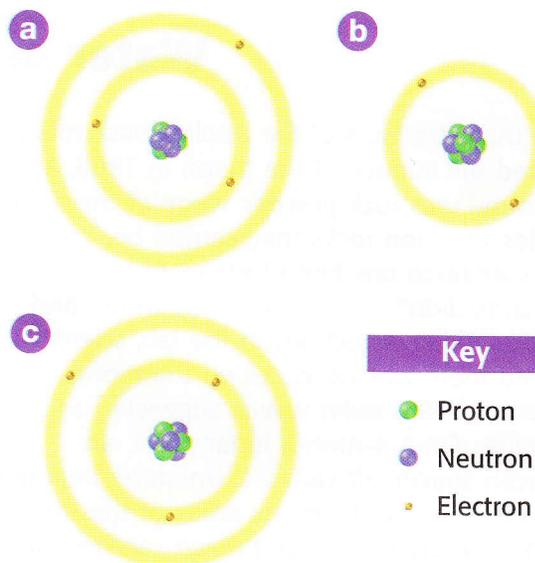
19. John Dalton made a number of statements about atoms that are now known to be incorrect. Why do you think his atomic theory is still found in science textbooks?

MATH IN SCIENCE

20. Calculate the atomic mass of gallium consisting of 60 percent gallium-69 and 40 percent gallium-71.
21. Calculate the number of protons, neutrons, and electrons in an atom of zirconium-90, which has an atomic number of 40.

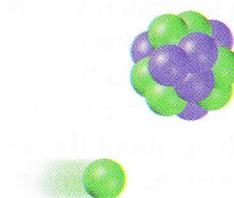
INTERPRETING GRAPHICS

22. Study the models below, and answer the questions that follow:



- a. Which models represent isotopes of the same element?
- b. What is the atomic number for (a)?
- c. What is the mass number for (b)?

23. Predict how the direction of the moving particle in the figure below will change, and explain what causes the change to occur.



NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 279. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

Water on the Moon?

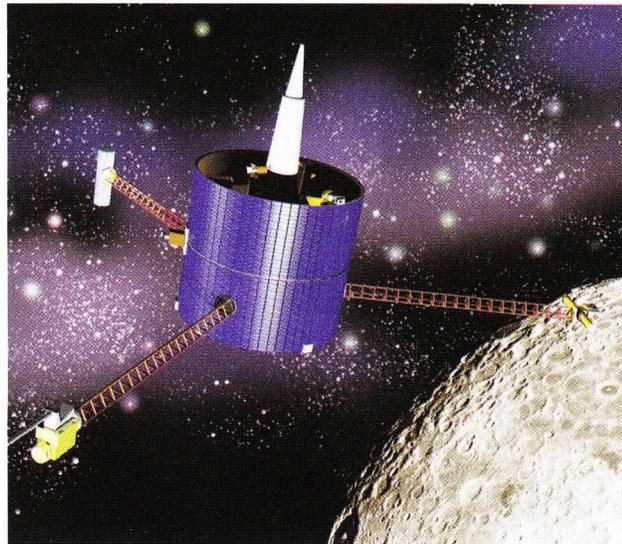
When the astronauts of the Apollo space mission explored the surface of the moon in 1969, all they found was rock powder. None of the many samples of moon rocks they carried back to Earth contained any hint of water. Because the astronauts didn't see water on the moon and scientists didn't detect any in the lab, scientists believed there was no water on the moon.

Then in 1994, radio waves suggested another possibility. On a 4-month lunar jaunt, an American spacecraft called *Clementine* beamed radio waves toward various areas of the moon, including a few craters that never receive sunlight. Mostly, the radio waves were reflected by what appeared to be ground-up rock. However, in part of one huge, dark crater, the radio waves were reflected as if by . . . ice.

Hunting for Hydrogen Atoms

Scientists were intrigued by *Clementine's* evidence. Two years later, another spacecraft, *Lunar Prospector*, traveled to the moon. Instead of trying to detect water with radio waves, *Prospector* scanned the moon's surface with a device called a *neutron spectrometer* (NS). A neutron spectrometer counts the number of slow neutrons bouncing off a surface. When a neutron hits something about the same mass as itself, it slows down. As it turns out, the only thing close to the mass of a neutron is an *atom* of the lightest of all elements, hydrogen. So when the NS located high concentrations of slow-moving neutrons on the moon, it indicated to scientists that the neutrons were crashing into hydrogen atoms.

As you know, water consists of two atoms of hydrogen and one atom of oxygen. The presence of hydrogen atoms on the moon is more evidence that water may exist there.



▲ The Lunar Prospector spacecraft may have found water on the moon.

How Did It Get There?

Some scientists speculate that the water molecules came from comets (which are 90 percent water) that hit the moon more than 4 billion years ago. Water from comets may have landed in the frigid, shadowed craters of the moon, where it mixed with the soil and froze. The Aitken Basin, at the south pole of the moon, where much of the ice was detected, is more than 12 km deep in places. Sunlight never touches most of the crater. And it is very cold—temperatures there may fall to -229°C . The conditions seem right to lock water into place for a very long time.

Think About Lunar Life

► Do some research on conditions on the moon. What conditions would humans have to overcome before we could establish a colony there?