SECTION 2

The Atom

Atoms are very small, and atoms are made up of even smaller things. But you can still learn a lot about the parts that make up an atom and what holds an atom together.

In this section, you'll learn about how atoms are alike and how they are different. But first you'll find out just how small an atom really is.

How Small Is an Atom?

Think about a penny. A penny contains about 2×10^{22} atoms (which can be written as 20,000,000,000,000,000,000,000 atoms) of copper and zinc. That's 20 thousand billion billion atoms—over 3,000,000,000,000 times more atoms than there are people on Earth! If there are that many atoms in a penny, each atom must be very small.

Scientists know that aluminum is made of average-sized atoms. An aluminum atom has a diameter of about 0.00000003 cm. That's three one-hundred-millionths of a centimeter. Take a look at **Figure 1.** Even things that are very thin, such as aluminum foil, are made up of very large numbers of atoms.

Figure 1 *This aluminum foil might seem thin to you. But it is about 50,000 atoms thick!*

READING WARM-UP

Objectives

- Describe the size of an atom.
- Name the parts of an atom.
- Describe the relationship between numbers of protons and neutrons and atomic number.
- State how isotopes differ.
- Calculate atomic masses.
- Describe the forces within an atom.

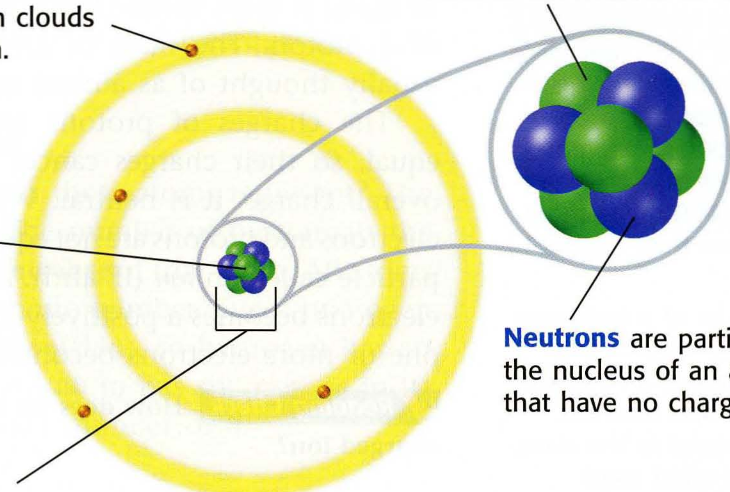
Terms to Learn

proton	atomic number
atomic mass unit	isotope
neutron	mass number
	atomic mass

READING STRATEGY

Reading Organizer As you read this section, make a concept map by using the terms above.

Figure 2 **Parts of an Atom**



What Is an Atom Made Of?

As tiny as an atom is, it is made up of even smaller particles. These particles are protons, neutrons, and electrons, shown in the model in **Figure 2.** (The particles in the pictures are not shown in their correct proportions. If they were, the electrons would be too small to see.)

The Nucleus

Protons are positively charged particles in the nucleus. The mass of a proton is about 1.7×10^{-24} g. This number can also be written as 0.0000000000000000000000017 g. Because the masses of particles in atoms are so small, scientists made a new unit for them. The SI unit used to express the masses of particles in atoms is the **atomic mass unit** (amu). Each proton has a mass of about 1 amu.

Neutrons are the particles of the nucleus that have no electrical charge. Neutrons are a little more massive than protons are. But the difference in mass is so small that the mass of a neutron can be thought of as 1 amu.

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

Reading Check **Name the two kinds of particles that can be found in the nucleus.** (*See the Appendix for answers to Reading Checks.*)

proton a subatomic particle that has a positive charge and that is found in the nucleus of an atom

atomic mass unit a unit of mass that describes the mass of an atom or molecule

neutron a subatomic particle that has no charge and that is found in the nucleus of an atom

Outside the Nucleus

Electrons are the negatively charged particles in atoms. Electrons are found around the nucleus within electron clouds. Compared with protons and neutrons, electrons are very small in mass. It takes more than 1,800 electrons to equal the mass of 1 proton. The mass of an electron is so small that it is usually thought of as almost zero.

The charges of protons and electrons are opposite but equal, so their charges cancel out. Because an atom has no overall charge, it is neutral. What happens if the numbers of electrons and protons are not equal? The atom becomes a charged particle called an *ion* (IE ahn). An atom that loses one or more electrons becomes a positively-charged ion. An atom that gains one or more electrons becomes a negatively-charged ion.

Reading Check **How does an atom become a positively-charged ion?**

CONNECTION TO Astronomy

Hydrogen 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.

Make a model of a hydrogen atom using materials of your choice to represent a hydrogen atom's proton and electron. Present the model to the class, and explain in what ways your model resembles a hydrogen atom.

ACTIVITY

How Do Atoms of Different Elements Differ?

There are more than 110 different elements. The atoms of each of these elements are different from the atoms of all other elements. What makes atoms different from each other? To find out, imagine that you could 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. The simplest atom is made of just one of each. It's so simple it doesn't even have a neutron. To "build" this atom, put just one proton in the center of the atom for the nucleus. Then, put one electron in the electron cloud. Congratulations! You have just made a hydrogen atom.

Now for Some Neutrons

Now, build an atom that has 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. To have a neutral charge, your new atom will also need two electrons outside the nucleus. What you have is an atom of the element helium. A model of this atom is shown in **Figure 3.**

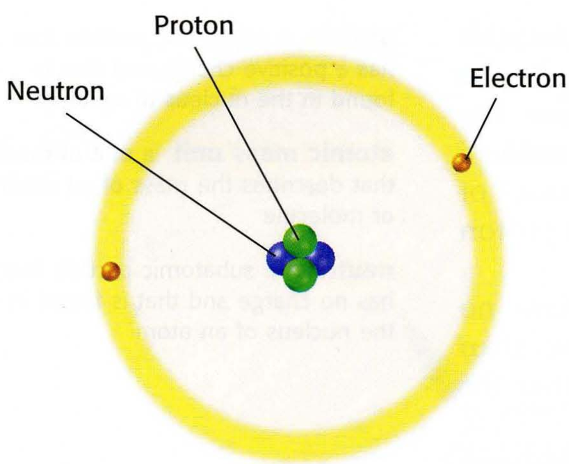


Figure 3 *A helium nucleus must have neutrons in it to keep the protons from moving apart.*

Building Bigger Atoms

You could build a carbon atom using 6 protons, 6 neutrons, and 6 electrons. 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.

Protons and Atomic Number

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.

INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HP5ATSW.**

Isotopes

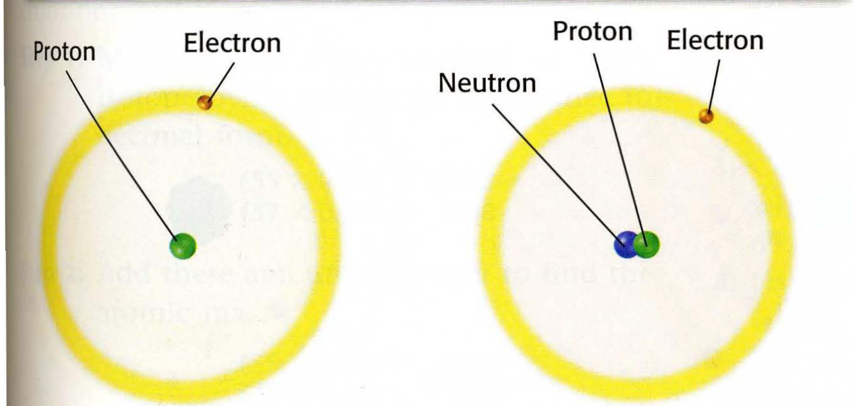
An atom that has one proton, one electron, and one neutron is shown in **Figure 4.** The atomic number of this new atom is 1, so the atom is hydrogen. However, this hydrogen atom's nucleus has two particles. Therefore, this atom has a greater mass than the hydrogen atom you made.

The new atom 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 isotopes always have the same number of protons. They have different numbers of neutrons, however, which gives them different masses.

atomic number the number of protons in the nucleus of an atom; the atomic number is the same for all atoms of an element

isotope an atom that has the same number of protons (or the same atomic number) as other atoms of the same element do but that has a different number of neutrons (and thus a different atomic mass)

Figure 4 Isotopes of Hydrogen



This isotope is a hydrogen atom that has one proton in its nucleus.

This isotope is a hydrogen atom that has one proton and one neutron in its nucleus.

Properties of Isotopes

Each element has a limited number of isotopes that are found in nature. Some isotopes of an element have special properties because they are unstable. An unstable atom is an atom with a nucleus that will change over time. This type of isotope is *radioactive*. Radioactive atoms spontaneously fall apart after a certain amount of time. As they do, they give off smaller particles, as well as energy.

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. Other isotopes of oxygen 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. Different isotopes of an element even behave the same in chemical changes in your body.

Reading Check **In what cases are differences between isotopes important?**

SCHOOL to HOME

Atomic Diagrams

Explain what you have learned about isotopes to a parent. Together, 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.

ACTIVITY

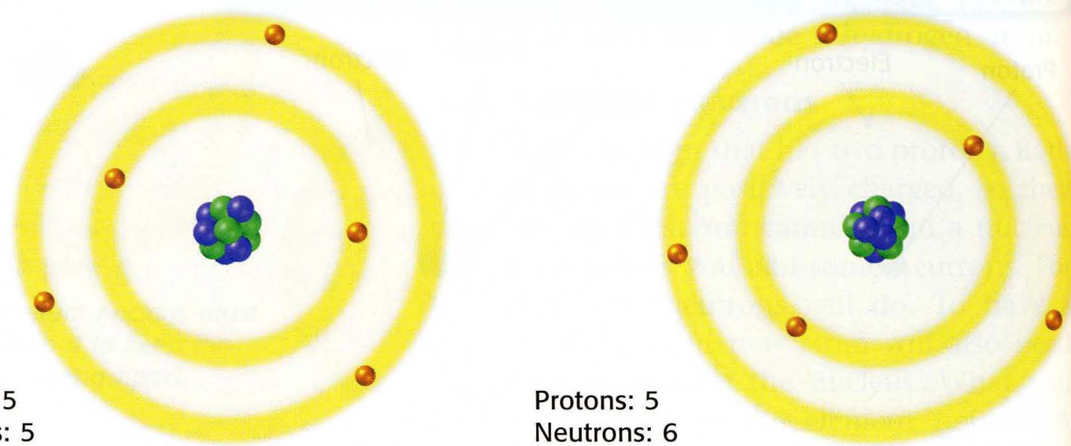
Telling Isotopes Apart

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 5** to see how to calculate an atom's mass number.

mass number the sum of the numbers of protons and neutrons in the nucleus of an atom

Figure 5 **Isotopes of Boron**

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

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

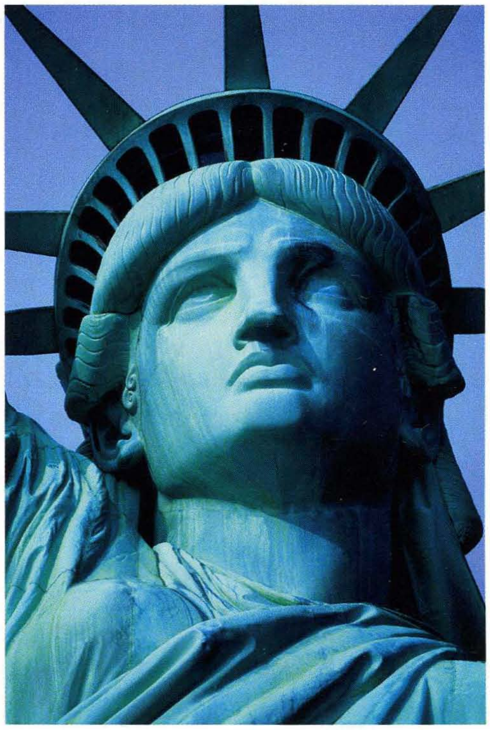


Figure 6 *The copper used to make the Statue of Liberty includes both copper-63 and copper-65. Copper's atomic mass is 63.6 amu.*

Calculating the Mass of an Element

Most elements contain a mixture of two or more isotopes. For example, all copper is composed of copper-63 atoms and copper-65 atoms. The **atomic mass** of an element is the weighted average of the masses of all the naturally occurring isotopes of that 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 6,** is 69% copper-63 and 31% copper-65. The atomic mass of copper is 63.6 amu.

atomic mass the mass of an atom expressed in atomic mass units

MATH FOCUS

Atomic Mass Chlorine-35 makes up 76% of all the chlorine in nature, and chlorine-37 makes up the other 24%. What is the atomic mass of chlorine?

Step 1: Multiply the mass number of each isotope by its percentage abundance in decimal form.

$$(35 \times 0.76) = 26.60$$
$$(37 \times 0.24) = 8.88$$

Step 2: Add these amounts together to find the atomic mass.

$$\begin{aligned}(35 \times 0.76) &= 26.60\\ (37 \times 0.24) &= \underline{+\ 8.88}\\ &\ 35.48 \text{ amu}\end{aligned}$$

Now It's Your Turn

1. Calculate the atomic mass of boron, which occurs naturally as 20% boron-10 and 80% boron-11.
2. Calculate the atomic mass of rubidium, which occurs naturally as 72% rubidium-85 and 28% rubidium-87.
3. Calculate the atomic mass of gallium, which occurs naturally as 60% gallium-69 and 40% gallium-71.
4. Calculate the atomic mass of silver, which occurs naturally as 52% silver-107 and 48% silver-109.
5. Calculate the atomic mass of silicon, which occurs naturally as 92% silicon-28, 5% silicon-29, and 3% silicon-30.

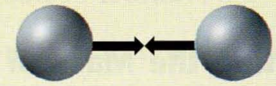
Forces in Atoms

You have seen that atoms are made of smaller particles. But what are the *forces* (the pushes or pulls between objects) acting between these particles? Four basic forces are at work everywhere, even within the atom. These forces are gravitational force, electromagnetic force, strong force, and weak force. These forces work together to give an atom its structure and properties. Look at **Figure 7** to learn about each one.

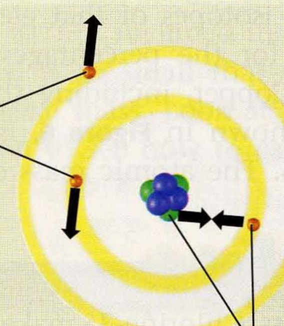
Reading Check **What are the four basic forces at work everywhere in nature?**

Figure 7 **Forces in the Atom**

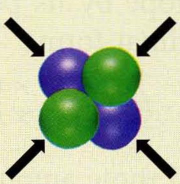
Gravitational Force Probably the most familiar of the four forces is *gravitational force*. Gravitational force acts between all objects all the time. The amount of gravitational force between objects depends on their masses and the distance between them. Gravitational force pulls objects, such as the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



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 and neutrons 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.

SECTION
Review

Summary

- Atoms are extremely small. Ordinary-sized objects are made up of very large numbers of atoms.
- Atoms consist of a nucleus, which has protons and usually neutrons, and electrons, located in electron clouds around the nucleus.
- The number of protons in the nucleus of an atom is that atom's atomic number. All atoms of an element have the same atomic number.
- Different isotopes of an element have different numbers of neutrons in their nuclei. Isotopes of an element share most chemical and physical properties.
- The mass number of an atom is the sum of the atom's neutrons and protons.
- Atomic mass is a weighted average of the masses of natural isotopes of an element.
- The forces at work in an atom are gravitational force, electromagnetic force, strong force, and weak force.

Using Key Terms

1. Use the following terms in the same sentence: *proton, neutron,* and *isotope.*

Complete each of the following sentences by choosing the correct term from the word bank.

atomic mass unit	atomic number
mass number	atomic mass

2. An atom's ___ is equal to the number of protons in its nucleus.

3. An atom's ___ is equal to the weighted average of the masses of all the naturally occurring isotopes of that element.

Understanding Key Ideas

4. Which of the following particles has no electric charge?
   a. proton
   b. neutron
   c. electron
   d. ion

5. Name and describe the four forces that are at work within the nucleus of an atom.

Math Skills

6. The metal thallium occurs naturally as 30% thallium-203 and 70% thallium-205. Calculate the atomic mass of thallium.

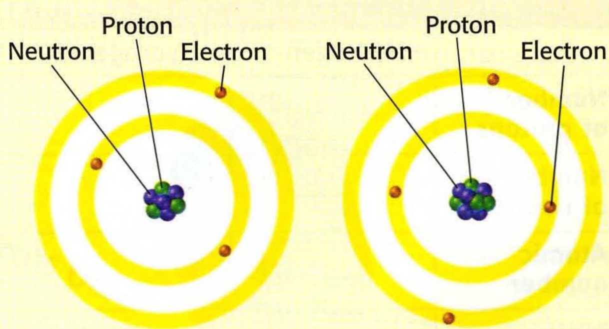
Critical Thinking

7. **Analyzing Ideas** Why is gravitational force in the nucleus so small?

8. **Predicting Consequences** Could a nucleus of more than one proton but no neutrons exist? Explain.

Interpreting Graphics

9. Look at the two atomic models below. Do the two atoms represent different elements or different isotopes? Explain.



For a variety of links related to this chapter, go to www.scilinks.org

Topic: Inside the Atom; Isotopes
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