SECTION 2

READING WARM-UP

The Atom

Terms to Learn

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

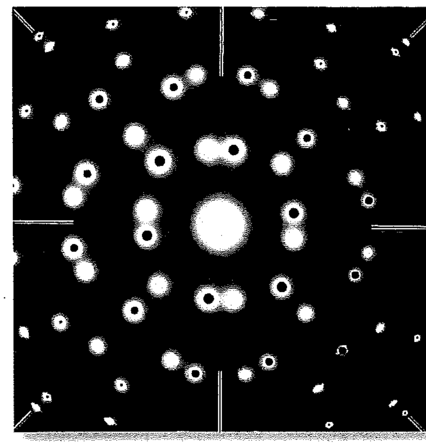
What You'll Do

- 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.

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 20,000,000,000,000,000,000,000 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.**

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!

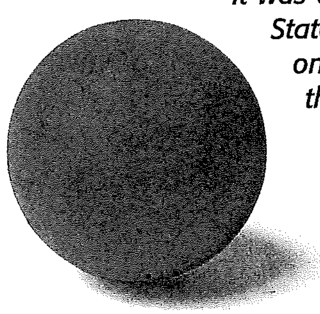
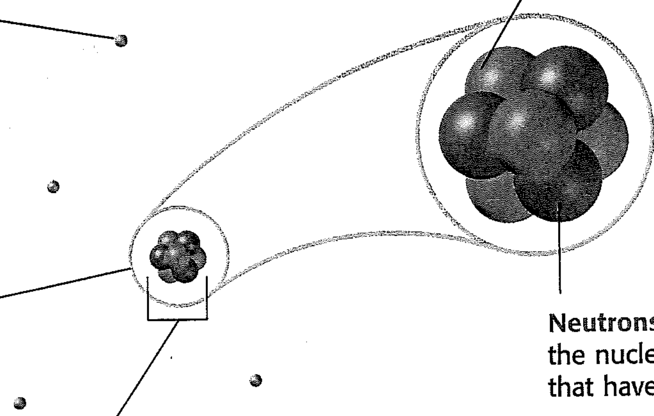


Figure 10 *If you could enlarge a penny until it was as wide as the continental United States, each of its atoms would be only about 3 cm in diameter—about the size of this table-tennis ball.*

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.)

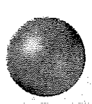
Figure 11 Parts of an Atom



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.

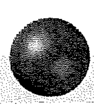
Neutrons are the particles of the nucleus that have no charge. All neutrons are identical. Neutrons are slightly more massive than protons, but the difference in mass is so small that neutrons are also given a mass of 1 amu.

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 a 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

SECTION 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?

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.

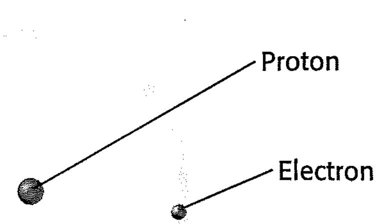
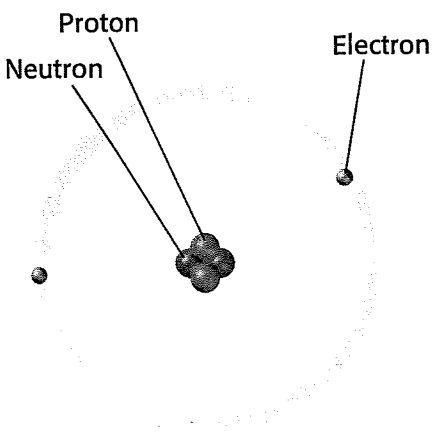


Figure 12 *The simplest atom has one proton and one electron.*

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.

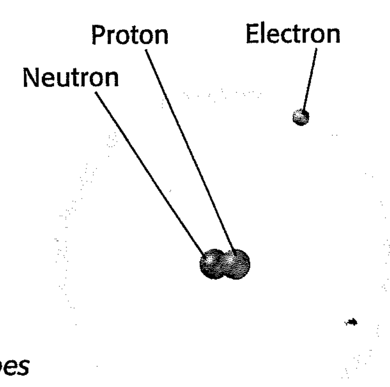


Figure 14 *The atom in this model and the one in Figure 12 are isotopes because each has one proton but a different number of neutrons.*

Astronomy CONNECTION

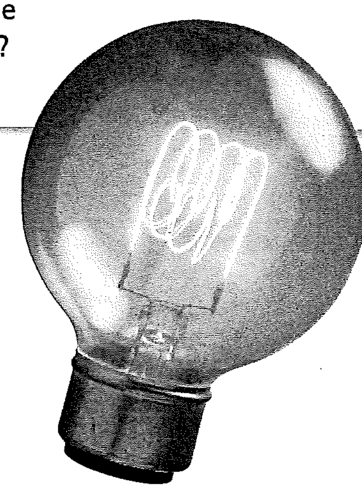
Hydrogen is the most abundant element in the universe. It is the fuel for the sun and other stars. It is currently believed that there are roughly 2,000 times more hydrogen atoms than oxygen atoms and 10,000 times more hydrogen atoms than carbon atoms.

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.

APPLY

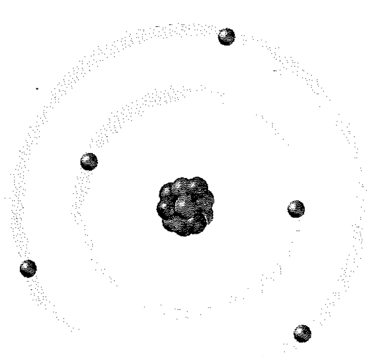
Isotopes and Light Bulbs

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.

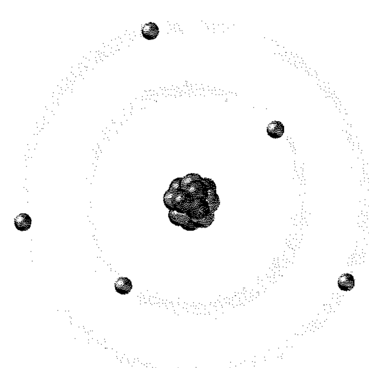


How Can You Tell One Isotope from Another? You can identify each isotope of an element by its mass number. The **mass number** is the sum of the protons and neutrons in an atom. Electrons are not included in an atom's mass number because their mass is so small that they have very little effect on the 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

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

÷ 5 ÷ Ω ≤ ∞ + Ω √ 9 ∞ ≤ Σ 2

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:

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

Now It's Your Turn

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

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.

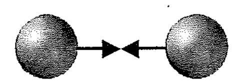
Figure 16 *The copper used to make the Statue of Liberty includes both copper-63 and copper-65. Copper's atomic mass is 63.6 amu.*

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.

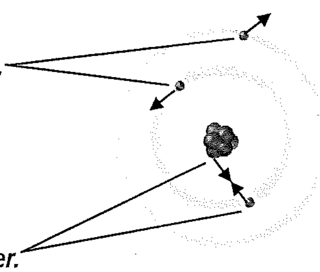
Forces in the Atom

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.



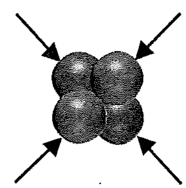
Electromagnetic Force As mentioned earlier, objects that have the same charge repel each other, while objects with opposite charge attract each other. This is due to the *electromagnetic force.* Protons and electrons are attracted to each other because they have opposite charges. The electromagnetic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

Particles with the same charges repel each other.

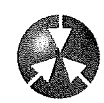


Particles with opposite charges attract each other.

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.



SECTION 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.

internet**connect**

sciLINKS. NSTA

TOPIC: Inside the Atom, Isotopes
GO TO: www.scilinks.org
***sci*LINKS NUMBER:** HSTP265, HSTP270