Section 3.1

Objectives

- **Describe** an atom and its components.
- **Relate** energy levels of atoms to the chemical properties of elements.
- **Define** the concept of isotopes.

Review Vocabulary

atom: the smallest particle of an element that retains all the properties of that element

New Vocabulary

matter
element
nucleus
proton
neutron
electron
atomic number
mass number
isotope
ion

Matter

MAIN Idea **Atoms are the basic building blocks of all matter.**

Real-World Reading Link Gold, which is often used in jewelry, is so soft that it can be molded, hammered, sculpted, or drawn into wire. Whatever its size or shape, the gold is still gold. Gold is a type of matter.

Atoms

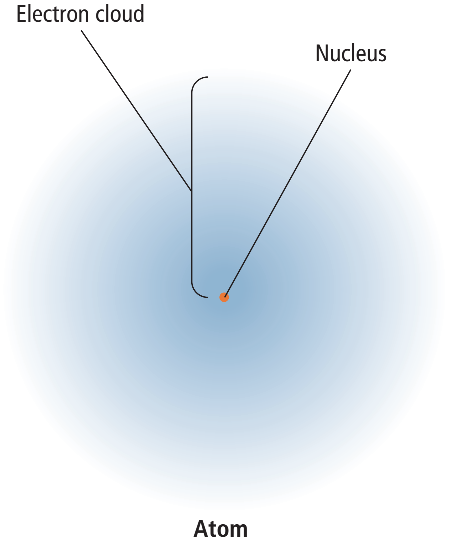
Matter is anything that has volume and mass. Everything in the physical world that surrounds you is composed of matter. On Earth, matter usually occurs as a solid, a liquid, or a gas. All matter is made of substances called elements. An **element** is a substance that cannot be broken down into simpler substances by physical or chemical means. For example, gold is still gold whether it is a gold brick, coins, or a statue.

Each element has distinct characteristics. You have learned some of the characteristics of the element gold. Although aluminum has different characteristics than gold, both aluminum and gold are elements that are made up of atoms. All atoms consist of even smaller particles—protons, neutrons, and electrons. **Figure 3.1** shows one method of representing an atom. The center of an atom is called the nucleus (NEW klee us) (plural, nuclei). The **nucleus** of an atom is made up of protons and neutrons. A **proton** is a tiny particle that has mass and a positive electric charge. A **neutron** is a particle with approximately the same mass as a proton, but it is electrically neutral; that is, it has no electric charge. All atomic nuclei have a positive charge because they are composed of protons with positive electric charges and neutrons with no electric charges.

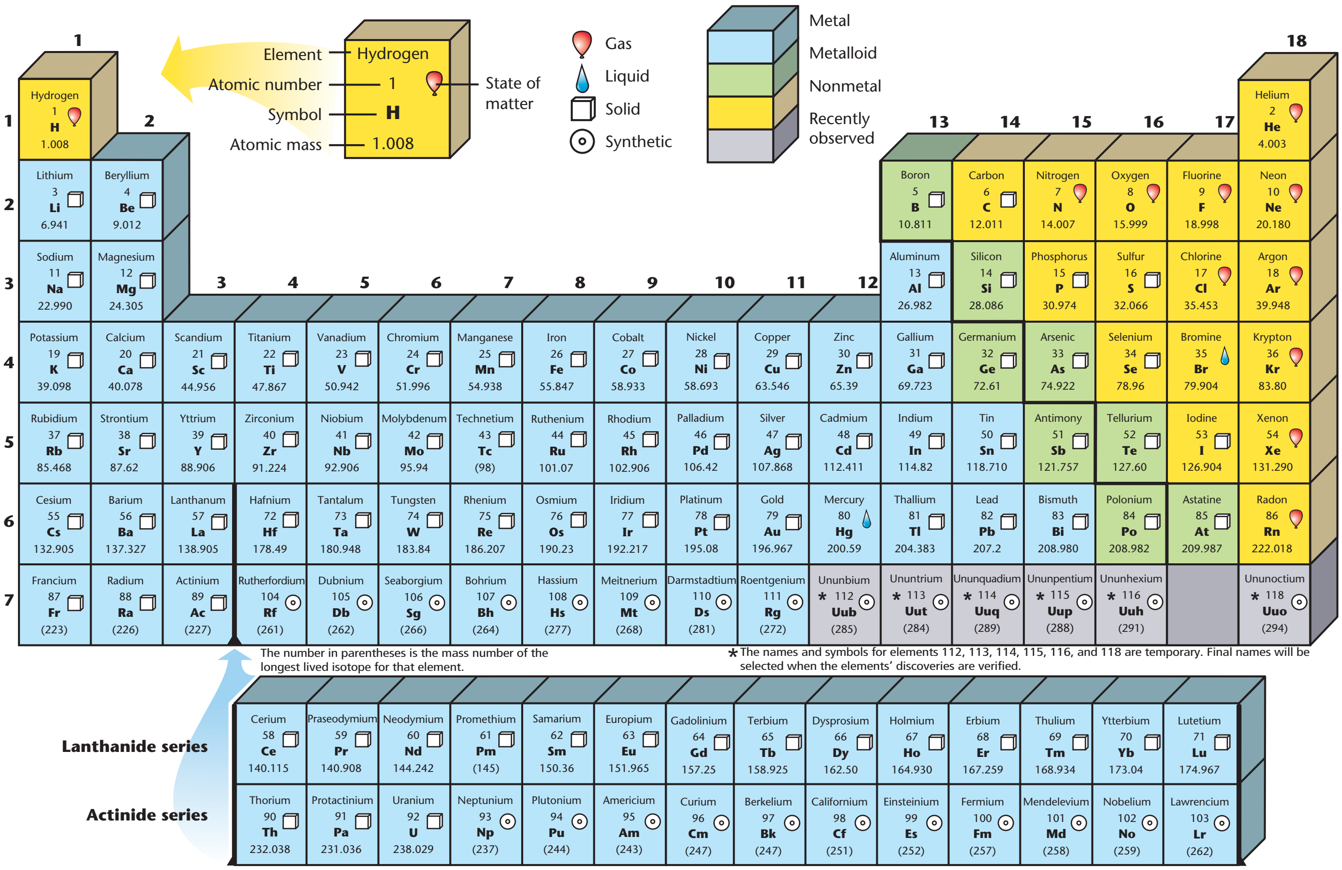
Figure 3.1 In this representation of an atom, the fuzzy area surrounding the nucleus is referred to as an electron cloud.

Concepts In Motion

Interactive Figure To see an animation of the electron cloud, visit glencoe.com.



PERIODIC TABLE OF THE ELEMENTS



Element — Hydrogen
Atomic number — 1
Symbol — H
Atomic mass — 1.008
State of matter

🎈 Gas
💧 Liquid
☐ Solid
⊙ Synthetic

🟦 Metal
🟩 Metalloid
🟨 Nonmetal
⬜ Recently observed

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Hydrogen 1 🎈 H 1.008																	Helium 2 🎈 He 4.003
2	Lithium 3 ☐ Li 6.941	Beryllium 4 ☐ Be 9.012											Boron 5 ☐ B 10.811	Carbon 6 ☐ C 12.011	Nitrogen 7 🎈 N 14.007	Oxygen 8 🎈 O 15.999	Fluorine 9 🎈 F 18.998	Neon 10 🎈 Ne 20.180
3	Sodium 11 ☐ Na 22.990	Magnesium 12 ☐ Mg 24.305											Aluminum 13 ☐ Al 26.982	Silicon 14 ☐ Si 28.086	Phosphorus 15 ☐ P 30.974	Sulfur 16 ☐ S 32.066	Chlorine 17 🎈 Cl 35.453	Argon 18 🎈 Ar 39.948
4	Potassium 19 ☐ K 39.098	Calcium 20 ☐ Ca 40.078	Scandium 21 ☐ Sc 44.956	Titanium 22 ☐ Ti 47.867	Vanadium 23 ☐ V 50.942	Chromium 24 ☐ Cr 51.996	Manganese 25 ☐ Mn 54.938	Iron 26 ☐ Fe 55.847	Cobalt 27 ☐ Co 58.933	Nickel 28 ☐ Ni 58.693	Copper 29 ☐ Cu 63.546	Zinc 30 ☐ Zn 65.39	Gallium 31 ☐ Ga 69.723	Germanium 32 ☐ Ge 72.61	Arsenic 33 ☐ As 74.922	Selenium 34 ☐ Se 78.96	Bromine 35 💧 Br 79.904	Krypton 36 🎈 Kr 83.80
5	Rubidium 37 ☐ Rb 85.468	Strontium 38 ☐ Sr 87.62	Yttrium 39 ☐ Y 88.906	Zirconium 40 ☐ Zr 91.224	Niobium 41 ☐ Nb 92.906	Molybdenum 42 ☐ Mo 95.94	Technetium 43 ☐ Tc (98)	Ruthenium 44 ☐ Ru 101.07	Rhodium 45 ☐ Rh 102.906	Palladium 46 ☐ Pd 106.42	Silver 47 ☐ Ag 107.868	Cadmium 48 ☐ Cd 112.411	Indium 49 ☐ In 114.82	Tin 50 ☐ Sn 118.710	Antimony 51 ☐ Sb 121.757	Tellurium 52 ☐ Te 127.60	Iodine 53 ☐ I 126.904	Xenon 54 🎈 Xe 131.290
6	Cesium 55 ☐ Cs 132.905	Barium 56 ☐ Ba 137.327	Lanthanum 57 ☐ La 138.905	Hafnium 72 ☐ Hf 178.49	Tantalum 73 ☐ Ta 180.948	Tungsten 74 ☐ W 183.84	Rhenium 75 ☐ Re 186.207	Osmium 76 ☐ Os 190.23	Iridium 77 ☐ Ir 192.217	Platinum 78 ☐ Pt 195.08	Gold 79 ☐ Au 196.967	Mercury 80 💧 Hg 200.59	Thallium 81 ☐ Tl 204.383	Lead 82 ☐ Pb 207.2	Bismuth 83 ☐ Bi 208.980	Polonium 84 ☐ Po 208.982	Astatine 85 ☐ At 209.987	Radon 86 🎈 Rn 222.018
7	Francium 87 ☐ Fr (223)	Radium 88 ☐ Ra (226)	Actinium 89 ☐ Ac (227)	Rutherfordium 104 ⊙ Rf (261)	Dubnium 105 ⊙ Db (262)	Seaborgium 106 ⊙ Sg (266)	Bohrium 107 ⊙ Bh (264)	Hassium 108 ⊙ Hs (277)	Meitnerium 109 ⊙ Mt (268)	Darmstadtium 110 ⊙ Ds (281)	Roentgenium 111 ⊙ Rg (272)	Ununbium * 112 ⊙ Uub (285)	Ununtrium * 113 ⊙ Uut (284)	Ununquadium * 114 ⊙ Uuq (289)	Ununpentium * 115 ⊙ Uup (288)	Ununhexium * 116 ⊙ Uuh (291)		Ununoctium * 118 ⊙ Uuo (294)

The number in parentheses is the mass number of the longest lived isotope for that element.

*The names and symbols for elements 112, 113, 114, 115, 116, and 118 are temporary. Final names will be selected when the elements' discoveries are verified.

Lanthanide series	Cerium 58 ☐ Ce 140.115	Praseodymium 59 ☐ Pr 140.908	Neodymium 60 ☐ Nd 144.242	Promethium 61 ☐ Pm (145)	Samarium 62 ☐ Sm 150.36	Europium 63 ☐ Eu 151.965	Gadolinium 64 ☐ Gd 157.25	Terbium 65 ☐ Tb 158.925	Dysprosium 66 ☐ Dy 162.50	Holmium 67 ☐ Ho 164.930	Erbium 68 ☐ Er 167.259	Thulium 69 ☐ Tm 168.934	Ytterbium 70 ☐ Yb 173.04	Lutetium 71 ☐ Lu 174.967
Actinide series	Thorium 90 ☐ Th 232.038	Protactinium 91 ☐ Pa 231.036	Uranium 92 ☐ U 238.029	Neptunium 93 ⊙ Np (237)	Plutonium 94 ⊙ Pu (244)	Americium 95 ⊙ Am (243)	Curium 96 ⊙ Cm (247)	Berkelium 97 ⊙ Bk (247)	Californium 98 ⊙ Cf (251)	Einsteinium 99 ⊙ Es (252)	Fermium 100 ⊙ Fm (257)	Mendelevium 101 ⊙ Md (258)	Nobelium 102 ⊙ No (259)	Lawrencium 103 ⊙ Lr (262)

■ **Figure 3.2** The periodic table of the elements is arranged so that a great deal of information about all of the known elements is provided in a small space.

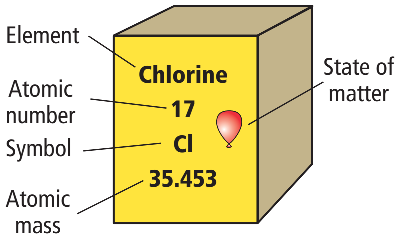
Surrounding the nucleus of an atom are smaller particles called electrons. An **electron** (e^-) has little mass, but it has a negative electric charge that is exactly the same magnitude as the positive charge of a proton. An atom has an equal number of protons and electrons; thus, the electric charge of an electron cancels the positive charge of a proton to produce an atom that has no overall charge. Notice that the electrons in **Figure 3.1** are shown as a cloudlike region surrounding the nucleus. This is because electrons are in constant motion around an atom's nucleus, and their exact positions at any given moment cannot be determined.

Symbols for elements There are 92 elements that occur naturally on Earth and in the stars. Other elements have been produced in laboratory experiments. Generally, each element is identified by a one-, two-, or three-letter abbreviation known as a chemical symbol. For example, the symbol H represents the element hydrogen, C represents carbon, and O represents oxygen. Elements identified in ancient times, such as gold and mercury, have symbols of Latin origin. For example, gold is identified by the symbol Au for its Latin name, *aurum.* All elements are classified and arranged according to their chemical properties in the periodic table of the elements, shown in **Figure 3.2.**

Concepts In Motion

Interactive Figure To see an animation of the periodic table of elements, visit glencoe.com.

■ **Figure 3.3** The element chlorine is atomic number 17.
Infer ***In what state is chlorine at room temperature?***



Mass number The number of protons and neutrons in atoms of different elements varies widely. The lightest of all atoms is hydrogen, which has only one proton in its nucleus. The heaviest naturally occurring atom is uranium. Uranium-238 has 92 protons and 146 neutrons in its nucleus. The number of protons in an atom's nucleus is its **atomic number.** The sum of the protons and neutrons is its **mass number.** Because electrons have little mass, they are not included in determining mass number. For example, the atomic number of uranium is 92, and its mass number is 238 (92 protons + 146 neutrons). **Figure 3.3** explains how atomic numbers and mass numbers are listed in the periodic table of the elements.

Isotopes

Recall that all atoms of an element have the same number of protons. However, the number of neutrons of an element's atoms can vary. For example, all chlorine atoms have 17 protons in their nuclei, but they can have either 18 or 20 neutrons. This means that there are chlorine atoms with mass numbers of 35 (17 protons + 18 neutrons) and 37 (17 protons + 20 neutrons). Atoms of the same element that have different mass numbers are called **isotopes.** The element chlorine has two isotopes: Cl-35 and Cl-37. Because the number of electrons in an atom equals the number of protons, isotopes of an element have the same chemical properties.

Look again at the periodic table in **Figure 3.2.** Scientists have measured the mass of atoms of elements. The atomic mass of an element is the average of the mass numbers of the isotopes of an element. Most elements are mixtures of isotopes. For example, notice in **Figure 3.2** that the atomic mass of chlorine is 35.453. This number is the average of the mass numbers of the naturally occurring isotopes of chlorine-35 and chlorine-37.

MiniLab

Identify Elements

What elements are in your classroom? Most substances on Earth occur in the form of chemical compounds. Around your classroom, there are numerous objects or substances that consist mostly of a single element.

Procedure

1. Read and complete the lab safety form.
2. Create a data table with the following column headings: Article, Element, Atomic Number, Properties.
3. Name three objects in your classroom and the three different elements of which they are made.
4. List the atomic numbers of these elements and describe some of their properties.

Analysis

1. **Categorize** List two examples of a solid, a liquid, and a gaseous object or substance.
2. **Compare and contrast** liquids, solids, and gases.

Radioactive isotopes The nuclei of some isotopes are unstable and tend to break down. When this happens, the isotope also emits energy in the form of radiation. Radioactive decay is the spontaneous process through which unstable nuclei emit radiation. In the process of radioactive decay, a nucleus can lose protons and neutrons, change a proton to a neutron, or change a neutron to a proton. Because the number of protons in a nucleus identifies an element, decay changes the identity of an element. For example, the isotope polonium-218 decays at a steady rate over time into bismuth-214. The polonium originally present in a rock is gradually replaced by bismuth. You will learn about the use of radioactive decay to calculate the ages of rocks in Chapter 21.

Electrons in Energy Levels

Although the exact position of an electron cannot be determined, scientists have discovered that electrons occupy areas called energy levels. Look again at **Figure 3.1.** The volume of an atom is mostly empty space. However, the size of an atom depends on the number and arrangement of its electrons.

Filling energy levels **Figure 3.4** presents a model to help you visualize the position of atomic particles. Note that electrons are distributed over one or more energy levels in a predictable pattern. Keep in mind that the electrons are not sitting still in one place. Each energy level can hold only a limited number of electrons. For example, the smallest, innermost energy level can hold only two electrons, as illustrated by the oxygen atom in **Figure 3.4**. The second energy level is larger, and it can hold up to eight electrons. The third energy level can hold up to 18 electrons and the fourth energy level can hold up to 32 electrons. Depending on the element, an atom might have electrons in as many as seven energy levels surrounding its nucleus.

■ **Figure 3.4** Electrons occupy one energy level in hydrogen, two energy levels in oxygen, and three energy levels in aluminum.

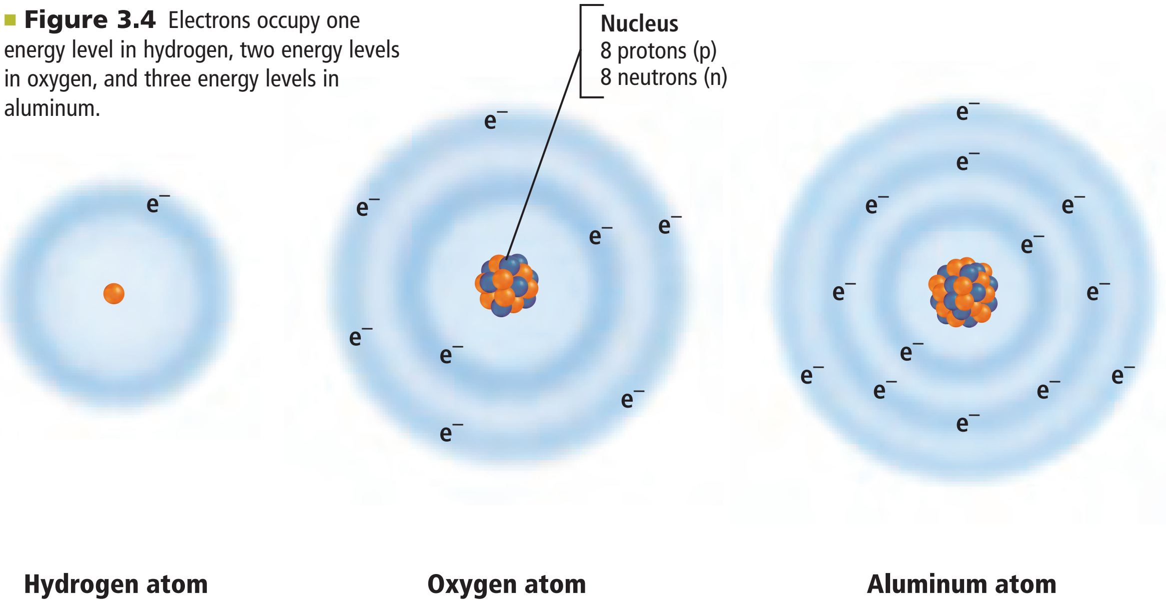
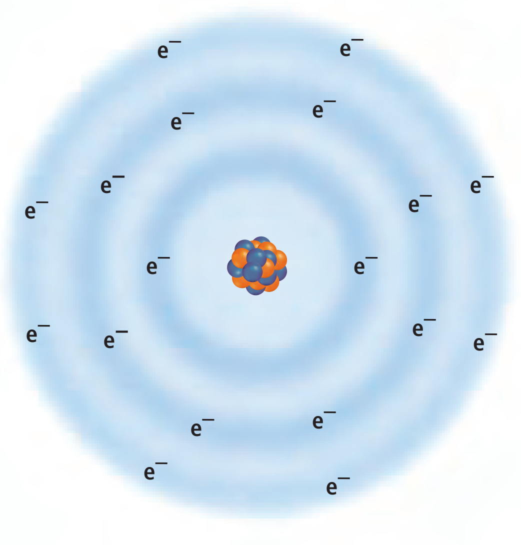


Figure 3.5 The inert nature of argon makes it an ideal gas to use inside an incandescent light bulb because it does not react with the extremely hot filament.



Argon atom

Valence electrons The electrons in the outermost energy level determine the chemical behavior of the different elements. These outermost electrons are called valence electrons. Elements with the same number of valence electrons have similar chemical properties. For example, both a sodium atom, with the atomic number 11, and a potassium atom, with the atomic number 19, have one valence electron. Thus both sodium and potassium exhibit similar chemical behavior. These elements are highly reactive metals, which means that they combine easily with many other elements.

Elements such as helium and argon have full outermost energy levels. For example, an argon atom, shown in **Figure 3.5,** has 18 electrons, with two electrons in the first energy level and eight electrons in the second and outermost energy levels. Elements that have full outermost energy levels are highly unreactive. The gases helium, neon, argon, krypton, xenon, and radon have full outer energy levels.

Ions

Sometimes atoms gain or lose electrons from their outermost energy levels. Recall that atoms are electrically neutral because the number of electrons, which have negative charges, balances the number of protons, which have positive charges. An atom that gains or loses an electron has a net electric charge and is called an **ion.** In general, an atom in which the outermost energy level is less than half-full—that is, it has fewer than four valence electrons—tends to lose its valence electrons. When an atom loses valence electrons, it becomes positively charged. In chemistry, a positive ion is indicated by a superscript plus sign. For example, a sodium ion is represented by Na^+. If more than one electron is lost, that number is placed before the plus sign. For example, a magnesium ion, which forms when a magnesium atom has lost two electrons, is represented by Mg^{2+}.

✓ **Reading Check** **Explain** what makes an ion positive.

An atom in which the outermost energy level is more than half-full—that is, it has more than four valence electrons—tends to fill its outermost energy level. Such an atom forms a negatively charged ion. Negative ions are indicated by a superscript minus sign. For example, a nitrogen atom that has gained three electrons is represented by N^{3-}. Some substances contain ions that are made up of groups of atoms—for example, silicate ions. These complex ions are important constituents of most rocks and minerals.

VOCABULARY

ACADEMIC VOCABULARY

Region
a continuous part of an area or body, with or without definite boundaries or with certain characteristics
The region surrounding the flood was labeled as a disaster area.

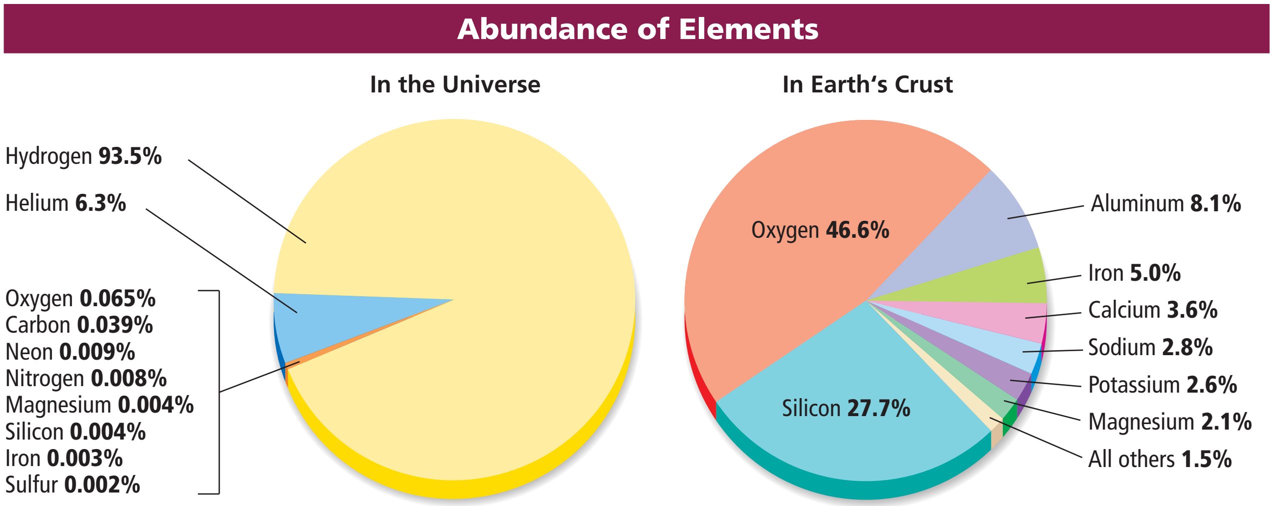


Figure 3.6 The most abundant elements in the universe are greatly different from the most abundant elements on Earth.

Hypothesize *Where might most of the hydrogen and helium in the universe be found?*

What elements are most abundant?

Astronomers have identified the two most abundant elements in the universe as hydrogen and helium. All other elements account for less than 1 percent of all atoms in the universe, as shown in **Figure 3.6.** Analyses of the composition of rocks and minerals on Earth indicate that the percentages of elements in Earth's crust differ from the percentages in the universe. As shown in **Figure 3.6,** 98.5 percent of Earth's crust is made up of only eight elements. Two of these elements, oxygen and silicon, account for almost 75 percent of the crust's composition. This means that most of the rocks and minerals on Earth's crust contain oxygen and silicon. You will learn more about these elements and the minerals they form in Chapter 4.

Section 3.1 Assessment

Section Summary

- Atoms consist of protons, neutrons, and electrons.
- An element consists of atoms that have a specific number of protons in their nuclei.
- Isotopes of an element differ by the number of neutrons in their nuclei.
- Elements with full outermost energy levels are highly unreactive.
- Ions are electrically charged atoms or groups of atoms.

Understand Main Ideas

1. MAIN Idea **Differentiate** among the three parts of an atom in terms of their location, charge, and mass.
2. **Explain** why the elements magnesium and calcium have similar properties.
3. **Illustrate** how a neutral atom becomes an ion.
4. **Compare and contrast** these isotopes: uranium-239, uranium-238, and uranium-235.

Think Critically

5. **Design** an illustration using the concepts of valence electrons and energy levels to explain why oxygen might combine with magnesium.
6. **Interpret** the representation of magnesium in the periodic table. Explain why the atomic mass of magnesium is not a whole number.

MATH in Earth Science

7. As the radioactive isotope radium-226 decays, it emits two protons and two neutrons. How many protons and neutrons are now left in the nucleus? What is the atom's new atomic number? What is the name of this element?

Earth Science Online **Self-Check Quiz** glencoe.com