# 2–1 The Nature of Matter

L ife depends on chemistry. When you eat food or inhale oxygen, your body uses these materials in chemical reactions that keep you alive. Just as buildings are made from bricks, steel, glass, and wood, living things are made from chemical compounds. If the first task of an architect is to understand building materials, then the first job of a biologist is to understand the chemistry of life.

### **Atoms**

The study of chemistry begins with the basic unit of matter, the **atom.** The Greek word *atomos*, which means "unable to be cut," was first used to refer to matter by the Greek philosopher Democritus nearly 2500 years ago. Democritus asked a simple question: If you take an object like a stick of chalk and break it in half, are both halves still chalk? The answer, of course, is yes. But what happens if you go on? Suppose you break it in half again and again. Can you continue to divide without limit, or does there come a point at which you cannot divide the fragment of chalk without changing it into something else? Democritus thought that there had to be a limit. He called the smallest fragment the atom, a name scientists still use today.

Atoms are incredibly small. Placed side by side, 100 million atoms would make a row only about 1 centimeter long—about the width of your little finger! Despite its extremely small size, an atom contains subatomic particles that are even smaller.

Figure 2–1 shows the subatomic particles in a helium atom. The subatomic particles that make up atoms are protons, neutrons, and electrons. Protons and neutrons have about the same mass. However, protons are positively charged particles (+) and neutrons carry no charge. Their name is a reminder that they are neutral particles. Strong forces bind protons and neutrons together to form the **nucleus**, which is at the center of the atom.

The **electron** is a negatively charged particle (-) with 1/1840 the mass of a proton. Electrons are in constant motion in the space surrounding the nucleus. They are attracted to the positively charged nucleus but remain outside the nucleus because of the energy of their motion. Because atoms have equal numbers of electrons and protons, and because these subatomic particles have equal but opposite charges, atoms are neutral.

### SECTION RESOURCES

#### Print:

- **Teaching Resources**, Lesson Plan 2–1, Adapted Section Summary 2–1, Adapted Worksheets 2–1, Section Summary 2–1, Worksheets 2–1, Section Review 2–1
- **Reading and Study Workbook A**, Section 2–1
- Adapted Reading and Study Workbook B, Section 2–1

#### Technology:

- **BioDetectives DVD**, "History's Mystery: An Introduction to Forensic Science"
- iText, Section 2-1
- **Animated Biological Concepts DVD**, 1 Atomic Structure, 2 Energy Levels and Ionic Bonding, 3 Covalent Bonding
- Transparencies Plus, Section 2-1

### Guide for Reading

#### Key Concepts

- What three subatomic parti-
- cles make up atoms?How are all of the isotopes of an element similar?
- What are the two main types of chemical bonds?

#### Vocabulary

atom nucleus electron element isotope compound ionic bond ion covalent bond molecule van der Waals forces

#### Reading Strategy: Using Prior Knowledge

Before you read, write down what you already know about atoms, elements, and compounds. As you read, note the main new concepts you learn.



Helium Atomic number = 2 Mass number = 4

### Section 2–1

### 1 FOCUS

#### **Objectives**

- **2.1.1** *Identify* the three subatomic particles found in atoms.
- **2.1.2** *Explain* how all of the isotopes of an element are similar and how they are different.
- **2.1.3** *Explain* what chemical compounds are.
- **2.1.4** *Describe* the two main types of chemical bonds.

### **Guide for Reading**

#### **Vocabulary Preview**

Before students read the section, ask them to find each Vocabulary term and preview its meaning.

#### **Reading Strategy**

Encourage students to refer back regularly to their initial thoughts about atoms, elements, and compounds, editing their sentences as they revise their thinking in light of the section's discussion.

### 2 INSTRUCT\_\_\_\_\_

### Atoms Build Science Skills

Using Models Display a model of an atom, and have students identify the nucleus, protons, neutrons, and electrons. Then, have students build their own models of atoms, using toothpicks and gumdrops. Assign each student one or more of the elements mentioned in this sectionhelium, hydrogen, oxygen, carbon, sodium, and chlorine-and elements that will be discussed in future sections, such as nitrogen and calcium. Stress that all models have limitations. In the Figure 2-1 drawing, for example, electrons are shown as equal in size to the more massive protons and neutrons, and the constant motion of the electrons cannot be shown. **L2** 

#### 2–1 (continued)

### Elements and lsotopes

#### **Make Connections**

**Chemistry** Display a wall-sized periodic table of elements and review with students the information it contains. Focus first on the names and symbols. Explain that new elements are assigned three-letter symbols until they are officially named. Ask: How are the elements arranged in the table? (In order by increasing atomic number) Remind students that the atomic number equals the number of protons in an atom. Ask: What else does the atomic number equal? (The number of electrons in the atom) Use the table to discuss the average atomic masses and the concept of a weighted average after students have learned about isotopes. **L2** 

#### **Build Science Skills**

Using Models Help students grasp the concept of isotopes by using marbles of two different colors. Have dark-colored marbles represent protons and light-colored marbles represent neutrons. Place six of each color of marble in a student's hand, and explain that this represents the nucleus of a carbon-12 atom. Add a light-colored marble to the hand, and ask: What do the marbles now represent? (The nucleus of a carbon-13 atom) How many electrons does this isotope of carbon contain? (The isotope has six electrons.) Add another dark-colored marble to the hand, and ask: Is the nucleus the marbles now represent a nucleus of a carbon isotope? (No. Carbon isotopes always have six protons.) Which element has seven protons? (Nitrogen) **L1 L2** 

▼ Figure 2-2 ○ Because they have the same number of electrons, these isotopes of carbon have the same chemical properties. The difference among the isotopes is the number of neutrons in their nuclei.

### **Elements and Isotopes**

A chemical **element** is a pure substance that consists entirely of one type of atom. More than 100 elements are known, but only about two dozen are commonly found in living organisms. Elements are represented by a one- or two-letter symbol. C, for example, stands for carbon, H for hydrogen, and Na for sodium. The number of protons in an atom of an element is the element's atomic number. Carbon's atomic number is 6, meaning that each atom of carbon has six protons and, consequently, six electrons. See Appendix G, The Periodic Table, which shows the elements.

**Isotopes** Atoms of an element can have different numbers of neutrons. For example, some atoms of carbon have six neutrons, some have seven, and a few have eight. Atoms of the same element that differ in the number of neutrons they contain are known as **isotopes.** The sum of the protons and neutrons in the nucleus of an atom is called its mass number. Isotopes are identified by their mass numbers. **Figure 2–2** shows the subatomic composition of carbon-12, carbon-13, and carbon-14 atoms. The weighted average of the masses of an element's isotopes is called its atomic mass. "Weighted" means that the abundance of each isotope in nature is considered when the average is calculated. **Because they have the same number of electrons, all isotopes of an element have the same chemical properties.** 

**Radioactive Isotopes** Some isotopes are radioactive, meaning that their nuclei are unstable and break down at a constant rate over time. The radiation these isotopes give off can be dangerous, but radioactive isotopes have a number of important scientific and practical uses.

Geologists can determine the ages of rocks and fossils by analyzing the isotopes found in them. Radiation from certain isotopes can be used to treat cancer and to kill bacteria that cause food to spoil. Radioactive isotopes can also be used as labels or "tracers" to follow the movements of substances within organisms.



#### SUPPORT FOR ENGLISH LANGUAGE LEARNERS

#### **Comprehension: Link to Visual**

**Beginning** Use Figure 2–1 (page 35) to help students understand the structure of the atom. Review the terms *atom*, *proton*, *neutron*, and *electron* by pointing out the appropriate parts of the figure. Use the figure to differentiate between the similar-sounding terms *neutron* and *nucleus*. Add these terms to a word wall with other Vocabulary terms from the chapter. **L1** 

Intermediate Pair ESL students with Englishproficient students to construct a three-column table on subatomic particles. They can use both the text on page 35 and the information in Figure 2–1. The column heads should be *Particle, Charge,* and *Location.* The left column should list the subatomic particle (proton, neutron, electron), the middle column should list the charge (positive, negative, or none), and the right column should list the location (inside nucleus or outside nucleus). **12** 



## **Careers in Biology**

#### **Forensic Scientist**

Job Description: work as a forensic scientist for local, state, or federal investigative agencies in order to conduct scientific forensic examinations in criminal investigations

Education: a bachelor's degree in science biology, physics, chemistry, metallurgy; some states require several years of forensic laboratory experience

Skills: analytical, logical, computer literate, detail oriented, able to take meticulous notes and to prepare evidence for presentation in court as well as to testify as an expert witness

Highlights: have the opportunity to use logic and science to solve unique or unusual problems in criminal investigations and to work collaboratively with other scientists

### **Chemical Compounds**

In nature, most elements are found combined with other elements in compounds. A chemical **compound** is a substance formed by the chemical combination of two or more elements in definite proportions. Scientists show the composition of compounds by a kind of shorthand known as a chemical formula. Water, which contains two atoms of hydrogen for each atom of oxygen, has the chemical formula H<sub>2</sub>O. The formula for table salt. NaCl, indicates that the elements from which table salt forms—sodium and chlorine—combine in a 1:1 ratio.

The physical and chemical properties of a compound are usually very different from those of the elements from which it is formed. For example, hydrogen and oxygen, which are gases at room temperature, can combine explosively and form liquid water. Sodium is a silver-colored metal that is soft enough to cut with a knife. It reacts explosively with cold water. Chlorine is very reactive, too. It is a poisonous, greenish gas that was used to kill many soldiers in World War I. Sodium and chlorine combine to form sodium chloride (NaCl), or table salt. Sodium chloride is a white solid that dissolves easily in water. As you know, sodium chloride is not poisonous. In fact, it is essential for the survival of most living things.



CHECKPOINT) What information is contained in a chemical formula?

### **HISTORY OF SCIENCE**

#### Same element, different atoms

In the early nineteenth century, British chemist John Dalton expounded a number of postulates about matter, including that all atoms of a given element are identical. His work had tremendous influence. About a century later, though, scientists working on radioactive decay detected scores of atoms that seemed to refute Dalton's postulate. English chemist Frederick Soddy provided a solution. In working with neon atoms, he found some

atoms with a mass number of 20 and others with a mass number of 22. He suggested that atoms with both mass numbers can be considered neon because they have the same number of protons, even though they have different numbers of neutrons in their nuclei. Because both types of atoms could occupy the same place on the periodic table, he called them isotopes, from the Greek words for "same" and "place."

### **Careers in Biology**

When a criminal investigation is needed, forensic scientists—also called criminalists-examine, compare, and analyze various types of physical evidence, including blood and other body fluids, hair and fibers, DNA and fingerprints.

An entry-level job as a forensic scientist usually requires a bachelor's degree in forensic science or some other science. **L2** 

**Resources** Encourage interested students to contact a local university to see if it has a degree program in forensic science and what the program entails. Students might also contact a local police department and ask to talk to a forensic scientist or criminalist.



You can have students write a more extensive job description as well as list the educational requirements for a career in this field.

### 🕲 Quick View Video

**Discovery School DVD** Encourage students to view track 1 "History's Mystery: An Introduction to Forensic Science" on the BioDetectives DVD.

### **Chemical** Compounds

#### **Address Misconceptions**

Many students may think that the smallest unit of every compound is a molecule. Chemists use the term molecule to describe the smallest unit of compounds whose atoms are joined by covalent bonds. You may want to note that atoms of some elements can join with other atoms of the same element and form molecules. For ionic compounds, the formula represents the lowest whole-number ratio of ions in the compound. **L2** 

#### Answer to . . .

CHECKPOINT The types of elements that are in the compound and the ratio in which atoms of those elements combine



Discovery School Video To find out

track 1 "History's Mystery: An

on the BioDetectives DVD.

more about forensic science, view

Introduction to Forensic Science"



### **2–1** (continued)

### Chemical Bonds Build Science Skills

Using Models Arrange two circles of eight chairs each. The circles should be next to each other, about 1 meter apart. Then, invite nine students to take seats in one circle and seven students to take seats in the other. One student invited to sit in a circle will be left without a chair. Encourage that student to walk around the circle of eight chairs, looking for a place to sit. Then, ask: How can this student's problem be resolved? (The student could sit in the empty seat in the other circle of chairs.) Assume the student is an electron. If the student takes a seat in the other circle, what kind of bond is being modeled? (An ionic bond, because the electron is transferred) L1 L2

#### **Use Visuals**

Figure 2–3 Explain that an element's chemical properties are determined by the number and location of the electrons in its atoms. Ask: Why does the transfer of an electron occur between a sodium atom and a **chlorine atom?** (The sodium atom. which has only one electron in its outermost level, easily loses that electron. The chlorine atom, which has seven electrons in its outermost level, easily gains an electron.) Explain that the ions are more stable than the neutral atoms because their outermost levels are filled with electrons. Ask: What is an ionic bond? (The attraction between two oppositely charged ions) Students may notice that the name for the ion formed from a chlorine atom has an -ide ending. This is true for all monatomic negative ions. 12



▲ Figure 2–3 ◆ The chemical bond in which electrons are transferred from one atom to another is called an ionic bond. The compound sodium chloride forms when sodium loses its valence electron to chlorine.



Water Molecule

▲ Figure 2-4 → The chemical bond in which electrons are shared between atoms is called a covalent bond. In a water molecule, each hydrogen atom shares two electrons with the oxygen atom.

### **Chemical Bonds**

The atoms in compounds are held together by chemical bonds. Much of chemistry is devoted to understanding how and when chemical bonds form. Bond formation involves the electrons that surround each atomic nucleus. The electrons that are available to form bonds are called valence electrons. The main types of chemical bonds are ionic bonds and covalent bonds.

**lonic Bonds** An **ionic bond** is formed when one or more electrons are transferred from one atom to another. Recall that atoms are electrically neutral because they have equal numbers of protons and electrons. An atom that loses electrons has a positive charge. An atom that gains electrons has a negative charge. These positively and negatively charged atoms are known as **ions**.

**Figure 2-3** shows how ionic bonds form between sodium and chlorine in table salt. A sodium atom easily loses its one valence electron and becomes a sodium ion (Na<sup>+</sup>). A chlorine atom easily gains an electron and becomes a chloride ion (Cl<sup>-</sup>). In a salt crystal, there are trillions of sodium and chloride ions. These oppositely charged ions have a strong attraction. The attraction between oppositely charged ions is an ionic bond.

**Covalent Bonds** Sometimes electrons are shared by atoms instead of being transferred. What does it mean to "share" electrons? It means that the moving electrons actually travel in the orbitals of both atoms. A **covalent bond** forms when electrons are shared between atoms. When the atoms share two electrons, the bond is called a single covalent bond. Sometimes the atoms share four electrons and form a double bond. In a few cases, atoms can share six electrons and form a triple bond.

The structure that results when atoms are joined together by covalent bonds is called a molecule. The **molecule** is the smallest unit of most compounds. The diagram of a water molecule in **Figure 2-4** shows that each hydrogen atom forms a single covalent bond with the oxygen atom.

# TEACHER TO TEACHER

When I introduce chemical bonding, I remind the students that bonding, in general, means holding together. I use the following analogies: a shoe sole is bonded to the upper part of a shoe, a book cover is bonded to the pages within it, and paint is bonded to a surface. For covalent bonding, I use analogies such as the use of the prefix *co*- meaning together or jointly, as in soccer *co-captains* or *co-valedictorians*. For ionic bonding, I find that an analogy can also be used. Just as the opposite (positive and negative) poles of a magnet attract and exhibit holding power, so do oppositely charged ions: The positive sodium ion and the negative chloride ion attract and hold each other together.

> —Dale Faughn Biology Teacher Caldwell County High School Princeton, KY

**Van der Waals Forces** Because of their structures, atoms of different elements do not all have the same ability to attract electrons. Some atoms have a stronger attraction for electrons than do other atoms. Therefore, when the atoms in a covalent bond share electrons, the sharing is not always equal. Even when the sharing is equal, the rapid movement of electrons can create regions on a molecule that have a tiny positive or negative charge.

When molecules are close together, a slight attraction can develop between the oppositely charged regions of nearby molecules. Chemists call such intermolecular forces of attraction **van der Waals forces**, after the scientist who discovered them. Although van der Waals forces are not as strong as ionic bonds or covalent bonds, they can hold molecules together, especially when the molecules are large.

People who keep geckos as pets have already seen van der Waals forces in action. These remarkable little lizards can climb up vertical surfaces, even smooth glass walls, and then hang on by a single toe despite the pull of gravity. How do they do it? No, they do not have some sort of glue on their feet and they don't have suction cups.

A gecko foot like the one shown in **Figure 2-5** is covered by as many as half a million tiny hairlike projections. Each projection is further divided into hundreds of tiny, flat-surfaced fibers. This design allows the gecko's foot to come in contact with an extremely large area of the wall at the molecular level. Van der Waals forces form between molecules on the surface of the gecko's foot and molecules on the surface of the wall. The combined strength of all the van der Waals forces allows the gecko to balance the pull of gravity. When the gecko needs to move its foot, it peels the foot off at an angle and reattaches it at another location on the wall.

### 2–1 Section Assessment

- 1. **Example 1** Concept Describe the structure of an atom.
- 3. **Key Concept** What is a covalent bond? An ionic bond?

**4.** What is a compound? How are compounds related to molecules?

- 5. How do van der Waals forces hold molecules together?
- 6. Critical Thinking Comparing and Contrasting How are ionic bonds and van der Waals forces similar? How are they different?

▼ Figure 2–5 Van der Waals forces help geckos to grip smooth, vertical surfaces. Applying Concepts Which product(s) might be developed based on van der Waals forces? Explain.

#### **Use Visuals**

**Figure 2–5** Ask students: Are van der Waals forces stronger than ionic or covalent bonds? (*No, they are much weaker.*) How can such weak forces keep a gecko attached to a smooth vertical surface despite the gecko's weight? (*The combined strength of all the van der Waals forces that form between molecules on the gecko's hairlike projections and the surface of the wall balance the pull of gravity.*) **12** 

### 3 ASSESS \_\_\_\_

#### **Evaluate Understanding**

Call on students at random to define each of the section's Vocabulary terms. Then, ask students to explain the difference between the chemical bond in a water molecule and the chemical bond in table salt.

#### Reteach

Have students write answers to the three Key Concept questions listed on the first page of the section.

#### Writing in Science

A good response will include several paragraphs, with an engaging "hook" about a crime scene that sets the stage for a description of what a forensic scientist does. Students should briefly describe some technical details about a career in forensic science as well as list the educational requirements needed to pursue such a career.



If your class subscribes to the iText, use it to review the Key Concepts in Section 2–1.

### 2–1 Section Assessment

- 1. Atoms have a nucleus made up of protons and neutrons. Electrons are in constant motion in the space around the nucleus.
- 2. They have the same number of electrons. They differ in number of neutrons.
- **3.** A covalent bond forms when electrons are shared between atoms. An ionic bond forms when electrons are transferred.
- 4. A compound is a substance formed by the chemical combination of two or more ele-

ments in definite proportions. A molecule is the smallest unit of most compounds.

Writing in Science

newspaper on forensic science

forensic scientist who works for

a law enforcement agency. The

words long. Hint: Consider the

as a career. Assume that you

have already interviewed a

article should be about 500

interests of your readers.

Writing an Article Write an article for your school

- 5. When the sharing of electrons is unequal, a molecule has regions that are charged. An attraction can occur between oppositely charged regions of nearby molecules.
- 6. In both cases, particles are held together by attractions between opposite charges, but the attractions are stronger between the ions than they are between the molecules.

#### Answer to . . .

Figure 2–5 Answers may vary. Students should describe a product with tiny projections that provide a large surface area at the molecular level in order to utilize van der Waals forces to counterbalance the pull of gravity.