2.1 Atoms, Ions, and Molecules

VOCABULARY

atom
element
compound
ion
ionic bond
covalent bond
molecule

KEY CONCEPT **All living things are based on atoms and their interactions.**

MAIN IDEAS

- Living things consist of atoms of different elements.
- Ions form when atoms gain or lose electrons.
- Atoms share pairs of electrons in covalent bonds.

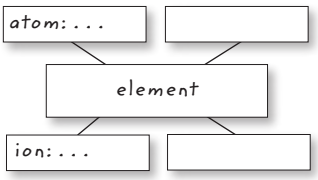
Connect to Your World

The Venus flytrap produces chemicals that allow it to consume and digest insects and other small animals, including an unlucky frog. Frogs also produce specialized chemicals that allow them to consume and digest their prey. In fact, all organisms depend on many chemicals and chemical reactions. For this reason, the study of living things also involves the study of chemistry.

READING TOOLBOX

TAKING NOTES

Use a main idea web to help you make connections among elements, atoms, ions, compounds, and molecules.



MAIN IDEA

Living things consist of atoms of different elements.

What do a frog, a skyscraper, a car, and your body all have in common? Every physical thing you can think of, living or not, is made of incredibly small particles called atoms. An **atom** is the smallest basic unit of matter. Millions of atoms could fit in a space the size of the period at the end of this sentence. And it would take you more than 1 trillion (1,000,000,000,000, or 10^{12}) years to count the number of atoms in a single grain of sand.

Atoms and Elements

Although there is a huge variety of matter on Earth, all atoms share the same basic structure. Atoms consist of three types of smaller particles: protons, neutrons, and electrons. Protons and neutrons form the dense center of an atom—the atomic nucleus. Electrons are much smaller particles outside of the nucleus. Protons have a positive electrical charge, and electrons have a negative electrical charge. Neutrons, as their name implies, are neutral—they have no charge. Because an atom has equal numbers of positively charged protons and negatively charged electrons, it is electrically neutral.

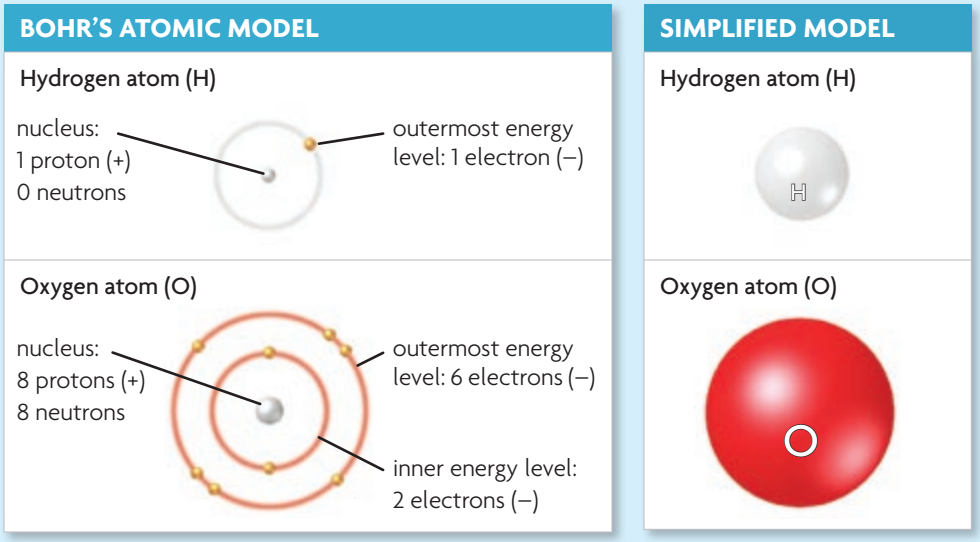
An **element** is one particular type of atom, and it cannot be broken down into a simpler substance by ordinary chemical means. An element can also refer to a group of atoms of the same type. A few familiar elements include the gases hydrogen and oxygen and the metals aluminum and gold. Because all atoms are made of the same types of particles, what difference among atoms makes one element different from other elements? Atoms of different elements differ in the number of protons they have. All atoms of a given element have a specific number of protons that never varies. For example, all hydrogen atoms have one proton, and all oxygen atoms have eight protons.

The electrons in the atoms of each element determine the properties of that element. As **FIGURE 1.1** shows, electrons are considered to be in a cloud around the nucleus. The simplified models of a hydrogen atom and an oxygen atom on the left side of **FIGURE 1.2** illustrate how electrons move around the nucleus in regions called energy levels. Different energy levels can hold different numbers of electrons. For example, the first energy level can hold two electrons, and the second energy level can hold eight electrons. Atoms are most stable when they have a full outermost energy level.

Of the 91 elements that naturally occur on Earth, only about 25 are found in organisms. Just 4 elements—carbon (C), oxygen (O), nitrogen (N), and hydrogen (H)—make up 96 percent of the human body's mass. The other 4 percent consists of calcium (Ca), phosphorus (P), potassium (K), sulfur (S), sodium (Na), and several other trace elements. Trace elements are found in very small amounts in your body, but you need them to survive. For example, iron (Fe) is needed to transport oxygen in your blood. Chromium (Cr) is needed for your cells to break down sugars for usable energy.

FIGURE 1.1 The exact position of electrons cannot be known. They are somewhere in a three-dimensional electron cloud around the nucleus.

FIGURE 1.2 Representing Atoms



The model of the atom developed by Niels Bohr (left) shows that an atom's electrons are located outside the nucleus in regions called energy levels. Different types of atoms have different numbers of electrons and energy levels.

Often, atoms are shown as simplified spheres (right). Different types of atoms are shown in different sizes and colors.

Apply **How many electrons would need to be added to fill the outermost energy level of hydrogen? of oxygen?**

Compounds

The atoms of elements found in organisms are often linked, or bonded, to other atoms. A **compound** is a substance made of atoms of different elements bonded together in a certain ratio. Common compounds in living things include water (H_2O) and carbon dioxide (CO_2). A compound's properties are often different from the properties of the elements that make up the compound. At temperatures on Earth, for example, hydrogen and oxygen are both gases. Together, though, they can form water. Similarly, a diamond is pure carbon, but carbon atoms are also the basis of sugars, proteins, and millions of other compounds.

Contrast **How are elements different from compounds?**

MAIN IDEA

Ions form when atoms gain or lose electrons.

CONNECT TO

CELL STRUCTURE AND FUNCTION

Several different ions are transported across cell membranes during cell processes. You will learn how this transport occurs in **Cell Structure and Function** and **Cells and Energy.**

An **ion** is an atom that has gained or lost one or more electrons. An ion forms because an atom is more stable when its outermost energy level is full; the gain or loss of electrons results in a full outermost energy level. An atom becomes an ion when its number of electrons changes and it gains an electrical charge. This charge gives ions certain properties. For example, compounds consisting only of ions—ionic compounds—easily dissolve in water.

Some ions are positively charged, and other ions are negatively charged. The type of ion that forms depends on the number of electrons in an atom's outer energy level. An atom with few electrons in its outer energy level tends to lose those electrons. An atom that loses one or more electrons becomes a positively charged ion because it has more protons than electrons. In contrast, an atom with a nearly full outer energy level tends to gain electrons. An atom that gains one or more electrons becomes a negatively charged ion because it has more electrons than protons.

Ions play large roles in organisms. For example, hydrogen ions (H^+) are needed for the production of usable chemical energy in cells. Calcium ions (Ca^{2+}) are necessary for every muscle movement in your body. And chloride ions (Cl^-) are important for a certain type of chemical signal in the brain.

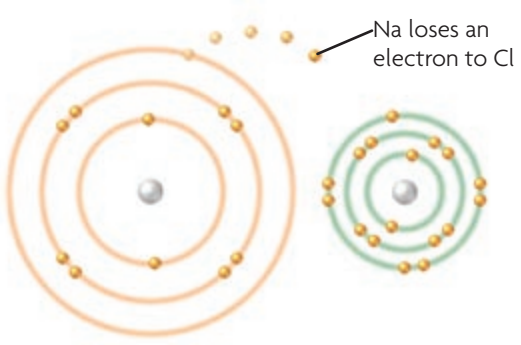
Ions usually form when electrons are transferred from one atom to another. For example, **FIGURE 1.3** shows the transfer of an electron from a sodium atom (Na) to a chlorine atom (Cl). When it loses its one outer electron, the sodium atom becomes a positively charged sodium ion (Na^+). Its second energy level, which has eight electrons, is now a full outermost energy level. The transferred electron fills chlorine's outermost energy level, forming a negatively charged chloride ion (Cl^-). Positive ions, such as Na^+, are attracted to negative ions, such as Cl^-. An **ionic bond** forms through the electrical force between oppositely charged ions. Salt, or sodium chloride (NaCl), is an ionic compound of Na^+ and Cl^-. Sodium chloride is held together by ionic bonds.

Apply **What determines whether an atom becomes a positive ion or a negative ion?**

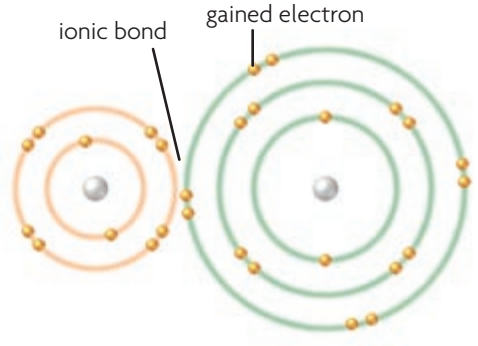
Animated Biology
HMDScience.com
PREMIUM CONTENT
Atoms and Bonding

FIGURE 1.3 IONS AND IONIC BONDS

1 The sodium atom (Na) loses its one outer electron to the chlorine atom (Cl).



2 The positive sodium ion (Na^+) and negative chloride ion (Cl^-) attract each other and form an ionic bond.



MAIN IDEA

Atoms share pairs of electrons in covalent bonds.

Not all atoms easily gain or lose electrons. Rather, the atoms of many elements share pairs of electrons. The shared pairs of electrons fill the outermost energy levels of the bonded atoms. A **covalent bond** forms when atoms share a pair of electrons. Covalent bonds are generally very strong, and depending on how many electrons an atom has, two atoms may form several covalent bonds to share several pairs of electrons. **FIGURE 1.4** illustrates how atoms of carbon and oxygen share pairs of electrons in covalent bonds. All three atoms in a molecule of carbon dioxide (CO_2) have full outer energy levels.

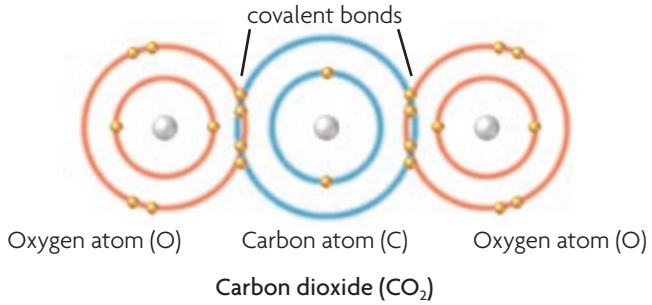
READING TOOLBOX

VOCABULARY

The prefix *co-* means "together," and *valent* comes from a Latin word that means "power" or "strength."

FIGURE 1.4 COVALENT BONDS

A carbon atom needs four electrons to fill its outer energy level. An oxygen atom needs two electrons to fill its outer energy level. In carbon dioxide, carbon makes a double bond, or shares two pairs of electrons, with each oxygen atom.



Carbon dioxide (CO_2)

A **molecule** is two or more atoms held together by covalent bonds. In the compound carbon dioxide, each oxygen atom shares two pairs of electrons (four electrons) with the carbon atom. Some elements occur naturally in the form of diatomic, or "two-atom," molecules. For example, a molecule of oxygen (O_2) consists of two oxygen atoms that share two pairs of electrons. Almost all of the substances that make up organisms, from lipids to nucleic acids to water, are molecules held together by covalent bonds.

Summarize **What happens to electrons in outer energy levels when two atoms form a covalent bond?**

2.1 Formative Assessment

REVIEWING MAIN IDEAS

1. What distinguishes one **element** from another?
2. Describe the formation of an **ionic compound.**
3. What is the difference between an **ionic bond** and a **covalent bond**?

CRITICAL THINKING

4. **Compare and Contrast** How does a **molecule** differ from an **atom**?
5. **Apply** Explain why a hydrogen atom can become either an **ion** or a part of a molecule.

SELF-CHECK Online
HMDScience.com
PREMIUM CONTENT

CONNECT TO CHEMISTRY

6. A sodium atom has one outer electron, and a carbon atom has four outer electrons. How might this difference be related to the types of compounds formed by atoms of these two elements?