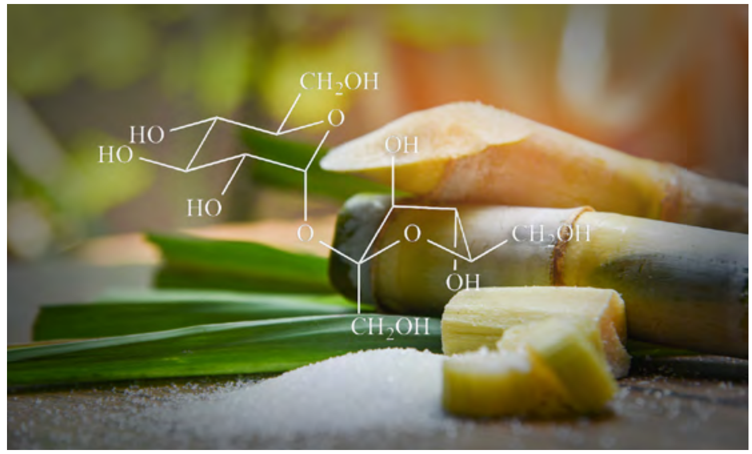
Chapter 2

The Chemistry of Life



2.2 Chemical Compounds

When atoms of different elements bond to one another, they make a **chemical compound**. Sodium atoms and chlorine atoms, for example, bond to make the compound sodium chloride, commonly known as table salt. Nitrogen atoms and hydrogen atoms can join to make the compound ammonia, which is a common household cleaner.

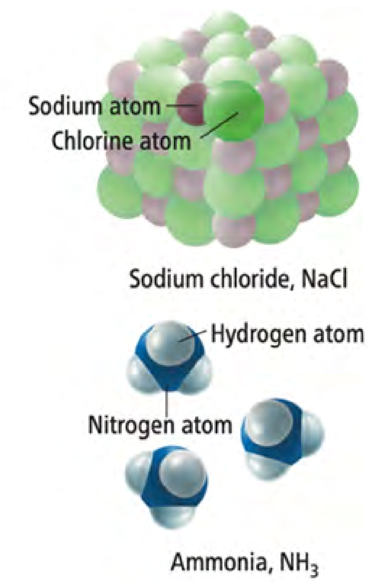


FIGURE 2.6

The compounds sodium chloride and ammonia are represented by their chemical formulas, NaCl and NH_3. A chemical formula shows the ratio of atoms that make up the compound.

A chemical compound is represented by its **chemical formula**. The chemical formula for sodium chloride is NaCl, and the formula for ammonia is NH3. Numerical subscripts indicate the ratio of atoms combining. By convention, the subscript 1 is understood and omitted. So, the chemical formula NaCl tells us that the compound sodium chloride has one sodium atom for every chlorine atom; the chemical formula NH3 tells us that the compound ammonia has one nitrogen atom for every three hydrogen atoms, as Figure 2.6 shows.

Compounds have physical and chemical properties completely different from the properties of their elemental components. The sodium chloride, NaCl, shown in Figure 2.7 is very different from elemental sodium and elemental chlorine. Elemental sodium, Na, consists of nothing but sodium atoms, which form a soft, silvery metal that can be cut easily with a knife. Its melting point is 97.5°C, and it reacts violently with water. Elemental chlorine, Cl_2, consists of chlorine molecules. This material, a yellow-green gas at room temperature, is very toxic; it was used as a chemical warfare agent during World War I. Its boiling point is -34°C. The compound sodium chloride, NaCl, is a translucent, brittle, colorless crystal with a melting point of 800°C. Sodium chloride does not react chemically with water and is nontoxic. It is an essetial component of all living organisms. Sodium chloride is not sodium, nor is it chlorine; it is uniquely sodium chloride, a tasty chemical compound when sprinkled lightly over popcorn.

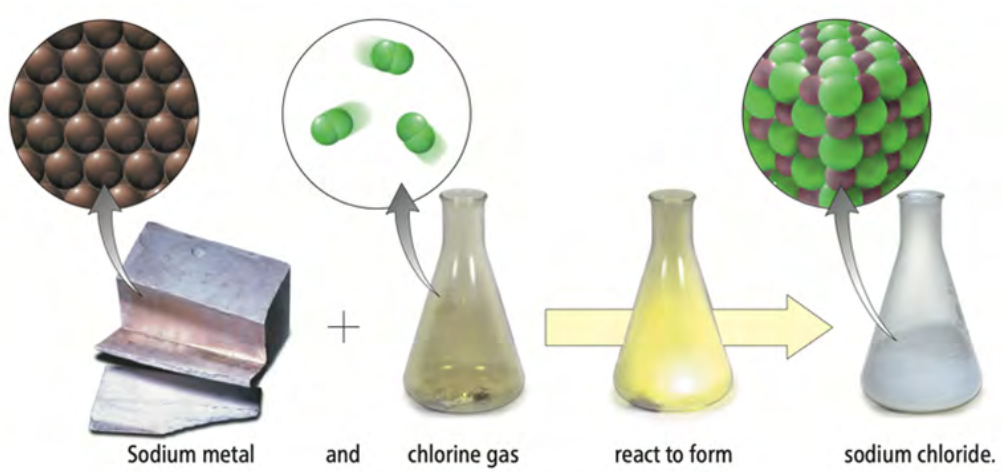


FIGURE 2.7

Sodium metal and chlorine gas react together to form sodium chloride. Although the compound sodium chloride is composed of sodium and chlorine, the physical and chemical properties of sodium chloride are very different from the physical and chemical properties of either sodium metal or chlorine gas.

READING CHECK

Hydrogen sulfide H_2S, is one of the smelliest compounds. Rotten eggs get their characteristic bad smell from the hydrogen sulfide they release. Can you infer from this information that elemental sulfur, S_8, is just as smelly?

CHECK YOUR ANSWERS

No. In fact, the odor of elemental sulfur is negligible compared with that of hydrogen sulfide. Compounds are different from the elements from which they are formed. Hydrogen sulfide, H_2S, is as different from elemental sulfur, S_8, as water, H_2O, is from elemental oxygen, O_2.

How are atoms held together to form a chemical compound? The answer is through the chemical bond. There are three major types of chemical bonds: the ionic bond, the covalent bond, and the metallic bond. For the purposes of learning biology, it works to focus only on the ionic and covalent bonds.

Atoms can lose or gain electrons. Upon losing an electron the atom will have more protons than electrons. Recall that electrons are negatively charged and protons are positively charged. This means that an atom that loses one or more electrons will have a net positive charge. For example, the calcium atom easily loses two electrons. What remains is an atom with 20 positively charged protons and only 18 negatively charged electrons. The net charge of this calcium atom thus becomes 2+.

Any atom with a different number of protons versus electrons is called an **ion**. When calcium loses two electrons it transforms into the calcium ion, which we represent as Ca^{2+}. As another example, the fluorine atom tends to gain one electron forming the fluoride ion represented as F^{1-}.

Now consider what might happen when a calcium atom that tends to lose two electrons is brought adjacent to two fluorine atoms, which each tend to gain one electron? Answer: There is an exchange of electrons. The electrons from the calcium atom will jump to each of the fluorine atoms. The result is a calcium ion, Ca^{2+}, and two fluoride ions, F^{1-}. Because opposite signs attract, the ions become held together as the chemical compound calcium fluoride, CaF_2, as shown in Figure 2.8. What we have just described is called the **ionic bond**, which is the electrical attraction between oppositely charged ions.

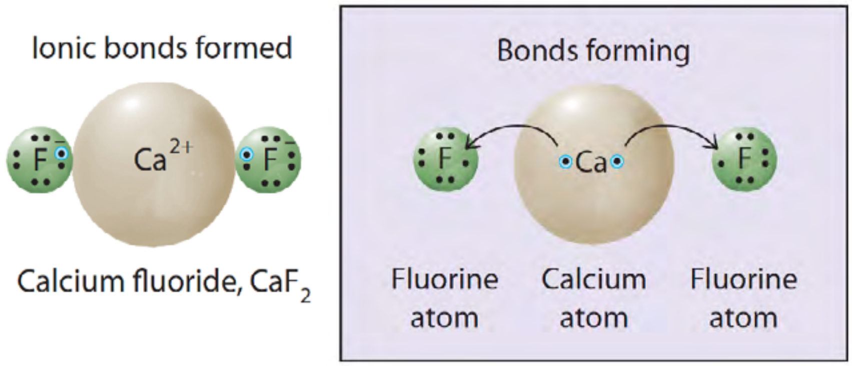


FIGURE 2.8

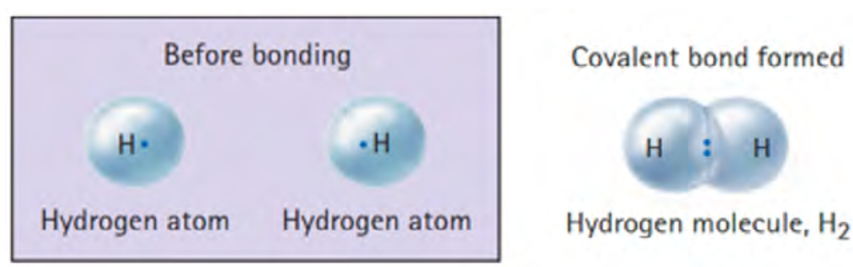
A calcium atom loses two electrons to become a positively charged calcium ion, Ca_2^+. These two electrons can be captured by two fluorine atoms, which thus become fluoride ions, $F1^-$. All three ions then bind together to form the compound calcium fluoride, CaF_2.

Ionic bonds tend to form between atoms of elements found on opposite sides of the periodic table. The hydrogen atom plus atoms of elements found to the upper right side of the periodic table are able to connect with each other through a different kind of bond called the *covalent bond*.

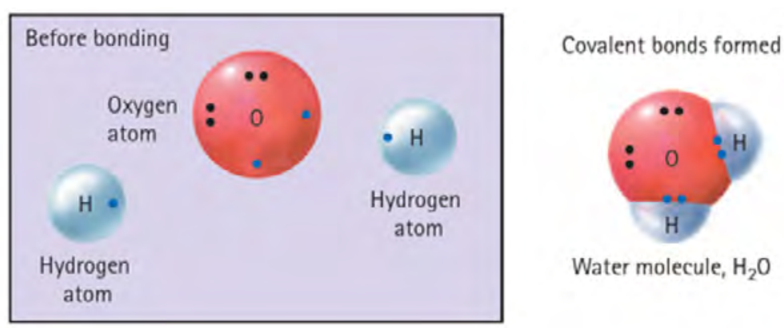
A **covalent bond** occurs when two atoms become attracted to each other's electrons. But rather than the electrons fully jumping from one atom to the other (as in an ionic bond), the electrons merely congregate in between the two atoms. By analogy, consider two kids playing with two toys that they share. You'll find the toys located between the two kids. You'll find each kid is attracted to those two toys. You'll also find that the kids tend to stay connected because of this attraction to the toys. Similarly, two atoms can be attracted two electrons that they share. This is the nature of the covalent bond. It is the covalent bond that holds two or more atoms together in a molecule, as shown in Figure 2.9. A covalent bond is often indicated merely by drawing a line between the two covalently bonded atoms, as shown in Figure 2.9c.

FIGURE 2.9

(a) Two hydrogen atoms can share their electrons resulting in a covalent bond.



(b) The oxygen atom is able to share electrons with two adjacent hydrogen atoms to form the compound water, H2O.



(c) The common representation of hydrogen and water molecules.

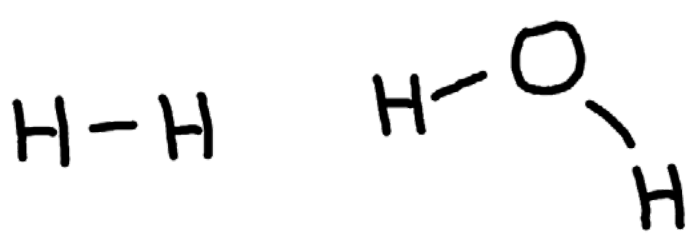
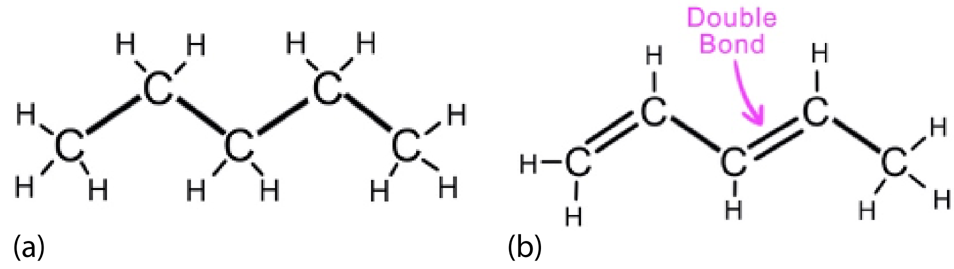


FIGURE 2.10

(a) All the bonds within the pentane molecule, C5H12, are single covalent bonds.
(b) The pentadiene molecule, C5H10, has two double bonds.

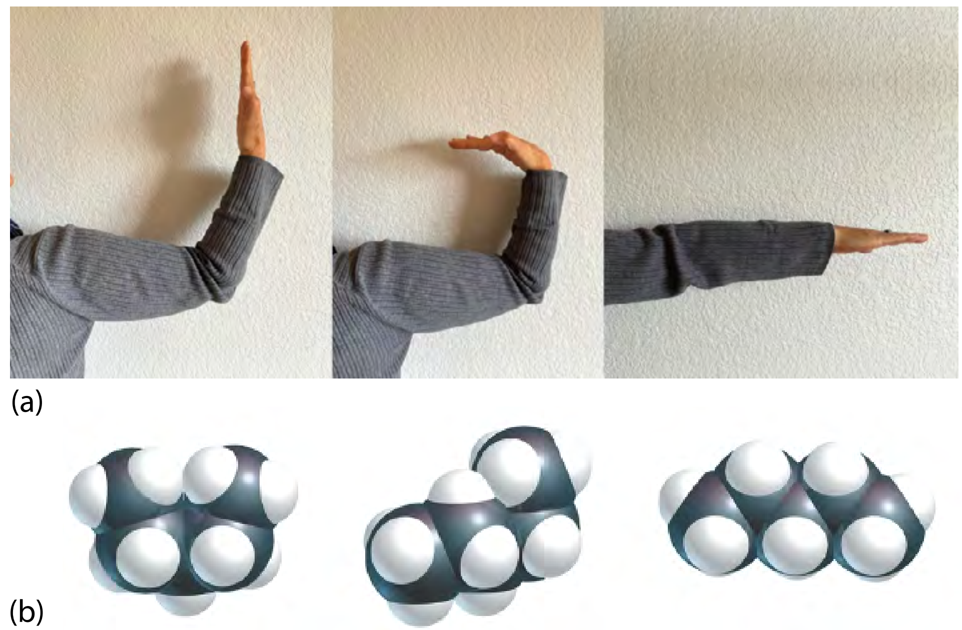


When each atom shares one of its electrons it is called *single covalent bond*. When each atom shares two of its electrons, it forms a stronger bond called the *double covalent bond*, which can be represented as a double line as shown in Figure 2.10.

FIGURE 2.11

(a) These photos show the same arm but in three different conformations.

(b) Similarly, these molecular models represent the same molecule, pentane, but in three different conformations. Carbon atoms (shown in black) held together by single covalent bonds are able to rotate relative to one another. This means the molecule as a whole can twist and turn into different conformation. This explains how larger organic biomolecules, such as proteins and nucleic acids, are also able to twist and turn into different shapes.



Interestingly, the single covalent bond can rotate. This means that molecules made of single bonds can have all sorts of different shapes, which are called *conformations*, as shown in Figure 2.11. The double bond, by contrast cannot rotate. Any double bond within a molecule restricts the number of potential different shapes.

READING CHECK

1. **Magnesium tends to lose two electrons while oxygen tends to gain two electrons. What is the chemical formula for the ionic compound magnesium oxide?**
2. **How many electrons make up a single covalent bond?**

CHECK YOUR ANSWER

1. A magnesium atom loses two electrons to form a Mg^{2+} ion. An oxygen atom gains two electrons to form an O^{2-} ion. These charges balance in a one-to-one ratio, and so the formula for magnesium oxide is MgO.
2. Two—one from each participating atom.