Chapter 2

The Chemistry of Life

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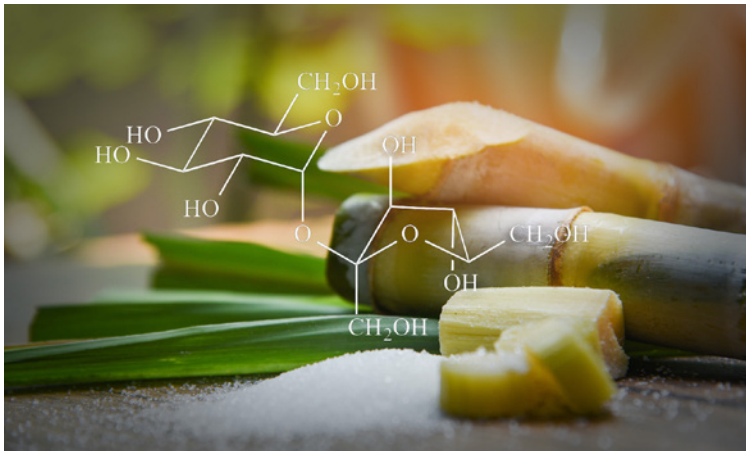

2.1 Atoms and Molecules

In many ways, a knowledge of chemistry lays a foundation for a knowledge of biology. Consider this: If chemistry is the physics of atoms and molecules, then biology is the *chemistry* of life. The focus of this chapter, therefore, is on the concepts of chemistry key for a meaningful perspective on biology.

The behavior of atoms and molecules is spelled out by the science of chemistry. If you have already taken a chemistry course, then this chapter should serve as a helpful review. If you're coming into the study of biology with a minimal background in chemistry, then this chapter will be particularly important.

An **atom** is an incredibly small fundamental unit of matter. Hydrogen, the lightest atom, makes up more than 90% of the atoms in the known universe. Most of these hydrogen atoms were formed during the beginning of our universe about 13.8 billion years ago. Heavier atoms are produced in stars, which are massive collections of hydrogen atoms pulled together by gravitational forces. The great pressures and temperatures deep in a star's interior cause hydrogen atoms to combine into heavier atoms. With the exception of hydrogen, and the next lightest atom, helium, all the atoms that occur naturally on Earth—including those in your body—are the products of stars. You are made of stardust, as is everything that surrounds you.

Atoms are so small that each breath you exhale contains more than 10 billion trillion of them. And atoms are so small that they can't be seen with visible light because they are even smaller than the wavelengths of visible light. We could stack microscope on top of microscope and never "see" an atom. Photographs of atoms, as in Figure 2.1, however, are obtained with a scanning probe microscope, an imaging device that bypasses light and optics altogether.

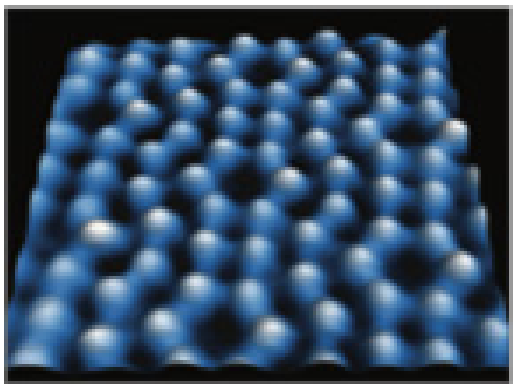

FIGURE 2.1

An image of carbon atoms obtained with a scanning probe microscope.

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An atom is made of smaller "subatomic" particles—*electrons, protons*, and *neutrons*. We know that atoms differ from one another only in the number of subatomic particles they contain. **Protons** and **neutrons** are subatomic particles bound together at the atom's center to form the **atomic nucleus.** The atomic nucleus is a dense, positively charged center of every atom. This nucleus is a relatively heavy particle that makes up most of an atom's mass. Each proton carries a +1 charge while each neutron has a neutral charge. Surrounding the nucleus are the ultra-tiny **electrons**, which swarm to create an electron cloud, as shown in Figure 2.2. Each electron carries a -1 charge. Within a neutral atom, the number of protons in the nucleus equals the number of surrounding electrons.

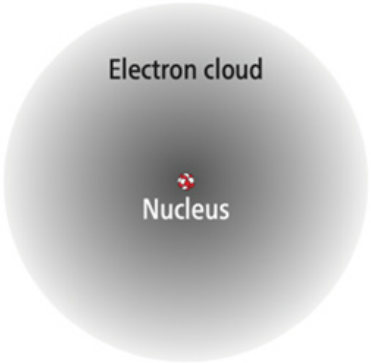

FIGURE 2.2

Electrons whiz around the atomic nucleus, forming what can be described as a cloud that is more dense where the electrons tend to spend most of their time. Furthermore, if this illustration were drawn to scale, the atomic nucleus with its protons and neutrons would be too small to be seen.

In the outer regions of any atom are electrons, which repel the electrons of neighboring atoms. Two atoms, therefore, can get only so close to each other before they start repelling (provided they don't join in a chemical bond, as will be discussed in a bit). When the atoms of your hand push against the atoms of a wall, electrical repulsions between electrons in your hand and electrons in the wall prevent your hand from passing through the wall. These same electrical repulsions prevent us from falling through the solid floor. They also allow us the sense of touch. Interestingly, when you touch someone, your atoms and those of the other person do not meet. Instead, atoms from the two of you get close enough so that you sense an electrical repulsion. A tiny, though imperceptible, gap still exists between the two of you (Figure 2.3).

FIGURE 2.3

When we physically touch, we feel an electric force of repulsion between our atoms that prevents us from getting even closer. An emotional touch, by contrast, holds no such boundaries.

Given all the types of materials, you might think there must be many kinds of atoms. But the number of different kinds of atoms is surprisingly small. The great variety of substances results from the many ways a few kinds of atoms can be combined. Just as the three colors red, green, and blue can be combined to form any color on a computer screen or the 26 letters of the alphabet make up all the words in a dictionary, only a few kinds of atoms combine in different ways to produce all substances. To date, we know of about 118 distinct atoms. Of these, about 90 are found in nature. The remaining atoms have been created in the laboratory.

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Any material made of only one type of atom is classified as an **element.** Three examples are shown in Figure 2.4. Pure gold, for example, is an element— it contains only gold atoms. Nitrogen gas is an element because it contains only nitrogen atoms. Likewise, the graphite in your pencil is an element—carbon. Graphite is made up solely of carbon atoms. All of the elements are listed in a chart called the **periodic table**, shown in Figure 2.5.

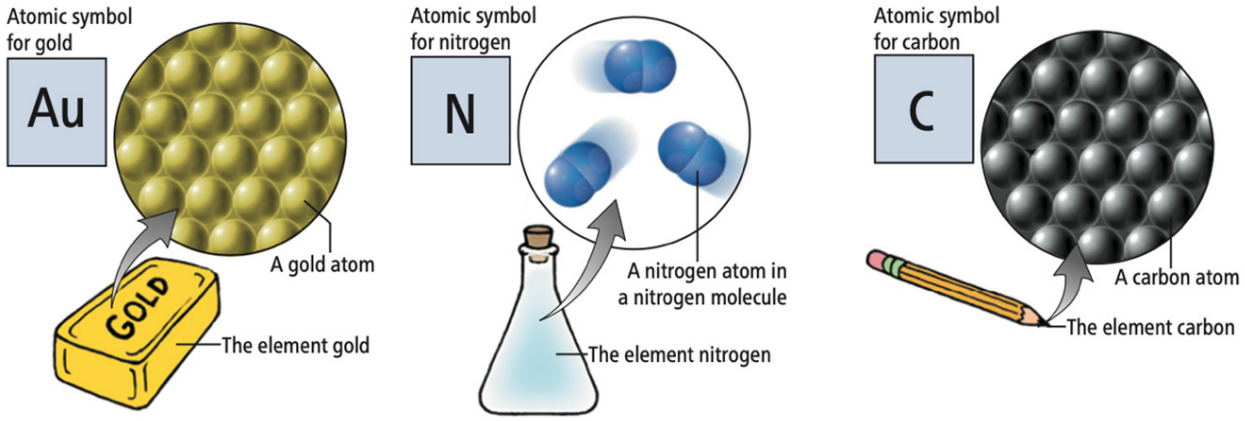

FIGURE 2.4 Any element consists of only one kind of atom.

As you can see from the periodic table, each element is designated by its **atomic symbol**, which comes from the letters of the element's name. For example, the atomic symbol for carbon is C, and the symbol for chlorine is Cl. In many cases, the atomic symbol is derived from the element's Latin name. Gold has the atomic symbol Au after its Latin name, *aurum*. Lead has the atomic symbol Pb after its Latin name, *plumbum*. Elements with symbols derived from Latin names are usually those that were discovered earliest.

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
			58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
			90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

FIGURE 2.5 The periodic table lists all the known elements.

Note that only the first letter of an atomic symbol is capitalized. The symbol for the element cobalt, for instance, is Co, but CO is a combination of two elements: carbon, C, and oxygen, O.

The terms *element* and *atom* are often used in a similar context. You might hear, for example, that gold is an element made of gold atoms. Generally, *element* is used in reference to an entire macroscopic or microscopic sample, and *atom* is used when speaking of the submicroscopic particles in the sample. The important distinction is that elements are made of atoms and not the other way around.

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Atoms can combine to form a **molecule**, which is a group of atoms held tightly together by chemical bonds. Two oxygen atoms, for example, form an oxygen molecule. We use the elemental formula to indicate multiple atoms of the same element bonded into a molecule. An **elemental formula** shows the atomic symbol followed by a numeral subscript indicating the number of atoms in each molecule. Thus, a molecule of two oxygen atoms has the elemental formula O_2. Similarly, a molecule of eight sulfur atoms has the elemental formula S_8. For elements in which the basic units are individual atoms (no molecules), the elemental formula is simply the chemical symbol. This is the case for most elements.

READING CHECK

1. **Are atoms made of molecules or are molecules made of atoms?**
2. **Are atoms made of elements or are elements made of atoms?**

CHECK YOUR ANSWERS

1. A molecule is a group of atoms held together by chemical bonds. Thus, molecules are made of atoms.
2. An element can be considered a macroscopic sample of matter containing only one type of atom. Thus, elements are made of atoms.

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