2 The Chemistry of Life

CHAPTER OUTLINE

LEARNING OBJECTIVES

- Describe the basic structure of an atom in terms of three atomic particles (2.1.1).
- Explain why electrons determine the chemical behavior of atoms (2.1.2).
- Explain how electrons carry energy (2.1.3).
- Differentiate between a cation and an anion (2.2.1).
- Differentiate between an ion and an isotope (2.2.2).
- Define a chemical bond, and describe the three principal kinds (2.3.1).
- Explain how ionic bonds promote crystal formation (2.3.2).
- Explain why most chemical bonds in organisms are covalent bonds, and distinguish between polar and nonpolar covalent bonds (2.3.3).
- Predict which molecules will form hydrogen bonds with each other (2.3.4).
- Distinguish between a chemical bond and van der Waals interactions (2.3.5).
- Explain why water heats up so slowly (2.4.1).
- Explain why ice floats (2.4.2).
- Explain why sweating cools you (2.4.3).
- Distinguish cohesion from adhesion (2.4.4).
- Explain why oil will not dissolve in water (2.4.5).
- Define pH, and predict the change in hydrogen ion concentration represented by a difference of 1 on the pH scale (2.5.1).

Some Simple Chemistry (p. 36)

2.1 **Atoms** (p. 36; Figs. 2.1–2.4; Table 2.1)

A. All matter is composed of atoms and atoms are the smallest particles into which a substance can be divided and still retain its chemical properties.
B. An atom has positively charged protons and neutrally charged neutrons in the nucleus, with tiny negatively charged electrons whizzing around the nucleus.
C. The number of protons of an atom is referred to as its atomic number.
D. Atomic mass includes the number of protons and neutrons.
E. Electrons Determine What Atoms Are Like
   1. Electrons determine the behavior of atoms because they are the parts of the atom that come into contact with each other.
F. Electrons Carry Energy
   1. Electrons possess potential energy, and energy levels surrounding the nucleus reflect the amount of energy possessed by an electron existing there.
   2. Less energy is present in electrons closer to the nucleus.
   3. Electrons are most likely to be found in volumes of space called orbitals.
   4. Each orbital can hold only two electrons.
   5. The first energy level has one orbital, for a total of two electrons.
   6. The second and third energy levels each have four orbitals, and can hold up to eight electrons apiece.

7. When orbitals are not filled with electrons, the atoms are likely to react with atoms to fill orbitals.

2.2 Ions and Isotopes (p. 38; Figs. 2.5–2.7)

A. Ions
1. In an electrically neutral atom, there are equal numbers of protons and electrons.
2. Ions form when atoms do not have equal numbers of electrons and protons.

B. Isotopes
1. The number of neutrons for atoms of an element can vary, giving rise to isotopes of that element.
2. Some isotopes of elements break apart by radioactive decay.

C. Medical Uses of Radioactive Isotopes
1. Radioactive tracers are used for both the detection and treatment of human disorders.

2.3 Molecules (p. 39; Figs. 2.8–2.11)

A. A molecule is made up of two or more atoms held together by energy in the form of a chemical bond.

B. There are three types of chemical bonds: ionic bonds, covalent bonds, and hydrogen bonds. van der Waals forces are another type of chemical attraction.

C. Ionic Bonds
1. Ionic bonds form when ions are electrically attracted to each other by opposite charges.
2. Table salt is built of ionic bonds.
3. Sodium gives up an electron to chlorine; sodium then bears a positive charge, while chloride bears a negative charge; these two ions combine to form table salt (NaCl).
4. Ionic bonds are strong and not directional, two properties that help them form crystals.

D. Covalent Bonds
1. Covalent bonds form when electrons are shared between atoms.
2. Most organic molecules are formed from covalent bonds.
3. Two key properties make covalent bonds ideal for use in biological molecules: they are strong and they are very directional.
4. The nucleus of a particular atom may be better at attracting the shared electrons of a covalent bond, causing the electrons to spend more time in the vicinity of this atom; this creates tiny partial negative and positive charges within the molecule, which is called a polar molecule.

E. Hydrogen Bonds
1. Hydrogen bonds are the result of weak electrical attractions between the positive end of one polar molecule and the negative end of another.
2. Hydrogen bonds are weak and highly directional, and thus play an important role in maintaining the conformation of large, biologically important molecules.

Water: Cradle of Life (p. 44)

2.4 Unique Properties of Water (p. 44; Figs. 2.12–2.14; Table 2.2)

A. All organisms are made up of a large quantity of water.

B. Water is biologically important because it is a polar molecule and forms hydrogen bonds between its own molecules.

C. Heat Storage
1. Water has the capacity for heat storage because of its many hydrogen bonds.
2. Water changes temperature slowly, an attribute that is beneficial to living organisms.

D. Ice Formation
1. When water freezes, the hydrogen bonds space water molecules apart, making ice less dense than liquid water.

E. High Heat of Vaporization
1. Considerable energy is required to break the hydrogen bonds in water and turn liquid water into vapor.

2. The high heat of vaporization of water helps to explain why evaporative cooling removes heat from the body.

F. Cohesion
1. When the polar molecules of water are attracted to other molecules of water, this property is called cohesion.
2. The surface tension of water is created by cohesion.
3. When water molecules are attracted to the polar molecules of a substance other than water, the property is called adhesion.
4. Water clings to other substances, making them wet, as a result of adhesion.

G. High Polarity
1. Other polar, hydrophilic, molecules are “welcomed” by water molecules, which form shells of water molecules around each of the other polar molecules such that these molecules are soluble in water.
2. Nonpolar molecules, by contrast, are hydrophobic.

2.5 Water Ionizes (p. 46; Fig. 2.15)

A. Water ionizes spontaneously, forming hydrogen ions and hydroxide ions.

B. pH
1. The amount of hydrogen ions present in a solution can be measured by the pH scale, which indicates substances that are acids and bases.

C. Acids
1. An acid is a substance that increases the hydrogen ion concentration in a solution, thus decreasing the pH of the solution.

D. Bases
1. A base is a substance that combines with hydrogen ions in solution, thus increasing pH.

E. Buffers
1. Buffers resist changes in pH by either taking up or giving off hydrogen ions as needed.

KEY TERMS

- **atom** (p. 36)
- **proton** (p. 36)
- **neutron** (p. 36)
- **electron** (p. 36)
- **atomic number** (p. 36)
- **element** (p. 36)
- **mass number** (p. 36)
- **energy** (p. 37)
- **isotope** (p. 38)
- **radioactive decay** (p. 38)
- **molecule** (p. 39)
- **chemical bond** (p. 39)
- **ionic bond** (p. 39)
- **hydrogen bond** (p. 42)
- **van der Waals forces** (p. 42)
- **cohesion** (p. 45)
- **adhesion** (p. 45)
- **soluble** (p. 45)
- **hydrophobic** (p. 45)
- **hydrophilic** (p. 45)
- **pH scale** (p. 46)
- **buffer** (p. 46)

- **acid rain** (p. 47)

LECTURE SUGGESTIONS AND ENRICHMENT TIPS

1. Demonstrate chemical oxidation (loss of electrons) with the browning of freshly cut fruit. At the beginning of class, cut a fresh apple (or banana) into thin slices. Next, slice a lemon, but do not allow the lemon juice to come in contact with the other fruit. After 15–30 minutes, the flesh of the apple should turn noticeably brown. This is due to the interaction of the interior pigments of the apple (or other fruit) with atmospheric oxygen. Lemons do not turn brown because lemon plants can synthesize vitamin C from glucose. Vitamin C inhibits oxidation of the lemon because it interacts very quickly with oxygen, preventing the oxygen from interacting with the rest of the fruit. Vitamin C is often referred to as an antioxidant.
2. Demonstrate properties of water that contribute to capillary action by using a capillary tube to draw up a colored liquid.
3. If the time of year is right, encourage students to visit a local pond and observe the variety of insects that make use of water's cohesive property.
4. Using online resources have student's research applications of carbon dating in identifying the age of specific historically important artifacts.
5. If possible, arrange for a guest speaker in nuclear medicine to speak to the class about the medical applications of isotopes.

CRITICAL THINKING QUESTIONS

1. The human body uses several methods to carefully regulate the pH of the blood, including the bicarbonate system within the blood and adjustments to breathing depth and rate that alter the CO_2 content of the blood. Why are several buffer systems needed?
2. Which unique features of water help to support pond life, even in the winter months when water is frozen? Which other physical properties of water are beneficial to pond water organisms? How might these properties have played a part in sustaining life during the progression of an ice age?