

2 Atoms and Molecules: The Chemical Basis of Life

Key Concepts

- 2.1 Carbon, hydrogen, oxygen, and nitrogen are the most abundant elements in living things.
- 2.2 The chemical properties of an atom are determined by its highest energy electrons, known as valence electrons.
- 2.3 A molecule consists of atoms joined by covalent bonds. Other important chemical bonds include ionic bonds. Hydrogen bonds and van der Waals interactions are weak attractions.
- 2.4 The energy of an electron is transferred in a redox reaction.
- 2.5 Water molecules are polar, having regions of partial positive charge and partial negative charge that permit them to form hydrogen bonds with one another and with other charged substances.
- 2.6 Acids are hydrogen ion donors; bases are hydrogen ion acceptors. The pH scale is a convenient measure of the hydrogen ion concentration of a solution.

Learning Objectives

- 2-1 Name the principal chemical elements in living things and provide an important function of each.
- 2-2 Compare the physical properties (mass and charge) and locations of electrons, protons, and neutrons. Distinguish between the atomic number and the mass number of an atom.
- 2-3 Define the terms *orbital* and *electron shell*. Relate electron shells to principal energy levels.
- 2-4 Explain how the number of valence electrons of an atom is related to its chemical properties.
- 2-5 Distinguish among simplest, molecular, and structural chemical formulas.
- 2-6 Explain why the mole concept is so useful to chemists.
- 2-7 Distinguish among covalent bonds, ionic bonds, hydrogen bonds, and van der Waals interactions. Compare them in terms of the mechanisms by which they form and their relative strengths.

Chapter Outline

- I. Elements and Atoms
 - A. An atom is uniquely identified by its number of protons
 - B. Protons plus neutrons determine atomic mass
 - i. Isotopes of an element differ in number of neutrons
 - C. Electrons move in orbitals corresponding to energy levels
- II. Chemical Reactions
 - A. Atoms form compounds and molecules
 - B. Simplest, molecular, and structural chemical formulas give different information
 - C. One mole of any substance contains the same number of units
 - D. Chemical equations describe chemical reactions

III. Chemical Bonds

- A. In covalent bonds electrons are shared
- B. The function of a molecule is related to its shape
- C. Covalent bonds can be nonpolar or polar
- D. Ionic bonds form between cations and anions
- E. Hydrogen bonds are weak attractions

IV. van der Waals interactions are weak forces

V. Redox Reactions

VI. Water

- A. Hydrogen bonds form between water molecules
- B. Water molecules interact with hydrophilic substances by hydrogen bonding
- C. Water helps maintain a stable temperature

VII. Acids, Bases, and Salts

- A. pH is a convenient measure of acidity
- B. Buffers minimize pH change
- C. An acid and a base react to form a salt

Research and Discussion Topics

- Investigate the roles of some of the trace elements in living things. Some are well known, like iron and iodine, but what is the importance of copper, zinc, selenium, vanadium, silicon, or chromium? Include in the discussion the possible deleterious effects of too much of a certain trace element.
- Investigate the medical uses of radioisotopes. What radioisotopes are used to date recent fossils? Very old fossils? Why would different isotopes be used?
- Research the disposal of radioisotopes. How does their disposal impact the environment?
- Compare and contrast the halogens and the noble gases. Elements in which group are likely to be involved in chemical reactions? Why?
- Chemical formulas can be written as empirical formulas, molecular formulas, or structural formulas. Explain why these different forms of molecular expression are necessary.
- What are the pros and cons of the utilization of hydrogen gas as a source of energy? What are the obstacles that have prevented its widespread use?

Teaching Suggestions

- A good demonstration of surface tension may be accomplished if you have an overhead projector. Bring in a Petri dish filled nearly to the brim with water. Put it on the overhead projector. If your hands are steady, you will be able to put a razor blade on the surface and it will float there. Try using a pair of tweezers to place it on the water. On the screen, the students will be able to see the blade floating on the water. You can exhibit capillary action in the same way. Bring a capillary tube. Put the end in the water in the Petri dish. On the screen, the students can see the water rise in the tube.
- The central concept of hydrogen bonding and how this bonding makes water such a unique substance can't be emphasized enough. There are many common examples, in this and other texts, familiar to students that illustrate these concepts. You might also discuss these concepts in relation to aquatic organisms. What would happen to a turtle in a lake if water froze from the bottom to the top?
- Remind students that the pH scale is logarithmic. Log scales are often difficult for students to conceptualize. The Richter scale for earthquakes is a familiar example and is similar to the pH scale. Just as an earthquake measuring 4 is actually 10 times greater in magnitude than an earthquake measuring 3 on the Richter scale, a solution of pH 5 is 10 times more acidic than a solution of pH 6. A solution of pH 2 is 100 times more acidic than a solution of pH 4. On the Richter scale, earthquakes measuring 1 point higher have a more than 20-times increase in energy.
- It is difficult to lecture on things that can't be seen or touched, particularly for visual and tactile learners. Use models when discussing atoms, elements, and bonding. Balloons work well for demonstrating atomic structure. Springs, tennis balls, and bar magnets work well for demonstrating covalent, ionic, and hydrogen bonding, respectively.

Lecture Enrichment

- Relative sizes

Students need to get a feel for the size of atoms. Some may think that atoms or molecules are large enough to be seen easily. The fact that a million atoms would be as big as the period at the end of this sentence puts perspective to actual size. The fact that an atom is mostly empty space can be envisioned by the comparison of a golf ball representing a nucleus, and the electrons orbiting 1 km (over a half mile) away.

- Characteristics of water

The importance of hydrogen bonding can be made more interesting, and perhaps more enigmatic, by telling students that the bond lasts $1/100,000,000,000^{\text{th}}$ of a second, yet it is one of the most important bonds on Earth!

One additional example of hydrogen bonding results in surface tension of water. This is one familiar to many children (and adults)—skipping rocks on water. An additional interesting example is animals that can ‘walk’ on water. The basilisk lizard and the water strider accomplish this in two different ways, but both exploit the surface tension created by water molecules.

Students are often under the mistaken impression that all hydrophilic substances dissolve in water. Hydrophilic means having an affinity for water; not all hydrophilic substances dissolve, because their molecules are too large. Cellulose is a familiar example. Later in this course, they will see the movement of water into plant roots partially because of the affinity for water of the cell walls composed of cellulose. One might point out that towels are made of cotton (100% cellulose) rather than nylon. The hydrophilic nature of cotton allows the towel to dry us off by absorbing the water, but the towel doesn’t dissolve in water.

- Chemical elements necessary for human life

We have known for centuries that carbon, copper, iron, and sulfur are necessary components of the human body. However, the discovery that some of the micronutrients such as boron, potassium, selenium, and silicon, and even the macronutrients sodium and calcium, are required for life was not made until the 1800s. Zinc is one of the most important trace elements necessary for bodily function, involved in everything from homeostasis to immune response. Many cold and flu products sold in stores contain zinc. Discuss with students the natural sources for many of the trace elements required by the human body.

- Some of the most commonly used radiometric dating methods

Parent Isotope	Half-Life (years)	Parent Isotope Abundant In
Potassium-40	1.3 billion	Potassium-rich minerals including feldspar, mica
Rubidium-87	48.8 billion	Potassium-rich minerals
Uranium-238	4.5 billion	Uranium ores: zircon and other minor minerals
Carbon-14*	5730	Organic matter, atmospheric carbon dioxide, dissolved carbonate

* Because of the relatively short half-life of carbon, it is used primarily in archaeological, not fossil, dating.

- Iron

Iron is well known as the important central atom to the hemoglobin molecule, as well as other biologically important molecules. But iron pills are a leading cause of childhood poisoning deaths in the U.S. In the early 1990s, over 10,000 children accidentally swallowed these pills annually. Just as many as five high-potency over-the-counter tablets could be fatal for a small child. The FDA now requires warnings to be placed on these pill bottles, and the pills are often in packaging that is difficult—even for an adult—to open.

Suggested Readings

Acids and Bases Problem Set. 3 November 2004. University of Arizona. 6 September 2006. http://www.biology.arizona.edu/biochemistry/problem_sets/ph/ph.html. Interactive pH tutorial from “The Biology Project.”

Anthony, C. “Acids and Bases: An Introduction,” 2003. Vision learning CHE-2.2, 6 September 2006. http://www.visionlearning.com/library/module_viewer.php?mid=58. Provides a good summary of the history, basics, and examples of acids and bases.

Chemicals and Human Health. 11 May 2005. University of Arizona. 4 September 2006. <http://www.biology.arizona.edu/chh/default.html>. Includes problem sets relating to toxicology, such as “Are manmade chemicals more toxic than those found in nature?” Students read an engaging article and answer critical thinking questions.

Driscoll, C.T., Lawrence, G.B., Bulger, A.J., Butler, T.J., Cronan, C.S., Eagar, C., Lambert, K.F., Likens, G.E., Stoddard, J.L., Weathers, K.C. (2001). Acid Rain Revisited: Advances in Scientific Understanding Since the Passage of the 1970 and 1990 Clean Air Act Amendments. *Hubbard Brook Research Foundation* Vol. 1 No. 1. <http://hubbardbrookfoundation.org/acid-rain-revisited/>.

Expanded Academic ASAP. Thomson Gale. 4 September 2006. <http://find.galegroup.com/itx/>. Anaerobic respiration contribution to energy supply during exercise. This is a good way to interest students in redox reactions.

Lemly, B. “Lovin’ Hydrogen.” *Discover*. November 2001. 53–57, 86. The future of hydrogen as a “wonder” fuel.

Scott, C. B. and R. B. Kemp. “Direct and Indirect Calorimetry of Lactate Oxidation: Implications for Whole-Body Energy Expenditure.” *Journal of Sports Sciences*. 23 January 2005: 15.5.

Tennesen, M. (2008, June). Sour Showers: Acid Rain Returns—This Time It Is Caused by Nitrogen Emissions. *Scientific American*. <http://www.scientificamerican.com/article.cfm?id=acid-rain-caused-by-nitrogen-emissions>. Online article discussing how acid rain has changed.