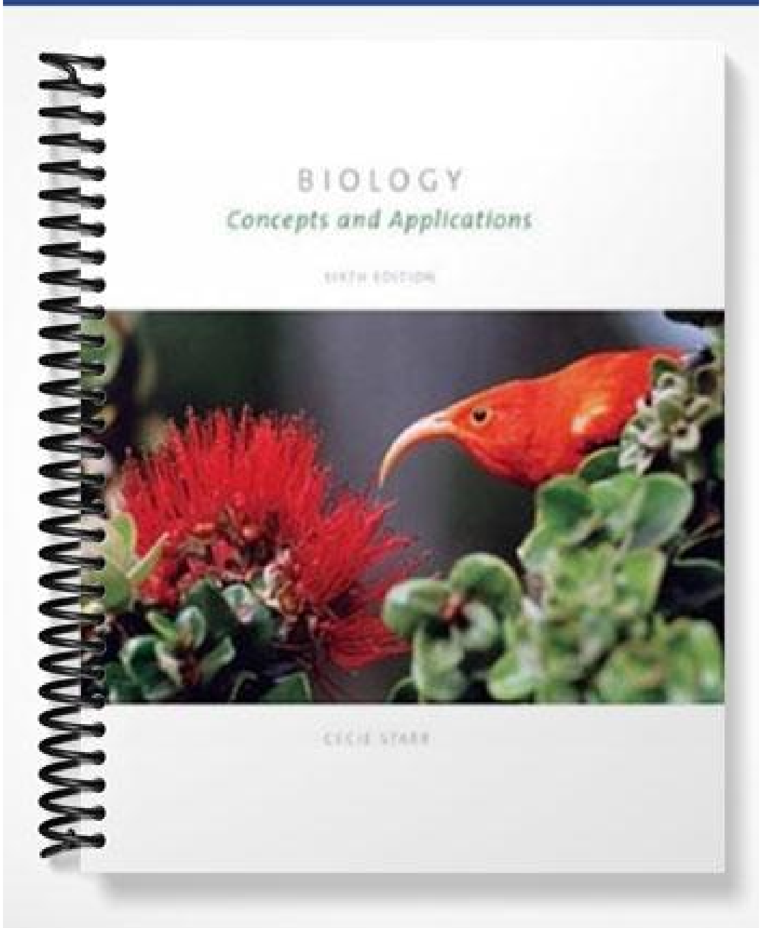
SOLUTIONS MANUAL



2

LIFE'S CHEMICAL BASIS

Chapter Outline

Objectives

1. Understand how protons, electrons, and neutrons are arranged into atoms and ions.
2. Explain how the distribution of electrons in an atom or ion determines the number and kinds of chemical bonds that can be formed.
3. Know the various types of chemical bonds, the circumstances under which each forms, and the relative strengths of each type.
4. Understand the essential chemistry of water and of some common substances dissolved in it.
5. Understand the relationships of acids, bases, and salts.

Key Terms

element
atom
proton
neutron
electron
atomic number
mass number
periodic table
isotopes
radioactive decay
radioisotopes
tracers
orbital
shell model
chemical bonding
molecule
compound
mixture
ion
ionic bond
covalent bond
double covalent bond
nonpolar covalent bond
polar covalent bond
hydrogen bond
hydrophilic substances
hydrophobic substances
temperature
evaporation
solvent
solute
sphere of hydration
cohesion
hydrogen ion, H^+
hydroxide ion, OH^-
pH scale
acid, acidic
base, basic
salt
buffer system

Lecture Outline

Impacts, Issues: What Are You Worth?

A. Chemically, how much is a human body really worth?
   1. The body is a collection of elements.
   2. The smallest units of elements are atoms.
B. Quantities of elements in the body vary.
   1. Oxygen, hydrogen, carbon, and nitrogen are the most abundant.
   2. Trace elements include selenium, mercury, arsenic, and lead.
C. All of the elements in the human body could be bought for $118.63.

2.1 Start With Atoms

A. An atom is the smallest unit of matter that is unique to a particular element.
   1. Atoms are composed of three particles:
      a. *Protons* (p^+) are part of the atomic nucleus and have a positive charge. Their quantity is called the atomic number (unique for each element).
      b. *Neutrons* are also a part of the nucleus; they are neutral. Protons plus neutrons = atomic mass.
      c. *Electrons* (e^-) have a negative charge. Their quantity is equal to that of the protons. They move around the nucleus.
   2. Atomic numbers and mass numbers give us an idea of whether and how substances will react.
B. The periodic table is an arrangement of elements based on their chemical properties.
   1. Those in the same column of the table have the same number of electrons available for interactions with other atoms.
   2. This allows chemists to predict the chemical behavior of an element.

2.2 Radioisotopes

A. Isotopes are variant forms of atoms.
   1. Atoms with the same number of protons (for example, carbon with six) but a different number of neutrons (carbon can have six, seven, or eight) are called isotopes (^{12}C, ^{13}C, ^{14}C).
   2. Some radioactive isotopes are unstable and tend to decay into more stable atoms.
      a. They can be used to date rocks and fossils.
      b. Some can be used as tracers to follow the path of an atom in a series of reactions.
B. Radioisotopes are used in PET to follow a particular chemical in the body and determine its patterns of metabolism.

2.3 What Happens When Atom Bonds With Atom?

A. Electrons and Energy Levels
   1. Electron behavior influences atom bonding.
      a. Electrons are attracted to protons but are repelled by other electrons.
      b. Orbitals are like volumes of space around the atomic nucleus in which electrons are likely to be at any instant.
      c. Each orbital contains one or two electrons.
   2. Orbitals can be thought of as occupying shells around the nucleus.
      a. The shell closest to the nucleus has one orbital holding a maximum of two electrons.
      b. The next shell can have four orbitals with two electrons each for a total of eight electrons.
   3. A chemical bond is a union between the electron structures of atoms.
      a. Atoms with "unfilled" orbitals in their outermost shell tend to be reactive with other atoms.

b. The number or the distribution of its electrons changes when an atom gives up, gains, or shares electrons.

B. From Atoms to Molecules
1. A molecule is a bonded unit of two or more (same or different) atoms.
2. A compound is a substance in which the relative percentages of two or more elements never vary.
3. In a mixture, two or more elements simply intermingle in proportions the can vary.

2.4 Bonds in Biological Molecules

A. Ion Formation and Ionic Bonding
1. When an atom loses or gains one or more electrons, it becomes positively or negatively charged—an ion.
2. In an *ionic bond,* (+) and (–) ions are linked by mutual attraction of opposite charges—for example, NaCl.

B. Covalent Bonding
1. A *covalent bond* holds together two atoms that share one or more pairs of electrons.
2. In a *nonpolar covalent bond*, atoms share electrons equally.
3. In a *polar covalent bond*, because atoms share the electron unequally, there is a slight difference in charge between the two poles of the bond; water is an example.

C. Hydrogen Bonding
1. In a *hydrogen bond,* an atom of a molecule interacts weakly with a hydrogen atom already taking part in a polar covalent bond.
2. These bonds impart structure to liquid water and stabilize nucleic acids and other large molecules.

2.5 Water's Life-Giving Properties

A. Polarity of the Water Molecule
1. Water is a polar molecule because of a slightly negative charge at the oxygen end and a slightly positive charge at the hydrogen end.
2. Water molecules can form hydrogen bonds with each other.
3. Polar substances are hydrophilic (water loving); nonpolar ones are hydrophobic (water dreading) and are repelled by water.

B. Water's Temperature-Stabilizing Effects
1. Water tends to *stabilize* temperature because it can absorb considerable heat before its temperature changes.
2. In evaporative processes the input of heat energy increases the molecular motion so much that hydrogen bonds are broken and water molecules escape into the air, thus cooling the surface.
3. In freezing, the hydrogen bonds resist breaking and lock the water molecules in the bonding patterns of ice.

C. Water's Solvent Properties
1. The *solvent properties* of water are greatest with respect to polar molecules with which they interact.
2. "Spheres of hydration" are formed around the solute (dissolved) molecules.

D. Water's Cohesion
1. Hydrogen bonding of water molecules provides *cohesion* (capacity to resist rupturing), which imparts surface tension.
2. Cohesion is especially important in pulling water through plants.

2.6 Acids and Bases

A. The pH Scale
1. pH is a measure of the H^+ concentration in a solution; the greater the H^+ the lower the pH scale.
2. The scale extends from 0 (acidic) to 7 (neutral) to 14 (basic).

B. How Do Acids and Bases Differ?

1. A substance that releases hydrogen ions (H^+) in solution is an *acid*—for example, HCl.
2. Substances that release ions such as (OH^-) that can combine with hydrogen ions are called *bases*.

C. Salts and Water
1. A salt is an ionic compound formed when an acid reacts with a base; example: HCl + NaOH → NaCl + H_2O.
2. Salts dissociate into useful ions (examples: Na^+ and Ca^{++}) in body fluids.

D. Buffers Against Shifts in pH
1. Buffer molecules combine with, or release, H^+ to prevent drastic changes in pH.
2. Bicarbonate is one of the body's major buffers.

Suggestions for Presenting the Material

- There is no escaping the fact that Chapter 2 is chemistry. And chemistry can be intimidating—especially to nonscience majors. The material in the book is elementary and written in a lucid manner, but the quality of presentation is up to the individual instructor.
- Perhaps a quick survey of class members who have, and have not, had high school chemistry will aid in adjusting your level of presentation.
- One approach that might help your students in organizing this material is to write it in outline form on an overhead transparency. This may work especially well for this chapter because a large portion of the material consists of definitions.
- The use of ball-and-stick models (see the Enrichment section below) is very helpful. If the lecture room is large, you may have to "tour" the room with the models for better viewing.
- If students become discouraged, assure them that several of these topics will be reinforced in future chapters (hopefully before the next exam).
- The text gives careful attention to useful examples of isotopes, electron excitation, bonding, buffers, and water.
- Using Figure 2.12 as your visual reference will help in explaining acid, base, and pH scale. Note particularly the pH values of common household products. Emphasize that acids and bases are not necessarily terms that describe *corrosive* substances!
- The properties of water are important to life on Earth. Describe the polarity of water molecules; then proceed to the influence that water molecules have on cells and cellular environments.

Classroom and Laboratory Enrichment

- Students often approach even basic chemistry with considerable trepidation, especially if they lack sufficient high school background in this area or they have been out of school for several years. Emphasize the biological significance of chemistry; stress that an elemental knowledge of chemistry is essential to understanding the structure and function of living things. Give students frequent opportunities to use new terms. Using overheads or diagrams, pause often and interject questions to gauge their level of understanding.
- Use as many models and diagrams as possible. If you wish to emphasize electron orbitals, use foam-and-stick models of the orbitals to make this concept seem clearer.
- Students frequently have trouble visualizing atoms and molecules as real entities. To help them get a clearer mental picture of some of the basic atoms and molecules, use ball-and-stick models that are very large and easy to see from the back of the room. These models will help students to understand the size relationships among molecules. Overhead transparencies of ball-and-stick diagrams will also help. Such models and diagrams will be especially useful when covering the larger carbon compounds.

- Present sketches of a polar covalent molecule and a nonpolar covalent molecule. Ask students to identify which molecule is polar and which is nonpolar and to explain their choices.
- Ball-and-stick models are also useful for demonstrating the hydrogen bonding that occurs between water molecules and the latticework structure of ice.
- Fill a large jar with water, then add salad oil. Shake the bottle, then allow it to sit on the front desk. Ask students to explain what has happened. Add a few drops of methylene blue (a polar dye) and sudan III fat stain (a nonpolar dye) to the jar and shake. Students will note that the water layer is blue and the oil layer is red; ask them why this is so.
- Draw a pH scale on the board (or use an overhead transparency of Figure 2.12), and discuss pH values of familiar substances.
- If your class is small, demonstrate the use of a pH meter. For larger groups, pH paper can be used to give each student a chance to quickly determine the pH of some sample solutions.
- If you are teaching in a room with a "periodic table of the elements" hanging on the wall, point out the major elements, or use an overhead transparency to show the same items.
- Prepare a glass of iced tea (instant mix) with added sugar and lemon. Which ingredients are compounds? What are the components of the mixture?
- Bring a package of "buffered" and "regular" aspirin to class. Ask students to discover the difference(s) in ingredients.
- Using the names of the active ingredients on an antacid package, explain how they act as *buffers* to stomach acid.

Impacts, Issues Classroom Discussion Ideas

- What food molecules are constructed from the "big four" elements?
- What does the word "trace" mean when speaking of trace elements?
- The difference between a trace element being toxic and actually beneficial to the body is often a matter of ____.
- If humans are made of the same elements as are found in the earth and non-living things, what is it that makes us "alive?"

Additional Ideas for Classroom Discussion

- Distinguish between a compound and a mixture, an atom and a molecule.
- What chemicals are in the human body? Ask students to name as many as they can; help them complete their list.
- What is the difference between polar and nonpolar covalent bonds?
- Why do soft drinks have such a low pH? What ingredient is responsible for this low pH?
- What is acid precipitation? What chemical reaction is responsible for the mildly acidic pH of normal rainwater? What chemicals are responsible for acid precipitation?
- What would happen to aquatic organisms living in temperate climates if water sank when it froze instead of floated?
- What is the difference between the composition of a *molecule* of a substance and an *atom* of that substance?
- If atoms are beyond the reach of visualization even by "super" electron microscopes, how then do we know so much about their structure?
- Water is the "universal solvent" for Earth. Do you know of any other compound that would serve as well or better?

- Some pain relievers are advertised as "tribuffered." Is this a real advantage or just a sales gimmick?
- Television commercials portray the "acid stomach" as needing immediate R-O-L-A-I-D-S. Is the stomach *normally* acid? How do you know when there is too much acid down there?
- Why do alcohols dissolve in water?
- What is the difference between methyl alcohol and ethyl alcohol? How is each of these alcohols processed by the human body?

How Would You Vote? Classroom Discussion Ideas

- Monitor the voting for the online question. Many years ago, even before the Internet, stories spread through the media and word of mouth, that adding fluoride to the drinking water was some sort of "communist plot" to drug Americans into submission. Of course, there was no validity to this, or even any danger, but it will not go away. There is ample proof that fluoride helps to prevent tooth decay, but communities still fight it.

Term Paper Topics, Library Activities, and Special Projects

- How are hydrophobic substances such as fats broken down in the human digestive tract? What chemicals are released by the body to assist with fat breakdown?
- Why are the cells lining the stomach able to withstand pH ranges between 1 and 3?
- How does the body measure blood pH? What are the homeostatic mechanisms that help the human body to regulate blood pH?
- Discuss strategies currently being considered by the United States and other nations to remedy acid precipitation. What suggestions would you make to help solve this problem?
- Describe some of the roles played by ions in the human body.
- Many elements have radioactive isotopes that are useful as tracers in biological systems. Show how $^{14}CO_2$ can be used to follow the fate of carbon as it is incorporated into carbohydrate.
- The structure of atoms can be deduced using nuclear magnetic resonance (NMR) and mass spectrometer machines. Report on the principles underlying the performance of each of these instruments.
- Using a pH meter, test the degree of acidity/alkalinity of common household products. If the substance is not a liquid, mix it with water according to package directions before testing.
- Most of the content of human blood is water. However, synthetic blood has been made and tested. What is the base in this fluid? Is it a feasible substitute? Report on its advantages and disadvantages.
- Describe the effects of alcohol on the human body.

Possible Responses to *Critical Thinking* Questions

1. Possibly, hydrogen is the most abundant element in the universe because it is the stuff of stars and planets.

2. Ozone is so reactive because of the unequal binding of the oxygen atoms. Two of the atoms are joined by double bonds (O=O), but the second atom is joined to a third by a single bond, which is

more easily broken. The unequal sharing of electrons in ozone makes it a less stable molecule than oxygen.

3. When an acid is mixed with water, it dissociates and becomes more reactive.

4. To change lead (atomic number 82) into gold (atomic number 79) would necessitate a change in the number of protons. This is not possible, for the very definition of an element tells us that this is a form of substance that is unchangeable.

5. The explanation for why water in the pan heats more slowly than the metal of the pan can be complicated and explained that way by a physicist. It can also be simple: water heats more slowly and cools more slowly because of the hydrogen bonds in the water molecules (see section 2.3 in the text). The extensive hydrogen bonding both within the water molecules and between the water molecules confers this and many other unique properties that make life and all of nature possible.

6. Insects such as a water strider can walk on the surface of water because of the hydrophobic waxes on their feet, which do not break the surface of the water. Thus the feet do not sink into the water and the insect is not pulled into the water to drown.

7. H^+ can be written as H_3O^+ to indicate that when hydrogen ions are present they will tend to attach to water molecules.