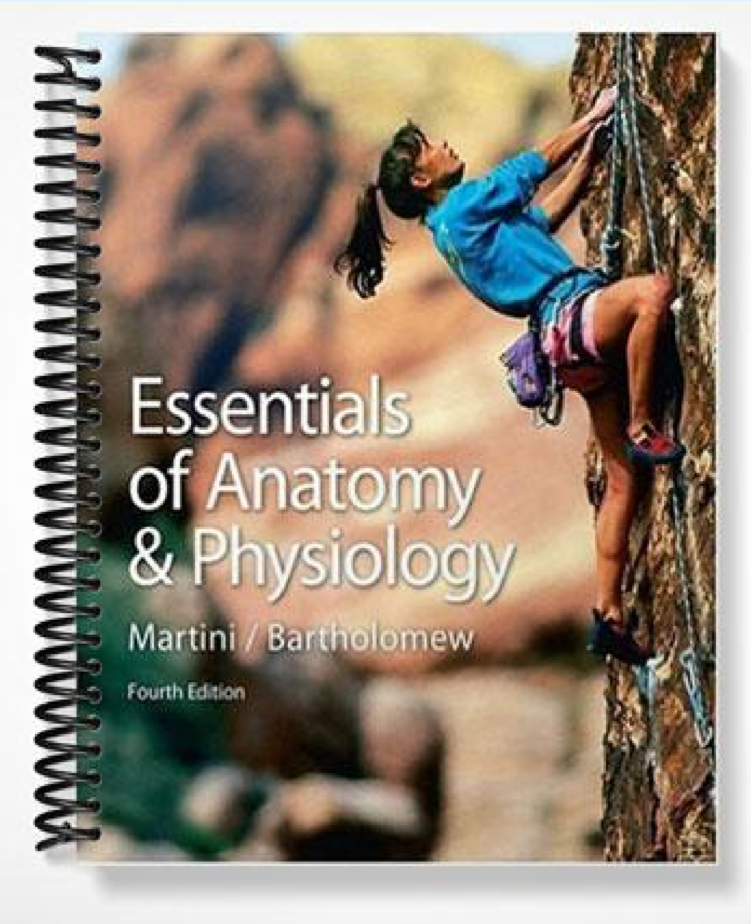
SOLUTIONS MANUAL



2 The Chemical Level of Organization

Chapter Preview

Chemistry is the study of matter in its varied forms. The basic building blocks of matter are *atoms*. Each kind of atom has a characteristic size, weight, and ability to interact with other atoms. Each atomic structure corresponds to the smallest unit of the diverse *elements*. Joining atoms by both strong covalent and ionic *bonds* and weak hydrogen bonds forms *molecules*. Chemists have developed a special system of chemical notation to describe molecules.

Chemical compounds may be classified as inorganic or organic. In general, inorganic compounds lack the element carbon (exceptions include CO_2). Important inorganic compounds include water and mineral salts that dissolve (and ionize) in water. Organic compounds are based on a backbone of carbon atoms, with nitrogen, oxygen, hydrogen, and other elements contributing to the structure as well. Biologically important classes of organic compounds include carbohydrates, lipids, amino acids, vitamins, proteins, and nucleic acids (DNA and RNA). By weight, proteins are the most abundant organic compounds in the body. They contribute approximately 20 percent of total body weight and make up about 60 to 80 percent of the dry weight of a cell. Nucleic acids are information molecules that store and transfer genetic information within individual cells, directing cellular activities by precisely controlling which proteins are made.

Instructional Goals

1. Provide the basic background in chemistry needed for later chapters.
2. Familiarize students with the methods of chemical notation used elsewhere in the text.
3. Introduce the major chemical constituents of the body.
4. Introduce the concept of an equilibrium state.
5. Show students how becoming familiar with basic chemistry allows one to predict the behavior of molecules in a living system.
6. Try to allay student fear of chemistry and encourage their interest by showing how important chemistry is for understanding events in the body.

Learning Objectives

1. Describe an atom and an element.
2. Compare the ways in which atoms combine to form molecules and compounds.

3. Use chemical notation to symbolize chemical reactions.
4. Distinguish among the three major types of chemical reactions that are important for studying physiology.
5. Describe the important role of enzymes in metabolism.
6. Distinguish between organic and inorganic compounds.
7. Explain how the chemical properties of water make life possible.
8. Describe the pH scale and the role of buffers in body fluids.
9. Describe the physiological roles of inorganic compounds.
10. Discuss the structure and functions of carbohydrates, lipids, proteins, nucleic acids, and high-energy compounds.

Suggested Lecture Time: 3 Hours

General Remarks

Students generally approach the study of chemistry with dread for two reasons: They perceive the concepts as abstract and difficult to visualize, and they are not convinced of the relevance of chemical principles to the study of anatomy and physiology. Here are several suggestions to help alleviate some of the initial anxiety and lack of interest:

- Reiterate the concept of the hierarchy of the organization of living things, and emphasize that each level relies on and is affected by the preceding level. In particular, cellular and organ system function depend upon and influence the body's chemistry. Emphasize that understanding what happens to the body at the visible level requires knowing and understanding what is happening at the invisible chemical level.
- Discuss several "real world" examples that relate the importance of understanding the chemical nature of anatomical and physiological events to a student's future professional career. Some examples include: advising a patient regarding the ingestion and action of medications, the cause of respiratory acidosis, effects of dehydration, disruption of glucose metabolism, interpretation of ECGs, etc.
- Make explanations of basic principles as simple and clear as possible. Use simplified drawings and schematic representations. Require that students be able to recreate your drawings in a way that demonstrates understanding.

Outline and Strategies

I. Introduction

II. Atoms and Molecules

A. Structure of the Atom

1. Isotopes

2. Atomic Weights

3. Electrons and Electron Shells

Strategy: Direct the students to the periodic table in Appendix II in the textbook. Using the table as a guide, reiterate the concepts that were introduced in the outline: atomic number, chemical symbol, element, and atomic weight. Explain the horizontal and vertical arrangement of the elements, and what gives the table its "periodicity."

B. Chemical Bonds and Chemical Compounds

1. Ionic Bonds

Strategies:

1. Think of male and female snap fasteners as ionic charges. When these atoms "snap together," they form ionic compounds. NaCl is a familiar and important example.
2. Think of the "t" in cation as a "+" sign to remember that a ca**t**ion has a *positive* charge. A*n*ion is therefore *negative*.

2. Covalent Bonds

a. Nonpolar Covalent Bonds

Strategy: Anthropomorphize molecules by describing them as taking the path of least resistance when forming covalent bonds. If they need less than half of the outer electrons to complete the shell, they will take electrons to do it. However, if their outer shell is less than half full, they give up the electrons in the outer energy level. A few molecules (inert gases) are lucky enough to come equipped with complete outer energy levels, and so they are happy to just sit around and not interact with anyone.

b. Polar Covalent Bonds

Points to Emphasize: This bond results when a strongly electronegative atom (such as oxygen) or electropositive atom (such as nitrogen) participates in forming a covalent bond. Orbital electrons spend relatively more time around the former, creating two partially charged atoms. These can interact with water molecules to form hydrogen bonds. Emphasize that polar covalent bonds are very different from ionic bonds since they are partially, not fully, charged.

Strategy: Compare the words *polar* and *nonpolar* to the poles of a flashlight battery. If something is closer to the positive or negative pole, we say it is polar. If it is located in the middle, it is nonpolar.

3. Hydrogen Bonds

Points to Emphasize: Even though a single hydrogen bond is quite weak compared to an ionic or covalent bond, the total bonding energy of all hydrogen bonds within a single molecule can be quite substantial. Hydrogen bonds are responsible for stabilizing the three-dimensional shape of large molecules such as proteins and nucleic acids. In addition, molecular changes that occur in response to altered pH and temperature are often due to effects on hydrogen bonds.

Strategy: It is important to illustrate that H-bonds occur between separate molecules or between distant regions of a large molecule whose atoms are joined by polar covalent bonds. A board drawing of several water molecules that shows the polar covalent bonds between hydrogen and oxygen atoms within a water molecule and hydrogen bonds between H and O atoms on neighboring water molecules will clarify this point.

III. Chemical Notation

IV. Chemical Reactions

A. Basic Energy Concepts

1. Kinetic Energy

2. Potential Energy

3. Thermal Energy (Heat)

Strategy: Demonstrate the conversion of potential to kinetic energy and then to heat using an eraser or other handy object. Lift it from the floor to demonstrate that it now has additional potential energy due to its position and the work done against the force of gravity acting to lift it. Then, allow it to drop. The sound and bounce it makes as it strikes the floor are proof of the conversion of potential energy to kinetic energy. Point out at the end of the demo that the situation is back to how it was originally and thus all the energy has now been lost as heat.

B. Types of Reactions

Points to Emphasize: Introduce *metabolism* here to reinforce in students' minds that the sum of all chemical activities of living cells constitutes metabolism.

1. Decomposition

Points to Emphasize: Cellular reactions that break covalent bonds constitute *catabolism*.

2. Synthesis

Points to Emphasize: Cellular reactions that form covalent bonds constitute *anabolism*.

3. Exchange

Strategy: Illustrate the three types of reactions by breaking bonds in food molecules to release energy (catabolism), using that energy to form a new molecule by forming covalent bonds (anabolism), and then using the molecule to bind oxygen, for example, to hemoglobin (exchange).

C. Reversible Reactions

D. Enzymes and Chemical Reactions

V. Inorganic Compounds

A. Carbon Dioxide and Oxygen

B. Water and Its Properties

1. Properties of Water

- Water is an excellent solvent.
- Water has a very high heat capacity.
- Water is a common reactant in the chemical reactions of living systems.

Strategies:

1. A useful exercise is for students to list all of the properties essential to life that are due to water's unique properties (such as the fact that ice floats, bodies of water are slow to heat and cool, etc.).
2. This is also an excellent place to reintroduce the importance of hydrogen bonds in biological reactions.

2. Solutions

Points to Emphasize: SOLUTION = SOLVENT + SOLUTE
Make sure to emphasize the distinction between the parts of a solution and also emphasize that *concentration* refers to the *quantity* of solute dissolved in a given *volume* of solution. A reminder of this terminology will be necessary when discussing osmosis.

C. Inorganic Acids and Bases

1. pH

Points to Emphasize: The bigger the pH value, the lower the concentration of H^+ ions (and vice versa). If blood pH is 7.3, it is said to be acidic compared to the normal pH of blood (7.35–7.45). Using Figure 2-9, point out the pH of common substances with which students are already familiar. Also point out the huge difference in pH between stomach acid and the blood. Ask the students to think about how the body creates such a big difference in concentration.

2. Buffers and pH

Strategy: H^+ ions can only affect the pH of a solution if they are floating free. A buffer acts like a sponge for H^+ ions, holding the H^+ ions or releasing them as needed.

D. Salts

VI. Organic Compounds

Strategies:

1. Emphasize the association of *organic* compounds with living *organisms*.
2. Also discuss construction of large organic compounds by joining repeating building blocks or subunits.
3. Use simplified structural representations of the major organic compounds (for example, an "E" with three squiggly lines attached for a triglyceride, or three hexagons and a pentagon for a cholesterol nucleus).

A. Carbohydrates

1. Monosaccharides (e.g., glucose)

2. Disaccharides and Polysaccharides

- Sucrose
- Glycogen
- Starch
- Cellulose

B. Lipids

1. Fatty Acids (saturated and unsaturated)

2. Fats

3. Steroids

Points to Emphasize: Explain the dual roles, structural and hormonal, of cholesterol.

4. Phospholipids

Points to Emphasize: Explain the structural role of this class of membrane-forming lipids briefly, but postpone a discussion of membrane structure until Chapter 3.

C. Proteins

1. Protein Function

- Support
- Movement
- Transport
- Buffering
- Metabolic regulation
- Coordination, communication, and control
- Defense

2. Protein Structure

Points to Emphasize: Relating the structure of proteins with their functions is the first application of the central principal that structure and function are intimately linked. For example, a fibrous protein confers flexibility and strength on the tough sinews (ligaments) that hold bones together or attach muscles to bones (tendons).

Strategy: Compare the linear primary structure of a protein to a train made up of 20 different kinds of cars (amino acids). The look and function of the train will depend upon how many of each type of car are linked to form the train. A train with an engine, 1 flat bed, 1 box car, 1 coal car, 4 sleepers, 2 club cars, and a caboose will look and perform differently than a train with an engine, 100 grain cars, and a caboose. Note that each car has a front and back coupling, so the front coupling of one car can hook up to the back coupling of the preceding car just as the peptide bond holds amino acids together to form a linear polypeptide.

3. Enzymes and Chemical Reactions

Points to Emphasize: Enzymes act as catalysts and as such are not consumed by the reaction they catalyze. Point out that the substrate fits into the enzyme active site as a "lock and key"; just as a key will only open a particular lock, a particular substrate will only fit a particular enzyme. Enzymes will work at their optimum rate as long as there is plenty of substrate, and the temperature and pH are constant.

D. Nucleic Acids

Strategies

1. Require students to draw each of the component parts of the nucleotide separately before putting them together in a complete nucleotide. Then have them draw three nucleotides, hooked together thru 3' and 5' bonds. Emphasize that the sugar and phosphate are constant repetitive pieces; it is only the base that varies.
2. Compare the double-stranded DNA structure to a spiral staircase: The sugar and phosphate make up the railings and side supports, while the bases are analogous to the steps.

E. High-Energy Compounds

VII. Chemicals and Living Cells