CHAPTER 2
THE CHEMICAL BASIS OF LIFE

CHAPTER OVERVIEW

This chapter introduces very basic concepts of chemistry, emphasizing the structure of atoms and how they combine (form bonds). The types of bonds, which include ionic, covalent, and hydrogen bonds, are introduced, and their importance in various molecules in the human body is discussed. Ions are defined, and a list of ions that will be discussed in later chapters is presented. Types of chemical reactions are considered, and the factors that influence reaction rates, including enzymes, are discussed. Students are introduced to the concept of pH, and the characteristics that make water so important for living things. The chapter also discusses the structure, building blocks, important examples, and functions of large organic molecules, including carbohydrates, proteins, lipids, and nucleic acids. Adenosine triphosphate and its importance as the energy storage form of the body is also discussed.

STUDENT LEARNING OUTCOMES

After reading this section, the student should be able to:

2.01A. Define chemistry and state its relevance to anatomy and physiology.
2.01B. Define matter, mass, and weight.
2.01C. Distinguish between an element and an atom.
2.01D. Define atomic number and mass number.
2.01E. Name the subatomic particles of an atom, and indicate their location.
2.01F. Compare and contrast ionic and covalent bonds.
2.01G. Explain what creates a hydrogen bond and relate its importance.
2.01H. Differentiate between a molecule and a compound.
2.01I. Describe the process of dissociation.
2.02A. Summarize the characteristics of synthesis, decomposition, and exchange reactions.
2.02B. Explain how reversible reactions produce chemical equilibrium.
2.02C. Distinguish between chemical reactions that release energy and those that take in energy.
2.02D. Describe the factors that can affect the rate of chemical reactions.
2.03A. Describe the pH scale and its relationship to acidic and basic solutions.
2.03B. Explain the importance of buffers in organisms.
2.04A. Distinguish between inorganic and organic molecules.
2.04B. Describe how the properties of oxygen, carbon dioxide, and water contribute to their physiological functions.
2.05A. Describe the structural organization and major functions of carbohydrates, lipids, proteins, and nucleic acids.
2.05B. Explain how enzymes work.

KEY POINTS TO EMPHASIZE WHEN TEACHING THE CHEMICAL BASIS OF LIFE

Relationship between structure and function:

The structure of an atom, particularly its outermost electrons, determines its chemical behavior. The electron arrangement determines whether an atom gains electrons, loses electrons, or shares electrons. Atoms that gain or lose electrons form ions (and ionic bonds), and atoms that share electrons form covalent bonds. The type of bond, and how many bonds each atom forms, determine the structure and future reactivity of molecules. Life depends on a relatively small number of different elements, because only those elements can form stable, functional molecules. It is also important for students to recognize the structure-function relationships for enzymes and other protein molecules. The shape of protein molecules determines and constrains the function of that protein. Destroying that shape (denaturation) destroys that function. It is a good idea to spend a bit of time discussing what denaturing actually does to the shape of a molecule and therefore the availability of active sites or binding sites for other molecules. Students have a difficult time thinking of molecules in three dimensions so models or demonstration aides may be necessary. The concept of denaturation should be stressed when you discuss the actions of enzymes and their regulation. The idea of an optimal range for each enzyme is essential to understanding many regulatory pathways later on. Additionally, you can highlight several genetic disorders that have their roots in non-functional enzymes. Remember that students with poorer science backgrounds tend to have trouble developing mental pictures of things that are as small as atoms. Anything that you can bring into the classroom or lab that helps students form robust mental images will be helpful. One has to be careful to point out the limitations of any specific three-dimensional model or simulation, however.

Homeostasis:

The concept of chemical equilibrium is, in its essence, a simpler formation of the dynamic equilibrium established and maintained by all of the body's processes. Help students explore the similarities and differences between chemical equilibria and biological homeostasis. One of the key concepts that is often overlooked in this regard is the fact that biological organisms are open systems, so the metaphor of chemical equilibrium as an equivalent for homeostasis quickly breaks down, since a true stable chemical equilibrium presumes a closed system.

Change through time:

This is a harder theme to link specifically to this chapter. The easiest long-term change examples are in the context of how the chemical structure of compounds (collagen fibers in connective tissue) become altered through time (more cross-linking), and as a result the properties at the next level of organization also become altered through time (less flexibility). The short-term changes associated with energy transformation reactions are very important. Understanding of later processes, such as the mechanism of muscle cell contraction, is easier if students are already familiar with the pivotal role of ATP in mediating the cell's ability (or inability) to produce a particular change in function at a particular time.

Cell theory and biochemistry:

As the foundational levels of biological organization, the pivotal position of cells and biochemistry in understanding higher levels of organization cannot be stressed too strongly. This very centrality is hard for many students to appreciate and so needs to be reinforced in as many places as possible. That

students have not achieved this foundational understanding may become apparent in their answers to questions concerning physiological mechanisms of control and cell-to-cell communication. Students should understand that without enzymes, many (if not most) essential chemical reactions would not occur fast enough to sustain life. They should also understand that enzymes determine which chemical reactions occur in a cell; this determines a cell's "occupation." For example, liver cells do "liver" things because their "liver" enzymes are active. It should be stressed again that everything that happens at the organelle, cell, tissue, organ, organ system, and organism level is determined by the things that happen at the chemical level. Later discussions of membrane receptors and intracellular communication all have biochemical bases.

CONTENT OUTLINE

Topic	Page(s)	Figures and Tables
2.1 Basic Chemistry	21-26	
A. Matter, mass, and weight		
1. Definitions of matter, mass, and weight		
2. Introduction to the international standard		
B. Elements and atoms		Table 2.1 p. 22
C. Atomic structure		Fig. 2.1 p. 22
1. Subatomic particles		Fig. 2.2 p. 23
a. Nucleus		
• Neutrons (neutral)		
• Protons (positive charge)		
b. Electron cloud		
Electrons (negative charge)		
2. Atomic number		
3. Mass number		
D. Electrons and chemical bonding		
1. Ionic bonding		
2. Covalent bonding		Fig. 2.3 p. 23
a. Single		Table 2.2 p. 24
b. Double		Fig. 2.4 p. 24
c. Polar		Fig. 2.5 p. 25
E. Hydrogen bonding		Fig. 2.6 p. 25
F. Molecules and compounds		Table 2.3 p. 25
G. Dissociation		
		Fig. 2.7 p. 26
Clinical Impact: "Clinical Uses of Atomic Particles"	28	
2.2 Chemical Reactions	26-30	Fig. 2.8 p. 29
A. Classification of chemical reactions		
1. Synthesis reactions		
2. Decomposition reactions		

3. Exchange reactions
B. Reversible reactions—equilibrium
C. Energy and chemical reactions
2. Kinetic energy
3. Mechanical energy
4. Chemical energy
D. Rate of chemical reactions
1. Reactants
2. Concentration
3. Temperature
4. Catalysts—enzymes

2.2 Acids and Bases	30-31	Fig. 2.9 p. 30
A. The pH scale		Fig. 2.10 p. 31
1. Neutral solution		
2. Acidic solution		
3. Alkaline, or basic solution		
B. Salts		
C. Buffers		
2.4. Inorganic Molecules	31	
A. Oxygen and carbon dioxide		
B. Water		
1. Properties		
a. Stabilizes body temperature—absorbs heat		
b. Protection—lubricant		
c. Chemical reactions		
d. Transport—dissolve in water		
2.5 Organic Molecules	31-39	Table 2.4 p. 32
A. Carbohydrates		Fig. 2.11 p. 33
1. Monosaccharides		
2. Disaccharides		
3. Polysaccharides		
B. Lipids		Fig. 2.12 p. 34
1. Fats (triglycerides)		Fig. 2.13 p. 34
a. Saturated		
b. Unsaturated		
i.Monounsaturated		
ii.Polyunsaturated		
2. Phospholipids		
a. Hydrophobic		Fig. 2.14 p. 35
b. Hydrophilic		
3. Eicosanoids		
a. Prostaglandins		
b. Thromboxanes		
c. Leukotrienes		
4. Steroids		
C. Proteins		Fig. 2.15 p. 35

1. Amino acids
2. Denaturation — Fig. 2.16 p. 37
3. Enzymes
    a. Activation energy
    b. Enzyme action — Fig. 2.17 p. 38

D. Nucleic acids — Fig. 2.18 p. 38
1. DNA
2. RNA — Fig. 2.19 p. 38

E. Adenosine triphosphate

Fig. 2.20 p. 39

A Case in Point: "Cyanide Poisoning" 39

Learning Outcomes Correlation with Question Types

Question Type	Question#	Bloom's Level	Learning Outcome
Learn to Predict	1	Comprehension	2.4b
Predict	2	Comprehension	2.1b
Predict	3	Comprehension	2.1d
Predict	4	Comprehension	2.1f
Predict	5	Comprehension	2.2b
Predict	6	Comprehension	2.2c
Predict	7	Comprehension	2.3a,b
Review/Comp	1	Knowledge, Comprehension	2.1a
Review/Comp	2	Knowledge, Analysis	2.1b
Review/Comp	3	Knowledge, Comprehension	2.1c
Review/Comp	4	Knowledge, Comprehension	2.1e
Review/Comp	5	Knowledge	2.1d
Review/Comp	6	Knowledge, Analysis	2.1f,g
Review/Comp	7	Analysis	2.1h
Review/Comp	8	Comprehension	2.1i
Review/Comp	9	Knowledge, Comprehension	2.2a
Review/Comp	10	Comprehension	2.2b
Review/Comp	11	Knowledge	2.2c
Review/Comp	12	Comprehension	2.2c
Review/Comp	13	Comprehension	2.2d
Review/Comp	14	Knowledge,	2.3a

Review/Comp	15	Comprehension Knowledge, Comprehension	2.3b
Review/Comp	16	Analysis	2.4a
Review/Comp	17	Comprehension	2.4b
Review/Comp	18	Knowledge	2.4b
Review/Comp	19	Knowledge	2.5a
Review/Comp	20	Comprehension	2.5b
Critical Thinking	1	Application	2.1e,f
Critical Thinking	2	Analysis	2.1i,2.2a
Critical Thinking	3	Comprehension	2.2a,c
Critical Thinking	4	Analysis	2.3a,b
Critical Thinking	5	Comprehension	2.2c
Critical Thinking	6	Comprehension	2.2d, 2.5a