Elements of Biochemistry

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Preface

Elements of Biochemistry was written in response to the demand for a comprehensive but concise biochemistry textbook. It is primarily designed for students majoring in nursing, medical technology, and the other allied health sciences, but can also be used in survey courses for slightly more advanced preprofessional students. It presents the core of biochemistry in clear and understandable terms to students who often have a limited background in chemistry, and it carefully interweaves examples from the clinical sciences and discussions of important disease states to motivate students and reinforce key biochemical concepts. Historical discussions and descriptions of experimental techniques have been intentionally eliminated in favor of the inclusion of more relevant examples from clinical medicine.

The book is composed of twenty chapters and presents a complete, up to date description of biochemistry. The organization follows a traditional approach. Chapter 1–7 provide a description of cells, buffers, amino acids, proteins, enzymes, and bioenergetics. Chapters 8–15 describe the basics of cellular metabolism (of carbohydrates, lipids, and amino acids). Chapters 16–18 describe the storage and transmission of genetic information. Finally, Chapter 19 covers hormones, and Chapter 20 gives a thorough but concise description of nutrition. A summary of photosynthesis and a mathematics review are found in the appendixes.

The organization is also versatile since specific chapters, or sections from a particular chapter, may be omitted without destroying the continuity of the book. To enhance student comprehension, the text is organized so that the chemistry of a particular class of biological molecule is first presented in one chapter then followed by discussions of the metabolism of that class of molecule (catabolism, then anabolism) in the next chapter.

The text contains complete descriptions of the absorption, digestion, and catabolism of carbohydrates, lipids, and amino acids. Discussions of important metabolic pathways are relatively detailed and are aided by the inclusion of many clear and unambiguous figures and charts. The compartmentalization and regulation of these pathways are also described. Minor pathways are summarized, but simple word-picture diagrams of such pathways are avoided. Rather the chemical structures of the starting materials, important intermediates, and end products are shown without clutter and confusion.

The writing style, it is hoped, will prove clear, concise and at the appropriate level. Important technical terms are defined within the sentence in which they first appear. Key words and phrases are boldfaced in order to highlight their significance, and some repetition of specific discussions and figures is intended to reiterate particular points.

Each chapter concludes with a summary, a list of suggested readings, and a comprehensive set of problems. The questions span a wide range of difficulty and include the standard but important review questions that help students define key terms and concepts. Intermediate level questions and more challenging "bonus questions," marked with an asterisk, are also provided. The Instructor's Manual provides complete answers to all end of chapter problems.

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Chapter 1

The Structure of Cells

1.1 INTRODUCTION

biochemistry

Biochemistry is the study of the chemical processes associated with living organisms. This exciting science arose largely within the last 100 years, and we have gained most of our knowledge of it only within the last 30 to 50 years. Thus, biochemistry, in contrast to other areas of scientific endeavor, is a relatively new field. Our understanding of living processes is constantly changing and becoming more complete as thousands of scientists continue to unravel the complex puzzle that we call life.

Most students reading this book will enter one of the allied health professions. The study of the human body and of various diseases will occupy a significant portion of their time. Since most diseases occur as a result of a malfunction at the molecular or cellular level, *a thorough understanding of biochemistry is of paramount importance.*

In this chapter, we shall first discuss the kinds of elements found in living systems and why these elements are important for life. Second, we will discuss the criteria that distinguish living matter from inanimate matter. Finally, we will discuss the different types of cells, as well as their structure and function.

1.2 THE CHEMICAL ELEMENTS OF LIFE

One of the amazing points to consider about "living" systems is the fact that these systems are constructed from nonliving—*inanimate*—matter. Apparently, it is the complex organization of inanimate matter within cells that produces what scientists call "the living state." Interestingly, only a very few of the 90 naturally occurring elements are commonly found in living cells. Among these are carbon, hydrogen, oxygen, and nitrogen, which make up approximately 99% of the mass of the cell. From these elements are constructed amino acids, proteins, carbohydrates, lipids, and other types of

biomolecules

biomolecules (molecules found in living cells and required for various biological functions). In addition to these, phosphorus and sulfur are present in smaller amounts and are also used to construct biomolecules.

A number of ions are found in cells. Among these are Na^+, K^+, Cl^-, Mg^{2+}, Mn^{2+}, Ca^{2+}, Fe^{2+}, Zn^{2+}, and Cu^{2+}. The monovalent ions (ions with a 1+ or 1− electrical charge) are required for transmitting nerve impulses and for maintaining blood electrolyte balance. The divalent ions (ions with a 2+ electrical charge) and trivalent ions (ions with a 3+ charge)

enzymes

are often associated with **enzymes** (biological catalysts that speed up chemical reactions) and are required for enzyme activity. A number of other elements are found in cells, but in very low concentrations. These elements are called *trace* elements because only a trace amount is required for normal cellular function. Table 1–1 summarizes the different elements commonly found in most cells.

We will now discuss some of the important chemical properties of carbon, oxygen, nitrogen, and hydrogen.

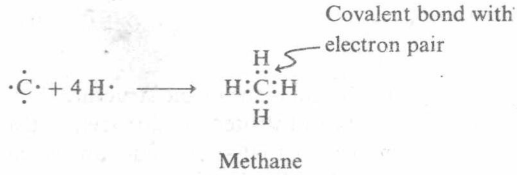
Six electrons are associated with the carbon nucleus. These are arranged in the following electronic structure: $C(1s^2, 2s^2, 2p^2)$. The notation means that elemental carbon has 2 electrons in each of the $1s$, $2s$, and $2p$ energy levels, or orbitals. Carbon does not lose electrons easily from the $2s$ and $2p$

TABLE 1–1 Common Elements Found in Cells

Elements Used in Constructing Biomolecules	Monovalent, Divalent, and Trivalent Ions	Other Trace Elements
Carbon (C)	Sodium (Na^+)	Cobalt (Co)
Hydrogen (H)	Potassium (K^+)	Boron (B)
Oxygen (O)	Chlorine (Cl^-)	Aluminum (Al)
Nitrogen (N)	Magnesium (Mg^{2+})	Vanadium (V)
Phosphorus (P)	Manganese (Mn^{2+})	Molybdenum (Mo)
Sulfur (S)	Calcium (Ca^{2+})	Iodine (I)
	Iron (Fe^{2+}, Fe^{3+})	Silicon (Si)
	Copper (Cu^{2+})	Nickel (Ni)
	Zinc (Zn^{2+})	Chromium (Cr)
		Fluorine (F)
		Selenium (Se)

Source: Adapted from Lehninger, A. L., *Biochemistry*, 2nd ed. (New York: Worth, 1975), p. 17.

orbitals (that is, it does not ionize easily). However, carbon can *share* electrons with other elements, forming **covalent bonds** by electron-pair sharing, as shown in Equation 1–1.



(1–1)

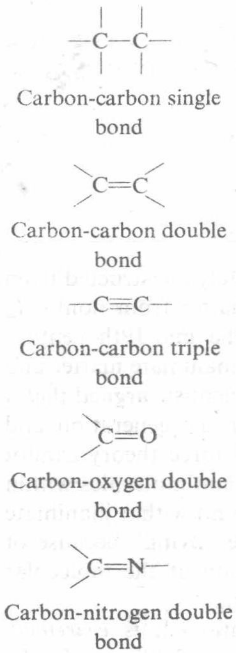


FIGURE 1–1
Multiple bonding arrangements.

Thus, carbon can easily form strong and stable covalent bonds with itself and with hydrogen, oxygen, or nitrogen. It should be noted that carbon can bond a maximum of *four* other atoms to itself. In addition, carbon can participate in single, double, and triple bonds, as shown in Figure 1–1. Because of these unique features of carbon, a diversity of covalent bonding arrangements is possible, leading to literally millions of different substances. Figure 1–2 summarizes a few of the bonding arrangements in which carbon can participate. It should be obvious that carbon is a versatile element, well suited for serving as the basis for life.

Oxygen, nitrogen, and hydrogen can also form strong and stable covalent bonds by electron-pair sharing. Oxygen and nitrogen usually form single or double bonds; hydrogen can form only single bonds (remember, hydrogen has only 1 electron available for bond formation).

Oxygen is a very **electronegative** element (electronegativity can be defined as the tendency of an atom to attract electrons to itself). As we shall see in the next chapter, this feature is the basis for the unusual properties of water and for the special type of bond called the *hydrogen bond*. Oxygen is also important to life because it serves as the final *electron acceptor* during energy production within the cells of our bodies (see Chapter 12).

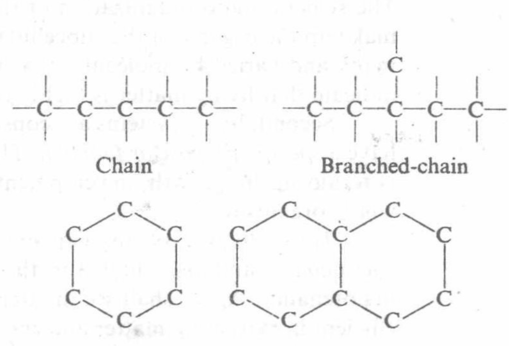
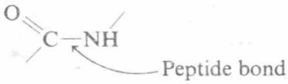


FIGURE 1–2 Some of the possible chemical bonding arrangements for carbon.

peptide bond

Nitrogen is an important element for living systems because it bonds with carbon, forming what is known as the **peptide bond**.



This bond is the prime structural bond for all proteins (see Chapter 3, Amino Acids and Proteins). Nitrogen is also used in constructing *nucleic acids*, the molecules that store and transfer genetic information.

Finally, hydrogen participates in hydrogen bonding and is associated with electron transport processes within cells (see Chapter 12).

1.3 WHAT CONSTITUTES THE "LIVING" STATE?

As we have already mentioned, living cells are ultimately constructed from nonliving matter. What, then, distinguishes living matter from nonliving matter? Scientists and philosophers living before the mid-19th century believed that living matter differed significantly from inanimate matter and that it obeyed a different set of physical laws. These scientists argued that a *vital force* within living systems was responsible for the generation and maintenance of life. Today, we realize that the vital force theory cannot adequately explain living systems and that the atoms and molecules within cells obey the same physical laws as do the atoms found within inanimate matter. Ultimately, it appears that living systems are "living" because of their complexity, diversity, and structural organization at the molecular level. A few generalizations about living matter may help.

First, living matter, as we have already mentioned, is *extremely complex and highly organized.* This is true on a number of different levels. The structure and organization of the organs of the body, of the cells that make up the organs, of the subcellular structures within the cells, and of the many and varied biomolecules that make up the subcellular structures, all indicate that living matter is highly organized.

Second, living systems are constructed from structures that all seem to have a *specific purpose or function.* The ultimate purpose of each component is to aid in the growth, development, replication, and biologic task of the whole organism.

Third, living systems can *extract both matter and energy from the environment* and use these for their normal growth, development, and maintenance. As we shall see in later chapters, living systems are extremely efficient in extracting matter and energy. Yet, living systems are not perfect; they produce waste matter and waste energy (heat) and, thus, pollute their environment. Still, the waste materials can often be used by other organisms, and most life systems recycle various constituents.

Fourth, living matter can undergo *self-replication* (that is, make an exact copy of itself). Specifically, living matter contains molecules that can store genetic information (**deoxyribonucleic acid, DNA**) and transfer that information from one generation to another. This information-storage system is extremely complex and versatile. It is essentially error-free and, when mistakes are made, usually self-correcting. Just think of it: Everything that you are—the color of your eyes, the color of your hair and skin, your sex—are all coded in the DNA contained within the nucleus of every cell in your body. The DNA within the nucleus may represent the *maximum amount of information that can be stored in the minimum amount of space*.

deoxyribonucleic acid (DNA)

> In essence, the living cell is a self-assembling, self-regulating, self-replicating, . . . open system of organic molecules operating on the principle of maximum economy of parts and processes; it fosters many consecutive linked organic reactions which are necessary for the extraction and transfer of energy and for the synthesis of its own components by means of enzyme catalysts that it produces itself.[1]

1.4 THE TYPES OF CELLS

Although there are many different kinds of cells, all cells can be classified according to two rather simple classification schemes. The first scheme classifies cells according to their size and complexity. The second scheme classifies cells according to how they extract matter and energy from the environment (or, simply, how they "feed themselves"). Using the first classification scheme, we find two basic types of cells: (1) **prokaryotes** ("before a nucleus") and (2) **eukaryotes** ("good nucleus"). The differences between the two cell types are summarized in Table 1–2. Using the second classification scheme, we find two basic types of cells: (1) **autotrophs** ("self-feeding") and (2) **heterotrophs** ("feeding-on-others"). The differences between these two types of cells are summarized in Table 1–3. One should note that the

prokaryotes
eukaryotes
autotrophs
heterotrophs

TABLE 1–2 The Differences Between Prokaryotic and Eukaryotic Cells

Criteria	Prokaryote	Eukaryote
Size	Small (1–2 μm)[a]	Large (20–30 μm diameter)
Complexity	Simple internal structure	Complex internal structure (organelles present)
Nucleus	None (the DNA is found in the cytoplasm)	Present (the DNA is contained in the nucleus)
Examples	Bacteria, blue-green algae	Cells of higher animals, plants, fungi, and most algae

[a] 1 μm = 1 micrometer = 1×10^{-4} cm (alternatively, 1 micron (μ).