Elementary Biochemistry

An Introduction to the Chemistry of Living Cells

Julian Davies & Barbara Shaffer Littlewood

Julian Davies
&
Barbara Shaffer Littlewood
University of Wisconsin, Madison

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"Science is nothing but trained and organized common sense"

Thomas Henry Huxley (1825–1895)

Preface

This text is designed to introduce the principles of biochemistry and their applications to undergraduate students who desire a basic knowledge of biochemistry. The text is aimed at students in nursing, nutrition, agriculture, and other sciences for which a survey course in biochemistry is sufficient. However, we believe that students in fields other than science can and should comprehend the material.

The book is based on lectures given in an introductory biochemistry course at the University of Wisconsin. In working with the undergraduates in this course, we have found that many students view biochemistry as an "ivory tower" science which bears little or no relationship to everyday life, and that they cannot visualize how the material presented will ever be useful to them. In the hope of stifling the "Why are we learning this stuff?" refrain, we have emphasized the fact that biochemical principles underlie many common phenomena. For example, we include information about the enzymatic basis of inherited disease, drug therapy when it involves enzyme inhibition, and the biochemical basis of wine making, pickling, and other food preparation. We have tried to include explanations of topics currently being discussed in popular periodicals and newspapers.

Our experience has indicated that the beginning student often reacts negatively to biochemistry because the courses consist of the memorization of countless chemical formulas and the minute details of metabolic pathways. We believe this to be an inappropriate and stifling approach to the subject. In writing this text, we started with the premise that by emphasizing the principles and unity of biochemistry and by deemphasizing organic chemistry, biochemistry can be understood and appreciated by students who lack the background in chemistry, physics, and mathematics necessary to benefit from advanced biochemistry courses. In our efforts to emphasize the underlying principles and unity of biochemistry, there occur errors of generality, but we anticipate that these exceptions can be turned to advantage by a good lecturer.

The title of the book may be misleading, since biochemistry is not an elementary subject. However, its principles are simple and the most important feature of biochemistry is not the endless learning of pathways, but an appreciation of how molecules, pathways, cells, and organs interact in a controlled fashion to create and maintain the biochemistry that we call life.

Although we have tried to deemphasize the purely chemical aspects of biochemistry, we realize, all too well, that a sound knowledge of chemistry is essential to a complete comprehension of biochemical principles. We have tried to reduce the amount of chemistry that we use, without the intention of implying that chemistry is not needed. It is. Anyone who wants to attain a more complete understanding will require a firm background in organic chemistry. Even for courses using this text, students who have completed an introductory course in organic chemistry will be at an advantage. Those with limited backgrounds in the subject may wish to begin with the Appendix, which summarizes those principles of organic chemistry that are relevant to a study of cell metabolism.

It has also been our experience that teaching elementary biochemistry can be facilitated by the use of thought-provoking problems. To emphasize understanding rather than memorization, each chapter includes a problem set intended to stimulate the "thinking through" of biochemical principles and their applications.

This text, then, is intended as the basis for an undergraduate survey course in biochemistry. It is our hope that for some people this book will not be enough, but that it will serve as an introduction to some of the excellent advanced texts that are available at present and encourage students to delve into some subjects in more detail. We sincerely hope that students who use this text will complete their biochemistry course with "a good taste in their mouths" and a feeling that they have learned important information about the fascinating world inside living cells. Biochemistry may not be easy, but it *is* fun.

We are grateful to the many people who encouraged us in the writing of this textbook. Special thanks go to our families for their continuing patience and support, and to the students and teaching assistants in Biochemistry 201 who served as (unknowing) fodder for our ideas and have made this effort worthwhile. We thank Patricia Omilianowski for typing the manuscript and Melanie Loo and Leon LeVan for "debugging" the problem sets.

Madison, Wisconsin

JULIAN DAVIES
BARBARA SHAFFER LITTLEWOOD

Contents

2
Protein Structure & Function

3
Determining Protein Structure

4
Enzymes

5
General Concepts in Metabolism

6
Energy for Cell Work: the Role of ATP

7
The Production of Energy & Intermediates from Glucose

8
Degradation of Carbohydrates: Energy & Intermediates from Krebs Cycle & Electron Transport

9
Carbohydrate Formation & Storage: How Cells Control Energy Supplies

10
Lipids

11

The Metabolism of Amino Acids & Other Nitrogen Compounds

12

Deoxyribonucleic Acid: the Genetic Material

13

Protein Synthesis: the Translation of Genetic Information into Protein Requires RNA

14

Regulation & Control: How Cells Turn Metabolic Reactions On & Off

15
Viruses Cell's Natural Enemies

16
Antimicrobial Agents

Appendix: Important Concepts in Organic Chemistry

1

Cells: the Basic Units of Life

Biochemistry is the study of the composition, the production, and the destruction of the chemical compounds found in living organisms. It encompasses all the chemical reactions carried out by cells and the relationships between these reactions. Biochemists work with a wide variety of biological materials, from the one-celled bacterium to the specialized multicellular tissues of man. Understanding this range of organisms would be a hopeless task except for the fact that the vast majority of biologically important reactions are common to all cells. The phrase "the unity of biochemistry" refers to the finding that the chemistry of all cells is remarkably similar.

1.1 Properties of living cells

The *cell* is the basic structural unit of all living organisms. Bacteria and blue-green algae, the smallest free-living organisms, consist of single, independent cells. Larger organisms—animals and plants—contain billions of cells organized into tissues with specialized functions. Before trying to understand the chemical basis of cellular phenomena, it is important to consider, in broad terms, those processes which characterize living cells. Although a precise definition of "life" is difficult, if not impossible, we *can* give a general description of the processes that distinguish living cells from the inanimate material found on the earth.

1. All cells are capable of metabolism; they can take up simple chemical compounds from their environment, modify them, and combine them into larger, more complex molecules. The newly synthesized compounds are then used to build the complicated structures necessary for cellular integrity and function. Metabolism is not a disorganized business; it is a tightly regulated network of reactions by which the cell produces (or degrades) thousands of different molecules in specific proportions, at specific rates, and often at specific times.
2. All cells are capable of energy transformation. During photosynthesis, green plant cells convert solar energy into the energy of the chemical bonds of sugar molecules. All cells degrade these sugars and store the released energy in the chemical bonds of "high-energy" compounds. Cells use their stored energy to perform cellular work such as biosynthesis, division, contraction, locomotion, and the transmission of electrical stimuli.
3. Cells are capable of self-directed growth and replication. By metabolic processes, cells increase their mass and at a critical time when all cellular constituents are present in the proper concentrations, cells divide, giving rise to two identical daughter cells. Each cell contains all the information necessary for perpetuating itself, and this information remains constant generation after generation.

1.2 Cell structure

Living cells carry out many different metabolic activities: the exchange of chemicals with the environment, the transformation of energy, the replication of informational material, and so on. To perform these tasks efficiently, an extraordinary system of internal organization has been developed. By (physically) grouping the chemical reactions concerned with specific metabolic activities, cells are able to perform and to regulate these activities with speed and efficiency.

Eucaryotic cells, the well-organized units of higher plants and animals, contain many different membrane-bound compartments, called *organelles* [Fig. 1.1(a)]. While the morphological appearance of these organelles may vary somewhat from cell to cell, their functions (Table 1.1) are identical in all cells. Eucaryotic cells always have a membrane-bound nucleus and usually have their DNA divided among several chromosomes. *Procaryotic cells* [Fig. 1.1(b)], those of lower organisms including bacteria and blue-green algae, are relatively small and lack most of the internal structures that characterize eucaryotic cells. Procaryotic cells have no membrane-enclosed nucleus and usually contain only one DNA molecule.