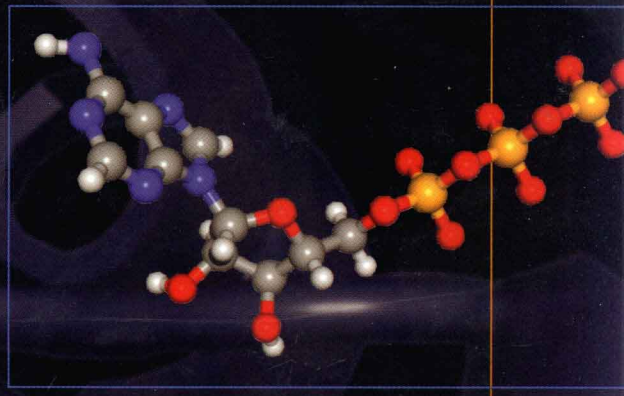
CHARLOTTE W. PRATT • KATHLEEN CORNELY

Essential Biochemistry



ESSENTIAL BIOCHEMISTRY

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About the cover

Cytochrome *c*, a small protein whose structure, function, and evolution have been thoroughly studied, symbolizes the major role of proteins in biochemistry. In addition, cytochrome *c* and its bound heme group participate in a central pathway for energy transduction. To this background is added the small molecule ATP, the energy currency of all living cells and, as a nucleotide, a representative of another category of ancient and essential biological molecules.

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ABOUT THE AUTHORS

CHARLOTTE PRATT received a B.S. in biology from the University of Notre Dame and a Ph.D. in biochemistry from Duke University. She is a protein chemist who has conducted research in blood coagulation and inflammation and was a member of the Center for Thrombosis and Hemostasis at the University of North Carolina at Chapel Hill. She is currently affiliated with Seattle Pacific University, where she has taught biochemistry. Her interests include molecular evolution, enzyme action, and the relationship between metabolic processes and disease. She has written numerous research and review articles, has worked as a textbook editor, and is a co-author, with Donald Voet and Judith G. Voet, of *Fundamentals of Biochemistry.*

KATHLEEN CORNELY holds a B.S. in chemistry from Bowling Green (Ohio) State University, an M.S. in biochemistry from Indiana University, and a Ph.D. in nutritional biochemistry from Cornell University. Her experimental research has included a wide range of studies of protein purification and chemical modification. She currently serves as a Professor of Chemistry and Biochemistry at Providence College where she has taught courses in biochemistry, organic chemistry, and general chemistry. Her recent research efforts have focused on issues related to chemical education, particularly the use of case studies in biochemistry education. Several of these case studies have been published in the chemical education literature and others are collected in her book *Cases in Biochemistry.* She also serves on the editorial board of *Biochemistry and Molecular Biology Education* and is a member of the Educational and Professional Development Committee of the American Society for Biochemistry and Molecular Biology.

PREFACE

WE SET OUT TO WRITE AN INTRODUCTORY BIOCHEMISTRY TEXTBOOK because we believed that there was a need for a new approach to the subject and that students could clearly benefit from our efforts. The result of our inspiration is *Essential Biochemistry,* a textbook that focuses on the chemistry of biochemistry and places it in biological context. Our experience with students as well as advances in cognitive theory prompted us to combine relatively short text chapters with extensive problems sets in order to maximize opportunities for students to learn through problem-solving. We also recognized the advantages of providing well-integrated multimedia exercises to reinforce and extend principles introduced in the text. For this reason, the text and media components were developed in tandem. We believe that this book provides an ideal balance of elements that will ease the efforts of instructors and facilitate learning by students.

A Modern Approach

Writing a new biochemistry textbook provides an opportunity not just to convey the latest research findings but also to approach the subject with a fresh perspective. Biochemistry is an enormous field, and it has always been a challenge to give students a solid foundation in the subject, particularly in a one-semester course. We saw the need for a modern textbook that would introduce students to a large and ever-growing subject, that would provide broad coverage without being overwhelming, that would explore important topics in detail, that would not minimize chemical rigor, and that would provide students with knowledge and tools that they could apply to other areas of chemistry and biology.

Essential Biochemistry differs somewhat from other textbooks in its organization and in the way material is presented. For example, there are no separate chapters devoted to carbohydrate and lipid structure. We believe that students can learn about molecular structures and terminology as they study molecules in the context of their biological functions and their metabolic transformations. We also chose to focus on aspects of biochemistry that tend to receive little coverage in other courses or present a challenge to many students. Thus, we include discrete chapters on motor proteins, enzyme mechanisms, enzyme kinetics, oxidative phosphorylation, photosynthesis, and DNA repair.

By departing somewhat from the traditional table of contents, we hope to provide students with a solid introduction to modern biochemistry. We believe that depth of coverage is often more important than breadth. Wherever possible, we describe the physiological context of biochemical processes. Finally, we present examples of chemical phenomena to illuminate general themes of biochemistry, not necessarily to illustrate all the details of a biochemical process.

In a short textbook, every example must count. For this reason, a single topic explored in depth not only tells an interesting story, it can provide insights into a number of biochemical principles. For example, myoglobin appears repeatedly in Chapter 4 to explain various aspects of protein structure and function. In Chapter 6, chymotrypsin highlights various features of enzyme action. Regulation of fuel metabolism by insulin and glucagon introduces the principles of signal transduction in Chapter 16.

In a similar vein, different topics within a chapter are linked by placing them in the broader context of a biological "story," often a disease. In Chapter 3, the genetic nature of cystic fibrosis provides a backdrop for topics ranging from DNA sequencing to protein expression. The generation of a nerve impulse ties together information about membrane permeability, transport, and fusion in Chapter 8. In Chapter 14, lipid metabolism is linked to atherosclerosis; in Chapter 18, cancer is the framework for a discussion of DNA repair.

In our experience, students sometimes miss the forest for the trees. To counteract this tendency, we have intentionally left out some details, particularly in the chapters on metabolic pathways. This allows us to focus on some general themes, including the stepwise nature of pathways (Chapter 10) and their evolution (Chapter 11).

It is our hope that by approaching biochemistry as a guidebook rather than as a catalog, this textbook will allow students to master the subject at several levels while minimizing the need for rote memorization.

Problem-Based Learning

Developments in cognitive learning theory as well as the results of classroom research indicate that students learn more when they can construct their own knowledge, for example, by answering questions and solving problems. Students who are actively engaged with the material are more likely to retain information. In fact, we designed *Essential Biochemistry* so that students can take an active role in their education. For example, each chapter begins with a list of Learning Objectives, and brief questions periodically prompt the students to review particular objectives. A checklist at the end of each chapter helps students organize their study efforts.

Most notably, each chapter includes an extensive problem set. The 20 chapters of *Essential Biochemistry* are intentionally succinct so that students can extend their learning through active problem-solving. Virtually all of the problems require analysis rather than simple recitation of facts. Many problems are case studies based on data from research publications and clinical reports. Not only do these problems provide a glimpse of the "real world" of science and medicine, they present students with novel situations and raw data that must be interpreted and analyzed. Complete solutions to all problems are placed in an appendix so that students can receive immediate feedback.

Of course, problem-solving is not the only route to understanding, and productive learning must incorporate both student-centered and instructor-centered approaches. By providing a generous selection of problem-solving opportunities, *Essential Biochemistry* can accommodate courses with varying emphasis on problem-based learning.

Multimedia Components

From the outset, we intended the media components to fully integrate with and complement the text. Although the book can stand alone, a full appreciation of the structural and dynamic aspects of biochemistry requires a medium more versatile than the printed page. The media package that accompanies *Essential*

aid the student, an overview figure introduced in Chapter 9 is repeated in each subsequent chapter, with the portion relevant to that chapter highlighted.

Chapter 10 introduces glucose structure as a prelude to glycolysis and other pathways of carbohydrate metabolism. The structures and metabolism of some other sugars are included in Chapter 10, but because there is no chapter solely dedicated to carbohydrate structure, students are spared the need to memorize structures and nomenclature that appear nowhere else in the book.

In order to emphasize biochemical principles and to minimize the number of structures and enzymes presented to students, some steps of some metabolic pathways are not shown. For example, the reactions in the rearrangement phase of the pentose phosphate pathway (Chapter 10) and the Calvin cycle (Chapter 13) are not shown explicitly. Only the major pathways of lipid metabolism are shown in Chapter 14, and much of the bulk of traditional amino acid and nucleotide metabolism has also been excluded from Chapter 15.

A short chapter on photosynthesis (Chapter 13) follows the chapter on oxidative phosphorylation (Chapter 12) so that students can more easily discern the similarities between these processes.

Chapter 15 covers amino acid and nucleotide metabolism by focusing on reactions involving nitrogen. This allows a complete overview of the "biological" nitrogen cycle by following nitrogen fixation, assimilation, synthesis and degradation of amino acids and nucleotides, and nitrogen disposal via the urea cycle. By covering nitrogen metabolism in this manner, students are exposed to all the relevant pathways and can focus on important reactions without getting bogged down in a comprehensive recounting of all the reactions of all these pathways. Thus, there is no separate chapter on nucleotides (their structures are first presented in Chapter 3 in the context of DNA structure, and their metabolism is described in the context of amino acid–derived biomolecules in Chapter 15).

Signal transduction is covered in the context of regulation of mammalian fuel metabolism (Chapter 16), which creates an opportunity to summarize the major features of the metabolic pathways described in Chapters 10–15.

In order to focus on principles rather than details, the discussions of DNA replication (Chapter 17) and transcription (Chapter 19) do not make a sharp distinction between prokaryotic and eukaryotic systems. The overall processes are presented using examples from both types of systems, and brief notes explain how they differ.

A chapter on cancer and DNA repair (Chapter 18) provides an opportunity to tie DNA metabolism to various aspects of cell biology (e.g., cell cycle control and apoptosis) and reinforces understanding of DNA structure and function (first presented in Chapter 3) by showing how DNA is damaged and how it can be repaired.

Because replication, transcription, and translation are typically also covered in other courses, Chapters 17–20 focus primarily on some of the biochemical details of these processes, such as topoisomerase action, nucleosome structure, mechanisms of polymerases and other enzymes, structures of accessory proteins, mechanisms for proofreading during polymerization and aminoacylation, and chaperone-assisted protein folding.

Pedagogical Features

Each chapter of *Essential Biochemistry* is designed to be self-contained so that it can be covered at any point in the syllabus.

- Each chapter begins with a paragraph **(This Chapter in Context)** to help orient the reader to the main topics of the chapter and how they relate to surrounding chapters.

- A short example of a **biochemical application** opens each chapter.
- A list of **Learning Objectives** precedes the text of each chapter. Students are periodically prompted to review the objectives and to answer **Study Questions** that reinforce each objective.
- Reminders to explore the **Media Exercises** appear at appropriate places in the chapter. The text includes additional cross-references to specific topics in the exercises. The exercises animate complex processes and show detailed molecular structures using a Chime-based interactive format. Four Review Exercises provide supplemental background material. Most of the media exercises are designed so that students can proceed at their own pace, viewing animations, manipulating molecular structures, and answering questions.
- Sentences summarizing **key points** are in italics. **Key terms** are in boldfaced. Their definitions are also included in the glossary and form the basis of the online quiz. **Key equations** are boxed for emphasis.
- **Sample Calculations** illustrate the use of important equations in thermodynamics (Chapter 1), acid–base chemistry (Chapter 2), binding phenomena (Chapter 4), enzyme kinetics (Chapter 7), transport processes (Chapter 8), equilibria (Chapter 9), and redox chemistry (Chapter 12).
- Some material that is of a higher level or that is thematically distinct from the bulk of the chapter is set off in **boxes** so as not to distract the reader from the main thread of the discussion.
- Illustrations include **photos from research publications** and **computer-generated molecular models** designed specifically for *Essential Biochemistry*. Many small figures are incorporated directly into the text. An **overview figure** illustrating all the major metabolic pathways is introduced in Chapter 9 and revisited in subsequent chapters on metabolism. Chapters 10 and 14, which focus heavily on pathways, include an additional summary figure as a study aid.
- Each chapter ends with a large selection of **Problems**, including some multistep case-type problems based on the recent literature. The problems require students to apply information rather than simply recall memorized details. **Complete Solutions** to all problems are provided in the appendix.
- An **annotated list of Selected Readings** following each chapter includes recent short papers, mostly reviews, that students are likely to find useful as sources of additional information. Some **Relevant Web Links** are included on the accompanying Web site (www.wiley.com/college/pratt).
- Each chapter includes a **Summary** of the main points. A **Checklist** at the end of the chapter reminds students to review the Learning Objectives, solve the problems, complete the relevant media exercises, take the glossary-based quiz, explore the Web sites listed online, and consult the list of selected readings for further information.
- Four **Instructor's Resources**, part of the media package, include lecture-ready slides and student activities on the Human Genome Project, bacterial drug resistance, proteomics, and phylogenetic trees.

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Many of the molecular graphics that illustrate this book were created using publicly available coordinates from the Protein Data Bank (www.rcsb.org). The figures were rendered with the Swiss-Pdb Viewer [Guex, N., Peitsch, M.C., SWISS-MODEL and the Swiss-Pdb Viewer: an environment for comparative protein modeling, *Electrophoresis* **18,** 2714–2723 (1997); program available at www.expasy.ch/spdbv] and Pov-Ray (available at www.povray.org).

FOR THE STUDENT

HOW TO USE THIS BOOK

Welcome to Biochemistry! Your success in this course will depend to a great extent on your willingness to take an active role in your education. Learning biochemistry requires more than simply reading the textbook, although we recommend that as a first step! *Essential Biochemistry* has been designed and written with you in mind, and we urge you to take advantage of all it has to offer.

Biochemical knowledge is cumulative; it is not something that can be learned all at once. We advise you to keep up with your reading and other assignments so that you have plenty of time to reflect, ask questions, and, if necessary, seek help from your instructor. As you read each chapter of the textbook, make sure you understand how it fits into the course syllabus. Use the study aids provided in the textbook: First, note the list of learning objectives at the start of the chapter. At the appropriate points, you will be asked to review each objective and answer one or more study questions. Be sure to view the media exercises that expand on material covered in the textbook. These exercises include animations of dynamic biochemical processes and interactive molecular graphics. You can enrich your understanding of biochemistry by exploring the exercises and answering the questions they pose. Consult the review exercises if your chemistry background is weak.

As you study, note the key sentences that are highlighted in italics. Be able to define terms in boldface, and test your knowledge by taking the online quiz. Most importantly, solve the problems at the end of each chapter. You should make every effort to complete all the problems without looking at the answers in the appendix. Developing problem-solving skills will facilitate your understanding of biochemistry and will help pave the way to success in any future academic or career endeavor.

Finally, use the summary and checklist at the end of every chapter as a guide to help you study. Take advantage of the additional resources available—such as the list of selected readings and Internet sites—if you need help, are curious about biochemistry, or need up-to-date information as a starting point for a class project.

In writing *Essential Biochemistry,* we endeavored to select topics that would provide a solid introduction to modern biochemistry, which is a vast and ever-changing field. We realize that most students who use this book will not become biochemists. Nevertheless, it is our hope that you will come to understand the major themes of biochemistry and see how they relate to current and future developments in science and medicine.

Charlotte W. Pratt
Kathleen Cornely

BRIEF CONTENTS

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PART I
MOLECULAR STRUCTURE AND FUNCTION