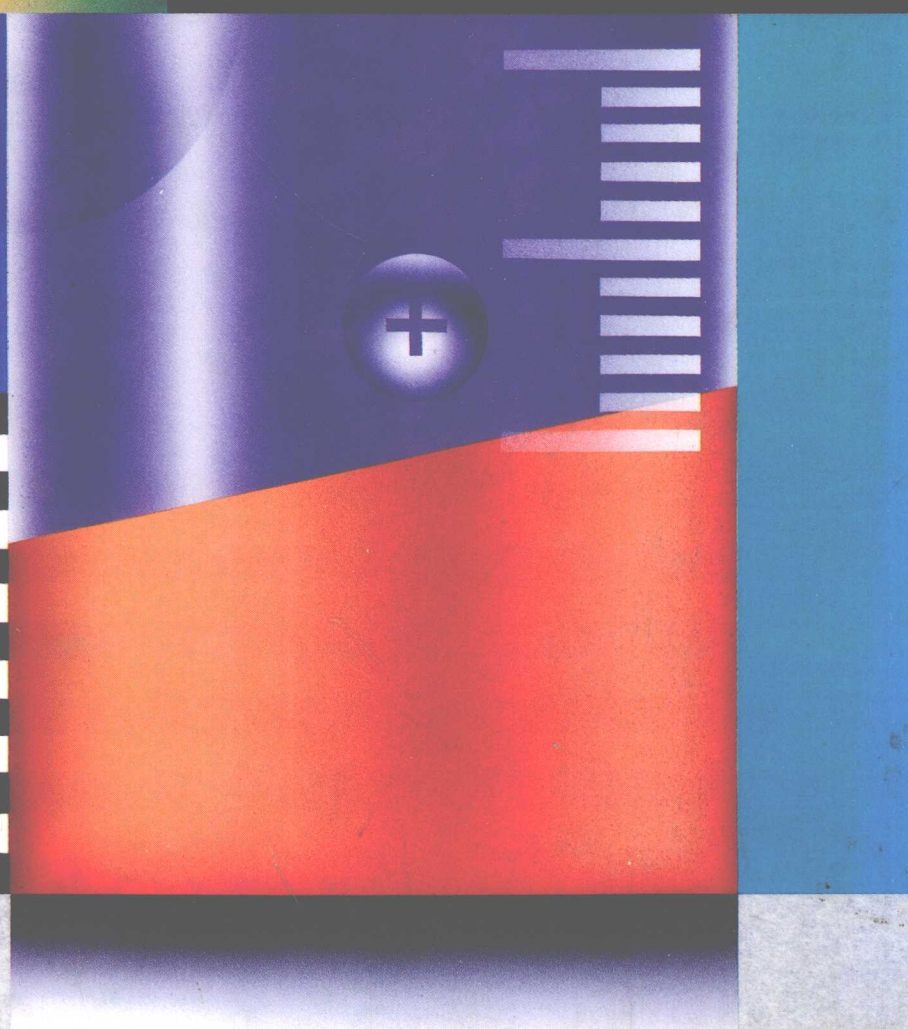
Elements of General and Biological Chemistry

John R. Holum

Eighth Edition



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About the Author

JOHN HOLUM is on the faculty of Augsburg College, Minneapolis, MN. He did his undergraduate work at St. Olaf College and earned his Ph.D. (organic chemistry) at the University of Minnesota. Additional studies were taken as sabbatical leaves at California Institute of Technology and Harvard University. In 1974 he was given the Distinguished Teaching Award of the Minnesota Section of the American Chemical Society. He is a member of Phi Beta Kappa, Phi Lambda Upsilon, Sigma Xi, and Sigma Pi Sigma. The National Science Foundation has awarded him several research grants and a Science Faculty Fellowship. He is the author or coauthor of several texts in chemistry, all published by John Wiley & Sons, and a reference work, *Topics and Terms in Environmental Problems* (Wiley – Interscience). He has also authored papers for the *Journal of the American Chemical Society,* the *Journal of Organic Chemistry,* and the *Journal of Chemical Education.* He has been active on the Examinations Committee and the Committee on Chemistry for Professional Health Care Students of the Division of Chemical Education of the ACS, and has spoken often at Divisional and Regional meetings, as well as at conferences of the Two-Year College Chemistry Association. His textbooks in chemistry for professional health care students have been widely used in America and abroad for over 25 years.

Preface

This book is a shorter version of the fourth edition of *Fundamentals of General, Organic, and Biological Chemistry* (1990), also published by John Wiley & Sons. Its content incorporates the recommendations of the Task Force on Chemical Education for Health Professions (M. Treblow, Chairman), sponsored by the Division of Chemical Education of the American Chemical Society and described in the *Journal of Chemical Education,* July 1984, page 620 ("A Syllabus for a One-Semester Chemistry Course for Health Professions"). Hence, this text meets the needs for a basic text in a one-term course in chemistry for students aiming for careers in professional health care fields.

There is more in this book than can reasonably be taught in just one term. But although general agreement exists about topics, there is not a similar agreement about emphasis. Moreover, the incoming preparations of students in this kind of course varies widely, ranging from classes in which all studied chemistry in high school to classes resulting from open admissions policies. This explains why many schools have used earlier editions for two-term courses.

The theme of the previous editions, the molecular basis of life, continues. Topics in general and organic chemistry are therefore included only if they are either essential background for the study of biochemistry or are directly related to the chemistry of living processes. Thus the first eight chapters, largely general chemistry, conclude with an emphasis on acids, bases, and buffers. These involve concepts directly related to perhaps the most important single topic for future nurses (if, indeed, just one can be named), the chemistry of the acid–base balance of blood.

One change in these chapters is to discontinue the use of the terms "Arrhenius acid" or "Arrhenius base." In aqueous media it all comes down to proton transfers, and the hydronium ion is only one proton donor.

In keeping with society's interest and concern about the environment, we now have a special topic on acid rain.

Another change is to discontinue the teaching of the concept of acid or base normalities.

Acid–base titration problems are solved simply as ordinary problems in stoichiometry. The concept of an *equivalent* is retained only in connection with equivalents of ions as they relate to ionic charges. Aqueous solutions of clinical interest still use the units of equivalent/liter or meq/mL, so this must be taught. It is used in a special topic on the anion gap and its significance for diagnosis. The study of how to do the calculations for making dilute solutions from concentrated solutions is now in a special topic.

A third change in the first section of the book is the reorganization of the chapter on solutions and colloids to place all aspects of colloids after the study of solutions.

The next five chapters, organic chemistry, include only those functional groups whose nature and chemistry are essential to the biochemistry that follows. These are the groups in carbohydrates, lipids, proteins, nucleic acids, and many important drugs.

Only the barest minimum organic chemistry is included, because the available time has to be very carefully allotted. Thus, alkyl halides are barely mentioned because this system occurs nowhere among the biochemicals to be studied later. Very little is done with aromatic chemistry, because the details of aromatic electrophilic substitution reactions will not be exploited later. (What it means to be *aromatic,* and some of the characteristic reactions of the benzene ring, are studied, because this ring does occur among some amino acids and proteins.)

When the study of organic chemistry starts, frequent mention is made of the kinds of biological chemicals that happen to have the particular functional group currently being studied, because students appreciate the reminders that the theme of the course continues throughout all of the study of organic chemistry. We believe, however, that the soundest pedagogical approach is to introduce these groups, one after the other, as they occur among the *simplest,* monofunctional compounds. Large, complex structures such as glucose or hemoglobin or DNA can be sources of terror rather than wonder when they are introduced too early.

The next eight chapters take up the major kinds of compounds found in the human body, how they are fitted for their uses in metabolism, and how they react in cells. We continue the segregation of catabolism and anabolism into separate chapters. Thus Chapter 19 ("Molecular Basis of Energy for Life") begins with a broad overview of biochemical energetics (which might serve in some courses as the only coverage of this topic), and then it takes up the ways in which carbohydrates, lipids, and amino acids can be broken down for energy. This chapter closes with the problems of acidosis that can arise when the body cannot bring a balanced use of various substances to bear on its needs for chemical energy.

Chapter 20 ("Metabolism and Molecule Building") goes into the absorption, distribution, and biosynthesis of carbohydrates, lipids, and amino acids. One of the special topics in this chapter concerns recent advances in our understanding of the relationships of lipoprotein complexes, cholesterol, liver receptors, and heart disease. Earlier, in Chapter 15 ("Lipids"), a new special topic on the omega-3 fatty acids and heart disease has been added.

Chapter 21 ("Nucleic Acids") continues in its former location because teachers of this course seem increasingly to omit the topic entirely. Those who do this argue that students have encountered several of its major points in earlier courses, including high school biology. Nonetheless, this chapter has been updated, and it now includes a special topic on genetic fingerprinting.

The book then closes with a chapter on radioactivity with an emphasis on health-related aspects. There is little reason why this chapter could not be studied much earlier, but its present location does take advantage of the prior study of nucleic acids, genes, and genetic damage that radiations can cause. A new special topic on radon-222 as part of background radiation is now provided.

The design of this edition is mostly like that of the previous edition. There are **margin comments.** Some are reminders. Some restate a point. Some are small, illustrative tables to which the neighboring paragraph refers. Some are structures that need not be memorized.

There are **Special Topics** on matters of current interest, and a list is provided following the Table of Contents. All have been updated as needed, and several new special topics,

mentioned above, appear. For the first time, sets of Review Exercises are now offered for the Special Topics.

A comprehensive package of instructional materials, described in detail on page xiii, is available to help the students.

A Teachers' Manual includes the answers to all of the Practice Exercises and Review Exercises.

Other Design Features That Aid Students

Chemistry is one of the disciplines in which important scientific terms can be sharply defined. We have tried to do so at the first occasion of using the term or as soon thereafter as possible, at or near the place where the **key term** is highlighted by a boldface color treatment. Then our aim has been to use these terms as carefully and consistently as possible. At the end of the book, there is a **glossary** where each of the key terms is defined. (The *Study Guide* has a Glossary for each chapter.)

Each chapter has a **Summary** that uses the key terms in a narrative survey. The main section of each chapter also begins with a **summary statement** that announces what is coming and that serves during test review periods to highlight the major topics.

Special labels identify sets of **Review Exercises** that are about a common topic. Within most chapters are several **Practice Exercises,** and most of these immediately follow a **worked example** that provides a step-by-step description of how to solve a certain kind of problem. The **factor-label** method is used for nearly all computations. The **answers** to all Practice Exercises are found at the back of the book together with the answers to selected Review Exercises.

The **Appendix on Mathematical Concepts** provides a review of what exponentials are and how to manipulate them. This Appendix also discusses how to use pocket calculators to handle exponentials and to carry out chain operations.

Continuing a long tradition, we have tried to make the **Index** the most thorough, most cross-referenced index in any text of this type.

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Acknowledgments

Over the many years of writing instructional materials, my family — Mary, my wife, and our daughters, Liz, Ann, and Kathryn — have been Gibralters of support. They, rather than my teaching or writing, are my career and so such teaching and writing are seen by us as one of the ways by which our family has tried to be of help to others. I am pleased to say "thank you" to them for being such nice people.

Here, at Augsburg College, I have enjoyed years and years of support from Dr. Earl Alton, Chemistry Department Chair, Dr. Ryan LaHurd, Dean, and Dr. Charles S. Anderson, President. My freedom to write stems in no small measure from the freedom that these caring people have accorded me.

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Special Acknowledgments to Professional Critiques. Thanks in part to the suggestions and critiques of teachers and scientists this book or its longer version, *Fundamentals of General, Organic, and Biological Chemistry* (Fourth edition, 1990), have been the first books of their kind to bring to the attention of students at this level the major developments concerning the molecular basis of life. I am particularly pleased to thank Sandra Olmsted,

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J.R.H.

Supplementary Materials for Students and Teachers

The complete package of supplements that are available to help students to study and teachers to plan the course and operate the associated laboratory work includes the following:

Laboratory Manual for Elements of General and Biological Chemistry, eighth edition. An instructor's manual for these experiments is a section in the general Teachers' Manual described below.

Study Guide for Elements of General and Biological Chemistry, eighth edition. This softcover book contains chapter objectives, chapter glossaries, additional worked examples and exercises, sample examinations for each chapter, and the answers to all Exercises.

Teachers' Manual for Elements of General and Biological Chemistry, eighth edition. This softcover supplement is available to teachers, and it contains all of the usual services for *both the text and the laboratory manual.*

Test Questions for Elements of General and Biological Chemistry, eighth edition. Multiple choice test questions in camera-ready form. Available without charge to instructors only who adopt this book. Write to Chemistry Editor, John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10158

Transparency Acetates. Instructors who adopt this book can receive from John Wiley & Sons, without charge, a set of transparencies of 100 figures and tables in this book. Write to Chemistry Editor, John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10158.

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Special Topics

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Goals, Methods, and Measurements

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Scientific Notation
Accuracy and Precision
The Factor-Label Method in Calculations
Heat Energy
Density

What this family of mute swans knows by instinct, we know by intellect: life is better if we work with nature, not against her. Knowing how nature works at the molecular level of life, the subject of this book, helps professional health care workers apply nature's gifts to the healing arts.

1.1 CHEMISTRY AND THE MOLECULAR BASIS OF LIFE

The theme of this book is the molecular basis of life.

Centuries ago, people surely noticed that many *different* animals drank at the same water holes, breathed the same air, ate the same kinds of food, and enjoyed the same salt licks. Ancient farmers knew that the droppings of animals nourished plants, and that animals prospered by eating plants. Some animals could eat weaker animals and grow.

Evidently, at some deep level of existence, living things can exchange parts. These parts are not organs and tissues but much smaller things, extremely tiny particles called molecules made of even smaller particles called atoms. All of life, whether plant or animal, has a *molecular* basis, and chemistry has been the route to its discovery. **Chemistry** is the study of that part of nature that deals with substances, their compositions and structures, and their abilities to be changed into other substances. There are so many different substances that we have to have a plan of study.

Well over 6 million chemical substances are known.

Our Strategy. Life at the molecular level involves molecules and chemical reactions that are often complicated. The symbols we use for them, however, are actually less complex than many symbol systems you have already mastered, like those used to draw maps. You learned how to read and understand dozens of maps by mastering just a few map symbols. Our symbols for molecules are like maps because the same pieces of molecules, like molecular "map signs," occur over and over again. It will be a good idea, therefore, before we study some of the most complicated molecules in nature (Chapters 14–22), to learn these "signs" among simpler substances. Our chapters on organic compounds (Chapters 9–13) do this.

The atoms of all of the kinds of matter are made of varying combinations of just three extremely tiny particles: electrons, protons, and neutrons.

As we said earlier, molecules are made of atoms. It really isn't possible to understand molecules without first learning about atoms and how their (even tinier) parts get reorganized into molecules. This study occurs mainly in the first eight chapters, together with the essential background about a variety of substances such as acids, bases, salts, and solutions. All these studies rest on experimental evidence that involved taking measurements of physical quantities. In this chapter we will learn about some of the measurements that have been useful.

1.2 PROPERTIES AND PHYSICAL QUANTITIES

A physical property differs from a chemical property by being observable without changing a substance into a different substance.

A **property** is any characteristic of something that we can use to identify and recognize it when we see it again. The observations of some properties, however, change an object or a sample of a substance into something else. For example, we can measure how much gasoline it takes to drive a car 100 miles, but this measurement uses up the gasoline. As it burns it changes into water and carbon dioxide (the fizz in soda pop). A property that, when observed, causes a substance to change into new substances is called a **chemical property,** and what is being observed is called a **chemical reaction.** A chemical property of iron, for example, is that it rusts in moist air; it changes slowly into a reddish, powdery substance, iron oxide, quite unlike metallic iron. **Chemistry** is the study of these kinds of changes in substances, how they occur, and how atoms become reorganized as they happen.

Properties such as color, height, or weight that can be observed without changing the object into something different are called **physical properties.** We usually rely on such properties to recognize and name things. For example, some physical properties of liquid water are that it is colorless and odorless; that it dissolves sugar and table salt but not butter; that it makes a thermometer read 100 °C (212 °F) when it boils (at sea level); and that if it is mixed with gasoline it will sink, not float. If you were handed a glass containing a liquid having these properties, your initial hypothesis undoubtedly would be that it is water. Think of how often each day you recognize things (and people) by simply observing physical properties.