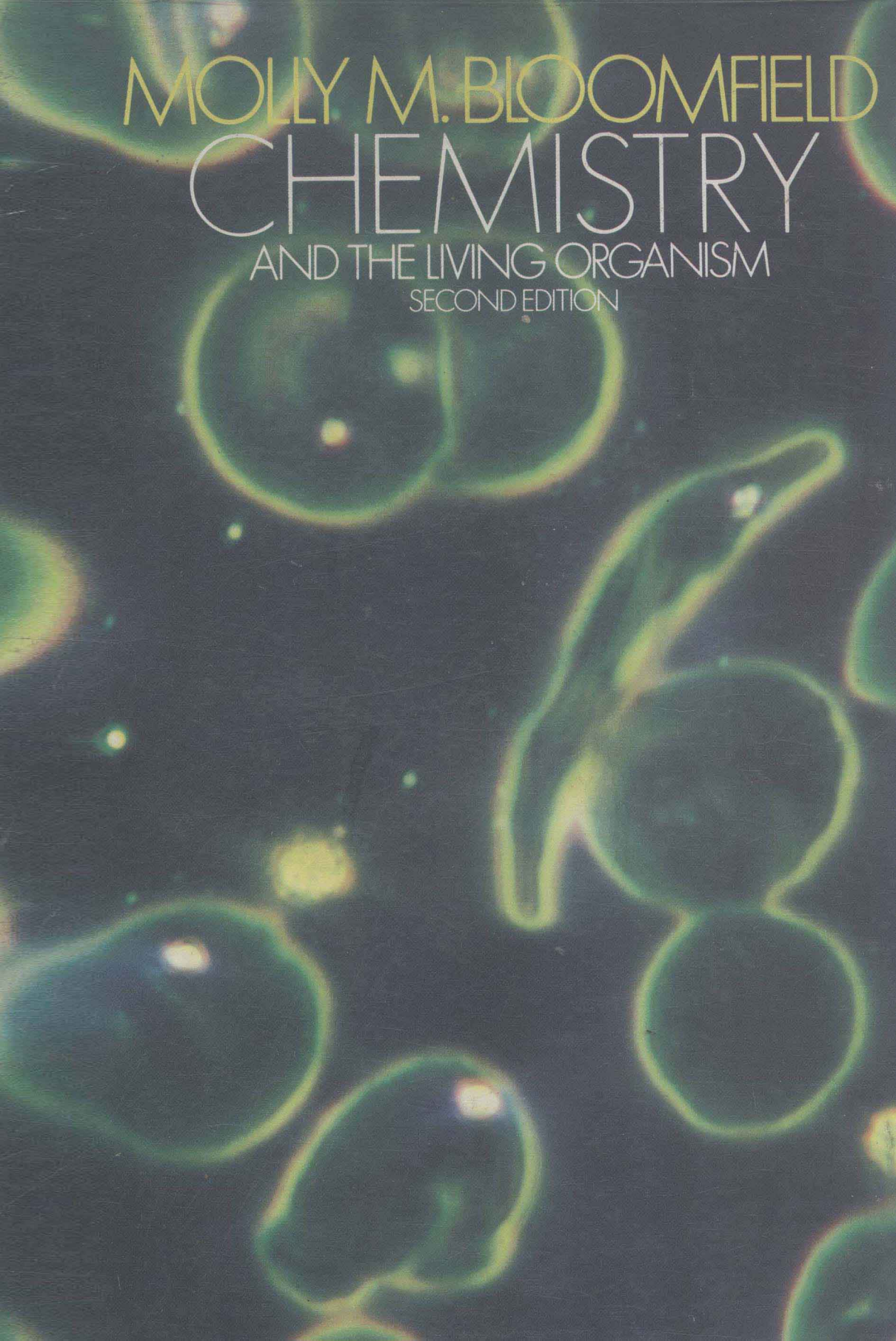
MOLLY M. BLOOMFIELD
CHEMISTRY
AND THE LIVING ORGANISM
SECOND EDITION

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SECOND EDITION

Molly M. Bloomfield

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Preface to the Second Edition

This second edition of *Chemistry and the Living Organism* provides a highly motivating and student-oriented approach to the study of chemistry. It is intended for survey courses for students seeking a basic understanding of chemical principles, and especially for students interested in the biological applications of those principles. This book, therefore, is particularly appropriate for students in the allied health sciences and related disciplines, such as physical education and home economics. All too often such students dread chemistry, imagining it as a subject taught in a highly technical language, with little relevance to their personal needs. This textbook addresses such concerns by including the student as an integral part of the subject matter. Because the principles of chemistry are presented in the context of their clinical and biological applications, the relevance of these concepts to the student's personal and professional life is constantly emphasized. Throughout, my purpose is to provide a complete and accurate introduction to the basic principles of chemistry in a style that is easy to understand and enjoyable to read.

Revising this textbook, however, has been a difficult exercise in self-restraint. New, fascinating, and important developments have continually been reported since the first edition appeared. Moreover, I have received suggestions to include additional technical topics which were deliberately omitted from the first edition. But the easy solution—that of including all of these worthwhile topics in the book—would have inevitably led to a text that contained much more material than could be adequately covered in many courses at this level. Thus, this revision is the result of a selective process of topic addition and modification. In choosing the concepts to be added I have tried to remain faithful to the spirit of the first edition, selecting only those recent developments and additional topics best illustrating the basic principles of chemistry as reflected in the life processes of the human body. In addition, the material remaining from the first edition has also been carefully revised to correct any weaknesses or deficiencies pointed out by colleagues, students, and reviewers, and to further build on those instructional techniques that have been well received.

Special Features of This Edition

Student-Oriented Approach

This book is dedicated to making chemistry as interesting as possible to the student. The principal strength of the text is its ability to capture the student's attention by emphasizing the direct application of fundamental chemical principles to the student's personal life. In this edition I have further stressed the usefulness of this subject through additional explanations of the basic chemistry underlying the tasks and standard procedures students will likely encounter in their fields of endeavor.

Conversational Writing Style

A major strength of the first edition was the comfortable, conversational style of its discussion. For the second edition I have worked to improve further the readability of the text, and have also made a conscientious effort to eliminate any sexual bias that might have been present in the first edition.

Scientific Terminology and Glossary

I have increased the scientific terminology in this edition to include more of the vocabulary commonly encountered in the classroom and medical laboratory. As in the first edition, careful attention has been given to defining all scientific terms the first time that they appear in the text, and the Index remains extremely detailed to permit easy reference to all scientific names and terms. In addition, a large Glossary has been included at the end of the textbook to further aid the learning of these terms.

Mathematical Concepts and Manipulations

The students using this textbook vary considerably in their mathematical skills. To provide as much help as possible I have included many more solutions to example problems within the chapters, and have considerably expanded the end-of-chapter problems to allow for more drill exercises. As a further learning aid, an Appendix has been provided that gives answers to selected end-of-chapter problems. And finally, a detailed review of basic mathematical concepts has been added to the *Student Study Guide* for those students who need such fundamental review. Some of the mathematical concepts added to this edition of the textbook are Graham's law, the universal gas constant, equivalents, and osmolarity. SI units are introduced and defined, but metric units (as well as other units commonly used in various medical fields) are also presented.

Case Histories

The chapter-opening case histories in the first edition proved extremely effective in capturing the student's interest and motivating the study of the fundamental concepts being presented. The second edition contains several new case histories. Moreover, some of the original cases have been modified to reflect changing medical developments and practices.

Learning Objectives

As in the first edition, each chapter is preceded by a list of learning objectives. In many instances I have rewritten these objectives to better help the student identify the important topics covered in the chapter, and to serve as a study guide for later review.

Chapter Summaries

A new feature of this second edition is the inclusion of summaries at the end of each chapter. These summaries highlight and review for the student the major concepts that have been discussed.

Topic Coverage

This second edition, like the first, is divided into four sections. The first section, "Introduction," uses a discussion of the disease phenylketonuria to motivate the study of chemistry. The second section, "A Chemical Background," then introduces the basic vocabulary of chemistry. To improve topic delineation in lectures and to facilitate review and testing of

the material, I have divided several chapters of the first edition into shorter chapters, each covering fewer topics. Thus, the material formerly found in Chapter 2 ("Matter and Energy") now appears in three chapters entitled "Matter," "Energy," and "The Three States of Matter." Similarly, the topics formerly discussed in Chapter 6 ("Combinations of Atoms") are now found in the two chapters "Combinations of Atoms" and "Chemical Equations and the Mole." And the material formerly found in Chapter 8 ("Water and Solution Chemistry") is now found in two chapters "Water and Solutions" and "Acids and Bases." The third section of the book, "The Elements Necessary for Life," examines the functions of the elements critical to living systems. This section also has been restructured, with the material formerly found in Chapter 9 ("Carbon and Hydrogen") now appearing in the two chapters "Introduction to Organic Chemistry" and "Carbon and Hydrogen." The fourth section, "The Compounds of Life," discusses the large molecules important to living organisms and the interactions among these molecules. A major change in this section is the revision and expansion of the material on vitamins (Chapter 21).

Although this second edition contains no specific chapter headings covering body fluids or concepts of nutrition, these important topics have been integrated into the discussion of associated chemical concepts. Thus, they are fully treated in a manner that emphasizes their fundamental chemical nature.

I have planned this book to accommodate many different approaches to teaching the course. In particular, I have tried to make each section within a chapter as self-contained as possible to allow maximum flexibility in selecting those sections that are most pertinent to the students' needs. Although most courses taught at this level are a semester or more in length, this textbook may also be used for courses lasting only one quarter. The following is a suggested list of sections that may be most easily omitted when time is limited:

Chapter 3, Sections 3.7 to 3.8.
Chapter 4, Sections 4.5 to 4.11.
Chapter 5, Sections 5.11 to 5.14.
Chapter 6, Sections 6.6 to 6.10.
Chapter 10, Section 10.9,
Chapter 11, Sections 11.16 to 11.19, and 11.21.
Chapter 12, Section 12.10.
Chapter 14, Sections 14.5 and 14.17.
Chapter 16, Sections 16.10, 16.11, and 16.13.
Chapter 17, Sections 17.7 to 17.14.
Chapter 18, Sections 18.3, 18.6, 18.8, and 18.17, and 18.29 to 18.31.
Chapter 19, Sections 19.5 to 19.7, 19.12 to 19.14, and 19.20.
Chapter 20, Section 20.3.
Chapter 21, Sections 21.15 to 21.17.
Chapter 22, Section 22.10.

Supplemental Materials

As with the first edition, this textbook is part of a complete and carefully integrated learning package that includes the following materials.

A **student's study guide** is available for this second edition. The study guide contains a brief summary and a list of important terms for each section in a chapter, as well as many worked out examples of mathematical problems and an extensive set of self-test questions and answers for each chapter. An important new feature of the study guide is a basic review of mathematical concepts and manipulations.

The **laboratory manual** written by Joseph Bauer of William Rainey Harper College has been completely revised for this second edition. Four new experiments have been included, and all experiments have been very carefully designed to avoid the use of hazardous reagents. Another feature of this laboratory manual is the addition of a new section that describes fundamental laboratory operations.

The **teacher's manual** for the second edition contains the answers to all exercises and problems in the textbook, answers to the laboratory exercises, and a list of chemicals and equipment (as well as some helpful hints) for the laboratory experiments. A set of **overhead transparency masters** selected from figures in the textbook, and including other more advanced illustrations, will be supplied to adopters on request.

Acknowledgments

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Many instructors have commented on the important role played by the chapter-opening case histories in sparking and maintaining the student's interest throughout the course. To this end I gratefully acknowledge the substantial help I have received from the doctors and staff of Good Samaritan Hospital in Corvallis, Oregon, who carefully checked the accuracy of each case history and provided many valuable insights into the relationship between chemistry and medical practice. I especially thank Dr. James Riley, Dr. William Lloyd, and Bob Vanderford for the time and effort they so generously provided.

Much of the final revised manuscript was prepared during a year at the University of Louvain in Louvain-la-Neuve, Belgium. During this period I profited greatly from the suggestions and helpful assistance of Yves Eeckhout of the International Institute of Cellular and Molecular Pathology. Thanks also to Mady Leroy for her fine job of typing in this very foreign language. As always, I am indebted to Gary Carlson and the staff at Wiley for their continuing encouragement and editorial support. But most of all I must thank my husband Stefan, whose editing and meticulous regard for details made my ideas a reality, and without whose support and understanding this second edition could not have been completed.

Louvain-la-Neuve, Belgium — Molly M. Bloomfield

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chapter 1

PKU—A Case for Understanding Chemistry

1.1 Why Study Chemistry?

Chemistry is the study of the composition and interaction of substances.

Now, this may sound like a pretty general definition for such a specialized field of study. However, the broad scope of this definition is one way of indicating just how thoroughly chemistry is involved in each of our lives. For example, you drink water from your tap at home without a second's hesitation, for someone has added chemicals to the water to insure its safety. You seldom need to use an iron, thanks to the development of chemicals that give your clothes a permanent press. Just picture your daily routine: You wake up in the morning under sheets made of synthetic fibers that were chemically produced in a factory, or sheets made of cotton fibers—which were created through chemical reactions in the blossom of the cotton plant. You put on clothes made largely of synthetic materials, brush your teeth with a toothpaste containing fluoride, and eat a breakfast fortified with minerals and synthetic vitamins. You may drive to school in a car powered by the energy released through chemical reactions in the engine, or perhaps you pedal a bicycle—powered by the energy released through chemical reactions in your muscles. And now you're reading this textbook, whose paper was created through a chemical process and whose ink is a blend of chemicals. Literally every part of your life is closely related to the field of chemistry, whether it be the synthetic chemistry of the test tube and the modern laboratory, or the natural chemistry that makes up all of nature.

Chemistry also affects each of our lives in very personal ways. For example, your physical appearance is governed by chemicals. Chemical substances called hormones help determine your height, your weight, your build, and your sexual characteristics. Your good health depends upon chemicals that preserve the food you eat, chemicals that protect you from disease, and chemicals (in the form of food) that supply your body with the nutrients it needs to function properly. Chemicals influence your behavior and your emotional feelings. Much of your memory may be chemical; your thoughts and experiences may be stored in your brain in the form of chemical compounds. What we are trying to say is that your entire life is chemical, so a basic knowledge of chemistry will allow you to be more aware of your total self and the way in which you interact with your environment.

1.2 A Case for Understanding Chemistry

To illustrate how a knowledge of chemistry might be helpful in understanding the events surrounding us, let's consider a story about a family—it could have been your family or the family of a friend. Don't concern yourself too much with the exact chemistry in this story now. We will return to this case later in the book when we have developed the basic vocabulary and background necessary to understand the chemical processes we will now be describing.

Billy was brought home from the hospital as a happy, healthy baby. People who came to visit the family commented on how fair his skin and hair looked compared with the rest of the family. As Billy entered his fourth month, his mother started noticing that he no longer watched his mobile as it turned above the crib, and he rarely returned her smiles. Billy was slow in learning to sit up by himself. But then again, his brother had also been late in doing such things and he had turned out to be a very active young child. As Billy grew older, however, his parents became increasingly concerned about his development and behavior. He had become irritable, and would have temper tantrums for no reason at all. Although his parents worked very hard to teach Billy to talk, he was able to learn only a few words. Furthermore, his mother noticed a strange musty odor about him when she changed his diapers, and his skin was often inflamed and flakey. As Billy neared the age of three, his parents began to admit that he was retarded. He still didn't walk or talk, and he was becoming uncontrollable.

Finally, a friend convinced them that the best thing for Billy and for themselves would be to take him to a clinic for diagnosis. At the clinic Billy was given a set of tests, which indicated that he had a disorder called phenylketonuria—PKU for short. Billy's parents were quite upset, and asked if there was any hope for Billy. The doctor replied that nothing could be done to reverse the retardation. When untreated, PKU causes irreversible brain damage, and Billy's IQ was found to be 40. (The average person's IQ is 100, and individuals with an IQ below 70 are considered retarded.) However, the doctor told them that Billy could be placed on a special diet which would improve his behavior and his skin condition. She further explained that PKU was a recessive inherited disease, which meant that each parent must be a carrier of the defective gene for that disease. Therefore, there was a 1 out of 4 chance that any other child that they might have would inherit the disease (Figure 1.1). Nevertheless, the doctor did not discourage Billy's parents from having more children. She explained that the disorder was now understood and could be treated, and that if PKU were diagnosed soon after birth, children having the disease could lead normal lives. Recent laws in most states have required the testing of newborn infants for PKU, so most new cases of PKU were being diagnosed soon after birth.

Billy was taken home, and his parents placed him on a special diet. Within a few weeks, his parents were pleased to find that he no longer had the musty odor, that his skin and hair color darkened, that his behavior improved, and that he even began to smile. To her relief, Billy's mother found that she was now able to take care of him.

Billy's sister Susan was born two years later. Before she was brought home from the hospital, a sample of blood was taken from her heel and placed on a piece of filter paper for testing. Three weeks later Susan was brought back to the clinic to have the test repeated. The doctor then told Susan's parents that the tests had revealed high levels of a substance called phenylalanine in Susan's blood. This meant that Susan, like Billy, had PKU. However, unlike Billy, the outlook for Susan was very hopeful. In order to reduce the abnormally high level of phenylalanine in her blood, Susan was immediately put on a low phenylalanine diet.

Figure 1.1 This family illustrates the characteristic genetic distribution of phenylketonuria. The parents are both carriers of the trait. By the laws of probability, each child has a 25% chance of being normal, a 50% chance of being a carrier of the trait, and a 25% chance of having PKU. The son at the right is normal, the two daughters are carriers, and the son in the wheelchair has PKU. (Courtesy Willard R. Centerwall, M.D., from *Phenylketonuria,* Frank L. Lyman, ed., Charles C. Thomas, 1963.)

To her parents' delight, Susan is growing into a healthy, active child with an above average IQ. As she grows into maturity and her brain completes its development, Susan's diet can become more varied. The contrast between Billy and Susan is remarkable, and it resulted entirely from high levels of one chemical compound in the blood (Figure 1.2).

The physical symptoms of PKU result from a chemical imbalance within the human body. You are probably aware of instances in which the chemical balance that exists within your own body has been disrupted. Hangovers or muscle cramps are the unpleasant results of some common minor disruptions in the body's chemistry.

The cause of the chemical disruption occurring in PKU is an error in the body's process for converting phenylalanine into another substance called tyrosine. Both of these chemicals, in proper amounts, are required for the normal functioning of the body—especially for the proper formation of nerve cells in the rapidly growing brain of a young child. It is the abnormally high level of phenylalanine, and the accompanying low level of tyrosine, that cause the various symptoms observed in Billy. If PKU is

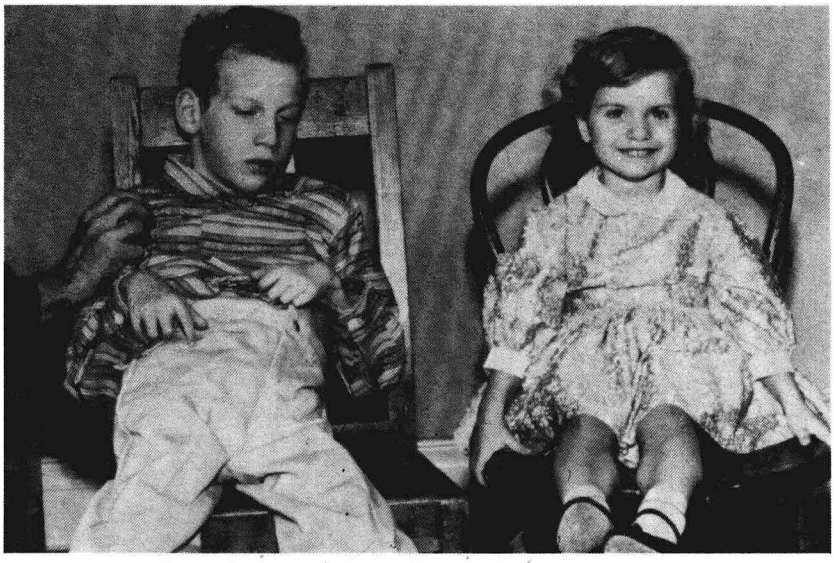

Figure 1.2 **Treated and untreated siblings with phenylketonuria. The eleven-year-old boy is severely retarded, while his $2\frac{1}{2}$-year-old sister is normal (Photo by Willard R. Centerwall, M.D. From *Phenylketonuria,* Frank L. Lyman, ed., Charles C. Thomas, 1963.)**

diagnosed soon after birth, a child can be placed on a special diet that will allow his brain to develop under normal chemical conditions. Otherwise the brain will be growing in an abnormal chemical environment, leading to severe and irreversible mental damage and retardation. Even then, however, some of the other clinical symptoms such as skin disease, musty odor, abnormally light skin and hair color, seizures, and destructive behavior are reversible, and will improve once the child is placed on the proper diet. This is possible because the body systems responsible for these abnormalities can begin to function normally when they are placed in the correct chemical environment.

There are other examples of similar diseases which will be discussed in later chapters, but the point of this story is to emphasize the extreme importance of the proper chemical balance in the body, from conception throughout life. As researchers become more knowledgable about the chemistry of living organisms, they will be able to control many more of the diseases that result from chemical irregularities.

1.3 This Textbook

If you had a PKU child in your family, you would certainly want to learn as much as you could about the disease, its cause, symptoms, and treatment. To understand the material written about PKU you would first need to learn the vocabulary used in such discussions, and perhaps you

would want to read some general books on chemistry, biology, and anatomy to gain a good background in this subject.

Actually, this is an approach with which you should be quite familiar. You might want to learn how to change the spark plug on a car, adjust the gears on a bicycle, or cook a Chinese dinner. In each case you would have to be familiar with the vocabulary used in the instruction manual, and would need to have at least some general knowledge about cars, bicycles, or kitchens. In the same way, before we can completely understand the many ways in which chemistry affects our lives we must first become familiar with the vocabulary used in chemical discussions, and with some of the basic principles and laws that govern the chemical reactions in living organisms. In Section II of this text we will introduce many of the vocabulary terms and basic concepts that you will need to know. In Sections III and IV we will use this new vocabulary to discuss the many chemical substances and processes that are essential to life.