Second Edition

Chemistry

A LIFE SCIENCE APPROACH

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Preface

This book, written for a two-semester or a three-quarter course, presents an integrated treatment of general chemistry along with organic chemistry and biochemistry. It provides the necessary background for students entering biological and biomedical fields of study including nursing, medical technology, dental hygiene, and nutrition. The level of the book is such that it assumes no high school chemistry course as a prerequisite. Students with a strong high school chemistry background might exempt one quarter (approximately the first eleven chapters) and begin study using the second two thirds of the book. It is anticipated that this book will be used for the terminal course in chemistry for most of these students. Our aim in writing this text is to assist the student in acquiring a sound background in the principles and concepts of general chemistry, organic chemistry, and biochemistry and a clear understanding of the functioning of biological systems at the molecular level. An attempt is made to achieve a logical progression in thinking so that chemical formulas and equations become meaningful symbols of the chemical language. Students need to understand the principles of general and organic chemistry before they can comprehend fully the complex transformations that occur in the cell. It is not sufficient to be able to draw the structure of a carbohydrate, a protein, or a lipid. Students must also understand clearly the interrelationships among these foodstuffs. They must be given an understanding and an appreciation of the superb chemical mechanisms that the body employs in transforming and conserving energy. Students who merely memorize the Krebs cycle and the electron transport chain are not learning biochemistry. It is necessary that they understand the significance of these processes.

This book is divided into three main sections. The first eleven chapters are devoted to establishing the fundamental principles of general chemistry. A balance of historical perspective, observations, models, and practical applications is given. Simple experimental observations are normally presented first, and models are deduced from them. Descriptive inorganic chemistry, organic chemistry, and biochemistry are used liberally for illustrative purposes. Chapter 1 can be covered in class or utilized for outside reading. Chapters 2–4 are complete in themselves and can be covered in any order. Parts of Chapters 2 and 3 are indicative of the fact that this book is not written in the fashion of the times, but is directed instead toward the need by certain students for fairly specific backgrounds. Certain terms or topics are consciously omitted when they are not absolutely necessary for the understanding of later topics. Chemical calculations are presented early (Chapter 4) so that they can be used as tools in later chapters or in a concurrent laboratory. Only simple algebra is utilized in the calculations, and the use of moles is stressed. Macroscopic properties of gases, liquids, solids, and solutions (Chapters 5–7) and reaction pathways (Chapter 8) are explained primarily on the basis of the microscopic bonding picture. Factors that affect the rates of reactions are discussed in Chapter 9. Chapter 10, "Chemical Equilibrium," emphasizes solution chemistry, pH, and buffers, particularly as these topics relate to biochemistry. The medical aspects of nuclear chemistry are stressed in Chapter 11.

Chapters 12–21 deal with the structure and properties of the different classes of organic compounds, with emphasis on the characteristic reactions of the various functional groups. A few selected reaction mechanisms have been presented in order to familiarize the student with such terms as free radical, carbonium ion, electrophile, and nucleophile. Chapter 22 deals with stereoisomerism, and its importance to an understanding of enzyme specificity is stressed.

The remaining chapters present the fundamental concepts of biochemistry in a form that will be understandable to students having only a limited background in organic chemistry. The major emphasis is placed on the dynamic nature of biochemistry and the interrelationships of the various metabolic pathways. Chapters 23–25 discuss the chemistry of the three major classes of foodstuffs—carbohydrates, lipids, and proteins. Enzymes (Chapter 26) are presented in a separate chapter as a special class of proteins. Because of the limited mathematics background of most of the students using this text, statements have to be qualitative rather than mathematical. Thus, for example, no extensive treatment of enzyme kinetics is attempted. In Chapter 27, the molecular basis of life is sketched by a clear and concise discussion of nucleic acid structure and replication, and by the role of nucleic acids in protein synthesis and in the action of viruses. Chapters 28–30 present the basic metabolic reaction sequences that occur within cells from the point of view of their interrelationships and integration into the fundamental whole. Metabolism is concerned with the production and utilization of energy, and it is here that the student is able to tie together the chemical principles learned in general chemistry and organic chemistry with biochemistry. The human body is viewed as an intricate machine that utilizes the energy of foods to run chemical reactions so as to meet its own needs. Chapter 31 discusses the blood, and it is especially well suited to those students who are majoring in one of the health sciences. The final chapter on nutrition and health appeared in an issue of *Chemical and Engineering News*. We are particularly pleased that the author, Howard J. Sanders, and the editor of that journal granted us permission to reprint the article. It is certain to be of interest and value to all readers of this text.

Many of the chapters in this second edition have been revised to reflect suggestions made by reviewers and users of the text. There is a much greater integration of biochemical examples throughout the discussions of organic compounds. Some added topics include aging, octane number, toxic compounds, vision, odor, laetrile, recombinant DNA, and the **R-S** convention for absolute configuration. At the end of each chapter we have included a selection of study questions and problems, ordered approximately according to topical coverage in each chapter. Students should be encouraged to work some of these exercises even while studying appropriate sections of each chapter. It is our contention that students learn chemistry only through repeated practice. The more questions that they are able to answer, the more confident they will be about their understanding of the subject. A supplementary Answer Book is available for students to check their answers.

In preparing this text, we received invaluable aid from many sources. We are indebted to one of our students, Mrs. Deborah S. Miller, for checking many of the numerical problems. We are particularly grateful for the suggestions and critical reviews provided by James A. Campbell, El Camino College; Andrew J. Glaid, Duquesne University; Truman A. Jordan, Cornell College; Lee Pike, East Tennessee State University; Thomas I. Pynadath, Kent State University; William H. Voige, James Madison University; and Ron Widera and Cornelia Lupash, Long Beach City College. We appreciate the efforts of Gregory W. Payne, Elisabeth Belfer, and other members of the staff of Macmillan who encouraged the writing of this book and saw it through production. Finally, we acknowledge the proofreading assistance and encouragements of our wives and the patience of our children during the preparation of the manuscript and the production of this book.

S. J. B.
C. W. J. S.

Contents

1

Some Fundamental Concepts

Chemistry is a study of the *composition, structure, and properties of matter.* What elements are present in water and with what abundance? How is water constructed on a microscopic and a macroscopic scale? What characteristics does water exhibit on a microscopic and a macroscopic scale?

Chemistry is a study of *the changes that matter undergoes.* What happens when water freezes, or when water reacts violently with sodium metal to yield bubbles of gas and a clear solution?

Chemistry is a study of *the related energy changes that accompany material changes.* Is energy released or absorbed when ice is formed from water, or when sodium nitrate is dissolved in water?

Chemistry is a study of *the reasons for particular compositions, structures, properties, material changes, and energy changes.* What is the relationship among these? How is the structure of water on a microscopic scale related to its macroscopic properties? How does the structure of water change upon the addition of ethyl alcohol to water?

Chemistry is concerned with matter and energy. The purpose of this chapter is to discuss the states and nature of matter and the various forms of energy.

1.1 Matter

Matter is *anything that has mass and occupies space.* Our entire universe is composed of matter. Familiar examples include wood, glass, paper, sugar, and air.

a. Mass and Weight

Mass is *a measure of the amount of matter.* The mass of a body is a fixed property of that body. It is *constant* everywhere, independent of other objects. The mass of a sample of moon rock is the same on the moon, in space, or at any altitude on the earth's surface. Mass is the property that gives matter the tendency to stay at rest when already at rest or to stay in motion when already in motion. Thus, riding on an express elevator as it begins its downward motion, one finds his body wanting to stay at rest. On the other hand, when the elevator suddenly stops descending, his body wants to continue in motion and to travel through the floor of the elevator.

Weight is *a measure of the pull of gravity on an object.* The magnitude of the gravitational pull is directly proportional to the mass of the object and the mass of the attracting body (usually the earth). Thus, the weight or pull of gravity on a moon rock is less the smaller the mass of the moon rock. Likewise, the weight of a given moon rock determined on the moon is smaller than the weight of the same moon rock determined in your laboratory because the less massive moon exerts less gravitational force on the rock than does our more massive earth. Moreover, the gravitational pull is inversely proportional to the distance between the centers of the attracting bodies; that is, the gravitational pull is larger when the bodies are closer together and is smaller when the bodies are farther apart. Thus, the gravitational pull and the weight vary depending upon where the measurement is made. The weight of the moon rock is smaller when determined at a higher altitude on earth or when determined eighty miles out in space than when determined in your laboratory. The distinction between mass and weight may be understood in terms of an astronaut in space. The astronaut is weightless whenever he is so far away from the earth or other planetary bodies as to be unaffected by their force of gravity, but the astronaut is never massless since mass is constant everywhere.

Mass and weight can be distinguished by the method of their determination. The mass of an object is determined by balancing it against standard masses, as shown in Figure 1.1a. The chemical balances in your laboratory (common types shown in Figure 1.1c and 1.1d) use this principle. By convention the mass of an object equals the weight of the same object only at sea level on the earth. The weight of an object is frequently determined by means of a spring balance (shown in Figure 1.1b). No standard masses are involved and the weight will depend only on the force of gravity at the point of measurement. Bathroom scales and grocer's scales use this principle. Unfortunately, determining mass and determining weight are both commonly called weighing.

You should recognize the difference between mass and weight and realize that you are using mass in laboratory experiments and calculations when you compare *amounts of matter.* Many texts use mass and weight interchangeably, but this one will try to use them correctly. In fact, mass will be the appropriate term in almost all cases in this book.

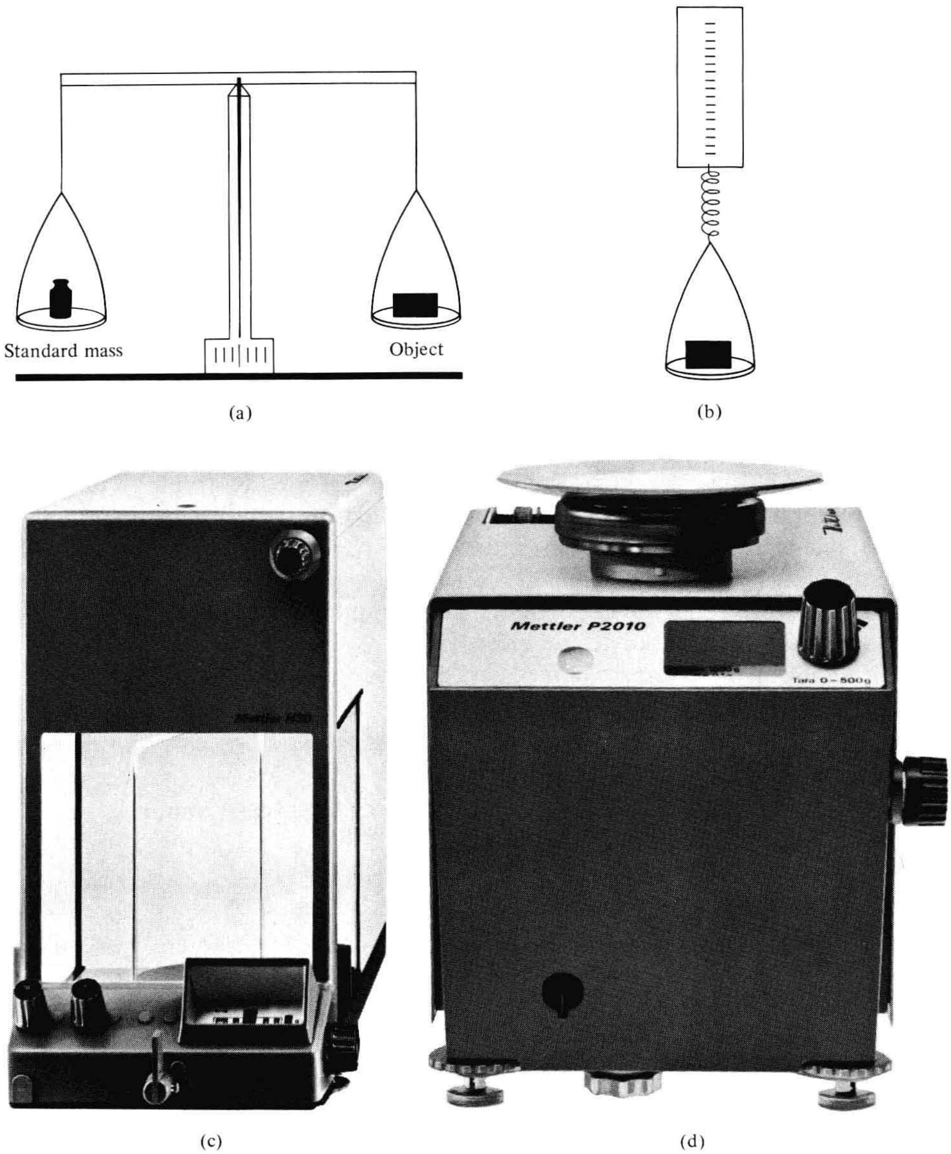

Figure 1.1 Devices for weighing. (a) Chemical balance for determining mass; (b) spring balance for determining weight; (c) single pan analytical balance; (d) top loading chemical balance. [Photos courtesy of Mettler Instrument Corporation, Princeton, N.J.]

b. States of Matter

The three states of matter—solid, liquid, and gas—have physical characteristics that are detectable by the human senses. Solids and liquids can usually be identified by sight and touch. A piece of iron has a definite shape and is hard, whereas liquid water takes the shape of its container and is soft