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chemistry

the central science

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to those from whom we have learned,
and to our wives and children

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preface

The preface is almost always the last part of a textbook to be written. Only when the book has assumed its final form can an author declare to the reader what he thinks he has accomplished. Thus, what is for students the beginning is, in one sense, for authors the culmination of a long, sometimes difficult journey. We have been at work on this book for more than 3 years. We have written, revised, and then revised again; we have put in, taken out, moved around; we have talked with our colleagues, with our students, and with our editors; we have studied industrial literature; we have spent time in libraries and in our laboratories. And while all this activity was taking place, we asked ourselves over and over again the same question: What is it that you as students need and should receive from the text you use in your study of chemistry? We believe that we have found some valuable new answers to that question, and in this preface we want to tell you (and your instructor) about these answers and about the ideas and concepts that have informed our writing of the text. We also want to tell you how we think you can best make use of this book.

Most of you are studying chemistry because it has been declared an essential part of the curriculum in which you are enrolled. That curriculum may be agriculture, dental hygiene, electrical engineering, geology, microbiology, metallurgy, paleontology, or one of many other related areas of study. It is fair to ask why it is that so many diverse areas of study should all relate in an essential way to chemistry. The answer is that chemistry is, by its nature, the *central* science. In any area of human

activity that deals with some aspect of the material world, there must inevitably be a concern for the fundamental character of the materials involved—their endurance, their interactions with other materials, their changes under a given set of conditions. This is true whether the materials involved are the rocks beneath our feet, the colors used by a Renaissance painter, or the blood cells of a child born with sickle-cell anemia. It is very likely that chemistry plays an important role in the profession to which you now aspire, or may decide later to pursue. You will be a better professional, a more creative and knowledgeable person, if you understand the chemical concepts applicable to your work and are able to apply these concepts as needed.

The relationship of chemistry to professional goals is important, and this factor provides reason enough for you to study chemistry. There is, however, an even more important reason. Because chemistry is so central and so intimately involved in almost every aspect of our contact with the material world, this science is an integral part of our culture. The involvement of chemistry in our lives goes much deeper than the well-known advertising slogan, "Better things for better living through chemistry." In addition to all the obvious ways in which we use the products of chemical research and production—plastic bags, children's toys, counter tops, weed and insect killers, photographic films—we indirectly use thousands of chemical products via the foods we eat, the cars we drive, the medical care we receive, and so forth. During the past several years, we have become increasingly aware that our use of chemicals has had a profound and frightening effect on our environment. Indeed, many scientists are convinced that we have so intensely polluted this planet and so unthinkingly sowed the seeds of future pollution that the fate of civilization is all but sealed. Whether this is so remains to be seen; however, if you are to be a responsible citizen, you will surely need to be informed on many complex issues involving chemistry and the use of chemicals. Because vested interests have a powerful stake in public policy, the public often is presented with conflicting information and claims. You can more fully appreciate and analyze the complex issues put before you if you understand the fundamental principles involved and keep them in mind during your reading and study.

With all of these considerations in mind, you should now be impatient and eager to begin your study of chemistry. Now that you are ready to go, we should say something about how this book can best help you. You might first take a few minutes to glance through the table of contents. The particular sequence of chapters that we have chosen is one that we feel promotes a natural unfolding of the science of chemistry. However, the order in which the chapters of the book are covered in the classroom will be determined by your instructor. You should not be disturbed if the order is not the same as the order in the book. The book has been written so as to make allowance for alternative chapter orders and, in some instances, for the complete omission of certain chapters. Notice that several chapters interspersed throughout the book deal with the chemical aspects of the world in which we live; the air, the earth, and the waters on the earth's surface. In these chapters we have attempted to connect the chemical facts and principles introduced in other, usually

earlier, chapters to the familiar (and sometimes not so familiar) aspects of our surroundings on earth. Your instructor, the person who will guide you through this book, may not feel that there is sufficient time to cover some or all of the materials in these chapters. We suggest that you read them anyway; they will help you appreciate the many ways in which chemical concepts and observations are related to contemporary life.

If you should at some point encounter a term or concept you are expected to know but can't remember, use the index at the back of the book. A good index is a rarity; we have worked hard to make your index in this book as complete and accurate as possible. Use it often. (Remember the index also when you later use the book as a reference, after having finished the course. It can help you find what you want more quickly than any other means.)

The difficulties that many chemistry students experience often can be traced to faulty exposition and confusing explanations in their text. This book has been worked on very thoroughly by many people to ensure that it is as clear, concise, and free of confusion as possible. However, you may find that a single reading of a chapter will not suffice if you are to use the book effectively as a learning tool. We suggest that you read every assigned chapter as early as possible, preferably before the material is covered in lecture. This will make you aware of important concepts and terms even before they are treated by the lecturer. Later, you will need to go through the assigned sections of the book much more carefully, making sure that you understand the new terms and problems put before you. We have inserted a great many *sample exercises* into the text, so that you might have clearly worked out examples of problem solving of various types. You should study these exercises carefully, noting every aspect of them, especially if numerical problem solving is involved.

The review section at the end of each chapter is an integrated package designed to help you determine whether you have in fact learned all the material assigned you in each chapter. The *summary* points out the highlights of the chapter; sometimes we say things a little differently in the summary in order to add an extra element of understanding to what you have gotten from the chapter itself. The *key terms* that you should know are also collected for your convenience. The *learning goals* are placed at the end of the chapter to enable you to test yourself. You should make sure that you can meet each learning goal. This can best be done if you state a definition and then check it, write a formula and then check it, or solve a problem and then check it. It may happen, of course, that your instructor will not have covered part of the material in a chapter. You can then skip over the learning goals for this material, but you should still read the complete summary and learn all of the key terms. By learning even nonrequired terms and concepts you can expand your chemical vocabulary with little effort.

The *exercises* at the back of each chapter are designed to test your understanding of the materials covered in the chapter. They are grouped according to topic, except for a number of general exercises. The purpose of the general exercises is to test your ability to solve a problem when it is not clearly identified as to topic. Also, some of the questions in this category require the application of material from more than one topic

area. Problems marked with brackets are, in general, a little more difficult to solve than the others. We have prepared a solutions manual that contains detailed answers to all the end-of-chapter exercises; you should consult this manual only after working out problems on your own.

Finally, you should note that there are several appendices following Chapter 25. These are designed to aid you in various ways. You should get acquainted with what is there by glancing through them before the course gets under way. In particular, note that answers are provided to many of the end-of-chapter exercises. Color question numbers in the text indicate that the answer to the question is in Appendix F.

Your instructor may have elected to have you purchase the *Student's Guide* designed for use with the text. This guide, written by Professor James C. Hill, of California State University, Sacramento, is a nicely organized and well-written supplement to the text. You will find it filled with helpful ideas, problem-solving techniques, and fresh insights into the materials presented in the text. We are very happy that Jim has agreed to write the study guide; we feel that it is valuable learning aid for use with the text.

Most general chemistry courses involve laboratory as well as classroom work. There is a very good reason for this. Chemistry is an experimental science; the entire theoretical structure of chemistry is based on the results of laboratory experiments. As you study chemistry, you should try to relate what you learn in the classroom and from the text to operations and observations made in the course of your laboratory work. A very fine laboratory manual for use with this text has been written by Professors John H. Nelson and Kenneth C. Kemp of the Department of Chemistry, University of Nevada, Reno. We believe that it is also an important learning tool in your study of chemistry.

During the many years that we have been practicing chemists, we have found chemistry to be an exciting intellectual challenge and an extraordinarily rich and varied part of our human cultural heritage. We hope that all the hassles you must face regarding course grades will not keep you from sharing with us some of that enthusiasm and appreciation. We have, in effect, been engaged by your instructor to help you learn chemistry. We are confident that we've done that job well. In any case, we would appreciate your writing us, either to tell us of the book's shortcomings, so that we might do better, or of its virtues, so that we'll know where we have helped you most.

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contents

introduction: some basic concepts

1

Perhaps the only thing permanent about our world is change. All around us are numerous examples of change in ourselves and our environment. Trees change color in autumn, iron rusts, snow melts, paint peels, seeds become flowers, and logs burn. We grow up, we grow old. Living plants and animals undergo continual change, and even dead plants and animals continue to change as they decay. Such changes have long fascinated people and have prompted them to look more closely at nature's working in hopes of better understanding themselves and their environment.

Understanding change is closely tied to understanding the nature and composition of **matter.** Matter is the physical material of the universe; it is anything that occupies space and has mass. Chemistry is the science that is primarily concerned with matter and the changes that it undergoes. Therefore, as we begin our study of chemistry, our primary focus will be on matter. First, however, let's sketch a somewhat broader picture of chemistry.

Chemistry is a changing science. Therefore, the questions that chemists seek to answer are constantly changing also. Because of this, we might define chemistry as what chemists do. In many regards this definition is unsatisfactory. Nevertheless, it does suggest that chemistry itself changes as chemists absorb new information from other fields, tackle new problems, or reexamine old ones in new ways. One of the important activities of chemists is the synthesis of new materials or the improvement in the ways of making old ones. This aspect of chemistry has had great impact on our lives; chemists have synthesized new fibers,

medicines, fertilizers, pesticides, and structural materials. Many new chemicals never find any commercial use but are nevertheless important to chemists in answering subtle questions about matter and its changes. In designing ways to synthesize new materials, it is useful to know the factors that determine how fast and to what extent the required changes proceed. Such knowledge allows chemists to improve, avoid, or control many changes of matter. This knowledge is necessary, for example, in devising ways to clean up automobile exhaust or to make fertilizers at lower cost. Chemists are also interested in determining the identity and concentration of substances. Such analysis may involve determining the quality of a soap in a manufacturing operation, the concentration of a pollutant in the air, the amount of gold in a potential ore, the amount of mercury in a lake,the identity of the substances in some physiologically active mixture, or the chemicals resulting from the utilization of a drug in the body. Chemists are interested not only in determining what things are made of, but also in discovering the ways their composition and structure are related to properties. For example, what makes a particular substance poisonous or sweet or hard or explosive?

The intent of this text is to introduce you to basic chemical facts and theories, not as ends in themselves, but as means to help you understand the material world and to recognize the constraints and opportunities it provides. We hope that this text will provide not only a firm foundation for further scientific studies, whether they be in chemistry or some other field, but also a background to enable you to evaluate scientific information found in news media and semiscientific periodicals. In the remainder of this chapter we shall consider some background material useful to your studies—the metric system, uncertainty in measurement, and problem solving in chemistry. We shall also briefly explore the historical and philosophical background of chemistry and the scientific approach to problems.

1.1 the emergence of chemistry: a historical perspective

Chemistry has two roots. First, it is rooted in the craft traditions such as metallurgy, brewing, tanning, and dyeing, which provided a practical understanding of how matter behaves. Second, it can also be traced to the philosophers of ancient Greece who concerned themselves with questions of the basic nature of matter. Through the years the growth of chemistry has reflected both man's desire to solve problems and his innate curiosity and desire to understand his surroundings without regard to the practical application of that understanding.

Metallurgy, the science and art of obtaining and working with metals, exemplifies the development of chemical knowledge through the craft traditions. This craft developed for many years and achieved considerable sophistication without any theoretical framework that would explain metallurgical operations and guide their development. Developments were made largely through trial and error and through accidental discoveries. For the most part, the early pattern of discovery of metals followed their ease of recovery from ores, the earthy mixtures that are mined as sources of metals. Gold was one of the first metals used because it is found in nature in an uncombined, metallic state, for