FOURTH EDITION

BASIC CONCEPTS OF CHEMISTRY

LEO J. MALONE

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PREFACE

Basic Concepts of Chemistry began life in 1981 as a text directed at students in a preparatory chemistry course. That is, it was intended for those planning to proceed to a main-sequence chemistry course, but who had little or no background in chemistry or who had a significant interruption of their studies. The acceptance of previous editions, however, indicates that this text has served a much broader mission. In addition to preparatory chemistry, it has found extensive use in one-semester, general-purpose courses. Such courses usually include a mix of students. For some of these students, it is a prelude to a main-sequence course; for others, a semester of organic-biochemistry may follow to satisfy allied health professions requirements. Still others are there to satisfy a science requirement. The Fourth Edition has been rewritten with this broader appeal in mind. Yet this text continues to emphasize the quantitative nature of real chemistry. Thus it will continue to satisfy the needs of those intending to continue on in chemistry and other sciences.

In preparing the Fourth Edition, the author and publisher obtained considerable input about how chemistry should be presented and what is needed by instructors at this level. As a result of our research, we have built on the strengths of previous editions to present what may be described as a "learning text." It is meant to be of maximum aid to the many dedicated teachers who believe that chemistry is a fascinating subject that serves as the basis of all sciences and technologies as well as to their students who have little or no background in chemistry.

We set out to accomplish three major goals with the Fourth Edition. They have been addressed by incorporating successful features of previous editions along with new, innovative approaches used for the first time in this edition. A discussion of these goals follows.

GOALS AND FEATURES OF THE FOURTH EDITION

To accomplish the goals of the Fourth Edition, the successful features of previous editions have been enhanced with some innovative pedagogical elements. Called "navigational devices," these learning aids are highlighted by marginal notations to help guide students in understanding basic chemical concepts.

Goal I. To introduce chemistry as a live, relevant science.

Presenting subject matter in a clear and readable style and a logical, smoothly flowing sequence helps achieve this goal.

- *A Friendly, Nonintimidating Writing Style.* The discussions in this text take nothing for granted. It is assumed that this is the first contact the students will have had with almost all concepts; thus a careful discussion is required. This edition continues and expands on the use of simple, understandable analogies that relate abstract concepts to concrete models. For example, in Chapter 5 the placement of electrons in orbitals is compared to the placement of students in dorm rooms. When possible, current topics of interest are used as examples. A case in point is found in Chapter 14 where chlorine is used as an example of a catalyst in a reaction that destroys ozone.

- *A Logical Sequence of Topics.* The sequence of chapters in the text allows a logical step-by-step development of the science. There have been some significant modifications in this edition. The new prologue covers scientific method and the study of chemistry. Chapter 1 proceeds directly to the measurements used in chemistry so that Chapters 2, 3, and 4 follow each other smoothly. An introduction to the periodic table and chemical nomenclature has been combined and moved forward to an earlier chapter (Chapter 4). Many have suggested that students benefit from an early introduction to the language of chemistry. After this chapter, two paths of development of chemistry are equally logical. Chapters on electron structure (Chapter 5) and bonding (Chapter 6) come first, followed by a comprehensive review of Chapters 4–6. However, if instructors prefer, they can proceed from Chapter 4 directly to the two quantitative chapters (Chapter 7 on the mole and Chapter 8 on equations and stoichiometry) followed by a comprehensive review of Chapters 4, 7, and 8. There is no mention of the content of Chapters 7 and 8 in Chapters 5 and 6, so either sequence works well. Another change involves moving nuclear chemistry to later in the book: Chapter 15. However, it can still be covered immediately after Chapter 3, if so desired.

- *Smooth Transitions Between Topics.* Sometimes, one hears the complaint that chemistry is difficult to learn because it is a collection of unrelated facts and concepts. In this edition, we have addressed that concern in two ways. First, each chapter begins with an improved introductory section, labeled as **Setting the Stage**, that sets up the purpose of the chapter by reference to current concerns—such as the greenhouse effect (Chapter 6), or the relevance of the supernova of 1987 (Chapter 3), or the nature of lightning (Chapter 13). Within the chapters, we have made a major effort to smooth the flow between topics by connecting each section to the next. A brief paragraph (labeled in the margin as **Looking Ahead**) lets the student know what comes next, why, and how it relates to the topic just covered.

- *The Use of Color.* Chemistry is indeed a colorful science and its use helps bring the subject to life. The colorful elements, minerals, and chemical reactions can now be shown as they actually appear. Relevant chemicals and chemical reactions are emphasized rather than pictures of chemical companies and manufacturing processes. Color is also used extensively in the illustrations, which adds to their appeal.

Goal II. To encourage not only learning but critical thinking.

Some effective ways of learning chemistry are by summarizing and recitation, critical questioning, and working problems.

- *Frequent Summarizing and Recitation.* The learning of chemistry requires reflection. This edition includes short summaries of two or three closely related sections within each chapter (labeled in the margin as **Looking Back**). The object is to encourage the student to pause, reflect, and mentally gather in the main points before proceeding to recitation and problem reinforcement. As in previous editions, the chapter concludes with a review that summarizes the whole chapter and is labeled in the margin as **Putting It Together**. This summary is often presented in a unique way by use of tables, diagrams, or flow charts. Key terms defined in the chapter are now used in the context of a discussion and are shown in bold type. In addition, a complete Glossary of Terms appears in Appendix G for easy reference.

  After the paragraph labeled **Looking Back**, a section called *Learning Check* follows—which is referred to in the margin as **Checking It Out**. The first part of the *Learning Check* summarizes recent topics with key words left out. By filling in the blanks, the student aids learning by recitation.

- *Critical Questioning.* The introductory section (**Setting the Stage**) ends with a series of questions that are to be addressed in the chapter that follows. These questions are labeled in the margin as **Formulating Some Questions**. In addition, other questions in the margins encourage critical thinking about the topic being discussed. Not just simple questions—such as "What is Charles's law?" that obviously is answered in the text—these questions are more thought-provoking. For example: "What keeps a hot-air balloon suspended in the air?" and "Why doesn't a water bug sink?" and "How do our bodies keep cool?"

- *Working Problems.* Real chemistry requires problem-solving skills. This text helps develop these skills in four steps.

  1. Example problems (labeled **Working It Out**) are carefully worked out in an easy-to-follow manner. Each step in a solution is explained or diagrammed. Most problems have a section labeled *Procedure* in which a strategy is outlined and a *Solution* where the strategy is carried out. Example problems have descriptive headings in this edition.
  2. Shortly after presentation of an example problem, the concept is reinforced with similar problems provided in the *Learning Check*. Worked-out answers to these problems in the *Learning Check* are

provided at the end of the chapter for easy reference. A few simple chapter-end problems are referenced in the *Learning Check* for additional practice.

3. Numerous chapter-end problems are listed by topic and range from the simplest to more complex applications. The hardest are indicated by an asterisk. Many new problems that illustrate practical applications of a concept have been added to this edition. About 60 percent of the answers are provided in Appendix H. Many of the quantitative problems also include worked-out solutions.

   In addition to the chapter-end problems that support a specific topic or concept, this edition includes a section of uncategorized problems titled *General Questions* where students must decide for themselves which concepts are being tested. Concepts from previous chapters may also be needed for these more challenging problems. Many of these problems require the application of several concepts.

4. *Comprehensive Review Tests* are available that integrate the content of three relevant chapters. These tests are found after Chapters 3, 6, 8, 11, and 14. They include multiple-choice questions that help test the material learned in recitation.

Goal III. To understand and provide help with the math anxieties that can distract students of chemistry.

The greatest fear of many of the students taking chemistry for the first time is the math involved. This text has been and remains sympathetic and encouraging to those students. It is understood that many, if not most, students require some preparation or review of mathematical concepts used in introductory chemistry. Extensive end-of-book appendixes (A–F) supplement Chapter 1 on measurements. These appendixes provide not only discussion but worked-out examples and sample problems (with answers provided) in the areas of basic arithmetic, algebra, and scientific notation. In addition, there are separate appendixes on logarithms, graphs, and calculators. These also provide sample problems to test one's understanding. Students have used these appendixes extensively, and they have helped reduce what can become an exaggerated fear of the math involved in this discipline. An acknowledgment of this difficulty and the extensive help provided are unique to this text.

Major efforts have been made throughout the book to ensure the needed math is meaningful. For example, the use of percent is illustrated in some problems concerning the composition of alloys in Chapter 2. Conversion factors between the metric and English systems are illustrated early in Chapter 1. In these and other cases the reviews in the appendixes are referred to in the margin.

SUPPLEMENTS

- *Study Guide/Solutions Manual* is available to accompany this text. In the Study Guide, related sections within a chapter that correspond to a *Learning Check* have been grouped for review, discussion, and testing. In this manner, the Study Guide can be put to use before the chapter is completed. Topics of current interest are included in the Study Guide, such as the demise of the dinosaurs, the greenhouse effect, and the reason for the "ozone hole." Selected solutions to text problems are also included in this edition. These solutions are to the quantitative problems that have answers but no solutions in the text.
- *Instructor's Manual,* by Leo J. Malone, St. Louis University, includes chapter objectives, teaching hints, and solutions to all text problems.
- *Transparencies.* 110 full-color figures from text, resized and edited for classroom use.
- *Test Bank,* by Stanley Grenda, University of Nevada, Las Vegas, contains approximately 1,000 test items consisting of multiple-choice, short answer, and critical thinking questions. These questions are also available as a computerized test bank.
- *Experiments in Basic Chemistry,* by Steven Murov and Brian Stedjee, Modesto Junior College, contains 26 experiments that parallel text organization and provides learning objectives, discussion sections outlining each experiment, easy-to-follow procedures, post-lab questions, additional exercises, and answers to pre-lab questions.
- *Instructor's Manual for Experiments in Basic Chemistry,* written by the lab manual authors, this instructor's manual contains answers to post-lab questions, list of chemicals needed, suggestions for other experiments, as well as suggestions for experiment set-ups.

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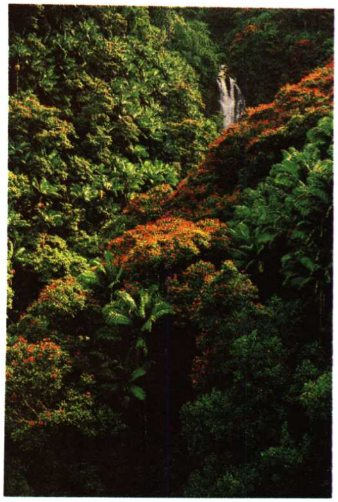

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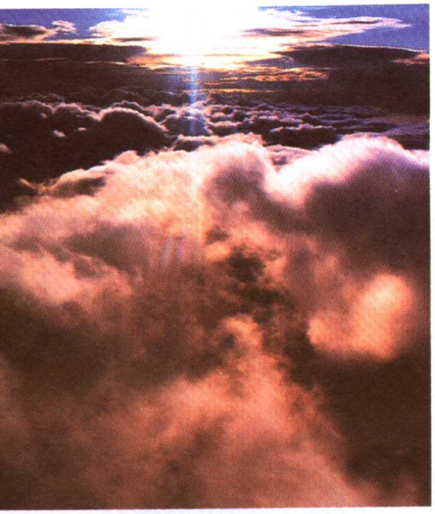

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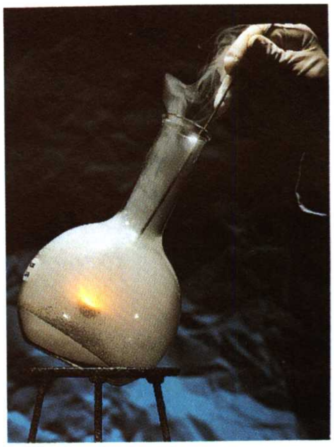

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PROLOGUE

INTRODUCTION TO THE STUDY OF CHEMISTRY

A. THE MYSTERY OF FIRE

Fire—the powerful and mystical force of nature! Out of control, it causes destruction, pain, and even death. For these reasons, we fear it. Under control, however, it heats our homes, cooks our meals, and transforms ores into metals. For these reasons, we welcome it. It is easy to understand how this awesome force was the source of so much mystery and speculation throughout the ages. For example, in Greek mythology there existed a god named Prometheus. He supposedly gave animals the special tools they needed to survive in a hostile world. Humans received the gift of fire. Legend has it that Prometheus went too far because this was a tool reserved for the gods themselves. As might be expected, the other gods proceeded to punish him for his unacceptable generosity.

Evidence indicates that fire has been used by humans for at least four hundred thousand years. It is difficult to imagine how our ancient ancestors could have managed without it. Humans do not have sharp night vision like raccoons, but fire brought light to the long, dark night. We have no protective fur like the deer, but fire lessened the chill of winter. We do not have sharp teeth or powerful jaws like the lion, but fire rendered meat tender. Humans are not as strong or as powerful as the other large animals, but fire repels even the most ferocious of beasts. It seems reasonable to suggest that the taming of fire was one of the most monumental events in the history of the human race. The use of fire made our species dominant over all others. It is truly the tool of the gods.

Let's fast-forward in time to near the end of the Stone Age, about ten thousand years ago. In the Stone Age, weapons and utensils were fashioned from rocks and a few chunks of native copper metal that were found in nature. Copper was superior to stone because it could easily be shaped into fine points and sharp blades by pounding. Unfortunately, native copper was quite rare. But about seven thousand years ago this changed. Anthropologists speculate that some resident of ancient Persia found copper metal in the ashes of a hot charcoal fire. The free copper had not been there before so it must have come from a green stone called malachite (see Figure P-1), which probably lined the fire pit.

Figure P-1
Malachite. Malachite is a copper ore.

Imagine the commotion that this discovery must have caused. A stone could be transformed by hot coals into a valuable metal! Fire was the key that launched the human population into the age of metals. The recovery of metals from their ores is now a branch of chemical science called *metallurgy*. The ancient Persians must have considered this discovery a dramatic example of the magic of fire.

Other civilizations used chemistry in various ways. About 3000 B.C., the Egyptians learned how to dye cloth and embalm their dead through the use of certain chemicals found in nature. They were very good at what they did. In fact, we can still determine from ancient mummies the cause of death and even diseases the person may have had. The Egyptians were good chemists, but they had no idea why any of these procedures worked. Every chemical process they used was discovered by accident.

Around 400 B.C., while the more mystical Greeks were speculating about their various gods, philosophers were trying to understand and describe nature. These great thinkers argued about why things occurred in the world around them, but they were not inclined (or able) to check out their ideas by experimentation or to put them to practical use. At the time, however, people believed that there were four basic elements of nature—earth, air, water, and fire. Of these, fire was obviously the most mysterious. It was the transforming element; that is, it had the capacity to change one substance into another (e.g., certain rocks into metals). We now call such transformations chemical reactions. Fire itself is simply the hot, glowing gases associated with certain chemical reactions. If fire is a result of an ongoing chemical transformation, then it is reasonable to suggest that chemistry and many significant advances in the human race are very much related.

The early centuries of the Middle Ages (A.D. 500–1600) are usually referred to as the Dark Ages in Europe because of the lack of art and literature and the decline of central governments. In fact, the civilizations that Egypt, Greece, and Rome had previously built disappeared. Chemistry, however, began to grow during this period, especially in the area of experimentation. Chemistry was considered a combination of magic and art rather than a science. Many of those who practiced chemistry in Europe were known as *alchemists*. Some of these alchemists were simply con artists who tried to convince greedy kings that they could transform cheaper metals such as lead and zinc into gold. Gold was thought to be the perfect metal. Such a task was impossible, of course, so many of these alchemists met a drastic fate for their lack of success. However, all was not lost. Many important laboratory procedures such as distillation and crystallization were discovered. Alchemists also prepared many previously unknown chemicals, which we now know as elements and compounds.

Modern chemistry has its foundation in the late 1700s when the use of the analytical balance became widespread. Chemistry then became a quantitative science in which theories had to be correlated with the results of direct laboratory experimentation. From these experiments and observations came the modern atomic theory, first proposed by John Dalton around 1803. This theory, in a slightly modified form, is still the