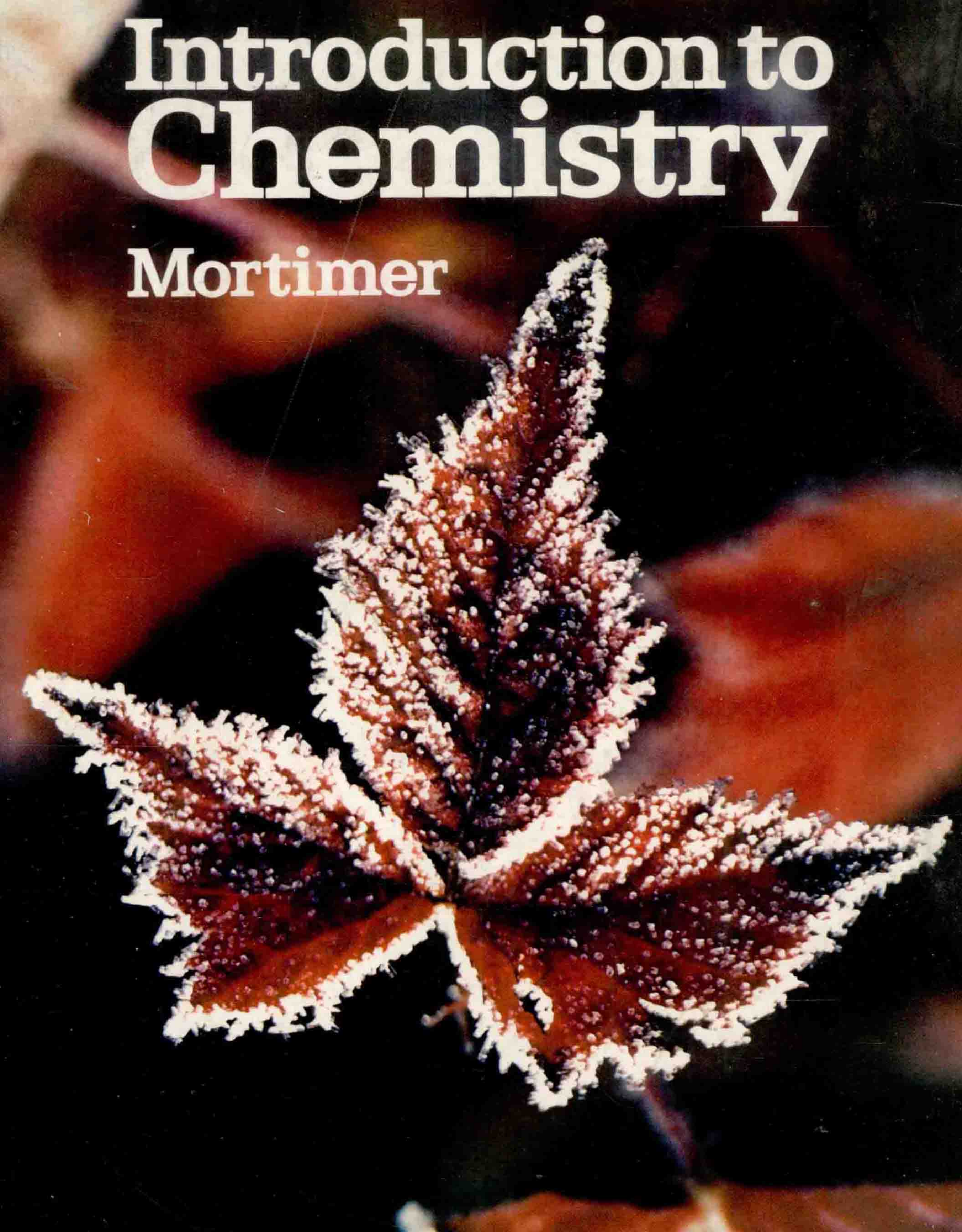
Introduction to Chemistry

Mortimer



Introduction to Chemistry

Charles E. Mortimer
Muhlenberg College

D. VAN NOSTRAND COMPANY
New York Cincinnati Toronto London Melbourne

TO L.R.M. AND E.H.M.

D. Van Nostrand Company Regional Offices:
New York Cincinnati

D. Van Nostrand Company International Offices:
London Toronto Melbourne

Library of Congress Catalog Card Number: 76-58670
ISBN: 0-442-25569-1

Published by D. Van Nostrand Company
450 West 33rd Street, New York, N.Y. 10001

10 9 8 7 6 5 4 3 2 1

Preface

Designing an introductory chemistry course for college students is difficult. The subject is large and growing. Today's students have widely different interests, academic backgrounds, and abilities. The course must take into account the requirements of diverse career objectives. A text should help instructors respond to their particular problems. INTRODUCTION TO CHEMISTRY was written as an alternative to *CHEMISTRY: A CONCEPTUAL APPROACH* and in response to some instructors' suggestions as to how their needs could be met, especially in the organization of topics.

The beginning chapters offer a gradual introduction to the subject. Atomic structure and chemical bonding, which some students find abstract and difficult, are postponed until the students are better able to handle them. The principles of stoichiometry, which are central to an understanding of all chemical concepts, are introduced in Chapter 2. The early introduction of this topic permits it to be expanded and reinforced throughout the entire course. The basic principles of thermochemistry, which also are of fundamental importance, are introduced in Chapter 3. The early and systematic discussion of thermochemistry prepares the way for the use of energy concepts (such as lattice energy, ionization energy, and bond energy) in the development of later topics that focus in other directions. The topical order of INTRODUCTION TO CHEMISTRY should facilitate the design of a good laboratory program closely correlated to classroom work.

At the same time, the format of this book is intended to permit relatively wide latitude in course organization. Instructors should not feel constrained to present all the material in this book in the exact order in which it is given.

In recent years, the career goals as well as the mathematical and scientific backgrounds of students who enroll in introductory chemistry have become more diverse than ever. Instructors, therefore, can assume no uniform level of attainment on the part of entering students. In INTRODUCTION TO CHEMISTRY, each concept is developed slowly and thoroughly in a way that should make it understandable to a student who has had no prior exposure to chemistry. Important terms are set in boldface type the first time they are used. Numerous problems are solved as examples. Step-by-step directions for the solution of basic types of problems are set off in boxes. Students will find this boxed material useful for initial assignments and also for reference in later work. The use of calculus is avoided.

Approximately one thousand chapter-end problems of varying difficulty are included. Similar problems are grouped together, and the problems of a chapter are arranged in the order in which the topics are discussed in that chapter. Answers to selected numerical problems are given in Appendix G. A *Solutions Manual* containing worked-out solutions for mathematical problems and an *Answer Booklet* containing answers only are available. The *Student Self-Study Guide,* by Michaeleen P. Lee, is keyed to the text and designed to be used independently by students.

Historical anecdotes appear throughout the text to enliven the material. They illustrate that chemistry is a human endeavor, that the science grows and changes, that creative imagination plays a role in the development of chemical thought, and that a full understanding of any phenomenon is never obtained—truth is only approached.

The growing acceptance of the International System of Units (SI) makes it important that students be introduced to this official metric system. With the exception of the United States, all the major industrial powers of the world have adopted SI units exclusively. In the interest of world-wide scientific communication and international trade, sooner or later the United States must convert. Many scientific groups and agencies (including the National Bureau of Standards) have recommended or officially adopted SI units. Some upper level chemistry and physics books use the units and the secondary schools of some states have begun to use SI units.

The rules for the use of the International System appear in *Le Système International d'Unités,* published by the International Bureau of Weights and Measures, which is available in an English translation prepared jointly by the National Bureau of Standards, of the United States, and the National Physical Laboratory, of the United Kingdom.* In INTRODUCTION TO CHEMISTRY, the joule, rather than the calorie is used for energy measurements. The ångstrom unit is not employed. Nanometers ($1\ nm = 10^{-9}\ m$) are used in place of ångstrom units for the wavelengths of spectral lines (4500 Å = 450 nm), and picometers ($1\ pm = 10^{-12}\ m$) are used for bond distances (1.98 Å = 198 pm). The standard atmosphere, which may be used with SI units for the present, is employed instead of the pascal, which is the SI unit of pressure. Since the International Committee of Weights and Measures considers it preferable to avoid the use of the torr, this unit is not employed to express the results of pressure measurements.

I sincerely thank the following for their suggestions and comments: David Herlocker, Western Maryland College, George B. Kauffman, California State University, Fresno, Michaeleen P. Lee, Bucks County Community College, Karl Marhenke, Cabrillo College, and Louise S. Shive, Muhlenberg College.

Suggestions for the improvement of this book will be welcomed.

Charles E. Mortimer

*Page, Chester H., and Vigoureux, Paul, ed. *The International System of Units (SI)*, National Bureau of Standards Special Publication 330, U.S. Government Printing Office, Washington, D.C. (1972).

Contents

Chapter 1

Introduction

Until the early years of the nineteenth century, the tendency to specialize in a particular branch of the sciences was not strong. Scientists commonly followed their interests no matter where they led. John Dalton (1766–1844) is best known for his atomic theory. But the scientific interests of Dalton ranged widely and included topics in botany, meteorology, chemistry, physiology, and physics.

As scientific knowledge grew, scientific specialization increased. In the first half of the nineteenth century, such specialization became the norm. Some older scientists resisted the change. Michael Faraday (1791–1867), whose major accomplishments are in the chemistry of electrolysis and the physics of electricity and magnetism, refused to be called a physicist, a chemist, or any other kind of -ist; he regarded himself as a natural philosopher.

By the beginning of the twentieth century, science had become highly organized. The interests of the various branches of science, however, frequently overlap. Ernest Rutherford (1871–1937), who is noted for his investigations into the nature of radioactive decay and the nuclear structure of the atom, considered himself to be a physicist. Rutherford, a man with a keen sense of humor, once wrote to a chemist friend that the authors of some articles that were critical of Rutherford's work were "damned fools, whom I think must once have been chemists."

In 1908, Rutherford, who was then a professor of physics at the University of Manchester, was awarded a Nobel prize. The prize was awarded, however, in chemistry, not physics! When the awards were presented, a banquet was given in Stockholm in honor of the prize winners. At the banquet, Rutherford made a speech in which he said that he had observed many transformations in his scientific work, but not one was as rapid as his own transformation from physicist to chemist.

The boundaries of the various branches of science are indistinct. The interests of the branches coincide at times, and they share common scientific concepts and methods. A precise definition of chemistry, therefore, is impossible.

Nevertheless, there is a common, if somewhat vague, understanding of what chemistry includes. **Chemistry** is usually defined as the science that deals with the composition, properties, and transformations of matter. Since matter is anything that occupies space and has mass, the scope of chemistry is enormous. This book should provide an introduction to chemistry and its unifying principles.

1.1 THE DEVELOPMENT OF MODERN CHEMISTRY

Modern chemistry, which emerged late in the eighteenth century, took hundreds of years to develop. The story of its development can be divided roughly into five periods.

1. **Practical arts (--- to 600 BC)** The production of metals from ores, the manufacture of pottery, brewing, baking, and the preparation of medicines, dyes, and drugs are ancient arts. Archaeological evidence proves that the inhabitants of ancient Egypt and Mesopotamia were skilled in these crafts, but how and when they developed is not known.

   These arts, which are chemical processes, became highly developed during this period. The development, however, was *empirical,* that is, based on practical experience alone without reference to underlying chemical principles. The Egyptian craftsman knew how to obtain copper by heating malachite ore with charcoal. He did not know, nor did he seek to know, why his process worked and what actually occurred in the fire.

2. **Greek (600 BC to 300 BC)** The philosophical aspect (or theoretical aspect) of chemistry began in classical Greece about 600 BC. The foundation of Greek science was the search for principles through which an understanding of nature could be obtained. Two theories of the Greeks became very important in the centuries that followed.
   - **a.** A concept that all substances are composed of four elements (earth, air, fire, and water) in various proportions originated with Greek philosophers of this period.
   - **b.** A theory that matter consists of separate and distinct units called **atoms** was proposed by Leucippus in the fifth century BC.

   Plato proposed that the atoms of one element differ in shape from the atoms of another. Furthermore, he believed that atoms of one element could be changed (or **transmuted**) into atoms of another by changing the shape of the atoms.

   The concept of transmutation is also found in Aristotle's theories. Aristotle (who did not believe in the existence of atoms) proposed that the elements, and therefore all substances, are composed of the same primary matter and differ only in the forms that this primary matter assumes. To Aristotle, the form included not only the shape but also the qualities (such as color and hardness) that distinguish one substance from others. He proposed that changes in form constantly occur in nature and that all material things (animate and inanimate) grow and develop from immature forms to adult forms. (Throughout the middle ages, men believed that minerals could grow and that mines would be replenished after minerals were removed from them.)

3. **Alchemy (300 BC to 1650 AD)** The philosophical tradition of ancient Greece and the craft tradition of ancient Egypt met in Alexandria, Egypt (the city founded by Alexander the Great in 331 BC), and *alchemy* was the result of the union. The early alchemists used Egyptian techniques for the handling of materials to investigate theories concerned with the nature of matter. Books written in Alexandria (the oldest known works on chemical topics) contain diagrams of chemical apparatus and descriptions of many laboratory operations, for example, distillation, crystallization, and sublimation.

   The philosophical content of alchemy incorporated elements of astrology and mysticism into the theories of the earlier Greeks. A dominant interest of the alchemists was the transmutation of base metals, such as iron or lead, into the noble metal, gold. They believed that a metal could be changed by changing its qualities (notably its color) and that such changes occur in nature—that metals strive for the perfection represented by gold. Furthermore, the alchemists believed that these changes could be brought about by means of a very small