Principles of Chemistry

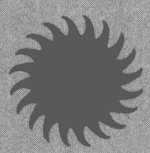
Davis, Gailey and Whitten

Principles of Chemistry

Raymond E. Davis
University of Texas, Austin

Kenneth D. Gailey
University of Georgia, Athens

Kenneth W. Whitten
University of Georgia, Athens



SAUNDERS COLLEGE PUBLISHING
Philadelphia New York Chicago
San Francisco Montreal Toronto
London Sydney Tokyo Mexico City
Rio de Janeiro Madrid

Address orders to:
383 Madison Avenue
New York, NY 10017

Address editorial correspondence to:
West Washington Square
Philadelphia, PA 19105

Text Typeface: Palatino
Compositor: Progressive Typographers
Acquisitions Editor: John Vondeling
Developmental Editor: Jay Freedman
Project Editors: Lynne Gery and Patrice L. Smith
Managing Editor & Art Director: Richard L. Moore
Art/Design Assistant: Virginia A. Bollard
Text Design: Caliber Design Planning, Inc.
Cover Design: Lawrence R. Didona
New Text Artwork: Philatek
Production Manager: Tim Frelick
Assistant Production Manager: Maureen Iannuzzi

Cover credit: Photomicrograph showing focal conic texture of a smectic A liquid crystal, by Alfred Saupe, Liquid Crystal Institute, Kent State University. Used with permission.

Library of Congress Cataloging in Publication Data

Davis, Raymond E., 1938–
Principles of chemistry.

Includes index.

1. Chemistry. I. Gailey, Kenneth D. II. Whitten, Kenneth W. III. Title.
QD31.2.D377 1984 540 83-19271
ISBN 0-03-060458-3

PRINCIPLES OF CHEMISTRY

ISBN 0-03-060458-3

Library of Congress catalog card number 83-19271.

4567 032 98765432

CBS COLLEGE PUBLISHING
Saunders College Publishing
Holt, Rinehart and Winston
The Dryden Press

Principles of Chemistry

Saunders College Publishing Complete Package for Teaching with Principles of Chemistry

by Davis, Gailey, and Whitten

Davis Study Guide to Accompany Principles of Chemistry
Lippincott, Meek, Gailey, & Whitten Experimental General Chemistry
Ragsdale Lecture Outline to Accompany Principles of Chemistry
DeKorte Solutions Manual to Accompany Principles of Chemistry
Whitten & Gailey Problem Solving in General Chemistry, 2nd edition
Davis Instructor's Manual to Accompany Principles of Chemistry
Davis, Gailey, & Whitten Overhead Transparencies
Davis, Gailey, & Whitten Test Bank
Wilkie Computer Tutorial for General Chemistry
Shakhashiri, Schreiner, & Meyer General Chemistry Audio-Tape Lessons, 2nd edition
Shakhashiri, Schreiner, & Meyer Workbook for General Chemistry Audio-Tape Lessons, 2nd edition

To: Sharon, Angela, Laura, and Brian Davis
Kathy, Kristen, and Karen Gailey
Betty, Andy, and Kathryn Whitten

To The Professor

As we surveyed the available principles textbooks in general chemistry, we concluded that there were major deficiencies in them. Some texts that claim to emphasize principles simply present theories "out of the blue." Students are thus deprived not only of the link to physical reality, which makes learning and using theories easier and more meaningful, but also of the basis for the intellectual integrity of science. None of these texts appeared to have been written for students, the people who use them most, and so we decided to write a principles textbook *for students.*

We emphasize that chemistry is an experimental science by always presenting first the observational bases upon which the theories depend, followed by descriptions of the classic experiments and their great importance to the evolution of modern chemical theories. We then emphasize the important role, and justify the validity, of modern theories by interpreting and explaining the significance of important observations as we develop each subsequent topic. To accomplish our goals, we have provided

1. The experimental basis for modern chemical theories.
2. Accurate statements of current theories.
3. Clear, concise definitions of important terms.
4. Simple, yet familiar, analogies that clarify fundamental ideas.
5. Carefully graded, detailed explanations of current theories and important concepts.
6. Numerous substantial illustrative examples that are solved and explained in detail.
7. Carefully graded, comprehensive sets of end-of-chapter exercises that progress from routine manipulations to a reasonable level of sophistication.
8. Plenty of descriptive chemistry to illustrate applications of modern theories.
9. Comprehensive appendices.
10. A great deal of flexibility for professors who teach general chemistry.

These important characteristics of *Principles of Chemistry* require amplification.

Because a clear understanding of modern chemical theories is vital to the study of chemistry, we have tried to state the essence of each theory as clearly and accurately as possible at this level. The significance of each theory is then emphasized and illustrated.

Many students experience difficulty in their study of general chemistry because they do not understand the vocabulary used to describe basic concepts. We have been careful to give clear, concise definitions of important terms *as they are introduced.* In the few cases in which this is not practical, we have included appropriate marginal notes.

Some students have difficulty in piecing together declarative statements in order to understand basic concepts. We have provided many simple, familiar analogies to improve students' comprehension. For example, the arbitrary nature of zero potential energy and the idea of negative potential energy in a chemical system are major obstacles for many students. We solve these problems by presenting a simple analogy in Figure 3–2. Many other examples are used throughout the textbook.

Many students have difficulty in gaining an appreciation of the significance of important theories and concepts. We have presented detailed *explanations* of current theories and concepts so that students can understand and appreciate their significance. Throughout we have provided *substantial* explanations.

Numerous carefully graded illustrative examples are invaluable to students, and so we have provided an abundance of them. We have included some simple examples, some of intermediate difficulty, as well as considerable numbers of *difficult* illustrative examples. For many topics, such as bonding and molecular structure, the illustrative examples are woven into the narrative and are not numbered.

Chemical reactions, and associated periodicity, are introduced early in Chapter 9 from a descriptive point of view. Chapter 10, "Chemical Analysis in Aqueous Solution," provides more descriptive chemistry as well as background for quantitative laboratory work.

Comprehensive appendices are included so that students have the data they need as they study and work problems. Professors have ready access to numerical data as they prepare lectures and construct tests and comprehensive examinations.

Flexibility is important because classes are so heterogeneous — some students have had no previous training in chemistry and others are well prepared. In Chapter 1, we start at a very basic level for students with no background in chemistry. Chapter 1 can be used as assigned reading for students with strong backgrounds.

Throughout the text each topic and its vocabulary are introduced at a very basic level, and through a series of carefully graded steps we progress to a reasonably sophisticated treatment of each topic. Some sections in each chapter (and, in fact, some chapters) may be used as assigned reading.

Basic stoichiometry is presented in Chapter 2, together with an introduction to concentrations of solutions and dilution calculations, to provide a firm foundation for meaningful laboratory experiences. We start at a very basic level, and our treatment of basic stoichiometry is the most comprehensive available. The mole method is used throughout.

In keeping with our philosophy of providing a sound background for laboratory work, we present thermochemistry, through Hess' Law, in Chapter 3. We have taken care to describe what energy is and how it is measured. The arbitrary nature of zero potential energy and negative potential energies in chemical systems are illustrated well.

Chapter 4, "Atoms and Subatomic Particles," provides descriptions of the classic experiments that led to our present ideas about the structures of atoms. Nuclear binding energy is included to avoid leaving a significant gap in background

information. Students learn why so many positively charged particles can occupy such a small volume in a stable atomic nucleus and still not "blow apart."

Electronic structures of atoms are presented in Chapter 5. Together, Chapters 4 and 5 are the most comprehensive treatments of these important topics on the market. For those who prefer to spend less time on electronic structures of atoms, several sections can be "slipped over" easily.

Chapter 6 is devoted to a detailed discussion of chemical periodicity and an introduction to bonding. It is beautifully illustrated. Many illustrative examples, some unnumbered, are provided. The treatment of Lewis formulas is quite comprehensive. Inorganic nomenclature, a possibility for assigned reading, completes Chapter 6.

Chapters 7 and 8 are devoted to molecular structure and covalent bonding. VSEPR theory, polarity and dipole moments, and bond energies are included in Chapter 7. The order of presentation is logical and pedagogically sound, starting with the simplest possible cases and progressing to the more complex. This chapter is unique.

Chapter 8 includes discussions of the Valence Bond Theory and Molecular Orbital theory for those who prefer to include these topics.

Chapters 9 and 10 include a great deal of descriptive chemistry. The emphasis in Chapter 9 is on chemical periodicity associated with chemical reactions; Chapter 10 emphasizes the quantitative aspects of acid-base reactions and redox reactions in aqueous solutions. Major emphasis is placed on the mole method and molarity; separate *optional* sections on equivalent weights and normality are included. Chapters 9 and 10 may be postponed until after gases and liquids and solids with no loss of continuity. They may also be covered only in part for those who wish to do so.

Chapters 11, 12, and 13 describe the states of matter and the physical properties of solutions (colloids are included). The treatment of the states of matter, the dissolving process, and colligative properties of solutions are detailed and illustrated well.

Chapter 14, "Chemical Thermodynamics: The Driving Force for Change," emphasizes the role of thermodynamics in assessing and predicting the *spontaneity* of chemical and physical changes, and its relation to *equilibrium.* The chapter opens with a descriptive discussion of spontaneity, with many illustrations that students find helpful. Building on the thermochemistry of Chapter 3, the chapter then progresses to the use of changes in entropy and Gibbs free energy as criteria of spontaneity. Rather than depend on abstract definitions or traditional heat-engine efficiency discussions, the chapter develops the idea of entropy so that students are able to predict system entropy changes for common processes. Finally, a qualitative discussion lays the groundwork for the relation between thermodynamics and equilibrium. In Chapter 15, the subject of "Chemical Kinetics" is presented from the same standpoint—experimental observations first, theoretical interpretations second. These two key chapters develop the ideas needed for a strong introduction to "Chemical Equilibrium," Chapter 16.

A comprehensive discussion of the concepts of acid-base behavior and ionic equilibria is presented in Chapters 17 and 18.

Chapter 19 is a widely acclaimed chapter on electrochemistry that completes the main principles section of the text. It enables professors to "tie together" most of the material presented earlier.

Chapters 20 through 23 provide a block of basically descriptive chapters on the metals and metallurgy (Chapter 20), the nonmetals (Chapters 21 and 22), and

coordination compounds (Chapter 23). The treatment of coordination chemistry is the most comprehensive available in a "principles" textbook.

Chapter 24, "Nuclear Chemistry," is entirely self-contained and can be covered at any point in the course after Chapter 4.

Chapter 25, "Organic Chemistry," is a strong introduction to organic chemistry that includes alkanes, alkenes, alkynes, aromatic hydrocarbons, organic nomenclature, and functional groups.

Because there is no consensus on the number of answers to the end-of-chapter exercises that should be available to students, we have tried to provide maximum flexibility. Answers to even-numbered *numerical* problems are included after the Appendices. Detailed solutions and answers to *all even-numbered exercises* are available in the *Solutions Manual* prepared by Professor DeKorte. Answers and solutions to all odd-numbered exercises are provided in the *Instructor's Manual* by Professor Davis. The *Instructor's Manual* may be made available to students, if professors wish to do so.

We welcome suggestions for improvements in future editions.

Acknowledgments

The list of individuals who contributed to the evolution of this book is long indeed. First, we would like to express our appreciation to the professors who contributed so greatly to our scientific education: Miss Dorothy Vaughn, Professors Ralph N. Adams, F. S. Rowland, Calvin Vanderwerf, A. Tulinsky, Wm. von E. Doering, and David Harker (RED); Professors R. D. Dunlap, C. R. Russ, H. H. Patterson, R. L. Wells, A. L. Crumbliss, P. Smith, D. B. Chesnut, R. A. Palmer, and B. E. Douglas (KDG); and Professors Arnold Gilbert, M. L. Bryant, W. N. Pirkle, the late Alta Sproull, C. N. Jones, S. F. Clark, and R. S. Drago (KWW).

Our reviewers were very helpful — they have made major contributions to the development of this text with positive suggestions and constructive criticism:

John M. DeKorte, Northern Arizona University
L. O. Gold, The Pennsylvania State University
W. R. Hall, Community College of Allegheny County
Forrest A. Hentz, Jr., North Carolina State University
Lloyd N. Jones, The United States Naval Academy
James Long, The University of Oregon
D. W. Meek, Ohio State University
L. G. Pederson, The University of North Carolina
R. O. Ragsdale, The University of Utah
S. L. Sincoff, United States Air Force Academy
Calvin A. Vanderwerf, The University of Florida
C. A. von Frankenberg, The University of Delaware

We received partial reviews from a number of professors whom we were unable to identify. We express our appreciation to these individuals.

We are especially indebted to the tens of thousands of students with whom we have interacted in our 51 years (cumulative) of teaching introductory chemistry classes. Their concerns, questions, discussions, and suggestions have made us better teachers and, hopefully, better scientists. We extend our special thanks to our students, who provide inspiration to us.

The staff at Saunders College Publishing has contributed immeasurably to the evolution of this book. Our development and copy editor, Jay Freedman, has done a superb job. We are convinced that he has no peer. Rick Moore and Tom Mallon have given us high quality design and artwork, respectively, that contribute to the appearance and the substance of the book. Additionally, we have drawn freely from the excellent artwork in other Saunders College Publishing texts. Our project editors, Lynne Gery and Patrice Smith, have handled innumerable details with skill and aplomb. Tricia Manning and Michelle Glazer, Assistants to John Vondeling, have facilitated communications and the flow of paper cheerfully and efficiently.

We express our deepest appreciation to our editor and friend, John Vondeling, the best editor in the business. John has guided us at every stage in the development of this book, and our respect and admiration for him have grown with each passing day.

Our secretary, Martha Dove, has been patient and skillful through the many revisions. We are indeed grateful for her patience, her skill, and her dedication.

Finally, our appreciation to our families — Sharon, Angela, Laura and Brian Davis; Kathy, Kristen, and Karen Gailey; and Betty, Andy, and Kathryn Whitten.

Raymond E. Davis
Kenneth D. Gailey
Kenneth W. Whitten

Supplements

Excellent ancillary materials have been prepared to assist students in their study and to aid the professor in teaching the courses.

1. *Lecture Outline for Principles of Chemistry,* Professor Ronald O. Ragsdale, The University of Utah. A comprehensive lecture outline that allows professors to use valuable classroom time more effectively. It provides great flexibility for the professor and makes available more time for special topics, increased drill, or whatever the professor chooses to do.
2. *Solutions Manual for Principles of Chemistry,* Professor John M. DeKorte, Northern Arizona University. A pace-setter! It includes detailed answers, solutions, and *explanations* for *all even-numbered* end-of-chapter exercises. In-depth answers are given for discussion questions, and helpful comments that reinforce basic concepts are included, as well as references to illustrative examples and appropriate sections of chapters in the text.
3. *Study Guide for Principles of Chemistry,* Professor R. E. Davis, The University of Texas at Austin. It includes brief summaries of important ideas in each chapter, study goals with references to text sections and exercises, and simple preliminary tests (averaging more than 80 questions per chapter, all with answers) that reinforce basic skills and vocabulary and encourage students to think about important ideas.
4. *Instructor's Manual to Accompany Principles of Chemistry,* Professor R. E. Davis, The University of Texas at Austin. Also includes solutions to *odd-numbered* end-of-chapter exercises and may be made available to students, if the professor chooses.
5. *Experimental General Chemistry,* W. T. Lippincott (The University of Arizona), D. W. Meek (Ohio State University), K. D. Gailey, and K. W. Whitten. A modern laboratory manual with excellent variety that includes descriptive, quantitative, and instrumental experiments. Designed for mainstream courses for science majors.
6. *Problem-Solving in General Chemistry,* 2nd Ed., K. W. Whitten and K. D. Gailey. Covers the common core of general chemistry courses for science majors.
7. *Computer Tutorial for General Chemistry,* Professor Charles A. Wilkie, Marquette University. Comprehensive review and drill in core topics. On diskettes for Apple II+ and Apple IIe computers.
8. *Test Bank,* Davis, Gailey, and Whitten
9. *Overhead Transparencies,* Davis, Gailey, and Whitten. One hundred figures from the text.
10. *Workbook for General Chemistry Audio-Tape Lessons,* 2nd Ed., B. Shakhashiri, R. Schreiner, and P. A. Meyer (all of The University of Wisconsin, Madison).
11. *General Chemistry Audio-Tape Lessons,* Shakhashiri, Schreiner, and Meyer. Adopters of the workbook or of the text will receive up to three free copies of these tapes along with unlimited duplication rights for student use; transcripts of the tapes are also available.
12. *Modern Descriptive Chemistry,* Eugene G. Rochow, Harvard University. A 250-page paperback for those who desire more descriptive chemistry.

To The Student

We have written this text to assist you as you study chemistry, a fundamental science — some call it the central science. As you pursue your career goals, you will find the vocabulary and ideas of chemistry useful in more ways than you may imagine now.

We begin with the most basic vocabulary and ideas. Then we carefully develop increasingly sophisticated ideas that are necessary and useful in all the other physical sciences, the biological sciences, and areas such as medicine, dentistry, engineering, agriculture, and home economics.

We have tried to make many of the early chapters as nearly self-contained as possible, so that the material can be presented in the order considered most appropriate by your professor.

Early in each section we have provided the experimental basis for the ideas we present. By *experimental basis* we mean the observations and experiments on the phenomena that have been most important in developing concepts. We then present explanations of these experimental observations.

Chemistry is an experimental science. We know what we know because we (literally thousands of scientists) have observed it to be true. Successful theories have evolved to explain many experimental observations (facts) fully and accurately; often they enable us to predict the results of experiments that have not yet been performed. Experiment and theory go hand-in-hand; they are intimately related parts of our attempt to understand and explain natural phenomena.

"What is the best way to study chemistry?" is a question we are asked often by our students. Although there is no single answer, the following suggestions may be helpful.

Read the assigned material *before* it is covered in class so that you become generally familiar with important ideas. Take careful class notes. At the first opportunity, recopy your notes, and try to work the illustrative examples without looking at the solutions in your notes. Read the assigned material again. Reading should be more informative the second time.

Review the "key terms" at the end of the chapter so that you know the exact meaning of each. Work the illustrative examples in the text (cover the solutions). If you find it necessary to look at the solutions, look at only one line at a time and try to figure out the next step. Work the assigned exercises at the end of the chapter. Become familiar with the Appendices and their contents so that you may use them whenever necessary. Answers to all even-numbered numerical problems are given at the end of the text so that you may check your work. The *Solutions Manual,* by Professor J. M. DeKorte, includes detailed solutions and explanations for all even-numbered end-of-chapter exercises.

Study Guide for Principles of Chemistry, by Professor Raymond E. Davis, provides an overview of each chapter and emphasizes the threads of continuity that run through chemistry. It lists study goals, tells why concepts are important, and provides references to the text. The *Study Guide* contains many easy-to-moderately-difficult preliminary test questions so you can gauge your progress. They provide excellent practice in preparing for examinations. Answers are provided, and many have explanations.

If you have suggestions for improving this text, please write to us and tell us about them.

RED, KDG, and KWW

Contents Overview

Contents