

The background of the book cover is a dark, abstract composition featuring numerous overlapping, translucent red geometric shapes, primarily cubes and rectangular prisms, which appear to be floating or stacked in a three-dimensional space. The lighting creates highlights and shadows on the edges of these shapes, giving them a crystalline appearance. The overall color palette is dominated by deep reds and blacks.

# Basic Concepts of Chemistry

second edition

Leo J. Malone



# **Basic Concepts of Chemistry**

**Second Edition**

**Leo J. Malone**

*Saint Louis University  
St. Louis, Missouri*

**John Wiley & Sons**

New York • Chichester • Brisbane • Toronto • Singapore

Production supervised by Linda R. Indig  
Interior designed by Laura C. Ierardi  
Cover designed by Lisa A. Krongold  
Copy editing supervised by Debbie Herbert  
Photo researched by Linda Gutierrez  
Cover photo by Phillip A. Harrington/The Image Bank

Copyright © 1981, 1985, by John Wiley & Sons, Inc.

All rights reserved. Published simultaneously in Canada.

Reproduction or translation of any part of  
this work beyond that permitted by Sections  
107 and 108 of the 1976 United States Copyright  
Act without the permission of the copyright  
owner is unlawful. Requests for permission  
or further information should be addressed to  
the Permissions Department, John Wiley & Sons.

***Library of Congress Cataloging in Publication Data:***

Malone, Leo J., 1938–

Basic concepts of chemistry.

Includes index.

1. Chemistry. I. Title.

QD31.2.M344 1985 540 84-19476

Printed in the United States of America

10 9 8 7 6 5 4 3 2

# Preface

*Basic Concepts of Chemistry* is not only an introduction to chemical concepts but is also an introduction to the way chemistry is studied and mastered. The level, content, and sequence of topics have been chosen with a sensitivity to students who have had little or no background in chemistry or who have had a significant interruption in their studies of chemistry. The text is primarily for students who wish to obtain the background and confidence needed to pursue a main sequence chemistry course. It can also be used in the general chemistry part of a course for the allied health professions or for a one-time course in chemistry.

The style is conversational but concise. The traditional sequence of topics provides a step-by-step construction of the science, with one topic building logically on the previous one. It is understood that many, if not most, students using this book will require some mathematical preparation or review in the extensive quantitative concepts applied to chemical systems. The text is written with this very important fact in mind. The mathematical tools of measurement and conversions are presented in Chapter 2 and are supplemented by detailed reviews in the appendixes. The next five chapters introduce many basic chemical concepts that are not primarily mathematical in nature. However, in Chapter 8 the quantitative nature of chemistry becomes apparent with the introduction of the mole. In between Chapters 2 and 8, the students, with the direction of the instructor, are given an opportunity to improve their mathematical, algebraic, and problem-solving skills. There are separate appendixes on basic math (Appendix A), basic algebra (Appendix B), scientific notation (Appendix C), logarithms (Appendix E), and graphs (Appendix F). The appendixes include discussions, worked-out examples, and drill problems (with the answers provided). They are specially designed for application to the types of problems encountered in chemistry. Appendixes A, B, and C also include self-diagnostic tests so that students can easily determine the extent of review they need.

Almost all introductory and general chemistry textbooks now use the

unit-factor (dimensional analysis) method of problem solving. I believe, however, that the typical student, who is not familiar with this method, needs more than a one- or two-page introduction to apply this tool consistently and confidently. In Chapter 2, there is a detailed introduction to the topic, *supplemented* by an extensive appendix (Appendix D) that develops the unit-factor method step by step from the construction of conversion factors, to simple one-step conversions, to more complex multiple-step conversions. Solved example and exercise problems (with answers) are provided. Diligent students should become comfortable with this problem-solving method by the time it is applied extensively to chemical systems.

The book is designed with considerable flexibility in the sequence of topics and chapters. Many may prefer to cover moles and stoichiometry as early as possible. Hence, the instructor may proceed directly from Chapter 3 (after Section 3-5) to Chapter 8 and then to Section 9-3 on stoichiometry. I feel that it is preferable to present the topic of moles in a thorough manner, as is done in Chapter 8, instead of superficially introducing this topic in an early chapter without detailed, supporting explanations and examples.

There is obviously more material in this book than can be easily covered in a one-semester course. Generally, Chapters 1 to 10 would be covered, but there will be much variation in later chapters depending on the topics that the instructor wishes to emphasize. The nuclear discussion in Chapter 3 is completely optional: discussion and problems are separated from the rest of the chapter so they can be included at any time. This topic is included here because it follows logically from the discussion of the nature of the nucleus and is effective in building early interest regarding the popular concerns in this area. It can be omitted or included later. The discussions of orbitals and box diagrams in Chapter 4 are also optional and may be deleted without prejudice in later discussions.

Many other features of this book are designed to help students understand and organize the sequence of topics. The following is a list of these special features retained from the first edition of this text.

- 比喻类推
- 1 Simple analogies are used that relate the concrete to the abstract. Analogies that are easily understood themselves can be helpful in making new concepts understandable.
  - 2 Introductions to each chapter discuss the overall objectives of the chapter, how it follows from previous discussions and, most important, what specific topics previously discussed are relevant and should be reviewed. This approach emphasizes the continuity of chemistry as a subject where topics build one upon another.
  - 3 Numerous example problems are worked out in the text, step by step. There are usually two or three examples of each type of problem with careful explanations of procedures.



- 4 End-of-chapter problems are assigned in the margins of the text after a particular topic has been discussed and examples are shown. This is designed to give students direction for the immediate reinforcement of a concept without affecting the continuity of the discussion.
- 5 End-of-chapter problems are numerous and of varying difficulty. They are categorized by topic. Over one half of the answers are provided in Appendix H (many of the quantitative problems include solutions).
- 6 New terms are introduced in boldface type. The definitions of the terms are in italics.
- 7 A comprehensive glossary of terms provides easy reference to the definitions used throughout the text.

The following are additions and other improvements that have been included in the second edition of the book.

- 1 The number of end-of-chapter exercises are nearly tripled.
- 2 A chapter purpose and a list of chapter objectives are included at the beginning of each chapter.
- 3 Chapter summaries are added that give a synopsis of the chapter by using tables, diagrams, and flow charts where appropriate.
- 4 Comprehensive review tests are added after Chapters 3, 7, 10, and 14. These are designed to integrate the material in the intervening chapters.
- 5 Chapters are extensively rewritten, and topics within the chapters have been reorganized for improved flow and clarity. Information of current interest is updated.
- 6 A chapter (Chapter 11) is added on the liquid and solid states of water and changes between states. Some other topics now covered in this text are: colligative properties (Chapter 12), specific heat (Chapter 2), and activation energy (Chapter 15). Two chapters on acid-base chemistry in the first edition are combined into one chapter (Chapter 13) in the second edition. All or parts of this chapter may be included depending on the depth of coverage desired.
- 7 Several additional study aid materials are now available. The Study Guide to accompany this text is rewritten to provide closer support. In the Study Guide, related sections within a chapter have been grouped for discussion and self-testing rather than the chapter as a whole. Some short stories of current interest are also included in the Study Guide. They stress how chemistry relates to the discoveries and progress in many other disciplines. An innovative, new laboratory manual, written



by Professors Steven Murov and Brian Stedjee, accompanies this text. Finally, excellent computer-assisted instructional software, prepared by Professor Frank P. Rinehart, is being made available to instructors of this course. It will help make the challenge of problem solving fun as well as satisfying. This software will supplement Chapter 9 Chemical Reactions and is one of a forthcoming series for Chemical Education.

I hope you find the study or the teaching of this course rewarding and that you sense the author's enthusiasm for this fascinating discipline.

Leo J . Malone

# Acknowledgments

Writing a book like this is never an individual project. I thank my colleagues in the Chemistry Department of the Saint Louis University for their many helpful comments, especially during the preparation of the first edition. My special thanks are owed to Dr. Judith Durham, who was particularly helpful. I am grateful to my family for their assistance in proofreading, especially my wife, Sharon, and my daughter, Mary. I thank my editors at Wiley, Cliff Mills and then Dennis Sawicki, for their help, humor, and encouragement. Finally, the following people reviewed the manuscript and offered many useful comments and suggestions:

Dr. Howard De Voe  
*Department of Chemistry*  
*University of Maryland*  
*College Park, Maryland 20742*

Prof. Robert O'Malley  
*Department of Chemistry*  
*Boston College*  
*Chestnut Hill, Massachusetts 02167*

Prof. Clarence Cunningham  
*Department of Chemistry*  
*Oklahoma State University*  
*Stillwater, Oklahoma 74078*

Prof. R. Dyal  
*Department of Chemistry*  
*University of Illinois*  
*Urbana, Illinois 61801*

Prof. James Weber  
*Department of Chemistry*  
*University of New Hampshire*  
*Durham, New Hampshire 03824*

James E. Hunter  
*Department of Chemistry*  
*University of Illinois*  
*Urbana, Illinois 61801*

Dr. Forrest C. Hentz  
*Department of Chemistry*  
*North Carolina State University*  
*Raleigh, North Carolina 27650*

Prof. Elizabeth P. Rogers  
*University of Illinois*  
*Urbana, Illinois 61801*



## Acknowledgments

Prof. Timothy A. Kling  
*Department of Chemistry*  
*Lakeland Community College*  
*1-90 and Route 306*  
*Mentor, Ohio 44060*

Prof. Moheb M. Seif El-Nasr  
*Department of Chemistry*  
*The Lindenwood Colleges*  
*Saint Charles, Missouri 63301*

Prof. K. Thomas Finley  
*Department of Chemistry*  
*State University College- Brockport*  
*Brockport, New York 14420*

Prof. Martha J. Gilleland  
*Department of Chemistry*  
*California State College*  
*Bakersfield, California 93309*

Prof. Roger Penn  
*Department of Chemistry*  
*Sinclair Community College*  
*444 West third Street*  
*Dayton, Ohio 45402*

Prof. Richard Monson  
*Department of Chemistry*  
*California State University Hayward*  
*Hayward, California 94542*

Prof. Sol Shulman  
*Department of Chemistry*  
*Illinois State University*  
*Normal, Illinois 61761*

Prof. Steven Murov  
*3912 Midcrest Ct.*  
*Modesto, California 95355*

# **Basic Concepts of Chemistry**



The emergence of the human race from among the other animals can be traced to the use of fire.

# Contents

## Chapter 1

### **Chemistry: Matter, Changes, and Energy 1**

1-1	The Study of Chemistry	3
1-2	Chemistry and the Nature of Matter	6
1-3	Classification of Homogeneous Matter	9
1-4	Classification of Pure Substances	11
1-5	The Names and Symbols of the Elements	12
1-6	Physical and Chemical Properties	13
1-7	Physical and Chemical Changes	14
1-8	The Conservation of Mass	15
1-9	Energy Changes in Chemical Reactions	15
1-10	The Relationship of Matter and Energy	17
1-11	Chapter Summary	17
	Exercises	18

## Chapter 2

### **Measurements in Chemistry 23**

2-1	Significant Figures	25
2-2	Significant Figures in Mathematical Operations	27
2-3	Scientific Notation	29
2-4	Length, Volume, and Mass in the Metric System	32
2-5	Conversion of Units by the Unit-Factor Method	36
2-6	Density	41
2-7	Temperature	45
2-8	Specific Heat	48
2-9	Chapter Summary	49
	Exercises	51

**Chapter 3****The Atom, the Structure of Matter, and Nuclear Reactions      57**

3-1	The Composition of the Atom	59	
3-2	Atomic Number, Mass Number, and Atomic Weight		60
3-3	The Basic Structures of the Elements	63	
3-4	Compounds and Formulas	64	
3-5	Ions and Ionic Compounds	65	
3-6	Nuclear Decay	68	
3-7	Rates of Decay of Radioactive Isotopes	70	
3-8	The Effects of Radiation	71	
3-9	Nuclear Reactions	73	
3-10	Nuclear Fission	76	
3-11	Nuclear Fusion	80	
3-12	Chapter Summary	81	
	Exercises	83	

**Review Test on Chapters 1–3      87****Chapter 4****The Arrangement of the Electrons in the Atom      91**

4-1	The Periodic Table of the Elements	92	
4-2	The Emission Spectra of the Elements	93	
4-3	A Model for the Electrons in the Atom	96	
4-4	Shells	98	
4-5	Sublevels	99	
4-6	Electron Configuration of the Elements	101	
4-7	Orbitals	106	
4-8	The Shapes of Orbitals	106	
4-9	Box Diagrams of the Elements	108	
4-10	Chapter Summary	110	
	Exercises	111	

**Chapter 5****The Periodic Nature of the Elements      115**

5-1	The Physical Properties of the Elements	116	
5-2	Periods and Groups	117	
5-3	Periodic Trends: Atomic Radius	124	
5-4	Periodic Trends: Ionization Energy	127	
5-5	Periodic Trends: Electron Affinity	129	

<b>5-6</b>	<b>Chapter Summary</b>	<b>131</b>
	<b>Exercises</b>	<b>133</b>

## Chapter 6

### **The Nature of the Chemical Bond**      **137**

<b>6-1</b>	<b>Bond Formation and the Representative Elements</b>	<b>138</b>
<b>6-2</b>	<b>Lewis Dot Structures</b>	<b>139</b>
<b>6-3</b>	<b>The Formation of Ions</b>	<b>140</b>
<b>6-4</b>	<b>Formulas of Binary Ionic Compounds</b>	<b>142</b>
<b>6-5</b>	<b>The Covalent Bond</b>	<b>144</b>
<b>6-6</b>	<b>Simple Binary Molecules</b>	<b>146</b>
<b>6-7</b>	<b>The Multiple Covalent Bond</b>	<b>149</b>
<b>6-8</b>	<b>Polyatomic Ions</b>	<b>149</b>
<b>6-9</b>	<b>Writing Lewis Structures</b>	<b>150</b>
<b>6-10</b>	<b>Resonance Hybrids</b>	<b>155</b>
<b>6-11</b>	<b>Electronegativity and Polarity</b>	<b>156</b>
<b>6-12</b>	<b>Molecular Polarity</b>	<b>159</b>
<b>6-13</b>	<b>Chapter Summary</b>	<b>161</b>
	<b>Exercises</b>	<b>163</b>

## Chapter 7

### **The Naming of Compounds**      **167**

<b>7-1</b>	<b>Oxidation States</b>	<b>168</b>
<b>7-2</b>	<b>Naming Metal-Nonmetal Binary Compounds</b>	<b>170</b>
<b>7-3</b>	<b>Naming Compounds with Polyatomic Ions</b>	<b>173</b>
<b>7-4</b>	<b>Naming Nonmetal-Nonmetal Binary Compounds</b>	<b>175</b>
<b>7-5</b>	<b>Naming Acids</b>	<b>176</b>
<b>7-6</b>	<b>Chapter Summary</b>	<b>178</b>
	<b>Exercises</b>	<b>180</b>

### **Review Test on Chapters 4–7**      **183**

## Chapter 8

### **Quantitative Relationships: The Mole**      **187**

<b>8-1</b>	<b>The Mole</b>	<b>188</b>
<b>8-2</b>	<b>The Molar Mass of the Elements</b>	<b>189</b>
<b>8-3</b>	<b>The Molar Mass of Compounds</b>	<b>194</b>
<b>8-4</b>	<b>Percent Composition</b>	<b>197</b>
<b>8-5</b>	<b>Empirical and Molecular Formulas</b>	<b>200</b>



8-6	The Use of Empirical and Molecular Formulas	203
8-7	Chapter Summary	205
	Exercises	206

## Chapter 9

### Chemical Reactions: Equations and Quantities 211

9-1	Chemical Equations	212
9-2	Types of Chemical Reactions	215
9-3	Stoichiometry	218
9-4	Percent Yield	225
9-5	Limiting Reactant	228
9-6	Chapter Summary	230
	Exercises	232

## Chapter 10

### The Gaseous State of Matter 239

10-1	The Pressure of a Gas	240
10-2	The Kinetic Theory of Gases	242
10-3	Boyle's Law	244
10-4	Charles' Law and Gay-Lussac's Law	247
10-5	The Combined Gas Law	251
10-6	Graham's Law	252
10-7	Dalton's Law of Partial Pressures	254
10-8	Avogadro's Law	257
10-9	The Ideal Gas Law	258
10-10	The Molar Volume and Density of a Gas	260
10-11	Stoichiometry Involving Gases	263
10-12	Chapter Summary	266
	Exercises	267

### Review Test on Chapters 8-10 273

## Chapter 11

### Water: The Liquid and the Solid States 279

11-1	The Structure and Polarity of Water	280
11-2	Hydrogen Bonding	281
11-3	A Comparison of the Three Physical States of Water	282
11-4	Melting and Boiling Points	283
11-5	Changes in State	284
11-6	Energy in Changes of State	286

11-7	Evaporation and Vapor Pressure	290
11-8	The Formation and Reactions of Water	293
11-9	Chapter Summary	295
	Exercises	297

## Chapter 12

### Aqueous Solutions 303

12-1	The Conductivity of Aqueous Solutions	304
12-2	Water As a Solvent	306
12-3	Solubility of Ionic Compounds	309
12-4	Ionic Equations and Metathesis Reactions	311
12-5	Concentration: Percent by Weight	314
12-6	Concentration: Molarity	315
12-7	Stoichiometry Involving Solutions	319
12-8	The Physical Properties of Solutions	321
12-9	Chapter Summary	326
	Exercises	328

## Chapter 13

### Acids, Bases, and Salts 333

13-1	The Nature of Acids and Bases	334
13-2	Neutralization and Salts	338
13-3	The Strength of Acids and Bases	341
13-4	The Equilibrium of Water	345
13-5	The pH Scale	347
13-6	Brønsted-Lowry Acids and Bases	350
13-7	Predicting Acid and Base Reactions in Water	353
13-8	Buffer Solutions	357
13-9	Oxides as Acids and Bases	360
13-10	Chapter Summary	362
	Exercises	364

## Chapter 14

### Oxidation-Reduction Reactions 371

14-1	The Nature of Oxidation and Reduction	372
14-2	Balancing Redox Equations: Oxidation State Method	375
14-3	Balancing Redox Equations: The Ion-Electron Method	378
14-4	Voltaic Cells	383
14-5	Electrolytic Cells	387

14-6	Predicting Spontaneous Redox Reactions	388
14-7	Chapter Summary	395
	Exercises	397

<i>Review Test on Chapters 11–14</i>	401
--------------------------------------	-----

## Chapter 15

### Chemical Kinetics and Equilibrium 405

15-1	Mechanisms and Equilibrium	406
15-2	Examples of Reactions and Equilibrium	409
15-3	Factors That Affect the Rate of a Reaction	410
15-4	The Law of Mass Action	414
15-5	Equilibria of Weak Acids and Bases in Water	418
15-6	The Effects of Stress and Catalysts on Equilibrium	425
15-7	Chapter Summary	430
	Exercises	431

## Chapter 16

### An Introduction to Organic Chemistry 437

16-1	Carbon and Its Chemical Bonds	438
16-2	Alkanes	442
16-3	Alkenes	448
16-4	Alkynes	449
16-5	Aromatic Compounds	453
16-6	Organic Functional Groups	455
16-7	Alcohols ( $\text{R}-\text{OH}$ )	455
16-8	Ethers ( $\text{R}-\text{O}-\text{R}'$ )	458
16-9	Amines ( $\text{R}-\text{NH}_2$ )	458
16-10	Aldehydes ( $\text{R}-\overset{\text{O}}{\underset{\parallel}{\text{C}}}-\text{H}$ ) and Ketones ( $\text{R}-\overset{\text{O}}{\underset{\parallel}{\text{C}}}-\text{R}'$ )	461
16-11	Carboxylic Acids ( $\text{R}-\overset{\text{O}}{\underset{\parallel}{\text{C}}}-\text{O}-\text{H}$ ), Esters ( $\text{R}-\overset{\text{O}}{\underset{\parallel}{\text{C}}}-\text{O}-\text{R}'$ ), and Amides ( $\text{R}-\overset{\text{O}}{\underset{\parallel}{\text{C}}}-\text{NH}_2$ )	463
16-12	Chapter Summary	467
	Exercises	469

<i>Foreword to the Appendixes</i>	473
-----------------------------------	-----