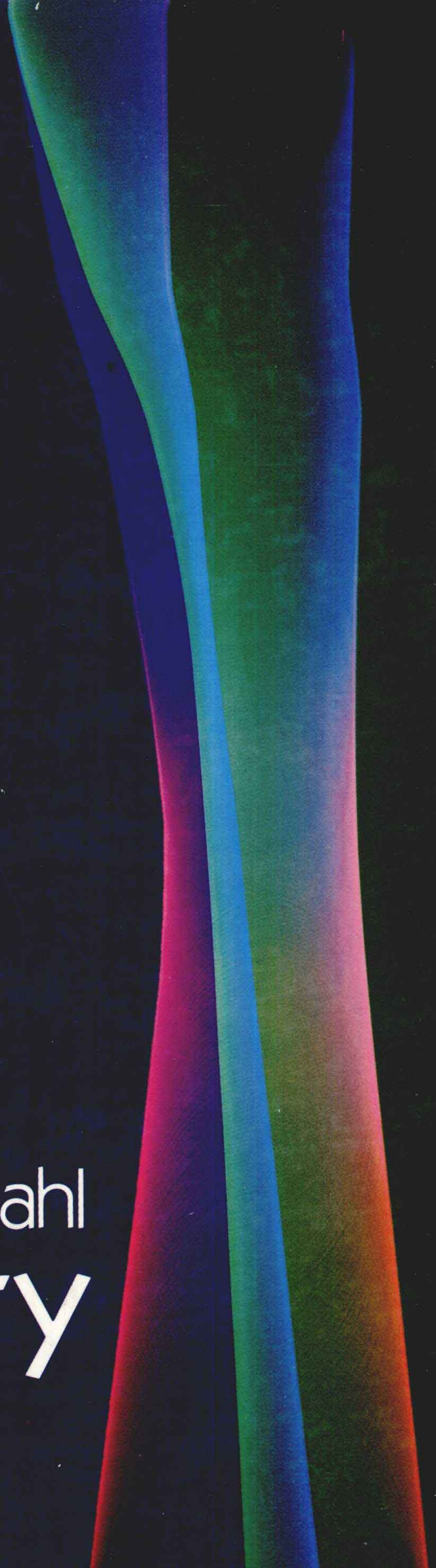
Steven S. Zumdahl

Chemistry



Steven S. Zumdahl
UNIVERSITY OF ILLINOIS

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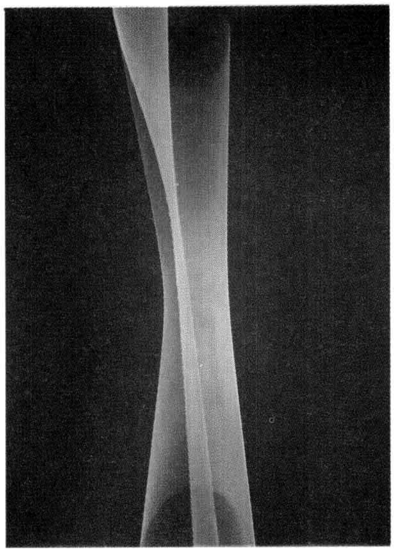

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To my parents and to Eunice, Whitney, and Leslie.

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TO THE PROFESSOR

The first question that comes to mind when looking at a new general chemistry textbook is: how is this book different from all of those others on the shelf? Although this book is not revolutionary in content or style, it does have important differences from the others. There are more figures than in any competing text. Since general chemistry typically gives a highly pictorial view of the chemical concepts with minimal mathematical complications, illustrations and photographs are invaluable.

With an unusually strong problem-solving orientation, this book talks to the student about how to approach and solve chemical problems. A strong pitch is made to the student to use a thoughtful and logical approach rather than to simply memorize procedures. In particular, an innovative method is given for dealing with acid-base equilibria, the material the typical student finds most difficult and frustrating. The key to this approach involves first deciding what species are present in solution and then thinking about the chemical properties of these species. This provides a general framework for approaching all types of solution equilibria.

This book features a thorough treatment of reactions that occur in solution, including acid-base reactions, precipitation reactions, and oxidation-reduction reactions. Although this material occurs early in the text (Chapter 4), where it can best support the laboratory portion of the course, it can be used in parts if the instructor prefers.

Descriptive chemistry and chemical principles are thoroughly integrated in this text. Chemical models are sterile and confusing without the observations that stimulated their invention. On the other hand, facts without organizing principles seem overwhelming. The observations and models must be integrated to make chemistry interesting and understandable. Also, in those chapters that deal systematically with the chemistry of the elements, there is a continuous effort to show how the properties and models correlate.

A unique feature of this text is the chapter on industrial chemistry (Chapter 24). This chapter describes several chemical industries ranging from the manufacture of polymers to winemaking with the purpose of showing the application of chemical principles in a setting where many factors, such as safety, environmental impact, and economics, must be considered in addition to the chemistry. This material can be used as a whole or individual sections can be used at any point in the course where the instructor feels it is relevant. The *Instructor's Guide* has suggestions on how to use this material.

Throughout the book there is a strong emphasis on models: how they are constructed, how they are tested, and what we learn when they inevitably fail. Models are developed naturally. Pertinent observations are always presented first, to show why a particular model was invented. In addition, chemistry is presented as a human activity carried out by real people, many of whom are described in-text, or in the interest features, called Chemical Impacts.

The end-of-chapter exercises are grouped according to topic. Although the exercises emphasize the fundamental principles, the context is often a real-life application of chemistry. This makes the exercises interesting to the student and provides a means for introducing more descriptive chemistry. The problems in the additional exercises section are not grouped by topic and tend to be more complicated than the earlier ones. This gives the student practice in recognizing the various applications of the concepts covered in the chapter and in synthesizing several concepts.

To make the book more flexible the derivation of the ideal gas law from the kinetic-molecular theory and quantitative analysis using spectroscopy are presented in the appendixes. While this material is typically not covered in a mainstream general chemistry course, it may be appropriate for some courses. The book is aimed at the mainstream course, but it should also be useful in many courses intended for majors. By using the optional material in the appendixes and by assigning the more difficult end-of-chapter exercises (from the additional exercises section) the level of the text should be quite appropriate for many majors courses.

A series of supplements has been designed to make this book more useful to both students and instructors. These include:

☐ *Instructor's Guide,* by Kenneth C. Brooks of the University of Colorado at Denver, includes suggested orders of the topics other than that in the text, amplification of strategies used in the various chapters, and answers to problems not found in the *Solutions Manual.*

☐ *Study Guide,* by Martha B. Barrett of the University of Colorado at Denver, is geared to the student and includes alternate strategies for solving various types of problems, supplemental explanations for the most difficult material, and self tests.

☐ *Solutions Guide,* by Kenneth C. Brooks of the University of Colorado at Denver, provides detailed solutions for two-thirds of the end-of-chapter exercises (designated by color question numbers or letters) using the strategies emphasized in the text.

☐ *Experimental Chemistry,* by James F. Hall of Northeastern University, Boston, provides a laboratory program compatible with the text. A wide variety of experiments is presented, emphasizing a thoughtful, investigative approach.

☐ The Test Item File consists of a diskette containing approximately 1000 exam questions organized according to the chapters in the text. The questions are in multiple-choice and long-answer formats.

Acknowledgments

Many people contributed tremendously to this text. I especially want to thank Mary Le Quesne, Acquisitions Editor, whose endless good humor, enthusiasm, and knowledge made this project a great pleasure. I also want to thank Peggy J. Flanagan, Senior Production Editor, whose professionalism and powers of organization were flawless in the face of a seemingly impossible task. I owe much to Ken Brooks, who collaborated in writing the end-of-chapter exercises and who contributed immeasurably to the project through his enthusiastic attitude and unerring suggestions concerning content and approach. In addition I want to thank Bruce Averill, Professor of Chemistry at the University of Virginia, who provided expert advice and valuable constructive criticism as the principle reviewer of the text. Roxy Wilson did an excellent job setting up laboratory demonstrations for several of the photographs in the book. I especially appreciate the contributions of Eunice Doden Zumdahl, who typed the first draft of manuscript, helped proofread the galleys and page proofs, and was supportive in every possible way. I am grateful to Whitney and Leslie for their patience during the many times I had to miss their activities because of "the book."

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I would very much appreciate comments and suggestions for improvement as you and your students use the book.

TO THE STUDENT

If you are typical of most students, you are probably worried about how you will do in this chemistry course. Learning chemistry is difficult; almost everyone seems to agree on that. In fact, learning chemistry can be so frustrating that it is easy to lose sight of how really important and interesting the subject is. You *can* learn chemistry and even enjoy the process, but you must understand that finesse works much better than brute force. Chemistry is difficult not so much because the concepts are hard, but because it deals with complicated systems. Before a problem can be solved a lot of facts must be sifted to find the pertinent ones. There is no alternative to thinking things through.

The major purpose of this book, of course, is to help you learn chemistry. However, this main thrust is closely linked to two other goals: to show how important and how interesting the subject is; and to show how to think like a chemist. To solve complicated problems the chemist uses logic, trial and error, intuition, and above all, patience. A chemist is used to being wrong. The important thing is to learn from a mistake, recheck assumptions, and try again. A chemist thrives on puzzles that seem to defy solutions.

The non-chemist can benefit from the chemist's attitude. Problem-solving is important in all professions and in all walks of life. That is, the techniques useful in solving chemistry problems are also applicable to "real life." Thus, I believe that the study of chemistry has much to offer the non-major, including an understanding of many fascinating and important phenomena and a chance to hone problem-solving skills.

This book attempts to present chemistry in a manner that is sensible to the novice. Chemistry is not the result of an inspired vision. It is the product of countless observations and many attempts, using logic and trial and error to account for these observations. In this book the concepts are developed in a natural way: the observations come first and then models are constructed to explain the observed behavior.

Models are a central theme in this book. The uses and limitations of models are emphasized and science is treated as a human activity, subject to all the normal human foibles. Mistakes are discussed as well as successes.

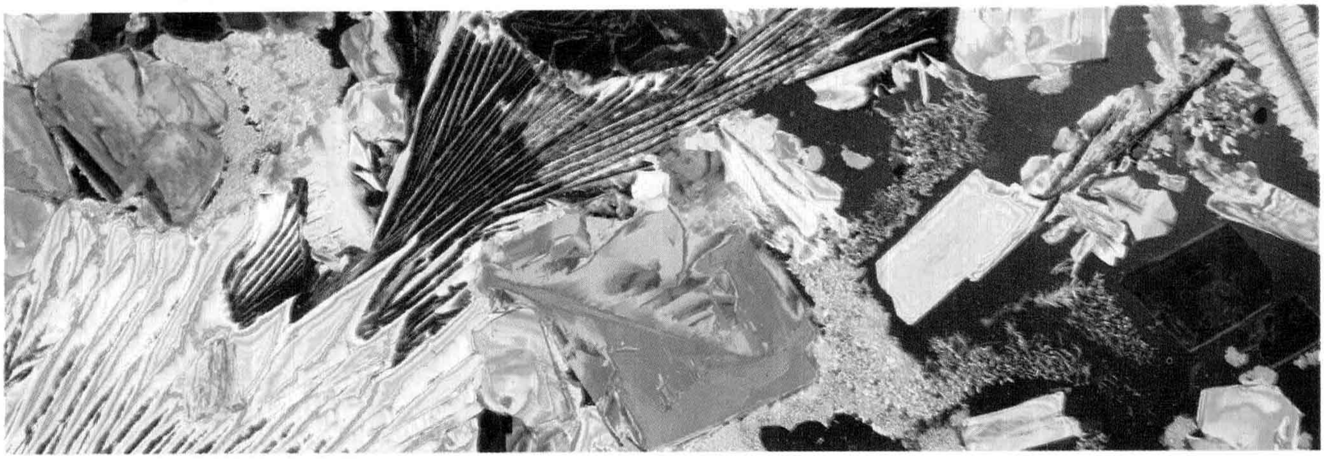
Another central theme of this book is a thoughtful, systematic approach to problem-solving. Learning is much more than memorizing facts. Truly educated people can use their factual knowledge as a starting point—a base for creative approaches to solving problems.

We have tried to ensure that the ideas in this book are presented as clearly as possible. However, learning chemistry requires real study: several careful readings of the material in the text, thorough examination of the worked-out sample exercises, and working the end-of-chapter exercises assigned by your professor. Answers to selected exercises are in the back of the book. Answers to exercises with color question numbers or letters are in the *Solutions Guide.*

It is very important to use the exercises to your best advantage. Your main goal should not be to simply get the correct answer but to *understand* the process for getting the answer. Memorizing the solutions for specific problems is not a very good way to prepare for an exam. Chemical systems are complex enough that a small change can mean a problem that looks very similar to one you have memorized actually requires a very different type of solution. The point is that there are too many pigeonholes required to cover every possible problem type. If you are to succeed, you must take the attitude that every problem is unique and requires a thoughtful approach. Look within the problem for the solution. Use the concepts you have learned along with a systematic, logical approach to find the solution. Learn to trust yourself to think it out. Do not just memorize everything in sight out of desperation. You will make mistakes as you try to figure things out, but the important thing is to learn from these errors. The only way to gain confidence is to do lots of practice problems and use these to diagnose your weaknesses.

Be patient, be thoughtful, and work hard to understand rather than simply memorize. I wish you a satisfying and interesting year.

CONTENTS



Chapter 1: Chemical Foundations 1

1.1 The Scientific Method □ 3
1.2 Units of Measurement □ 4
1.3 Uncertainty in Measurement □ 7
1.4 Significant Figures and Calculations □ 9
1.5 Dimensional Analysis □ 12
1.6 Temperature □ 15
1.7 Density □ 19
1.8 Classification of Matter □ 20
1.9 Separation of Mixtures □ 21
CHEMICAL IMPACT: Observations, Theories, and the Planets □ 25
Summary □ 26
Key Terms □ 27
Exercises □ 27

Chapter 2: Atoms, Molecules, and Ions 31

2.1 The Early History of Chemistry □ 31
2.2 Fundamental Chemical Laws □ 33
2.3 Dalton's Atomic Theory □ 35
2.4 Early Experiments to Characterize the Atom □ 37
2.5 The Modern View of Atomic Structure—An Introduction □ 40
2.6 Molecules and Ions □ 42
2.7 An Introduction to the Periodic Table □ 45
2.8 Naming Compounds □ 47
CHEMICAL IMPACT: Berzelius, Selenium, and Silicon □ 55
Summary □ 56
Key Terms □ 57
Exercises □ 57

Chapter 3: Stoichiometry 61

3.1 Atomic Masses □ 61
3.2 The Mole □ 64
3.3 Molecular Weight □ 68
3.4 Percent Composition of Compounds □ 71
3.5 Determining the Formula of a Compound □ 73
3.6 Chemical Equations □ 77
3.7 Balancing Chemical Equations □ 79
3.8 Stoichiometric Calculations: Amounts of Reactants and Products □ 83
3.9 Calculations Involving a Limiting Reagent □ 86
CHEMICAL IMPACT: Sulfuric Acid—The Most Important Chemical □ 93
Summary □ 94
Key Terms □ 94
Exercises □ 95

Chapter 4: Solution Stoichiometry and Chemical Analysis 101

4.1 Water, the Universal Solvent □ 102
4.2 The Nature of Aqueous Solutions—Strong and Weak Electrolytes □ 104
4.3 The Composition of Solutions □ 106
4.4 Describing Reactions in Solution □ 112
4.5 Precipitation Reactions □ 113
4.6 Qualitative Analysis—An Introduction □ 115
4.7 Quantitative Analysis by Precipitation □ 118
4.8 Acid-Base Reactions □ 122
4.9 Oxidation-Reduction Reactions □ 129
4.10 Balancing Oxidation-Reduction Equations □ 135
4.11 Oxidation-Reduction Titrations □ 143
CHEMICAL IMPACT: Arrhenius, A Man with Solutions □ 146
Summary □ 146
Key Terms □ 148
Exercises □ 149

Chapter 5: Gases 155

5.1 Early Experiments □ 155
5.2 The Gas Laws of Boyle, Charles, and Avogadro □ 157
5.3 The Ideal Gas Law □ 162
5.4 Gas Stoichiometry □ 166
5.5 Dalton's Law of Partial Pressures □ 170
5.6 The Kinetic Molecular Theory of Gases □ 174
5.7 Effusion and Diffusion □ 179
5.8 Real Gases □ 181
5.9 Chemistry in the Atmosphere □ 184
CHEMICAL IMPACT: Scuba Diving □ 189
Summary □ 189
Key Terms □ 190
Exercises □ 191

Chapter 6: Thermochemistry 197

6.1 The Nature of Energy □ 198
6.2 Enthalpy and Calorimetry □ 203
6.3 Hess's Law □ 209
6.4 Standard Enthalpies of Formation □ 212
6.5 Present Sources of Energy □ 218
6.6 New Energy Sources □ 222
CHEMICAL IMPACT: The Chemistry of Coal □ 228
Summary □ 229
Key Terms □ 229
Exercises □ 230

Chapter 7: Atomic Structure and Periodicity 237

7.1 Electromagnetic Radiation □ 238
7.2 The Nature of Matter □ 239
7.3 The Atomic Spectrum of Hydrogen □ 244
7.4 The Bohr Model □ 246
7.5 The Wave Mechanical Model of the Atom □ 249
7.6 Quantum Numbers □ 254
7.7 Orbital Shapes and Energies □ 256
7.8 Electron Spin and the Pauli Principle □ 258
7.9 Polyelectronic Atoms □ 259
7.10 The History of the Periodic Table □ 261
7.11 The Aufbau Principle and the Periodic Table □ 263
7.12 Further Development of the Polyelectronic Model □ 270
7.13 Periodic Trends in Atomic Properties □ 275
7.14 The Properties of a Group: The Alkali Metals □ 280
CHEMICAL IMPACT: Fireworks □ 285
Summary □ 286
Key Terms □ 288
Exercises □ 289

Chapter 8: Bonding—General Concepts 295

8.1 Types of Chemical Bonds □ 296
8.2 Electronegativity □ 299
8.3 Bond Polarity and Dipole Moments □ 301
8.4 Ions: Electron Configurations and Sizes □ 304
8.5 Binary Ionic Compounds □ 307
8.6 Partial Ionic Character of Covalent Bonds □ 311
8.7 The Covalent Chemical Bond—A Model □ 312
8.8 Covalent Bond Energies and Chemical Reactions □ 315
8.9 Covalent Bonding Models □ 319
8.10 Lewis Structures □ 320
8.11 Exceptions to the Octet Rule □ 325
8.12 Resonance □ 328
8.13 Molecular Structure: The VSEPR Model □ 330
CHEMICAL IMPACT: Chemical Structure and Communication: Semiochemicals □ 341
Summary □ 342
Key Terms □ 343
Exercises □ 344

Chapter 9: Covalent Bonding: Orbitals 349

9.1 Hybridization and the Localized Electron Model □ 349
9.2 The Molecular Orbital Model □ 362
9.3 Bonding in Homonuclear Diatomic Molecules □ 366
9.4 Bonding in Heteronuclear Diatomic Molecules □ 373
9.5 Combining the Localized Electron and Molecular Orbital Models □ 375
Summary □ 377
Key Terms □ 378
Exercises □ 379

Chapter 10: Liquids and Solids 383

10.1 Intermolecular Forces □ 384
10.2 The Liquid State □ 387
10.3 An Introduction to Structures and Types of Solids □ 390
10.4 Structure and Bonding in Metals □ 394
10.5 Carbon and Silicon: Network Atomic Solids □ 400
10.6 Molecular Solids □ 407
10.7 Ionic Solids □ 409
10.8 Vapor Pressure and Changes of State □ 412
10.9 Phase Diagrams □ 420
CHEMICAL IMPACT: Transistors and Printed Circuits □ 425
Summary □ 427
Key Terms □ 428
Exercises □ 428

Chapter 11: Properties of Solutions 435

11.1 Solution Composition □ 436
11.2 The Energies of Solution Formation □ 439
11.3 Factors Affecting Solubility □ 442
11.4 The Vapor Pressures of Solutions □ 447
11.5 Boiling-Point Elevation and Freezing-Point Depression □ 453
11.6 Osmotic Pressure □ 457
11.7 Colligative Properties of Electrolyte Solutions □ 461
11.8 Colloids □ 463
Summary □ 465
Key Terms □ 466
Exercises □ 466

Chapter 12: Chemical Kinetics 471

12.1 Reaction Rates □ 473
12.2 Rate Laws: The Effect of Concentration on Reaction Rate □ 476
12.3 The Integrated Rate Law □ 482
12.4 Reaction Mechanisms □ 493
12.5 A Model for Chemical Kinetics □ 498
12.6 Catalysis □ 504
CHEMICAL IMPACT: Enzymes: Nature's Catalysts □ 510
Summary □ 512
Key Terms □ 513
Exercises □ 514

Chapter 13: Chemical Equilibrium 521

13.1 The Equilibrium Condition □ 522
13.2 The Equilibrium Constant □ 524
13.3 Equilibrium Expressions Involving Pressures □ 528
13.4 Heterogeneous Equilibria □ 531
13.5 Applications of the Equilibrium Constant □ 533
13.6 Solving Equilibrium Problems □ 540
13.7 Le Châtelier's Principle □ 547
Summary □ 552
Key Terms □ 554
Exercises □ 554

Chapter 14: Acids and Bases 559

14.1 The Nature of Acids and Bases □ 559
14.2 Acid Strength □ 562
14.3 The pH Scale □ 567
14.4 Calculating the pH of Strong Acid Solutions □ 570
14.5 Calculating the pH of Weak Acid Solutions □ 571
14.6 Bases □ 581
CHEMICAL IMPACT: Amines □ 586
14.7 Polyprotic Acids □ 587
14.8 Acid-Base Properties of Salts □ 592
14.9 The Effect of Structure on Acid-Base Properties □ 599
14.10 Acid-Base Properties of Oxides □ 601
14.11 The Lewis Acid-Base Model □ 602
14.12 Strategy for Solving Acid-Base Problems—A Summary □ 604
Summary □ 606
Key Terms □ 608
Exercises □ 608

Chapter 15: Applications of Aqueous Equilibria 618

15.1 Solutions of Acids or Bases Containing a Common Ion □ 616
15.2 Buffered Solutions □ 618
15.3 Titrations and pH Curves □ 629
15.4 Acid-Base Indicators □ 644
15.5 Solubility Equilibria and the Solubility Product □ 649
15.6 Precipitation and Qualitative Analysis □ 657
15.7 Complex Ion Equilibria □ 663
Summary □ 669
Key Terms □ 670
Exercises □ 670

Chapter 16: Spontaneity, Entropy, and Free Energy 677

16.1 Spontaneous Processes and Entropy □ 678
16.2 Entropy and the Second Law of Thermodynamics □ 683
16.3 The Effect of Temperature on Spontaneity □ 684
16.4 Free Energy □ 688
16.5 Entropy Changes in Chemical Reactions □ 691
16.6 Free Energy and Chemical Reactions □ 695
16.7 The Dependence of Free Energy on Pressure □ 699
16.8 Free Energy and Equilibrium □ 702
16.9 Free Energy and Work □ 705
Summary □ 708
Key Terms □ 709
Exercises □ 709

Chapter 17: Electrochemistry 715

17.1 Galvanic Cells □ 716
17.2 Standard Reduction Potentials □ 718
17.3 Cell Potential, Electrical Work, and Free Energy □ 725
17.4 Dependence of Cell Potential on Concentration □ 728
17.5 Batteries □ 734
17.6 Corrosion □ 737
17.7 Electrolysis □ 739
17.8 Commercial Electrolytic Processes □ 743
CHEMICAL IMPACT: Batteries of the Future □ 749
Summary □ 752
Key Terms □ 753
Exercises □ 754

Chapter 18: The Representative Elements 759

18.1 A Survey of the Representative Elements □ 759
18.2 The Group 1A Elements □ 764
18.3 Hydrogen □ 767
18.4 The Group 2A Elements □ 769
18.5 The Group 3A Elements □ 773
18.6 The Group 4A Elements □ 775
Summary □ 778
Key Terms □ 779
Exercises □ 779

Chapter 19: Representative Elements: Groups 5A Through 8A 783

19.1 The Group 5A Elements □ 783
19.2 The Chemistry of Nitrogen □ 785
19.3 The Chemistry of Phosphorus □ 796
19.4 The Group 6A Elements □ 800
19.5 The Chemistry of Oxygen □ 801
19.6 The Chemistry of Sulfur □ 802
19.7 The Group 7A Elements □ 807
CHEMICAL IMPACT: Photography □ 809
19.8 The Group 8A Elements □ 817
Summary □ 818
Key Terms □ 820
Exercises □ 820

Chapter 20: Transition Metals and Coordination Chemistry 825

20.1 The Transition Metals—A Survey □ 826
CHEMICAL IMPACT: Transition Metals in Action □ 832
20.2 The First-Row Transition Metals □ 833
20.3 Coordination Compounds □ 837
CHEMICAL IMPACT: Alfred Werner—Coordination Chemist □ 839
20.4 Isomerism □ 843
CHEMICAL IMPACT: The Importance of Being *cis* □ 846
20.5 Bonding in Complex Ions—The Localized Electron Model □ 848
20.6 The Crystal Field Model □ 850
20.7 The Molecular Orbital Model □ 856
20.8 The Biological Importance of Coordination Complexes □ 858
Summary □ 862
Key Terms □ 864
Exercises □ 864

Chapter 21: The Nucleus—A Chemist's View 869

21.1 Nuclear Stability and Radioactive Decay □ 870
21.2 The Kinetics of Radioactive Decay □ 876
21.3 Nuclear Transformations □ 879
21.4 Detection and Uses of Radioactivity □ 880
21.5 Thermodynamic Stability of the Nucleus □ 885
21.6 Nuclear Fission and Nuclear Fusion □ 889
21.7 Effects of Radiation □ 894
CHEMICAL IMPACT: Stellar Nucleosynthesis □ 898
CHEMICAL IMPACT: Nuclear Physics—An Introduction □ 898
CHEMICAL IMPACT: Nuclear Waste Disposal □ 900
Summary □ 901
Key Terms □ 902
Exercises □ 902

Chapter 22: Organic Chemistry 907

22.1 Alkanes—Saturated Hydrocarbons □ 908
CHEMICAL IMPACT: Methane from Termites □ 911
22.2 Alkenes and Alkynes □ 918
22.3 Aromatic Hydrocarbons □ 922
22.4 Hydrocarbon Derivatives □ 924
22.5 Polymers □ 931
Summary □ 935
Key Terms □ 936
Exercises □ 937

Chapter 23: Biochemistry 941

23.1 Proteins □ 943
23.2 Carbohydrates □ 954
23.3 Nucleic Acids □ 959
23.4 Lipids □ 963
CHEMICAL IMPACT: The Chemistry of Vision □ 969
Summary □ 970
Key Terms □ 971
Exercises □ 971

Chapter 24: Industrial Chemistry 975

24.1 The Petrochemical Industry □ 977
24.2 Polymers □ 984
CHEMICAL IMPACT: Wallace Hume Carothers □ 987
CHEMICAL IMPACT: The Mechanism of Methane Combustion □ 995
CHEMICAL IMPACT: Supernylon □ 996
24.3 Pesticides □ 997
CHEMICAL IMPACT: Allelopathic Chemicals—Nature's Herbicides □ 1000
24.4 Metallurgy and Iron and Steel Production □ 1002
CHEMICAL IMPACT: Steel Bicycle Frames □ 1011
24.5 The Wine Industry □ 1012
Summary □ 1017
Key Terms □ 1018
Exercises □ 1018

Appendix One: Mathematical Procedures A1

A1.1 Exponential Notation □ A1
A1.2 Logarithms □ A4
A1.3 Graphing Functions □ A7
A1.4 Solving Quadratic Equations □ A9
A1.5 Uncertainties in Measurements □ A11

Appendix Two: The Quantitative Kinetic Molecular Model A15

Appendix Three: Spectral Analysis A19

Appendix Four: Selected Thermodynamic Data A22

Glossary A25

Answers to Selected Exercises A41

Photo Credits A60

Index B1

Chapter 1

An ice cube, although composed mainly of water in the solid state, can also contain pockets of gas (air), and liquid (liquid water). The inclusion of air bubbles indicates a fast rate of freezing.

Chapter 2

A silicon crystal shown growing from a pool of molten silicon at 1446°C, the melting point of silicon. Atoms from the pool attach themselves to a "seed" crystal, a small crystal of pure silicon. The growing crystal is rotated slowly during a period of from six to twelve hours, resulting in a cylinder of silicon about 1 m in length and 15 cm in diameter. This is the starting material in the manufacture of semiconductors.

Chapter 3

Molten bronze at 1232°C. Bronze, one of the earliest known alloys, is a mixture of copper (90%–95%) and tin (5%–10%). It is used for statues, marine apparatus, and other castings where resistance to corrosion is important.

Chapter 4

A multitude of reactions take place in solutions, so a wide variety of glassware is used in chemistry. The color of a solution depends on the ability of the molecules or ions in the solution to absorb light.

Chapter 5

Natural gas, shown burning in a domestic stove, is a major fuel source in the United States. The chief constituent of this mixture of gases is methane, CH_4.

Chapter 6

Solar panels at the Solar One facility, located in the desert near Barstow, California. This solar-thermal operation uses the sun's energy to produce steam to power an electricity-producing turbine.

Chapter 7

Some elements can be identified by the characteristic colors that their compounds impart to a flame. Some copper compounds give the beautiful blue color shown here. (See the Chemical Impact feature in this chapter.)

Chapter 8

Garnetiferous mica schist, magnified twenty times, from Gassetts, Vermont. Mica is a silicate mineral composed of flat sheets of silicate polymers with weak bonding between the sheets. The planar structure accounts for its ability to readily form flakes.

Chapter 9

A ball-and-stick model of the DNA helix. The determination of the DNA structure in the early 1950s allowed scientists to explain for the first time the mechanism of cell replication and hence the transfer of genetic traits.

Chapter 10

Crystals of chrome alum, which has the formula $KCr(SO_4)_2 \cdot 12H_2O$. These big beautiful purple crystals can easily be grown from saturated solutions.

Chapter 11

An oil slick showing diffraction patterns. The oil does not dissolve in water because it is nonpolar and thus immiscible with polar water.

Chapter 12

The combustion reaction between zinc and sulfur is very vigorous, releasing large quantities of energy.

Chapter 13

The effervescence of champagne, caused by the escape of carbon dioxide as the pressure is released, is a good example of Le Châtelier's principle.

Chapter 14

A crystal of histidine magnified sixty-three times. This amino acid is an essential building block of proteins.

Chapter 15

Limestone cave formation in the Bridal Cave in Missouri. Limestone, or calcium carbonate, the principal nonsilicate mineral, dissolves in acidic water to create a cavern and then re-forms on the cave ceiling (stalactites) or floor (stalagmites).

Chapter 16

An eruption of the Kilauea volcano. Vast quantities of energy are transferred as heat.

Chapter 17

Corrosion testing. The coatings on various metal objects are checked for resistance to corrosion by immersion in warm water. Air is bubbled through the water to speed up the oxidation process.

Chapter 18

An aluminum-magnesium alloy burning. Both metals burn in air with a brilliant white flame, a fact that explains the use of magnesium in flashbulbs and aluminum in producing the white flares in fireworks.

Chapter 19

A wax candle burning in a jar of chlorine (a pale yellow gas). The atmosphere need not be air to support a flame, provided it will support a chemical reaction. In this case the bonds between the carbon and hydrogen atoms in the wax molecules are being broken and new C—Cl bonds formed. Chlorine gas is denser than air and the reaction products that are seen near the jar's mouth.

Chapter 20

The surface of platinum, illuminated by a laser and magnified five times. The metal is an important industrial catalyst and platinum compounds are of great use in cancer chemotherapy.

Chapter 21

A black-and-white photograph of a bubble chamber, computer color-enhanced, showing tracks of protons and electrons from the bombardment of hydrogen molecules by a beam of protons. The straight tracks are those of protons that have not collided with other particles. The spiral tracks are those of electrons.

Chapter 22

A fiber of anthrone, an organic compound with three six-membered rings fused together. The compound is used in the colorimetric analysis for sugar in body fluids.

Chapter 23

A scanning electron micrograph (×675) of human red blood cells. These healthy cells are aggregating (clotting) due to the formation of filaments of fibrin.

Chapter 24

Liquid polyurethane is molded into a cylinder, which can then be cut on a lathe to make machinery parts. This polymer is used for many applications where formerly only metals were used.