

GLOBAL
EDITION



PRINCIPLES OF CHEMISTRY

A Molecular Approach

THIRD EDITION

Nivaldo J. Tro

ALWAYS LEARNING

PEARSON

Principles of Chemistry

A Molecular Approach

THIRD EDITION

Global Edition

NIVALDO J. TRO

Westmont College

PEARSON

Editor-in-Chief: Jeanne Zalesky
Senior Acquisitions Editor: Terry Haugen
Senior Acquisitions Editor, Global Editions: Priyanka Ahuja
Director of Development: Jennifer Hart
Marketing Manager: Will Moore
Development Editor: Erin Mulligan
Program Managers: Jessica Moro / Sarah Shefveld
Project Manager: Beth Sweeten
Project Editor, Global Editions: K.K. Neelakantan
Senior Production Manufacturing Controller, Global Editions: Trudy Kimber
Text Permissions Project Manager: Tim Nicholls
Media Production Manager, Global Editions: Vikram Kumar
Program Management Team Lead: Kristen Flatham
Project Management Team Lead: David Zielonka
Design Manager: Derek Bacchus
Interior Designer: Gary Hespeneide
Cover Designer: Lumina Datamatics, Inc.
Illustrator: Precision Graphics
Photo Researchers: Lauren McFalls / Mark Schaefer, Lumina Datamatics
Photo Leads: Maya Melenchuk / Eric Shrader
Operations Specialist: Maura Zaldivar-Garcia
Chapter Opening Illustrations: Quade Paul

Credits and acknowledgments for materials borrowed from other sources and reproduced, with permission, in this textbook appear on the appropriate page within the text or on p. C-1.

Pearson Education Limited
Edinburgh Gate
Harlow
Essex CM20 2JE
England

and Associated Companies throughout the world

Visit us on the World Wide Web at:
www.pearsonglobaleditions.com

© Pearson Education Limited 2016

The right of Nivaldo J. Tro to be identified as the author of this work has been asserted by him in accordance with the Copyright, Designs and Patents Act 1988.

Authorized adaptation from the United States edition, entitled Principles of Chemistry: A Molecular Approach, 3rd edition, ISBN 978-0-321-97194-4, by Nivaldo J. Tro published by Pearson Education © 2016.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without either the prior written permission of the publisher or a license permitting restricted copying in the United Kingdom issued by the Copyright Licensing Agency Ltd, Saffron House, 6–10 Kirby Street, London EC1N 8TS.

All trademarks used herein are the property of their respective owners. The use of any trademark in this text does not vest in the author or publisher any trademark ownership rights in such trademarks, nor does the use of such trademarks imply any affiliation with or endorsement of this book by such owners.

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

10 9 8 7 6 5 4 3 2 1

ISBN 10: 1-292-09728-0

ISBN 13: 978-1-292-09728-2

Typeset by Lumina Datamatics, Inc.

Printed and bound in China.

To Michael, Ali, Kyle, and Kaden



About the Author

Nivaldo Tro is a professor of chemistry at Westmont College in Santa Barbara, California, where he has been a faculty member since 1990. He received his Ph.D. in chemistry from Stanford University for work on developing and using optical techniques to study the adsorption and desorption of molecules to and from surfaces in ultrahigh vacuum. He then went on to the University of California at Berkeley, where he did postdoctoral research on ultrafast reaction dynamics in solution. Since coming to Westmont, Professor Tro has been awarded grants from the American Chemical Society

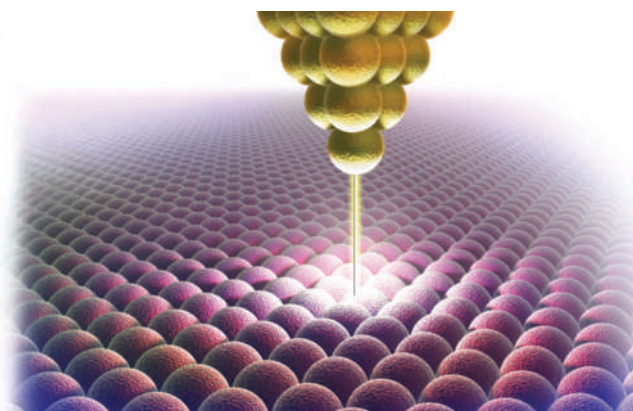
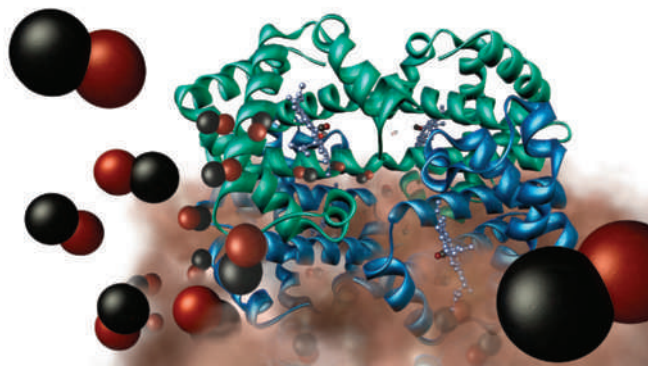
Petroleum Research Fund, from the Research Corporation, and from the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. He has been honored as Westmont's outstanding teacher of the year three times and has also received the college's outstanding researcher of the year award. Professor Tro lives in Santa Barbara with his wife, Ann, and their four children, Michael, Ali, Kyle, and Kaden. In his leisure time, Professor Tro enjoys mountain biking, surfing, reading to his children, and being outdoors with his family.

Brief Contents

Preface	15
1 Matter, Measurement, and Problem Solving	28
2 Atoms and Elements	68
3 Molecules, Compounds, and Chemical Equations	102
4 Chemical Quantities and Aqueous Reactions	150
5 Gases	202
6 Thermochemistry	246
7 The Quantum-Mechanical Model of the Atom	288
8 Periodic Properties of the Elements	326
9 Chemical Bonding I: The Lewis Model	366
10 Chemical Bonding II: Molecular Shapes, Valence Bond Theory, and Molecular Orbital Theory	404
11 Liquids, Solids, and Intermolecular Forces	454
12 Solutions	504
13 Chemical Kinetics	544
14 Chemical Equilibrium	588
15 Acids and Bases	628
16 Aqueous Ionic Equilibrium	672
17 Free Energy and Thermodynamics	718
18 Electrochemistry	760
19 Radioactivity and Nuclear Chemistry	802
Appendix I: Common Mathematical Operations in Chemistry	A-1
Appendix II: Useful Data	A-7
Appendix III: Answers to Selected Exercises	A-17
Appendix IV: Answers to In-Chapter Practice Problems	A-43
Glossary	G-1
Credits	C-1
Index	I-1

Contents

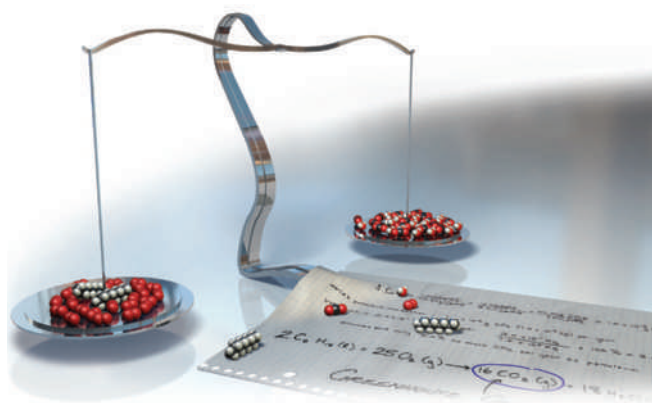
Preface	15
1 Matter, Measurement, and Problem Solving	28
1.1 Atoms and Molecules	29
1.2 The Scientific Approach to Knowledge	31
1.3 The Classification of Matter	33
The States of Matter: Solid, Liquid, and Gas 33 Classifying Matter According to Its Composition: Elements, Compounds, and Mixtures 34	
1.4 Physical and Chemical Changes and Physical and Chemical Properties	35
1.5 Energy: A Fundamental Part of Physical and Chemical Change	38
1.6 The Units of Measurement	39
The Standard Units 39 The Meter: A Measure of Length 40 The Kilogram: A Measure of Mass 40 The Second: A Measure of Time 40 The Kelvin: A Measure of Temperature 40 Prefix Multipliers 42 Derived Units: Volume and Density 43 Volume 43 Density 44 Calculating Density 44	
1.7 The Reliability of a Measurement	45
Counting Significant Figures 47 Exact Numbers 48 Significant Figures in Calculations 49 Precision and Accuracy 50	
1.8 Solving Chemical Problems	51
Converting from One Unit to Another 51 General Problem-Solving Strategy 53 Units Raised to a Power 55 Problems Involving an Equation 56	
Chapter in Review	59
Key Terms 59 Key Concepts 59 Key Equations and Relationships 60 Key Learning Objectives 60	
Exercises	60
Problems by Topic 60 Cumulative Problems 64 Challenge Problems 65 Conceptual Problems 66 Questions for Group Work 67 Answers to Conceptual Connections 67	



2 Atoms and Elements	68
2.1 Imaging and Moving Individual Atoms	69
2.2 Modern Atomic Theory and the Laws That Led to It	71
The Law of Conservation of Mass 71 The Law of Definite Proportions 72 The Law of Multiple Proportions 73 John Dalton and the Atomic Theory 74	
2.3 The Discovery of the Electron	74
Cathode Rays 75 Millikan's Oil Drop Experiment: The Charge of the Electron 76	
2.4 The Structure of the Atom	76
2.5 Subatomic Particles: Protons, Neutrons, and Electrons in Atoms	78
Elements: Defined by Their Numbers of Protons 79 Isotopes: When the Number of Neutrons Varies 80 Ions: Losing and Gaining Electrons 82	
2.6 Finding Patterns: The Periodic Law and the Periodic Table	83
Ions and the Periodic Table 85	
2.7 Atomic Mass: The Average Mass of an Element's Atoms	87
2.8 Molar Mass: Counting Atoms by Weighing Them	88
The Mole: A Chemist's "Dozen" 88 Converting between Number of Moles and Number of Atoms 89 Converting between Mass and Amount (Number of Moles) 90	
Chapter in Review	94
Key Terms 94 Key Concepts 95 Key Equations and Relationships 95 Key Learning Objectives 95	
Exercises	96
Problems by Topic 96 Cumulative Problems 98 Challenge Problems 99 Conceptual Problems 100 Questions for Group Work 100 Answers to Conceptual Connections 101	

3 Molecules, Compounds, and Chemical Equations 102

- 3.1 Hydrogen, Oxygen, and Water 103**
- 3.2 Chemical Bonds 105**
Ionic Bonds 105 Covalent Bonds 106
- 3.3 Representing Compounds: Chemical Formulas and Molecular Models 106**
Types of Chemical Formulas 106 Molecular Models 108
- 3.4 An Atomic-Level View of Elements and Compounds 108**
- 3.5 Ionic Compounds: Formulas and Names 112**
Writing Formulas for Ionic Compounds 113 Naming Ionic Compounds 113 Naming Binary Ionic Compounds Containing a Metal That Forms Only One Type of Cation 115 Naming Binary Ionic Compounds Containing a Metal That Forms More Than One Kind of Cation 116 Naming Ionic Compounds Containing Polyatomic Ions 117 Hydrated Ionic Compounds 118
- 3.6 Molecular Compounds: Formulas and Names 119**
Naming Molecular Compounds 119 Naming Acids 120 Naming Binary Acids 121 Naming Oxyacids 121
- 3.7 Formula Mass and the Mole Concept for Compounds 122**
Molar Mass of a Compound 123 Using Molar Mass to Count Molecules by Weighing 123
- 3.8 Composition of Compounds 125**
Conversion Factors from Chemical Formulas 127
- 3.9 Determining a Chemical Formula from Experimental Data 128**
Calculating Molecular Formulas for Compounds 130 Combustion Analysis 131
- 3.10 Writing and Balancing Chemical Equations 133**
Writing Balanced Chemical Equations 135
- 3.11 Organic Compounds 137**
- Chapter in Review 140**
Key Terms 140 Key Concepts 140 Key Equations and Relationships 141 Key Learning Objectives 142
- Exercises 143**
Problems by Topic 143 Cumulative Problems 146 Challenge Problems 147 Conceptual Problems 148 Questions for Group Work 148 Answers to Conceptual Connections 148



4 Chemical Quantities and Aqueous Reactions 150

- 4.1 Climate Change and the Combustion of Fossil Fuels 151**
- 4.2 Reaction Stoichiometry: How Much Carbon Dioxide? 153**
Making Pizza: The Relationships Among Ingredients 153
Making Molecules: Mole-to-Mole Conversions 154
Making Molecules: Mass-to-Mass Conversions 154
- 4.3 Limiting Reactant, Theoretical Yield, and Percent Yield 157**
Limiting Reactant, Theoretical Yield, and Percent Yield from Initial Reactant Masses 159
- 4.4 Solution Concentration and Solution Stoichiometry 163**
Solution Concentration 164 Using Molarity in Calculations 165 Solution Stoichiometry 169
- 4.5 Types of Aqueous Solutions and Solubility 170**
Electrolyte and Nonelectrolyte Solutions 171 The Solubility of Ionic Compounds 172
- 4.6 Precipitation Reactions 174**
- 4.7 Representing Aqueous Reactions: Molecular, Ionic, and Complete Ionic Equations 178**
- 4.8 Acid-Base and Gas-Evolution Reactions 180**
Acid-Base Reactions 180 Gas-Evolution Reactions 183
- 4.9 Oxidation-Reduction Reactions 185**
Oxidation States 187 Identifying Redox Reactions 189
Combustion Reactions 191
- Chapter in Review 193**
Key Terms 193 Key Concepts 193 Key Equations and Relationships 194 Key Learning Objectives 194
- Exercises 194**
Problems by Topic 194 Cumulative Problems 198
Challenge Problems 199 Conceptual Problems 200
Questions for Group Work 201 Answers to Conceptual Connections 201



5 Gases 202

- 5.1 Breathing: Putting Pressure to Work 203**
- 5.2 Pressure: The Result of Molecular Collisions 204**
Pressure Units 205



5.3 The Simple Gas Laws: Boyle's Law, Charles's Law, and Avogadro's Law	206
Boyle's Law: Volume and Pressure 207 Charles's Law: Volume and Temperature 209 Avogadro's Law: Volume and Amount (in Moles) 211	
5.4 The Ideal Gas Law	212
5.5 Applications of the Ideal Gas Law: Molar Volume, Density, and Molar Mass of a Gas	214
Molar Volume at Standard Temperature and Pressure 215 Density of a Gas 215 Molar Mass of a Gas 217	
5.6 Mixtures of Gases and Partial Pressures	218
Collecting Gases over Water 222	
5.7 Gases in Chemical Reactions: Stoichiometry Revisited	224
Molar Volume and Stoichiometry 226	
5.8 Kinetic Molecular Theory: A Model for Gases	227
The Nature of Pressure 228 Boyle's Law 228 Charles's Law 228 Avogadro's Law 228 Dalton's Law 228 Temperature and Molecular Velocities 229	
5.9 Mean Free Path, Diffusion, and Effusion of Gases	231
5.10 Real Gases: The Effects of Size and Intermolecular Forces	233
The Effect of the Finite Volume of Gas Particles 233 The Effect of Intermolecular Forces 234 Van der Waals Equation 235	
Chapter in Review	236
Key Terms 236 Key Concepts 236 Key Equations and Relationships 237 Key Learning Objectives 237	
Exercises	238
Problems by Topic 238 Cumulative Problems 241 Challenge Problems 243 Conceptual Problems 244 Questions for Group Work 244 Answers to Conceptual Connections 245	
6 Thermochemistry	246
6.1 Chemical Hand Warmers	247
6.2 The Nature of Energy: Key Definitions	248
Units of Energy 250	
6.3 The First Law of Thermodynamics: There Is No Free Lunch	251
Internal Energy 251	

6.4 Quantifying Heat and Work	256
Heat 256 Thermal Energy Transfer 258 Work: Pressure–Volume Work 260	
6.5 Measuring ΔE for Chemical Reactions: Constant-Volume Calorimetry	261
6.6 Enthalpy: The Heat Evolved in a Chemical Reaction at Constant Pressure	264
Exothermic and Endothermic Processes: A Molecular View 266 Stoichiometry Involving ΔH : Thermochemical Equations 267	
6.7 Constant-Pressure Calorimetry: Measuring ΔH_{rxn}	268
6.8 Hess's Law and Other Relationships Involving ΔH_{rxn}	270
6.9 Enthalpies of Reaction from Standard Heats of Formation	273
Standard States and Standard Enthalpy Changes 273 Calculating the Standard Enthalpy Change for a Reaction 275	
Chapter in Review	279
Key Terms 279 Key Concepts 279 Key Equations and Relationships 280 Key Learning Objectives 280	
Exercises	281
Problems by Topic 281 Cumulative Problems 284 Challenge Problems 285 Conceptual Problems 286 Questions for Group Work 286 Answers to Conceptual Connections 287	



7 The Quantum-Mechanical Model of the Atom	288
7.1 Schrödinger's Cat	290
7.2 The Nature of Light	290
The Wave Nature of Light 291 The Electromagnetic Spectrum 293 Interference and Diffraction 294 The Particle Nature of Light 296	
7.3 Atomic Spectroscopy and the Bohr Model	299
7.4 The Wave Nature of Matter: The de Broglie Wavelength, the Uncertainty Principle, and Indeterminacy	301
The de Broglie Wavelength 302 The Uncertainty Principle 303 Indeterminacy and Probability Distribution Maps 305	



7.5 Quantum Mechanics and the Atom 307

Solutions to the Schrödinger Equation for the Hydrogen Atom 307 Atomic Spectroscopy Explained 311

7.6 The Shapes of Atomic Orbitals 313

s Orbitals ($l=0$) 314 p Orbitals ($l=1$) 316 d Orbitals ($l=2$) 317 f Orbitals ($l=3$) 318 The Phase of Orbitals 318 The Shapes of Atoms 318

Chapter in Review 319

Key Terms 319 Key Concepts 320 Key Equations and Relationships 320 Key Learning Objectives 321

Exercises 321

Problems by Topic 321 Cumulative Problems 322 Challenge Problems 323 Conceptual Problems 324 Questions for Group Work 324 Answers to Conceptual Connections 325

8 Periodic Properties of the Elements 326

8.1 Nerve Signal Transmission 327

8.2 The Development of the Periodic Table 328

8.3 Electron Configurations: How Electrons Occupy Orbitals 329

Electron Spin and the Pauli Exclusion Principle 330 Sublevel Energy Splitting in Multielectron Atoms 330 Electron Spatial Distributions and Sublevel Splitting 332 Electron Configurations for Multielectron Atoms 334

8.4 Electron Configurations, Valence Electrons, and the Periodic Table 337

Orbital Blocks in the Periodic Table 338 Writing an Electron Configuration for an Element from Its Position in the Periodic Table 339 The Transition and Inner Transition Elements 340

8.5 The Explanatory Power of the Quantum-Mechanical Model 341

8.6 Periodic Trends in the Size of Atoms and Effective Nuclear Charge 342

Effective Nuclear Charge 344 Atomic Radii and the Transition Elements 345

8.7 Ions: Electron Configurations, Magnetic Properties, Ionic Radii, and Ionization Energy 347

Electron Configurations and Magnetic Properties of Ions 347 Ionic Radii 348 Ionization Energy 351

Trends in First Ionization Energy 351 Exceptions to Trends in First Ionization Energy 354 Trends in Second and Successive Ionization Energies 354

8.8 Electron Affinities and Metallic Character 355

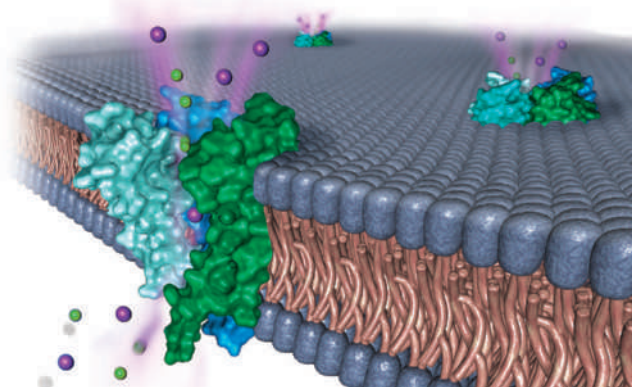
Electron Affinity 355 Metallic Character 356

Chapter in Review 360

Key Terms 360 Key Concepts 360 Key Equations and Relationships 361 Key Learning Objectives 361

Exercises 361

Problems by Topic 361 Cumulative Problems 363 Challenge Problems 364 Conceptual Problems 364 Questions for Group Work 365 Answers to Conceptual Connections 365



9 Chemical Bonding I: The Lewis Model 366

9.1 Bonding Models and AIDS Drugs 368

9.2 Types of Chemical Bonds 368

9.3 Representing Valence Electrons with Dots 370

9.4 Ionic Bonding: Lewis Symbols and Lattice Energies 371

Ionic Bonding and Electron Transfer 371 Lattice Energy: The Rest of the Story 372 Trends in Lattice Energies: Ion Size 373 Trends in Lattice Energies: Ion Charge 373 Ionic Bonding: Models and Reality 374

9.5 Covalent Bonding: Lewis Structures 375

Single Covalent Bonds 375 Double and Triple Covalent Bonds 376 Covalent Bonding: Models and Reality 376

9.6 Electronegativity and Bond Polarity 377

Electronegativity 378 Bond Polarity, Dipole Moment, and Percent Ionic Character 379

9.7 Lewis Structures of Molecular Compounds and Polyatomic Ions 382

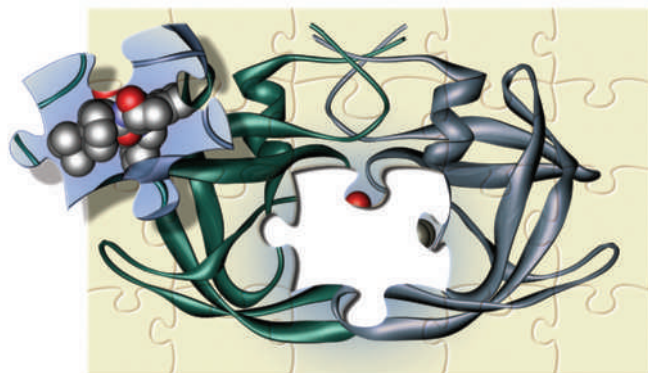
Writing Lewis Structures for Molecular Compounds 382 Writing Lewis Structures for Polyatomic Ions 383

9.8 Resonance and Formal Charge 384

Resonance 384 Formal Charge 386

9.9 Exceptions to the Octet Rule: Odd-Electron Species, Incomplete Octets, and Expanded Octets 389

Odd-Electron Species 389 Incomplete Octets 389 Expanded Octets 390



9.10 Bond Energies and Bond Lengths 391

Bond Energy 392 Using Average Bond Energies to Estimate Enthalpy Changes for Reactions 393 Bond Lengths 395

9.11 Bonding in Metals: The Electron Sea Model 396

Chapter in Review 398

Key Terms 398 Key Concepts 398 Key Equations and Relationships 399 Key Learning Objectives 399

Exercises 399

Problems by Topic 399 Cumulative Problems 401
Challenge Problems 402 Conceptual Problems 403
Questions for Group Work 403 Answers to Conceptual Connections 403

10 Chemical Bonding II: Molecular Shapes, Valence Bond Theory, and Molecular Orbital Theory 404

10.1 Artificial Sweeteners: Fooled by Molecular Shape 405

10.2 VSEPR Theory: The Five Basic Shapes 406

Two Electron Groups: Linear Geometry 407 Three Electron Groups: Trigonal Planar Geometry 407 Four Electron Groups: Tetrahedral Geometry 407 Five Electron Groups: Trigonal Bipyramidal Geometry 408 Six Electron Groups: Octahedral Geometry 409

10.3 VSEPR Theory: The Effect of Lone Pairs 410

Four Electron Groups with Lone Pairs 410 Five Electron Groups with Lone Pairs 412 Six Electron Groups with Lone Pairs 413

10.4 VSEPR Theory: Predicting Molecular Geometries 414

Representing Molecular Geometries on Paper 417 Predicting the Shapes of Larger Molecules 417

10.5 Molecular Shape and Polarity 418

10.6 Valence Bond Theory: Orbital Overlap as a Chemical Bond 421

10.7 Valence Bond Theory: Hybridization of Atomic Orbitals 423

sp^3 Hybridization 425 sp^2 Hybridization and Double Bonds 426 sp Hybridization and Triple Bonds 430 sp^3d and sp^3d^2 Hybridization 431 Writing Hybridization and Bonding Schemes 433

10.8 Molecular Orbital Theory: Electron Delocalization 435

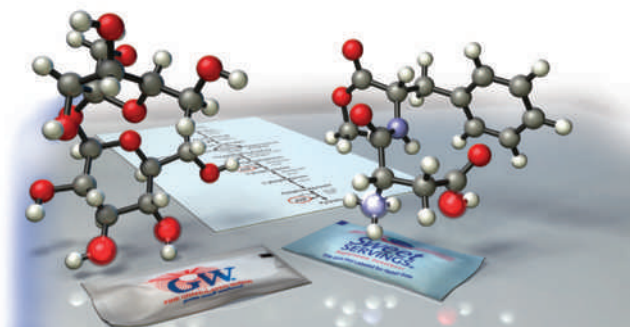
Linear Combination of Atomic Orbitals (LCAO) 436
Period Two Homonuclear Diatomic Molecules 439

Chapter in Review 446

Key Terms 446 Key Concepts 446 Key Equations and Relationships 447 Key Learning Objectives 447

Exercises 447

Problems by Topic 447 Cumulative Problems 450
Challenge Problems 452 Conceptual Problems 452
Questions for Group Work 453 Answers to Conceptual Connections 453



11 Liquids, Solids, and Intermolecular Forces 454

11.1 Water, No Gravity 455

11.2 Solids, Liquids, and Gases: A Molecular Comparison 456

Changes between States 458

11.3 Intermolecular Forces: The Forces That Hold Condensed States Together 458

Dispersion Force 459 Dipole-Dipole Force 461
Hydrogen Bonding 463 Ion-Dipole Force 465

11.4 Intermolecular Forces in Action: Surface Tension, Viscosity, and Capillary Action 466

Surface Tension 467 Viscosity 467 Capillary Action 468

11.5 Vaporization and Vapor Pressure 468

The Process of Vaporization 468 The Energetics of Vaporization 469 Heat of Vaporization 470 Vapor Pressure and Dynamic Equilibrium 471 Temperature Dependence of Vapor Pressure and Boiling Point 473 The Clausius-Clapeyron Equation 474 The Critical Point: The Transition to an Unusual State of Matter 476

11.6 Sublimation and Fusion 477

Sublimation 477 Fusion 478 Energetics of Melting and Freezing 478

11.7 Heating Curve for Water 479

11.8 Phase Diagrams 480

The Major Features of a Phase Diagram 480 Regions 480
Lines 481 The Triple Point 481 The Critical Point 481
Navigation within a Phase Diagram 482



11.9	Water: An Extraordinary Substance	482
11.10	Crystalline Solids: Unit Cells and Basic Structures	483
	Closest-Packed Structures	487
11.11	Crystalline Solids: The Fundamental Types	489
	Molecular Solids	490
	Ionic Solids	490
	Atomic Solids	491
11.12	Crystalline Solids: Band Theory	493
	Chapter in Review	495
	Key Terms	495
	Key Concepts	495
	Key Equations and Relationships	496
	Key Learning Objectives	497
	Exercises	497
	Problems by Topic	497
	Cumulative Problems	501
	Challenge Problems	502
	Conceptual Problems	502
	Questions for Group Work	503
	Answers to Conceptual Connections	503

12 Solutions 504

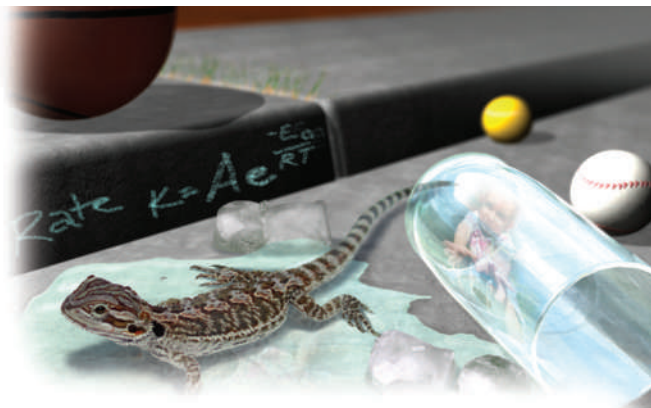
12.1	Thirsty Solutions: Why You Should Not Drink Seawater	505
12.2	Types of Solutions and Solubility	507
	Nature's Tendency toward Mixing: Entropy	507
	The Effect of Intermolecular Forces	508
12.3	Energetics of Solution Formation	511
	Aqueous Solutions and Heats of Hydration	512
12.4	Solution Equilibrium and Factors Affecting Solubility	515
	The Temperature Dependence of the Solubility of Solids	515
	Factors Affecting the Solubility of Gases in Water	516
12.5	Expressing Solution Concentration	518
	Molarity	519
	Molality	520
	Parts by Mass and Parts by Volume	520
	Mole Fraction and Mole Percent	521
12.6	Colligative Properties: Vapor Pressure Lowering, Freezing Point Depression, Boiling Point Elevation, and Osmotic Pressure	523
	Vapor Pressure Lowering	524
	Vapor Pressures of Solutions Containing a Volatile (Nonelectrolyte) Solute	527
	Freezing Point Depression and Boiling Point Elevation	528
	Osmosis	531

12.7	Colligative Properties of Strong Electrolyte Solutions	533
	Strong Electrolytes and Vapor Pressure	534
	Chapter in Review	536
	Key Terms	536
	Key Concepts	536
	Key Equations and Relationships	537
	Key Learning Objectives	537
	Exercises	538
	Problems by Topic	538
	Cumulative Problems	540
	Challenge Problems	542
	Conceptual Problems	542
	Questions for Group Work	543
	Answers to Conceptual Connections	543



13 Chemical Kinetics 544

13.1	Catching Lizards	545
13.2	The Rate of a Chemical Reaction	546
13.3	The Rate Law: The Effect of Concentration on Reaction Rate	549
	Determining the Order of a Reaction	551
	Reaction Order for Multiple Reactants	552
13.4	The Integrated Rate Law: The Dependence of Concentration on Time	555
	The Half-Life of a Reaction	559
13.5	The Effect of Temperature on Reaction Rate	562
	Arrhenius Plots: Experimental Measurements of the Frequency Factor and the Activation Energy	564
	The Collision Model: A Closer Look at the Frequency Factor	567
13.6	Reaction Mechanisms	568
	Rate Laws for Elementary Steps	568
	Rate-Determining Steps and Overall Reaction Rate Laws	569
	Mechanisms with a Fast Initial Step	570
13.7	Catalysis	572
	Homogeneous and Heterogeneous Catalysis	573
	Enzymes: Biological Catalysts	574
	Chapter in Review	577
	Key Terms	577
	Key Concepts	577
	Key Equations and Relationships	578
	Key Learning Objectives	578



Exercises	578
Problems by Topic	578
Cumulative Problems	583
Challenge Problems	585
Conceptual Problems	586
Questions for Group Work	587
Answers to Conceptual Connections	587

14 Chemical Equilibrium 588

14.1 Fetal Hemoglobin and Equilibrium	589
14.2 The Concept of Dynamic Equilibrium	591
14.3 The Equilibrium Constant (K)	592

Expressing Equilibrium Constants for Chemical Reactions 593 The Significance of the Equilibrium Constant 594 Relationships between the Equilibrium Constant and the Chemical Equation 595

14.4 Expressing the Equilibrium Constant in Terms of Pressure	597
Units of K	598

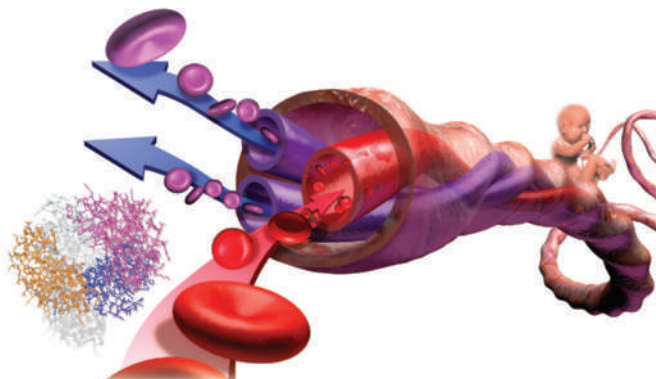
14.5 Heterogeneous Equilibria: Reactions Involving Solids and Liquids	599
--	------------

14.6 Calculating the Equilibrium Constant from Measured Equilibrium Concentrations	600
---	------------

14.7 The Reaction Quotient: Predicting the Direction of Change	603
---	------------

14.8 Finding Equilibrium Concentrations	605
--	------------

Finding Equilibrium Concentrations When We Are Given the Equilibrium Constant and All but One of the Equilibrium Concentrations of the Reactants and Products 605



Finding Equilibrium Concentrations When We Are Given the Equilibrium Constant and Initial Concentrations or Pressures 606 Simplifying Approximations in Working Equilibrium Problems 610

14.9 Le Châtelier's Principle: How a System at Equilibrium Responds to Disturbances 614

The Effect of a Concentration Change on Equilibrium 614

The Effect of a Volume (or Pressure) Change on Equilibrium 616 The Effect of a Temperature Change on Equilibrium 617

Chapter in Review 619

Key Terms 619 Key Concepts 620 Key Equations and Relationships 620 Key Learning Objectives 621

Exercises 621

Problems by Topic 621 Cumulative Problems 625

Challenge Problems 626 Conceptual Problems 626

Questions for Group Work 627 Answers to Conceptual Connections 627

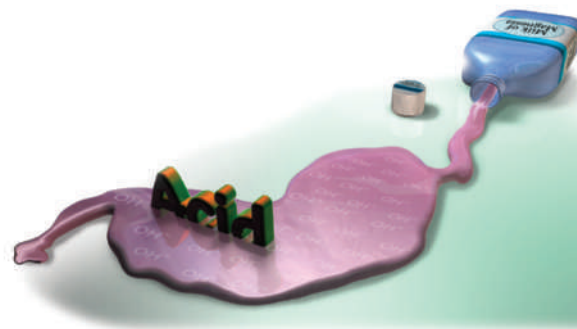
15 Acids and Bases 628

15.1 Heartburn	629
-----------------------	------------

15.2 The Nature of Acids and Bases	630
---	------------

15.3 Definitions of Acids and Bases	631
--	------------

The Arrhenius Definition 632 The Brønsted-Lowry Definition 632



15.4 Acid Strength and the Acid Ionization Constant (K_a)	634
---	------------

Strong Acids 634 Weak Acids 635 The Acid Ionization Constant (K_a) 636

15.5 Autoionization of Water and pH	637
--	------------

The pH Scale: A Way to Quantify Acidity and Basicity 639 pOH and Other p Scales 641

15.6 Finding the $[H_3O^+]$ and pH of Strong and Weak Acid Solutions	642
--	------------

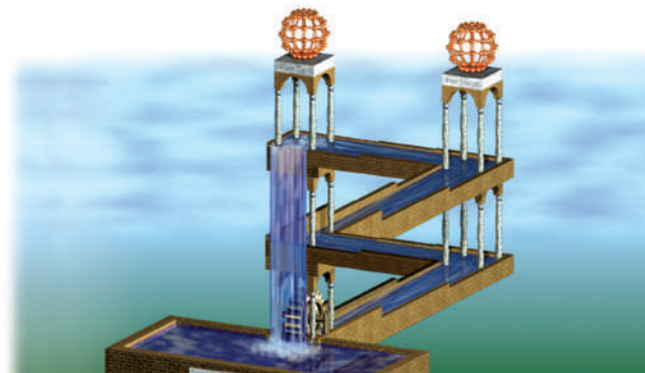
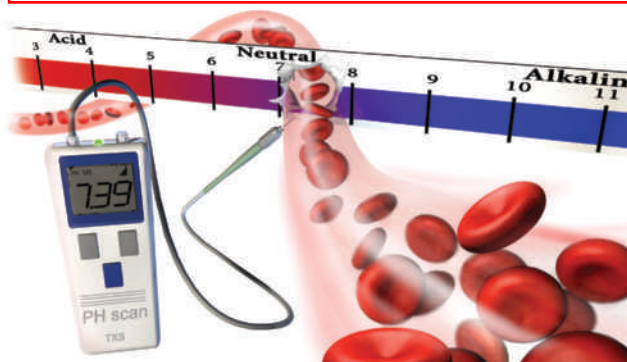
Strong Acids 642 Weak Acids 642 Polyprotic Acids 646 Percent Ionization of a Weak Acid 648

15.7 Base Solutions	650
----------------------------	------------

Strong Bases 650 Weak Bases 650 Finding the $[OH^-]$ and pH of Basic Solutions 652

15.8 The Acid–Base Properties of Ions and Salts	653
Anions as Weak Bases 654 Cations as Weak Acids 657	
Classifying Salt Solutions as Acidic, Basic, or Neutral 658	
15.9 Acid Strength and Molecular Structure	660
Binary Acids 660 Oxyacids 661	
15.10 Lewis Acids and Bases	662
Molecules That Act as Lewis Acids 663 Cations That Act as Lewis Acids 664	
Chapter in Review	665
Key Terms 665 Key Concepts 665 Key Equations and Relationships 666 Key Learning Objectives 666	
Exercises	666
Problems by Topic 666 Cumulative Problems 669	
Challenge Problems 670 Conceptual Problems 671	
Questions for Group Work 671 Answers to Conceptual Connections 671	

16.7 Complex Ion Equilibria	707
Chapter in Review	710
Key Terms 710 Key Concepts 710 Key Equations and Relationships 710 Key Learning Objectives 711	
Exercises	711
Problems by Topic 711 Cumulative Problems 714	
Challenge Problems 716 Conceptual Problems 716	
Questions for Group Work 717 Answers to Conceptual Connections 717	



16 Aqueous Ionic Equilibrium	672
16.1 The Danger of Antifreeze	673
16.2 Buffers: Solutions That Resist pH Change	674
Calculating the pH of a Buffer Solution 676	
The Henderson–Hasselbalch Equation 677 Calculating pH Changes in a Buffer Solution 680 The Stoichiometry Calculation 680 The Equilibrium Calculation 681 Buffers Containing a Base and Its Conjugate Acid 683	
16.3 Buffer Effectiveness: Buffer Range and Buffer Capacity	685
Relative Amounts of Acid and Base 685 Absolute Concentrations of the Acid and Conjugate Base 685 Buffer Range 686 Buffer Capacity 687	
16.4 Titrations and pH Curves	688
The Titration of a Strong Acid with a Strong Base 689	
The Titration of a Weak Acid with a Strong Base 692	
The Titration of a Weak Base with a Strong Acid 698	
The Titration of a Polyprotic Acid 698 Indicators: pH-Dependent Colors 699	
16.5 Solubility Equilibria and the Solubility Product Constant	701
K_{sp} and Molar Solubility 701 K_{sp} and Relative Solubility 703 The Effect of a Common Ion on Solubility 703 The Effect of pH on Solubility 705	
16.6 Precipitation	706

17 Free Energy and Thermodynamics	718
17.1 Nature's Heat Tax: You Can't Win and You Can't Break Even	720
17.2 Spontaneous and Nonspontaneous Processes	721
17.3 Entropy and the Second Law of Thermodynamics	722
Entropy 723 The Entropy Change Associated with a Change in State 728	
17.4 Heat Transfer and Changes in the Entropy of the Surroundings	729
The Temperature Dependence of ΔS_{surr} 730 Quantifying Entropy Changes in the Surroundings 730	
17.5 Gibbs Free Energy	732
The Effect of ΔH , ΔS , and T on Spontaneity 734	
17.6 Entropy Changes in Chemical Reactions: Calculating ΔS_{rxn}°	735
Standard Molar Entropies (S°) and the Third Law of Thermodynamics 736	
17.7 Free Energy Changes in Chemical Reactions: Calculating ΔG_{rxn}°	740
Calculating Free Energy Changes with $\Delta G_{rxn}^\circ = \Delta H_{rxn}^\circ - T\Delta S_{rxn}^\circ$ 740 Calculating ΔG_{rxn}° with Tabulated Values of Free Energies of Formation 741 Calculating ΔG_{rxn}° for a Stepwise Reaction from the Changes in Free Energy for Each of the Steps 743 Why Free Energy Is "Free" 744	
17.8 Free Energy Changes for Nonstandard States: The Relationship between ΔG_{rxn}° and ΔG_{rxn}	745
The Free Energy Change of a Reaction Under Nonstandard Conditions 746 Standard Conditions 746 Equilibrium Conditions 747 Other Nonstandard Conditions 747	
17.9 Free Energy and Equilibrium: Relating ΔG_{rxn}° to the Equilibrium Constant (K)	748

Chapter in Review 751

Key Terms 751 Key Concepts 752 Key Equations and Relationships 752 Key Learning Objectives 753

Exercises 753Problems by Topic 753 Cumulative Problems 756
Challenge Problems 757 Conceptual Problems 758
Questions for Group Work 758 Answers to Conceptual Connections 759**18 Electrochemistry** 760**18.1 Pulling the Plug on the Power Grid** 761**18.2 Balancing Oxidation–Reduction Equations** 762**18.3 Voltaic (or Galvanic) Cells: Generating Electricity from Spontaneous Chemical Reactions** 765

Electrochemical Cell Notation 767

18.4 Standard Electrode Potentials 768

Predicting the Spontaneous Direction of an Oxidation–Reduction Reaction 773 Predicting Whether a Metal Will Dissolve in Acid 775

18.5 Cell Potential, Free Energy, and the Equilibrium Constant 775The Relationship between ΔG° and E°_{cell} 776
The Relationship between E°_{cell} and K 777**18.6 Cell Potential and Concentration** 779

Concentration Cells 782

18.7 Batteries: Using Chemistry to Generate Electricity 783Dry-Cell Batteries 783 Lead–Acid Storage Batteries 784
Other Rechargeable Batteries 784 Fuel Cells 785**18.8 Electrolysis: Driving Nonspontaneous Chemical Reactions with Electricity** 786

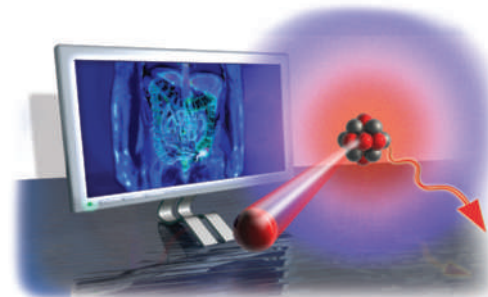
Stoichiometry of Electrolysis 789

18.9 Corrosion: Undesirable Redox Reactions 790

Preventing Corrosion 792

Chapter in Review 793

Key Terms 793 Key Concepts 793 Key Equations and Relationships 794 Key Learning Objectives 795

Exercises 795Problems by Topic 795 Cumulative Problems 798
Challenge Problems 799 Conceptual Problems 800
Questions for Group Work 800 Answers to Conceptual Connections 801**19 Radioactivity and Nuclear Chemistry** 802**19.1 Diagnosing Appendicitis** 803**19.2 Types of Radioactivity** 804Alpha (α) Decay 805 Beta (β) Decay 806 Gamma (γ)
Ray Emission 807 Positron Emission 807 Electron
Capture 807**19.3 The Valley of Stability: Predicting the Type of Radioactivity** 809

Magic Numbers 811 Radioactive Decay Series 811

19.4 The Kinetics of Radioactive Decay and Radiometric Dating 811The Integrated Rate Law 813 Radiocarbon Dating: Using
Radioactivity to Measure the Age of Fossils and
Artifacts 814 Uranium/Lead Dating 816**19.5 The Discovery of Fission: The Atomic Bomb and Nuclear Power** 817

Nuclear Power: Using Fission to Generate Electricity 819

19.6 Converting Mass to Energy: Mass Defect and Nuclear Binding Energy 820

Mass Defect 821

19.7 Nuclear Fusion: The Power of the Sun 823**19.8 The Effects of Radiation on Life** 824Acute Radiation Damage 824 Increased Cancer Risk 824
Genetic Defects 824 Measuring Radiation Exposure 824**19.9 Radioactivity in Medicine** 826

Diagnosis in Medicine 826 Radiotherapy in Medicine 827

Chapter in Review 828Key Terms 828 Key Concepts 829 Key Equations and
Relationships 830 Key Learning Objectives 830**Exercises** 830Problems by Topic 830 Cumulative Problems 832
Challenge Problems 832 Conceptual Problems 833
Questions for Group Work 833 Answers to Conceptual
Connections 833

Appendix I A-1

Appendix II A-7

Appendix III A-17

Appendix IV A-42

Glossary G-1

Credits C-1

Index I-1

This page intentionally left blank

Preface

To the Student

As you begin this course, I invite you to think about your reasons for enrolling in it. Why are you taking general chemistry? More generally, why are you pursuing a college education? If you are like most college students taking general chemistry, part of your answer is probably that this course is required for your major and that you are pursuing a college education so you can get a good job someday. While these are good reasons, I suggest a better one. I think the primary reason for your education is to prepare you to *live a good life*. You should understand chemistry—not for what it can *get* you—but for what it can *do* for you. Understanding chemistry, I believe, is an important source of happiness and fulfillment. Let me explain.

Understanding chemistry helps you to live life to its fullest for two basic reasons. The first is *intrinsic*: Through an understanding of chemistry, you gain a powerful appreciation for just how rich and extraordinary the world really is. The second reason is *extrinsic*: Understanding chemistry makes you a more informed citizen—it allows you to engage with many of the issues of our day. In other words, understanding chemistry makes *you* a deeper and richer person and makes your country and the world a better place to live. These reasons have been the foundation of education from the very beginnings of civilization.

How does chemistry help prepare you for a rich life and conscientious citizenship? Let me explain with two examples. My first one comes from the very first page of Chapter 1 of this book. There, I ask the following question: What is the most important idea in all of scientific knowledge? My answer to that question is this: **The properties of matter are determined by the properties of molecules and atoms.** That simple statement is the reason I love chemistry. We humans have been able to study the substances that compose the world around us and explain their behavior by reference to particles so small that they can hardly be imagined. If you have never realized the remarkable sensitivity of the world we *can* see to the world we *cannot*, you have missed out on a fundamental truth about our universe. To have never encountered this truth is like never having read a play by Shakespeare or seen a sculpture by Michelangelo—or, for that matter, like never having discovered that the world is round. It robs you of an amazing and unforgettable experience of the world and the human ability to understand it.

My second example demonstrates how science literacy helps you to be a better citizen. Although I am largely sympathetic to the environmental movement, a lack of science literacy within some sectors of that movement, and the resulting anti-environmental backlash, creates confusion that impedes real progress and opens the door to what could be misinformed policies. For example, I have heard conservative pundits say that volcanoes emit more carbon dioxide—the most

significant greenhouse gas—than does petroleum combustion. I have also heard a liberal environmentalist say that we have to stop using hairspray because it is causing holes in the ozone layer that will lead to global warming. Well, the claim about volcanoes emitting more carbon dioxide than petroleum combustion can be refuted by the basic tools you will learn to use in Chapter 4 of this book. We can easily show that volcanoes emit only 1/50th as much carbon dioxide as petroleum combustion. As for hairspray depleting the ozone layer and thereby leading to global warming: The chlorofluorocarbons that deplete ozone have been banned from hairspray since 1978, and ozone depletion has nothing to do with global warming anyway. People with special interests or axes to grind can conveniently distort the truth before an ill-informed public, which is why we all need to be knowledgeable.

So this is why I think you should take this course. Not just to satisfy the requirement for your major, and not just to get a good job someday, but also to help you to lead a fuller life and to make the world a little better for everyone. I wish you the best as you embark on the journey to understand the world around you at the molecular level. The rewards are well worth the effort.

To the Professor

First and foremost, thanks to all of you who adopted this book in its first and second editions. You helped to make this book successful and I am grateful beyond words. Second, I have listened carefully to your feedback on the previous edition. The changes you see in this edition are a direct result of your input, as well as my own experience in using the book in my general chemistry courses. If you have acted as a reviewer or have contacted me directly, you are likely to see your suggestions reflected in the changes I have made. The goal of this edition remains the same: *to present a rigorous and accessible treatment of general chemistry in the context of relevance.*

Teaching general chemistry would be much easier if all of our students had exactly the same level of preparation and ability. But alas, that is not the case. Even though I teach at a relatively selective institution, my courses are populated with students with a range of backgrounds and abilities in chemistry. The challenge of successful teaching, in my opinion, is therefore figuring out how to instruct and challenge the best students while not losing those with lesser backgrounds and abilities. My strategy has always been to set the bar relatively high, while at the same time providing the motivation and support necessary to reach the high bar. That is exactly the philosophy of this book. We do not have to compromise away rigor in order to make chemistry accessible to our students. In this book, I have worked hard to combine rigor with accessibility—to create a book that does not dilute the content, yet can be used and understood by any student willing to put in the necessary effort.

Principles of Chemistry: A Molecular Approach is first a *student-oriented* book. My main goal is to motivate students and get them to achieve at the highest possible level. As we all know, many students take general chemistry because it is a requirement; they do not see the connection between chemistry and their lives or their intended careers. *Principles of Chemistry: A Molecular Approach* strives to make those connections consistently and effectively. Unlike other books, which often teach chemistry as something that happens only in the laboratory or in industry, this book teaches chemistry in the context of relevance. It shows students *why* chemistry is important to them, to their future careers, and to their world.

Second, *Principles of Chemistry: A Molecular Approach* is a *pedagogically-driven* book. In seeking to develop problem-solving skills, a consistent approach (Sort, Strategize, Solve, and Check) is applied, usually in a two- or three-column format. In the two-column format, the left column shows the student how to analyze the problem and devise a solution strategy. It also lists the steps of the solution, explaining the rationale for each one, while the right column shows the implementation of each step. In the three-column format, the left column outlines a general procedure for solving an important category of problems that is then applied to two side-by-side examples. This strategy allows students to see both the general pattern and the slightly different ways in which the procedure may be applied in differing contexts. The aim is to help students understand both the *concept of the problem* (through the formulation of an explicit conceptual plan for each problem) and the *solution to the problem*.

Third, *Principles of Chemistry: A Molecular Approach* is a *visual* book. Wherever possible, images are used to deepen the student's insight into chemistry. In developing chemical principles, multipart images help to show the connection between everyday processes visible to the unaided eye and what atoms and molecules are actually doing. Many of these images have three parts: macroscopic, molecular, and symbolic. This combination helps students to see the relationships between the formulas they write down on paper (symbolic), the world they see around them (macroscopic), and the atoms and molecules that compose that world (molecular). In addition, most figures are designed to teach rather than just to illustrate. They are rich with annotations and labels intended to help the student grasp the most important processes and the principles that underlie them. The resulting images contain significant amounts of information but are also uncommonly clear and quickly understood.

Fourth, *Principles of Chemistry: A Molecular Approach* is a "*big picture*" book. At the beginning of each chapter, a short introduction helps students to see the key relationships between the different topics they are learning. Through focused and concise narrative, I strive to make the basic ideas of every chapter clear to the student. Interim summaries are provided at selected spots in the narrative, making it easier to grasp (and review) the main points of important discussions. And to make sure that students never lose sight of the forest for the trees, each chapter includes several *Conceptual Connections*, which ask them to think about concepts and solve problems without doing any math. I want students to learn the concepts, not just plug numbers into equations to churn out the right answer.

Principles of Chemistry: A Molecular Approach is, lastly, a book that delivers the core of the standard chemistry curriculum, without sacrificing depth of coverage. Through our research, we have determined the topics that most faculty do not teach and we have eliminated them. When writing a brief book, the temptation is great to cut out the sections that show the excitement and relevance of chemistry; *we have not done that here*. Instead, we have cut out pet topics that are often included in books simply to satisfy a small minority of the market. We have also eliminated extraneous material that does not seem central to the discussion. The result is a lean book that covers core topics in depth, while still demonstrating the relevance and excitement of these topics.

I hope that this book supports you in your vocation of teaching students chemistry. I am increasingly convinced of the importance of our task. Please feel free to email me with any questions or comments about the book.

Nivaldo J. Tro
tro@westmont.edu

What's New in This Edition?

The third edition has been extensively revised and contains many more small changes than I can detail here. Below is a list of the most significant changes from the previous edition.

- More robust media components have been added, including 80 Interactive Worked Examples, 39 Key Concept Videos, 14 additional Pause & Predict videos, 33 PHET simulations, and 5 new Mastering simulations with tutorials.
- Each chapter now has a 10–15 question multiple-choice end-of-chapter Self-Assessment Quiz. Since many colleges and universities use multiple-choice exams, and because standardized final exams are often multiple choice, students can use these quizzes to both assess their knowledge of the material in the chapter and to prepare for exams. These quizzes are also available on mobile devices.
- Approximately 100 new end-of-chapter group work questions have been added to encourage small group work in or out of the classroom.
- Approximately 45 new end-of-chapter problems have been added.
- New conceptual connections have been added and many from the previous edition have been modified. In addition, to support active, in class, learning, these questions are now available in Learning Catalytics.
- All data have been updated to the most recent available. See for example:

Section 1.7 *The Reliability of a Measurement* in which the data in the table of carbon monoxide concentrations in Los Angeles County (Long Beach) have been updated.

Figure 4.2 *Carbon Dioxide Concentrations in the Atmosphere* is updated to include information through 2013.

Figure 4.3 *Global Temperature* is updated to include information through 2013.

Figure 4.19 *U.S. Energy Consumption* is updated to include the most recent available information.

- Many figures and tables have been revised for clarity. See, for example:

Figure 3.6 *Metals Whose Charge Is Invariant* in Section 3.5. This replaces Table 3.2 *Metals Whose Charge Is Invariant from One Compound to Another*.

The weather map in Section 5.2 has been replaced, and the caption for the weather map has been simplified and linked more directly to the text discussion.

Figure 7.3 *Components of White Light* has been replaced with a corrected image of light passing through a prism.

Figure 7.4 *The Color of an Object* and Figure 7.17 *The Quantum-Mechanical Strike Zone* both have updated photos.

The orbital diagram figure in Section 7.5 *Quantum Mechanics and the Atom* that details the various principal levels and sublevels has been replaced with an updated version that is more student-friendly and easier to navigate.

Figure 8.2 *Shielding and Penetration* is modified so that there is a clear distinction between parts a and b.

Figure 10.15 *Molecular Orbital Energy Diagrams for Second-Row Homonuclear Diatomic Molecules* now has magnetic properties and valence electron configuration information.

Figure 12.10 *Solubility and Temperature*. Data for Na_2SO_4 have been deleted from the graph, and data $\text{Ce}_2(\text{SO}_4)_3$ have been added to the graph.

Figure 13.11 *Thermal Energy Distribution* is modified. It is now noted in the caption that E_a is a constant and does not depend on temperature; new notations have also been added to the figure.

Table 15.5 *Acid Ionization Constants for Some Monoprotic Weak Acids at 25 °C* has been modified to include $\text{p}K_a$ values.

The unnumbered photo of a fuel cell car in Section 18.1 *Pulling the Plug on the Power Grid* has been replaced with an updated image of a newer fuel cell car.

- In Section 10.5 and throughout Chapter 11, the use of electrostatic potential maps has been expanded. See, for example, Figures 11.6, 11.7, 11.9, and 11.10.
- In Section 10.8 *Molecular Orbital Theory: Electron Delocalization* in the subsection on *Linear Combination of Atomic Orbitals (LCAO)*, a discussion of molecular orbital electron configuration has been added.
- New chapter-opening art, briefer introductory material, and a new first section (11.1 *Water, No Gravity*) replace Section 11.1.
- In Section 13.4 *The Integrated Rate Law: The Dependence of Concentration on Time*, the derivation to integrate the differential rate law to obtain the first-order integrated rate law is now shown in a margin note.
- The format for all the ICE tables is new in Chapters 14, 15, and 16; the format has been modified to make them easier to read.

- A new section entitled *The Titration of a Polyprotic Acid* has been added to Section 16.4 *Titrations and Curves*. Content includes new Figure 16.8 *Titration Curve: Diprotic Acid with Strong Base*.
- Some new in-chapter examples have been added, including Example 4.14 *Writing Equations for Acid–Base Reactions Involving a Weak Acid* and Example 9.9 *Drawing Resonance Structures and Assigning Formal Charge for Organic Compounds*.

Acknowledgments

The book you hold in your hands bears my name on the cover, but I am really only one member of a large team that carefully crafted this book. Most importantly, I thank my editor, Terry Haugen, who has become a friend and colleague. Terry is a skilled and competent editor. He has given me direction, inspiration, and most importantly, loads of support. I am just as grateful for my program manager, Jessica Moro, and project manager, Beth Sweeten, who have worked tirelessly behind the scenes to bring this project to completion. I continue to be grateful for Jennifer Hart in her new role overseeing development. Jennifer, your guidance and wisdom are central to the success of my projects, and I am eternally grateful. I am also grateful to Caitlin Falco who helped with organizing reviews, as well as numerous other tasks associated with keeping the team running smoothly. I also thank Erin Mulligan, who has now worked with me on many projects. Erin is an outstanding developmental editor who not only worked with me on crafting and thinking through every word but is now also a friend and fellow foodie. I am also grateful to Adam Jaworski. Adam has become a fantastic leader at Pearson and a friend to me. Thanks also to Dave Theisen, who has been selling my books for 15 years and has become a great friend. Dave, I appreciate your tireless efforts, your professionalism, and your in-depth knowledge of my work. And of course, I am continually grateful for Paul Corey, with whom I have now worked for over 14 years and a dozen books. Paul is a man of incredible energy and vision, and it is my great privilege to work with him. Paul told me many years ago (when he first signed me on to the Pearson team) to dream big, and then he provided the resources I needed to make those dreams come true. *Thanks, Paul*. I would also like to thank my first editor at Pearson, Kent Porter-Hamann. Kent and I spent many good years together writing books, and I continue to miss her presence in my work.

I am also grateful to my marketing managers, Will Moore and Chris Barker, who have helped to develop a great marketing campaign for my books and are all good friends. I am deeply grateful to Gary Hespenheide for crafting the design of this text. I would like to thank Beth Sweeten and the rest of the Pearson production team. I also thank Francesca Monaco and her co-workers at CodeMantra. I am a picky author and Francesca is endlessly patient and a true professional. I am also greatly indebted to my copy editor, Betty Pessagno, for her dedication and professionalism, and to Lauren McFalls, for her exemplary photo research. I owe a special debt of gratitude to Quade and Emiko Paul, who continue to make my

ideas come alive in their art. Thanks also to Derek Bacchus for his work on the cover and with design.

I would like to acknowledge the help of my colleagues Allan Nishimura, Michael Everest, Kristi Lazar, Steve Contakes, David Marten, and Carrie Hill, who have supported me in my department while I worked on this book. Double thanks to Michael Everest for also authoring the Questions for Group Work. I am also grateful to those who have supported me personally. First on that list is my wife, Ann. Her love rescued a broken man fifteen years ago and without her, none of this would have been possible. I am also indebted to my children, Michael, Ali, Kyle, and Kaden, whose smiling faces and love of life always inspire me. I come from a large Cuban family whose closeness and support most people would envy. Thanks to my parents, Nivaldo and Sara; my siblings, Sarita, Mary, and Jorge; my siblings-in-law, Nachy, Karen, and John; my nephews and nieces, Germain, Danny, Lisette, Sara, and Kenny. These are the people with whom I celebrate life.

I would like to thank all of the general chemistry students who have been in my classes throughout my years as a professor at Westmont College. You have taught me much about teaching that is now in this book. I would also like to express my appreciation to Michael Tro, who also helped in manuscript development, proofreading, and working new problems.

Lastly, I am indebted to the many reviewers whose ideas are embedded throughout this book. They have corrected me, inspired me, and sharpened my thinking on how best to teach this subject we call chemistry. I deeply appreciate their commitment to this project. Thanks also to Frank Lambert for helping us all to think more clearly about entropy and for his review of the entropy sections of the book. Last but by no means least, I would like to record my gratitude to Brian Gute, Milton Johnston, Jessica Parr, and John Vincent whose alertness, keen eyes, and scientific astuteness help make this a much better book.

Reviewers

Patrice Bell, *Georgia Gwinnett College*
 Sharmaine Cady, *East Stroudsburg University*
 James Cleveland, *Northeast State Community College*
 Chris Collinson, *Rochester Institute of Technology*
 Charlie Cox, *Stanford University*
 Brent Cunningham, *James Madison University*
 Bridget Decker, *University of Wyoming-Laramie*
 William Deese, *Louisiana Tech University*
 Dawn Del Carlo, *University of Northern Iowa*
 Steve Everly, *Lincoln Memorial University*
 Daniel Finnen, *Shawnee State University*
 Paul Fischer, *Macalester College*
 David Geiger, *The State University of New York (Geneseo)*
 Patricia Goodson, *University of Wyoming*
 Burt Hollandsworth, *Harding University*
 Matthew Horn, *Utah Valley University*
 Mary Elizabeth Kinsel, *Southern Illinois University*
 Gerald Korenowski, *Rensselaer Polytechnic Institute*
 Hoitung Leung, *University of Virginia*

Clifford Padgett, *Armstrong State University*
 Andrew Price, *Temple University*
 Jennifer Schwartz Poehlmann, *Stanford University*
 Anthony Smith, *Walla Walla University*
 Thomas Sorensen, *University of Wisconsin (Milwaukee)*
 Kara Tierney, *Monroe Community College*
 Rosie Walker, *Metropolitan State University of Denver*

Accuracy Reviewers

Brian Gute, *University of Minnesota, Duluth*
 Milton Johnston, *University of South Florida*
 Jessica Parr, *University of Southern California*
 John Vincent, *University of Alabama*

Previous Edition Reviewers

Patricia G. Amateis, *Virginia Tech*
 T.J. Anderson, *Francis Marion University*
 Paul Badger, *Robert Morris University*
 Yiyang Bai, *Houston Community College*
 Maria Ballester, *Nova Southeastern University*
 Rebecca Barlag, *Ohio University*
 Shuhsien Batamo, *Houston Community College (Central Campus)*
 Craig A. Bayse, *Old Dominion University*
 Maria Benavides, *University of Houston, Downtown*
 Charles Benesh, *Wesleyan College*
 Silas C. Blackstock, *University of Alabama*
 Justin Briggles, *East Texas Baptist University*
 Ron Briggs, *Arizona State University*
 Katherine Burton, *Northern Virginia Community College*
 David A. Carter, *Angelo State University*
 Linda P. Cornell, *Bowling Green State University, Firelands*
 Charles T. Cox, Jr., *Georgia Institute of Technology*
 David Cunningham, *University of Massachusetts, Lowell*
 Michael L. Denniston, *Georgia Perimeter College*
 Ajit S. Dixit, *Wake Technical Community College*
 David K. Erwin, *Rose-Hulman Institute of Technology*
 Giga Geme, *University of Central Missouri*
 Vincent P. Giannamore, *Nicholls State University*
 Pete Golden, *Sandhills Community College*
 Robert A. Gossage, *Acadia University*
 Susan Hendrickson, *University of Colorado (Boulder)*
 Angela Hoffman, *University of Portland*
 Andrew W. Holland, *Idaho State University*
 Narayan S. Hosmane, *Northern Illinois University*
 Jason C. Jones, *Francis Marion University*
 Jason A. Kautz, *University of Nebraska, Lincoln*
 Chulsung Kim, *Georgia Gwinnett College*
 Scott Kirkby, *East Tennessee State University*
 Richard H. Langley, *Stephen F. Austin State University*
 Christopher Lovallo, *Mount Royal College*
 Eric Malina, *University of Nebraska, Lincoln*
 David H. Metcalf, *University of Virginia*
 Dinty J. Musk, Jr., *Ohio Dominican University*
 Edward J. Neth, *University of Connecticut*
 MaryKay Orgill, *University of Nevada, Las Vegas*

Gerard Parkin, *Columbia University*
 BarJean Phillips, *Idaho State University*
 Nicholas P. Power, *University of Missouri*
 Changyong Qin, *Benedict College*
 William Quintana, *New Mexico State University*
 Valerie Reeves, *University of New Brunswick*
 Dawn J. Richardson, *Collin College*
 Thomas G. Richmond, *University of Utah*
 Melinda S. Ripper, *Butler County Community College*
 Jason Ritchie, *The University of Mississippi*
 Christopher P. Roy, *Duke University*
 Jamie Schneider, *University of Wisconsin (River Falls)*
 John P. Scovill, *Temple University*
 Thomas E. Sorensen, *University of Wisconsin, Milwaukee*
 Vinodhkumar Subramaniam, *East Carolina University*
 Dennis Swauger, *Ulster County Community College*
 Ryan Sweeder, *Michigan State University*
 Chris Syvinski, *University of New England*
 Dennis Taylor, *Clemson University*
 David Livingstone Toppen, *California State University,
 Northridge*
 Harold Trimm, *Broome Community College*
 Tommaso A. Vannelli, *Western Washington University*
 Kristofoland Varazo, *Francis Marion University*
 Susan Varkey, *Mount Royal College*
 Joshua Wallach, *Old Dominion University*
 Clyde L. Webster, *University of California, Riverside*
 Wayne Wesolowski, *University of Arizona*
 Kurt Winkelmann, *Florida Institute of Technology*
 Edward P. Zovinka, *Saint Francis University*

Previous Edition Accuracy Reviewers

Margaret Asirvatham, *University of Colorado, Boulder*
 Rebecca Barlag, *Ohio University*

Angela Hoffman, *University of Portland*
 Louis Kirschenbaum, *University of Rhode Island*
 Richard Langley, *Stephen F. Austin State University*
 Kathleen Thrush Shaginaw, *Particular Solutions, Inc.*
 Sarah Siegel, *Gonzaga University*
 Steven Socol, *McHenry County College*

Focus Group Participants

Yiyang Bai, *Houston Community College*
 Silas Blackstock, *University of Alabama*
 Jason Kautz, *University of Nebraska (Lincoln)*
 Michael Mueller, *Rose-Hulman Institute of Technology*
 Tom Pentecost, *Grand Valley State University*
 Andrew Price, *Temple University*
 Cathrine Reck, *Indiana University*
 Sarah Siegel, *Gonzaga University*
 Shusien Wang-Batamo, *Houston Community College*
 Lin Zhu, *Indiana University–Purdue University Indianapolis*

Pearson would like to thank and acknowledge the following people for their work on the Global Edition.

Contributor

Erode N. Prabhakaran, *Indian Institute of Science*

Reviewers

D.V.S Jain, *Panjab University*
 Debajyoti Mahanta, *Gauhati University*
 Prasanna Ghalsasi, *MS University*
 Wouter Herrebout, *University of Antwerpen*
 Chitralekha Sidana

Chemistry through Relevancy

Chemistry is relevant to every process occurring around us at every second. Niva Tro helps students understand this connection by weaving specific, vivid examples throughout the text and media that tell the story of chemistry. Every chapter begins with a brief story showing how chemistry is relevant to all people, at every moment.

11

Liquids, Solids, and Intermolecular Forces

It's a wild dance floor there at the molecular level.
—Roald Hoffmann (1937-)



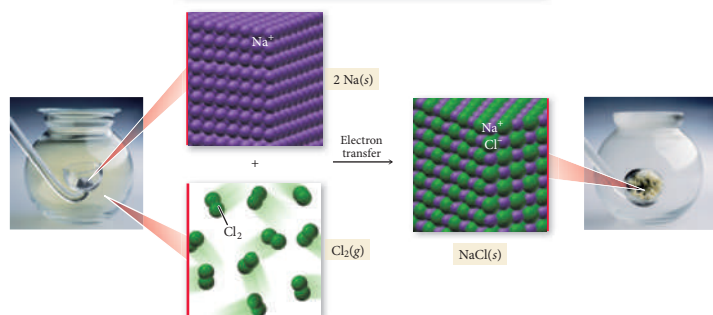
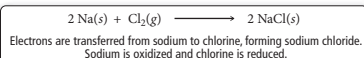
WE LEARNED IN CHAPTER 1 THAT matter exists primarily in three states: solid, liquid, and gas. In Chapter 5, we examined the gas state. In this chapter we turn to the solid and liquid states, known collectively as the condensed states (or condensed phases). The solid and liquid states are more similar to each other than they are to the gas state. In the gas state, the constituent particles—atoms or molecules—are separated by large distances and do not interact with each other very much. In the condensed states, the constituent particles are close together and exert moderate to strong attractive forces on one another. Whether a substance is a solid, liquid, or gas at room temperature depends on the magnitude of the attractive forces among the constituent particles. In this chapter, we will see how the properties of a particular atom or molecule determine the magnitude of those attractive forces.

- 11.1 Water, No Gravity 429
 - 11.2 Solids, Liquids, and Gases: A Molecular Comparison 430
 - 11.3 Intermolecular Forces: The Forces That Hold Condensed States Together 432
 - 11.4 Intermolecular Forces in Action: Surface Tension, Viscosity, and Capillary Action 440
 - 11.5 Vaporization and Vapor Pressure 442
 - 11.6 Sublimation and Fusion 451
 - 11.7 Heating Curve for Water 453
 - 11.8 Phase Diagrams 454
 - 11.9 Water: An Extraordinary Substance 456
 - 11.10 Crystalline Solids: Unit Cells and Basic Structures 457
 - 11.11 Crystalline Solids: The Fundamental Types 463
 - 11.12 Crystalline Solids: Band Theory 467
- Key Learning Objectives 471

11.1 Water, No Gravity

In the space station there are no spills. When an astronaut squeezes a full water bottle, the water squirts out like it does on Earth, but instead of falling to the floor and forming a puddle, the water sticks together to form a floating, oscillating, blob of water. Over time, the blob stops oscillating and forms a nearly perfect sphere. Why?

Oxidation–Reduction Reaction without Oxygen



▲ FIGURE 4.17 Oxidation–Reduction without Oxygen When sodium reacts with chlorine, electrons are transferred from the sodium to the chlorine, resulting in the formation of sodium chloride. In this redox reaction, sodium is oxidized and chlorine is reduced.

The reaction between sodium and oxygen forms other oxides as well.

Visualizing Chemistry

Student-friendly, multipart images include macroscopic, molecular, and symbolic perspectives with the goal of connecting you to what you see and experience (macroscopic) with the molecules responsible for that world (molecular) and with the way chemists represent those molecules (symbolic). Illustrations include extensive labels and annotations to highlight key elements and to help differentiate the most critical information (white box) to secondary information (beige box).

Interactive Problem-Solving Strategy

A unique yet consistent step-by-step format encourages logical thinking throughout the problem-solving process rather than simply memorizing formulas.

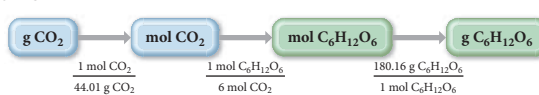
Icons appear next to examples indicating a digital version is available in the etext and on mobile devices via a QR code located here, and on the back cover of your textbook.

EXAMPLE 4.1 Stoichiometry

During photosynthesis, plants convert carbon dioxide and water into glucose ($C_6H_{12}O_6$) according to the reaction:

$$6 CO_2(g) + 6 H_2O(l) \xrightarrow{\text{sunlight}} 6 O_2(g) + C_6H_{12}O_6(aq)$$

Suppose a particular plant consumes 37.8 g CO_2 in one week. Assuming that there is more than enough water present to react with all of the CO_2 , what mass of glucose (in grams) can the plant synthesize from the CO_2 ?

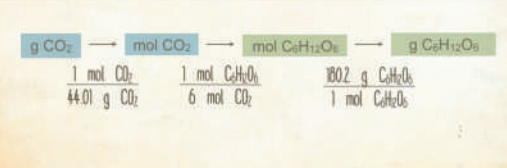
SORT The problem gives the mass of carbon dioxide and asks you to find the mass of glucose that can be produced.	GIVEN 37.8 g CO_2 FIND g $C_6H_{12}O_6$
STRATEGIZE The conceptual plan follows the general pattern of mass A \rightarrow amount A (in moles) \rightarrow amount B (in moles) \rightarrow mass B. From the chemical equation, you can deduce the relationship between moles of carbon dioxide and moles of glucose. Use the molar masses to convert between grams and moles.	CONCEPTUAL PLAN 
SOLVE Follow the conceptual plan to solve the problem. Begin with g CO_2 and use the conversion factors to arrive at g $C_6H_{12}O_6$.	RELATIONSHIPS USED molar mass $CO_2 = 44.01 \text{ g/mol}$ $6 \text{ mol } CO_2 : 1 \text{ mol } C_6H_{12}O_6$ molar mass $C_6H_{12}O_6 = 180.16 \text{ g/mol}$ SOLUTION $37.8 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{1 \text{ mol } C_6H_{12}O_6}{6 \text{ mol } CO_2} \times \frac{180.16 \text{ g } C_6H_{12}O_6}{1 \text{ mol } C_6H_{12}O_6} = 25.8 \text{ g } C_6H_{12}O_6$
CHECK The units of the answer are correct. The magnitude of the answer (25.8 g) is less than the initial mass of CO_2 (37.8 g). This is reasonable because each carbon in CO_2 has two oxygen atoms associated with it, while in $C_6H_{12}O_6$ each carbon has only one oxygen atom associated with it and two hydrogen atoms, which are much lighter than oxygen. Therefore the mass of glucose produced should be less than the mass of carbon dioxide for this reaction.	
FOR PRACTICE 4.1 Magnesium hydroxide, the active ingredient in milk of magnesia, neutralizes stomach acid, primarily HCl, according to the reaction: $Mg(OH)_2(aq) + 2 HCl(aq) \rightarrow 2 H_2O(l) + MgCl_2(aq)$ What mass of HCl, in grams, is neutralized by a dose of milk of magnesia containing 3.26 g $Mg(OH)_2$?	

Stoichiometry

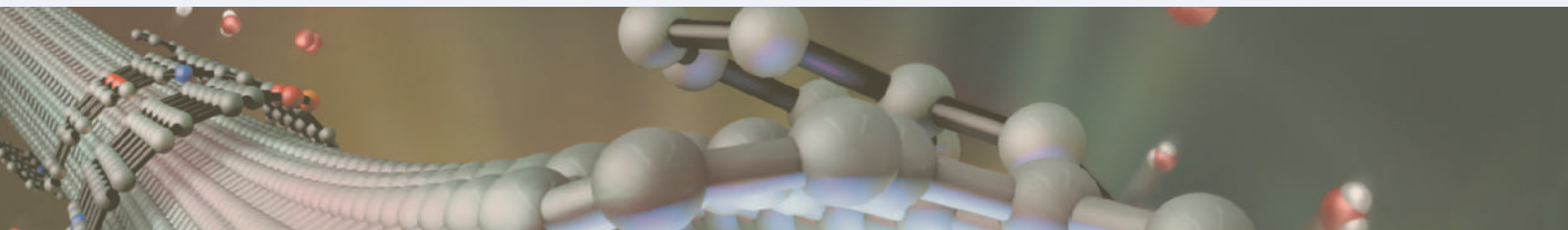
Given: 37.8 g of CO_2

$$6 CO_2(g) + 6 H_2O(l) \xrightarrow{\text{sunlight}} 6 O_2(g) + C_6H_{12}O_6(aq)$$

Find: g $C_6H_{12}O_6$



NEW! 80 Interactive Worked Examples make Tro's unique problem-solving strategies interactive, bringing his award-winning teaching directly to all students using his text. In these digital, mobile versions, students are instructed how to break down problems using Tro's proven *Sort, Strategize, Solve, and Check* technique.



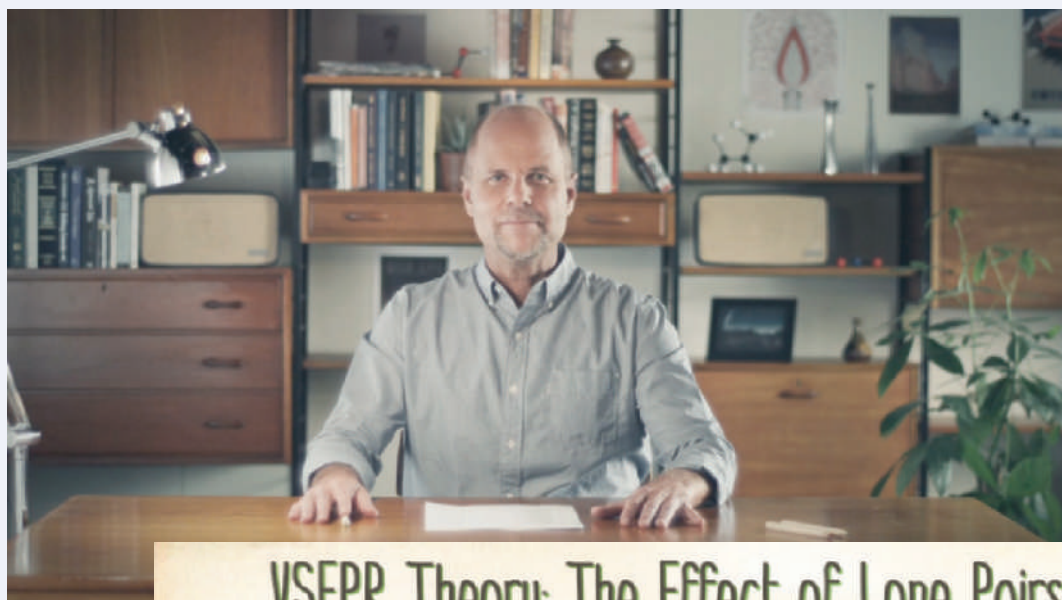
A Focus on Conceptual Understanding

Key Concept Videos

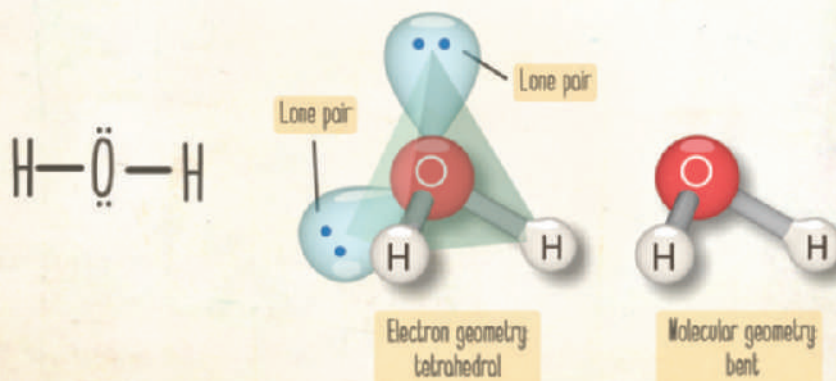
NEW! 39 Key Concept Videos combine artwork from the textbook with both 2D and 3D animations to create a dynamic on-screen viewing and learning experience. These short videos include narration and brief live-action clips of author Niva Tro explaining the key concepts of each chapter.



KEY CONCEPT VIDEO
VSEPR Theory: The Effect of Lone Pairs



VSEPR Theory: The Effect of Lone Pairs



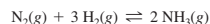
Conceptual Connections

Conceptual Connections are strategically placed to reinforce conceptual understanding of the most complex concepts.

CONCEPTUAL CONNECTION 5.5

PRESSURE AND NUMBER OF MOLES

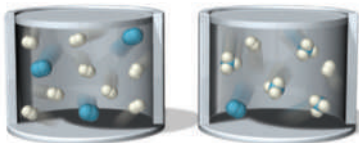
Nitrogen and hydrogen react to form ammonia according to the equation:



Consider the representations shown here of the initial mixture of reactants and the resulting mixture after the reaction has been allowed to react for some time.

If the volume is kept constant, and nothing is added to the reaction mixture, what happens to the course of the reaction?

- (a) The pressure increases.
- (b) The pressure decreases.
- (c) The pressure does not change.



CONCEPTUAL CONNECTION 17.7

K AND $\Delta G_{\text{rxn}}^{\circ}$

The reaction $\text{A}(\text{g}) \rightleftharpoons \text{B}(\text{g})$ has an equilibrium constant that is less than one. What can you conclude about $\Delta G_{\text{rxn}}^{\circ}$ for the reaction?

- (a) $\Delta G_{\text{rxn}}^{\circ} = 0$
- (b) $\Delta G_{\text{rxn}}^{\circ} < 0$
- (c) $\Delta G_{\text{rxn}}^{\circ} > 0$

Enhanced End-of-Chapter Material

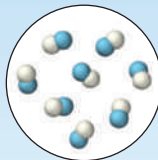
NEW! Self Assessment Quizzes contain 10–15 multiple-choice questions, authored in the ACS-exam and MCAT style to help students optimize the use of quizzing to improve their understanding and class performance.

The Self Assessment Quizzes are also assignable in MasteringChemistry and contain wrong-answer feedback as well as links to the eText.

Self-Assessment QUIZ

- Q1. A chemist mixes sodium with water and witnesses a violent reaction between the metal and water. This is best classified as:
- a. an observation
 - b. a law
 - c. a hypothesis
 - d. a theory

- Q2. This image represents a particulate view of a sample of matter. Classify the sample according to its composition.



- a. The sample is a pure element.
- b. The sample is a homogeneous mixture.
- c. The sample is a compound.
- d. The sample is a heterogeneous mixture.

- Q3. Which change is a physical change?
- a. wood burning
 - b. iron rusting
 - c. dynamite exploding
 - d. gasoline evaporating

- Q4. Which property of rubbing alcohol is a chemical property?
- a. its density (0.786 g/cm³)
 - b. its flammability
 - c. its boiling point (82.5 °C)
 - d. its melting point (-89 °C)

- Q5. Convert 85.0 °F to K.
- a. 181.1 K
 - b. 358 K
 - c. 29.4 K
 - d. 302.6 K

- Q6. Express the quantity 33.2×10^{-4} m in mm.
- a. 33.2 mm
 - b. 3.32 mm
 - c. 0.332 mm
 - d. 3.32×10^{-6} mm

- Q7. Determine the mass of a 1.75 L sample of a liquid that has a density of 0.921 g/mL.
- a. 1.61×10^3 g
 - b. 1.61×10^{-3} g
 - c. 1.90×10^3 g
 - d. 1.90×10^{-3} g

- Q8. Perform the calculation to the correct number of significant figures.

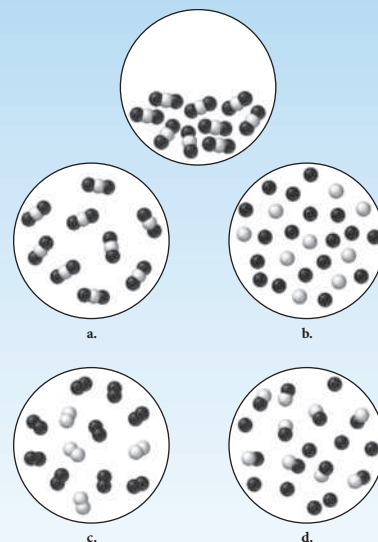
$$43.998 \times 0.00552 / 2.002$$

- a. 0.121
 - b. 0.12
 - c. 0.12131
 - d. 0.1213
- Q9. Perform the calculation to the correct number of significant figures.

$$(8.01 - 7.50) / 3.002$$

- a. 0.1698867
 - b. 0.17
 - c. 0.170
 - d. 0.1700
- Q10. Convert 1285 cm² to m².
- a. 1.285×10^2 m²
 - b. 12.85 m²
 - c. 0.1285 m²
 - d. 1.285×10^5 m²

- Q11. The first diagram shown here depicts a compound in its liquid state. Which of the diagrams that follow best depicts the compound after it has evaporated into a gas?



- Q12. Three samples, each of a different substance, are weighed and their volume is measured. The results are tabulated here. List the substances in order of decreasing density.

	Mass	Volume
Substance I	10.0 g	10.0 mL
Substance II	10.0 kg	12.0 L
Substance III	12.0 mg	10.0 μ L

- a. III > II > I
 - b. I > II > III
 - c. III > I > II
 - d. II > I > III
- Q13. A solid metal sphere has a radius of 3.53 cm and a mass of 1.796 kg. What is the density of the metal in g/cm³? (The volume of a sphere is $V = \frac{4}{3}\pi r^3$.)
- a. 34.4 g/cm³
 - b. 0.103 g/cm³
 - c. 121 g/cm³
 - d. 9.75 g/cm³
- Q14. A European automobile's gas mileage is 22 km/L. Convert this quantity to miles per gallon.
- a. 9.4 mi/gal
 - b. 1.3×10^2 mi/gal
 - c. 52 mi/gal
 - d. 3.6 mi/gal
- Q15. A wooden block has a volume of 18.5 in³. What is its volume in cm³?
- a. 303 cm³
 - b. 47.0 cm³
 - c. 1.13 cm³
 - d. 7.28 cm³

Active and Adaptive

Personalize Learning with MasteringChemistry®

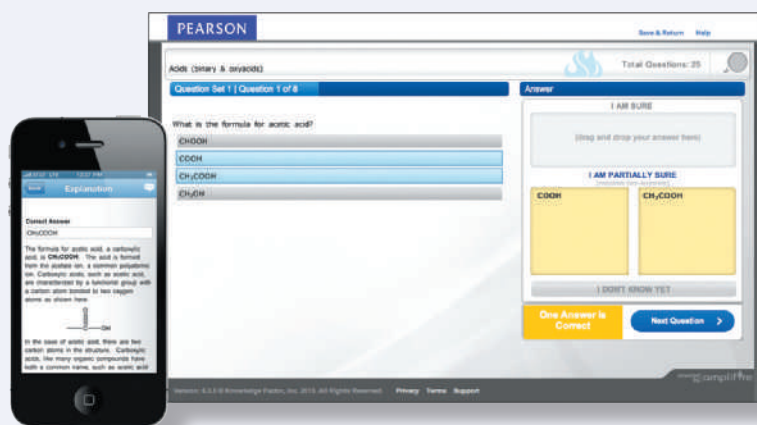
MasteringChemistry® from Pearson is the leading online homework, tutorial, and assessment system, designed to improve results by engaging students before, during, and after class with powerful content. Instructors ensure students arrive ready to learn by assigning educationally effective content before class, and encourage critical thinking and retention with in-class resources such as Learning Catalytics™. Students can further master concepts after class through traditional and adaptive homework assignments that provide hints and answer-specific feedback. The Mastering gradebook records scores for all automatically graded assignments in one place, while diagnostic tools give instructors access to rich data to assess student understanding and misconceptions.

Mastering brings learning full circle by continuously adapting to each student and making learning more personal than ever—before, during, and after class.

BEFORE CLASS

Dynamic Study Modules

Dynamic Study Modules are designed to enable students to study effectively on their own by helping them quickly access the information they need to be more successful on quizzes and exams. Utilizing a dynamic process of test-learn-retest, these modules adjust to the needs of each individual student and enable mastery of the material. They can be accessed on smartphones, tablets, or computers, and the results can be tracked in the Mastering Gradebook.



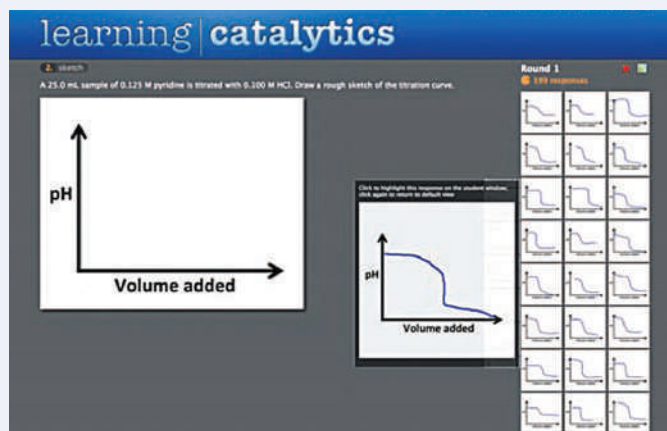
DURING CLASS

Learning Catalytics™

Learning Catalytics is a *bring your own device* student engagement, assessment, and classroom intelligence system. With Learning Catalytics, instructors can:

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students' critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics fit your course exactly.
- Manage student interactions with intelligent grouping and timing.

Learning Catalytics is a technology that has grown out of twenty years of cutting edge research, innovation, and implementation of interactive teaching and peer instruction.



AFTER CLASS

Tutorials

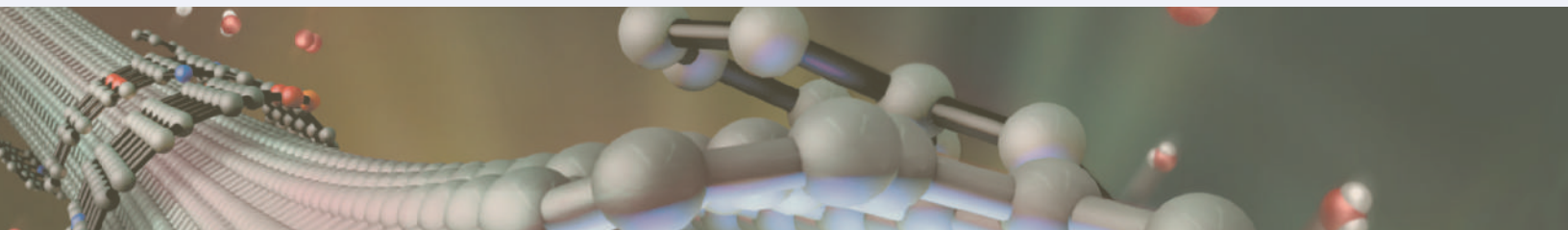
Tutorials, which feature specific wrong-answer feedback, hints, and a wide variety of educationally effective content, guide your students through the toughest topics in chemistry. The hallmark Hints and Feedback offer instruction similar to what students would experience in an office hour visit, allowing them to learn from their mistakes without being given the answer.

The screenshot shows a tutorial interface for 'Titration of Weak Acid with Strong Base'. It includes a problem description: 'A certain weak acid, HA, with a K_a value of 5.61×10^{-6} , is titrated with NaOH.' The problem is divided into two parts. Part A asks for the pH of a solution made by mixing 50.0 mL of HA and 30.0 mL of the strong base, with a text box containing the answer '5.73'. Below the text box is a feedback message: 'Incorrect; Try Again. Be sure to take the log of $[A^-]/[HA]$.' Part B asks for the pH at the equivalence point, with a text box for the answer.

Adaptive Follow-up Assignments in MasteringChemistry®

Instructors are given the ability to assign adaptive follow-up assignments to students for *Principles of Chemistry*. Adaptive follow-ups are personalized assignments that pair Mastering's powerful content with Knewton's adaptive learning engine to provide personalized help to students before misconceptions take hold. These assignments address topics students struggled with on assigned homework, including core prerequisite topics.

The screenshot shows a 'Chapter 17 Adaptive Follow-Up' assignment page. It includes a green header with a circular arrow icon and text: 'Chapter 17 Adaptive Follow-Up Due: 1:45pm on Sunday, September 8, 2013 Parent Assignment: Chapter 17 Question Sets: 3'. Below this is a list of question sets: 'QUESTION SET 1' (with sub-items 'Creating a Buffer Solution', 'Titration of Strong Acid with Strong Base', and 'Precipitation'), 'QUESTION SET 2', and 'QUESTION SET 3'. A 'SCORE SUMMARY' table at the bottom shows '0 / 5 points' and '0.0%'. An inset window shows a preview of a 'Titration of Strong Acid with Strong Base' problem: '160 mL of 0.200 M HCl is titrated with 0.200 M NaOH.' Part A asks for the pH after 50.0 mL of base is added, with a text box containing '1.30' and a 'Correct' feedback message. Part B asks for the pH at the equivalence point, with a text box containing '7.00' and a 'Correct' feedback message.



MasteringChemistry[®] for Instructors

www.masteringchemistry.com

The Mastering platform was developed by scientists for science students and instructors. Mastering has been refined from data-driven insights derived from over a decade of real-world use by faculty and students.

Gradebook

Every assignment is automatically graded. Shades of red highlight struggling students and challenging assignments.

NAME	IntroLab	Ch 2	Ch 3	Lab 2	Ch 4	Ch 5	Ch 6	Ch 7a	Chapter 7b	Lab 4	Ch 8	Ch 9	Ch 10	TOTAL
Class Average	78.4	66.0	82.4	81.1	85.5	86.7	81.8	83.7	90.0	86.4	77.7	81.4	87.4	265.6
Lavett, First...	84.4	73.3	83.3	102	88.8	83.3	85.8	101	100	88.8	88.3	87.4	88.9	262.2
Lavett, First...	78.3	64.9	82.8	88.0	85.5	86.2	72.8	11.5	80.0	88.9	88.3	87.3	87.9	277.0
Lavett, First...	72.8	48.0	81.9	104	102	84.9	89.0	100	88.0	88.7	87.3	88.3	88.3	303.3
Lavett, First...	72.8	53.8	81.0	14.3	88.3	85.3	89.0	83.4	91.0	88.2	87.0	88.3	87.0	319.0
Lavett, First...	78.8	89.3	78.8	88.0	91.8	85.2	82.5	14.8	85.0	88.2	87.7	88.3	87.7	319.0
Lavett, First...	77.8	88.7	81.8	191	88.1	85.8	88.0	78.7	85.0	84.8	78.8	88.3	87.7	232.2
Lavett, First...	84.4	78.7	82.8	85.3	89.8	100	85.0	100	100	100	88.8	88.3	88.3	367.2
Lavett, First...	88.2	78.8	78.8	104	100	88.8	78.3	78.8	88.8	84.3	82.3	88.3	88.3	319.0
Lavett, First...	78.1	78.8	78.8	105	84.8	84.8	82.1	91.8	100	88.8	87.8	88.3	87.8	198.0

Gradebook Diagnostics

This screen provides you with your favorite diagnostics. With a single click, charts summarize the most difficult problems, vulnerable students, grade distribution, and even score improvement over the course.



Learning Outcomes

Let Mastering do the work in tracking student performance against your learning outcomes:

- Add your own or use the publisher provided learning outcomes.
- View class performance against the specified learning outcomes.
- Export results to a spreadsheet that you can further customize and share with your chair, dean, administrator, or accreditation board.

MasteringChemistry[®]

Create/Edit Assignment: Homework Week 5

1 Start 2 Select Content 3 Organize Content 4 Specify Outcomes 5 Preview and Assign

To see student results organized by learning outcomes, choose learning outcomes to associate with these items. [Learn more.](#)

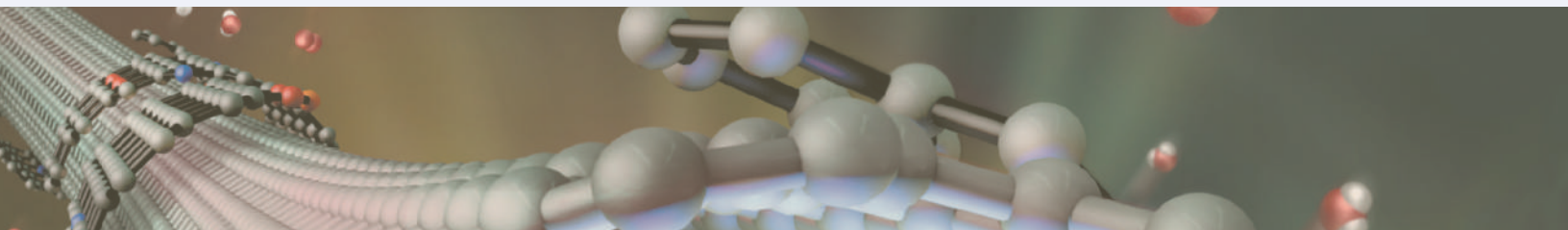
Not using learning outcomes? [Skip this step.](#)

Hide Provided Learning Outcomes [Add/Edit My Learning Outcomes](#)

ITEM	LEARNING OUTCOMES
Initiation Energy	Global: Demonstrate the ability to think critically and employ critical thinking skills. Use the electron configurations of elements to explain periodic trends.
Electron Configurations	Global: Demonstrate the ability to think critically and employ critical thinking skills. Global: Demonstrate the ability to make connections between concepts across General Chemistry. Draw the orbital diagram and write the electron configuration for an element.
Energy Levels	Global: Demonstrate the ability to think critically and employ critical thinking skills. Explain how atomic spectra correlates with the energy levels in atoms.
Electron Configuration for Elements	Global: Demonstrate the ability to think critically and employ critical thinking skills. Global: Demonstrate the quantitative skills needed to succeed in General Chemistry. Write the electron configuration for an atom using the sublevel blocks on the periodic table.
Problem 5.23	Compare the wavelength of radiation with its energy.
Problem 5.24	Compare the wavelength of radiation with its energy.
Problem 5.113	Compare the wavelength of radiation with its energy.
Problem 5.25	Describe the sublevels and orbitals in atoms.

Instructor and Student Resources

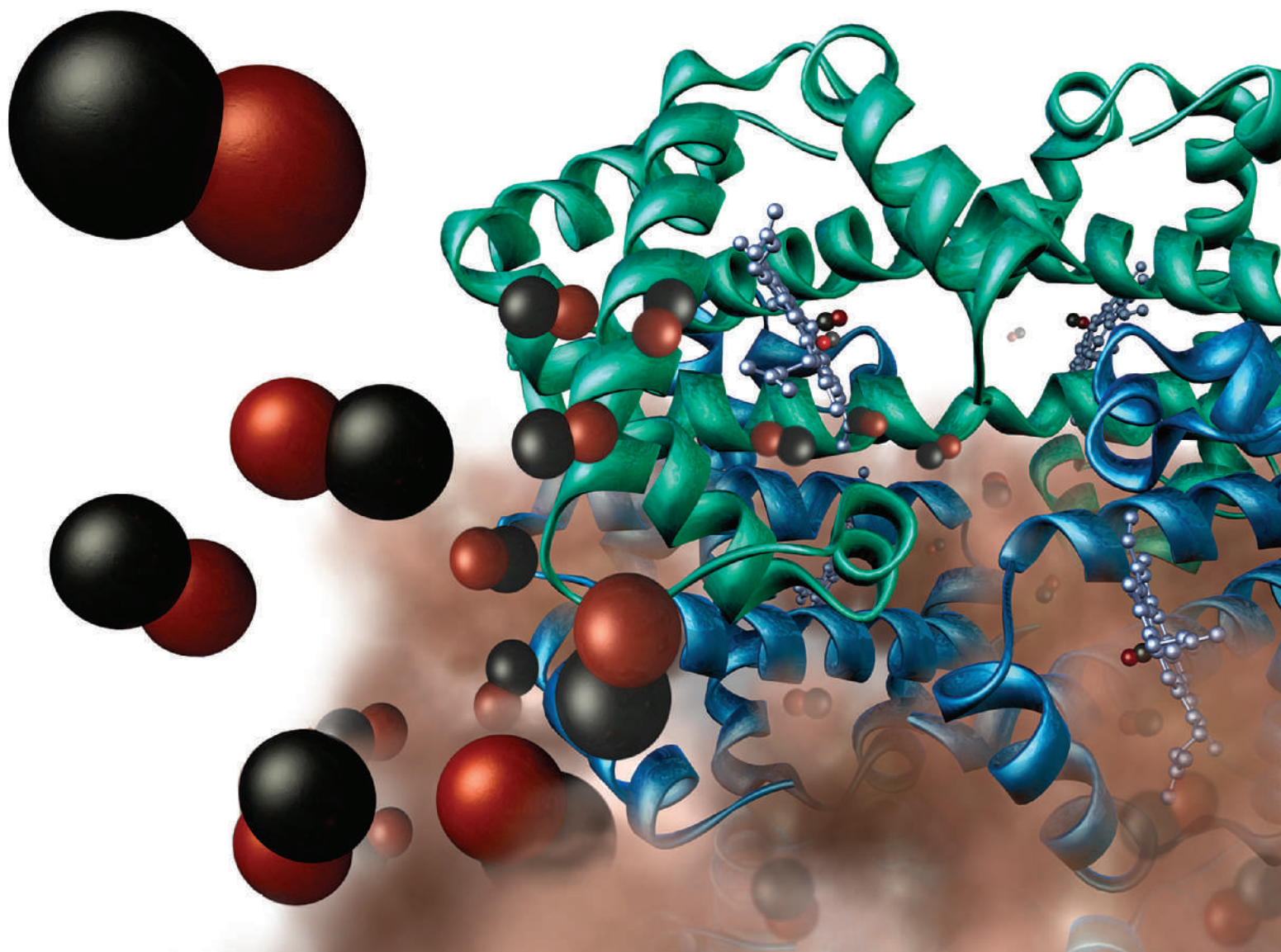
Resource	Available in Print	Available Online	Instructor or Student Resource	Description
Instructor Resource Center		✓	Instructor	This resource contains the following: <ul style="list-style-type: none">• All illustrations, tables, and photos from the text in JPEG format• Three pre-built PowerPoint Presentations (lecture, worked examples, and images)• TestGen computerized software with the TestGen version of the Testbank• Word files of the Test Item File
Instructor Resource Manual		✓	Instructor	Organized by chapter, this useful guide prepared by Sandra Chimon-Peszek (<i>Calumet College of St. Joseph</i>), includes objectives, lecture outlines, references to figures and solved problems, as well as teaching tips.
Test Bank		✓	Instructor	The Test Bank, prepared by Anil Bangeree (<i>Columbus State University</i>), contains more than 2,200 multiple choice, true/false, and short-answer questions.
Solutions Manual	✓		Instructor	Prepared by Kathy Shaginaw, this manual contains step-by-step solutions to all end-of-chapter exercises. With instructor permission, this manual may be made available to students.



1

Matter, Measurement, and Problem Solving

Hemoglobin, the oxygen-carrying protein in blood (depicted schematically here), can bind carbon monoxide molecules (the linked red and black spheres) as well as oxygen.



The most incomprehensible thing about the universe is that it is comprehensible.

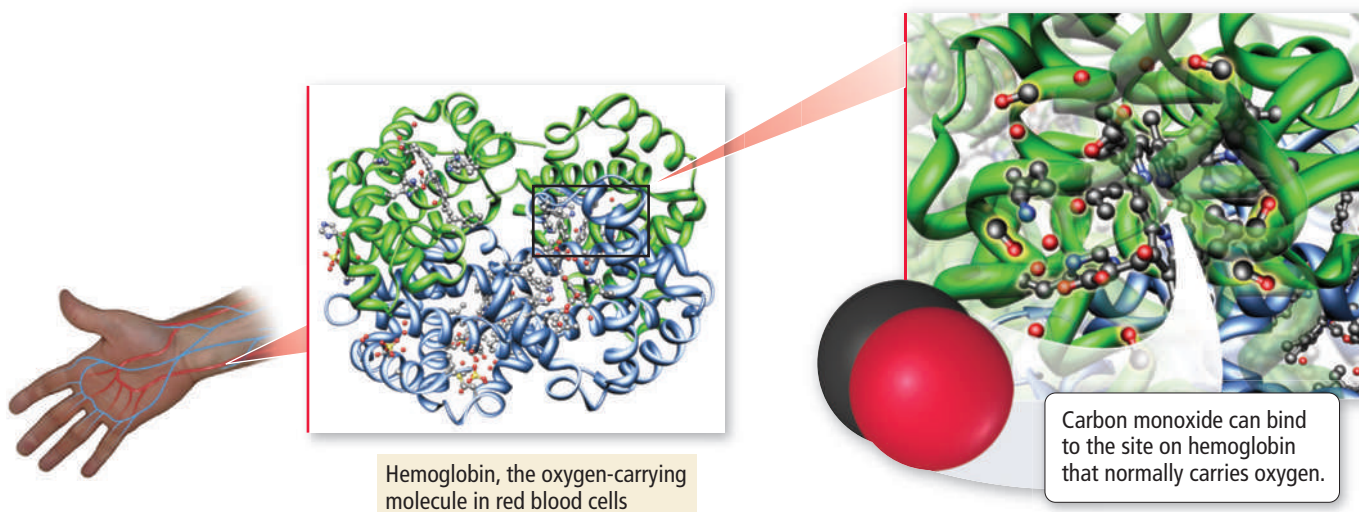
—Albert Einstein (1879–1955)

WHAT DO YOU THINK IS THE MOST important idea in all of human knowledge? There are, of course, many possible answers to this question—some practical, some philosophical, and some scientific. If we limit ourselves only to scientific answers, mine would be this: **The properties of matter are determined by the properties of molecules and atoms.** Atoms and molecules determine how matter behaves—if they were different, matter would be different. The properties of water molecules, for example, determine how water behaves; the properties of sugar molecules determine how sugar behaves; and the molecules that compose our bodies determine how our bodies behave. The understanding of matter at the molecular level gives us unprecedented control over that matter. For example, our understanding of the details of the molecules that compose living organisms has revolutionized biology over the last 50 years.

- 1.1** Atoms and Molecules 29
 - 1.2** The Scientific Approach to Knowledge 31
 - 1.3** The Classification of Matter 33
 - 1.4** Physical and Chemical Changes and Physical and Chemical Properties 35
 - 1.5** Energy: A Fundamental Part of Physical and Chemical Change 38
 - 1.6** The Units of Measurement 39
 - 1.7** The Reliability of a Measurement 45
 - 1.8** Solving Chemical Problems 51
- Key Learning Objectives** 60

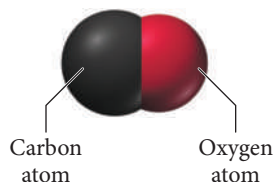
1.1 Atoms and Molecules

The air over most U.S. cities, including my own, contains at least some pollution. A significant component of that pollution is carbon monoxide, a colorless gas emitted in the exhaust of cars and trucks. Carbon monoxide *gas* is composed of carbon monoxide *molecules*, each of which contains a carbon atom and an oxygen atom held together by a chemical bond. **Atoms** are the submicroscopic particles that constitute the fundamental building blocks of ordinary matter. However, free atoms are rare in nature; instead, they bind together in specific geometric arrangements to form **molecules**.

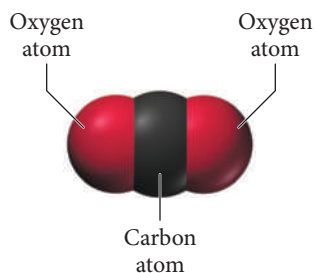


▲ **FIGURE 1.1 Binding of Oxygen and Carbon Monoxide to Hemoglobin** Hemoglobin, a large protein molecule, is the oxygen carrier in red blood cells. Each subunit of the hemoglobin molecule contains an iron atom to which oxygen binds. Carbon monoxide molecules can take the place of oxygen, thus reducing the amount of oxygen reaching the body's tissues.

Carbon monoxide molecule



Carbon dioxide molecule

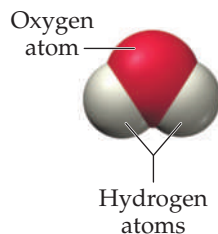


The properties of the substances around us depend on the atoms and molecules that compose them, so the properties of carbon monoxide *gas* depend on the properties of carbon monoxide *molecules*. Carbon monoxide molecules happen to be just the right size and shape, and happen to have just the right chemical properties, to fit neatly into cavities within hemoglobin—the oxygen-carrying molecule in blood—that normally carry oxygen molecules (FIGURE 1.1▲). Consequently, carbon monoxide diminishes the oxygen-carrying capacity of blood. Breathing air containing too much carbon monoxide (greater than 0.04% by volume) can lead to unconsciousness and even death because not enough oxygen reaches the brain. Carbon monoxide deaths have occurred, for example, as a result of running an automobile in a closed garage or using a propane burner in an enclosed space for too long. In smaller amounts, carbon monoxide causes the heart and lungs to work harder and can result in headache, dizziness, weakness, and confusion.

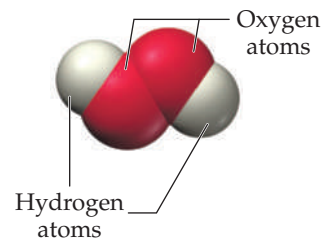
Cars and trucks emit a closely related molecule, called carbon dioxide, in far greater quantities than carbon monoxide. The only difference between carbon dioxide and carbon monoxide is that carbon dioxide molecules contain two oxygen atoms instead of just one. This extra oxygen atom dramatically affects the properties of the gas. We breathe much more carbon dioxide—which composes 0.04% of air and is a product of our own respiration as well—than carbon monoxide, yet it does not kill us. Why? Because the presence of the second oxygen atom prevents carbon dioxide from binding to the oxygen-carrying site in hemoglobin, making it far less toxic. Although high levels of carbon dioxide (greater than 10% of air) can be toxic for other reasons, lower levels can enter the bloodstream with no adverse effects. Such is the molecular world. Any differences between molecules—such as the presence of the extra oxygen atom in carbon dioxide compared to carbon monoxide—results in differences between the substances that the molecules compose.

As another example, consider two other closely related molecules, water and hydrogen peroxide:

Water molecule



Hydrogen peroxide molecule



In the study of chemistry, atoms are often portrayed as colored spheres, with each color representing a different kind of atom. For example, a black sphere represents a carbon atom, a red sphere represents an oxygen atom, and a white sphere represents a hydrogen atom. For a complete color code of atoms, see Appendix IIA.