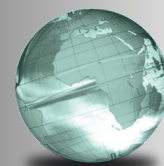


GLOBAL
EDITION



Principles of Chemistry

A Molecular Approach

FOURTH EDITION

Nivaldo J. Tro



List of Elements with Their Symbols and Atomic Masses

Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	227.03 ^a	Mendelevium	Md	101	258.10 ^a
Aluminum	Al	13	26.98	Mercury	Hg	80	200.59
Americium	Am	95	243.06 ^a	Molybdenum	Mo	42	95.95
Antimony	Sb	51	121.76	Moscovium	Mc	115	289 ^a
Argon	Ar	18	39.95	Neodymium	Nd	60	144.24
Arsenic	As	33	74.92	Neon	Ne	10	20.18
Astatine	At	85	209.99 ^a	Neptunium	Np	93	237.05 ^a
Barium	Ba	56	137.33	Nickel	Ni	28	58.69
Berkelium	Bk	97	247.07 ^a	Nihonium	Nh	113	284 ^a
Beryllium	Be	4	9.012	Niobium	Nb	41	92.91
Bismuth	Bi	83	208.98	Nitrogen	N	7	14.01
Bohrium	Bh	107	264.12 ^a	Nobelium	No	102	259.10 ^a
Boron	B	5	10.81	Oganesson	Og	118	294 ^a
Bromine	Br	35	79.90	Osmium	Os	76	190.23
Cadmium	Cd	48	112.41	Oxygen	O	8	16.00
Calcium	Ca	20	40.08	Palladium	Pd	46	106.42
Californium	Cf	98	251.08 ^a	Phosphorus	P	15	30.97
Carbon	C	6	12.01	Platinum	Pt	78	195.08
Cerium	Ce	58	140.12	Plutonium	Pu	94	244.06 ^a
Cesium	Cs	55	132.91	Polonium	Po	84	208.98 ^a
Chlorine	Cl	17	35.45	Potassium	K	19	39.10
Chromium	Cr	24	52.00	Praseodymium	Pr	59	140.91
Cobalt	Co	27	58.93	Promethium	Pm	61	145 ^a
Copernicium	Cn	112	285 ^a	Protactinium	Pa	91	231.04
Copper	Cu	29	63.55	Radium	Ra	88	226.03 ^a
Curium	Cm	96	247.07 ^a	Radon	Rn	86	222.02 ^a
Darmstadtium	Ds	110	271 ^a	Rhenium	Re	75	186.21
Dubnium	Db	105	262.11 ^a	Rhodium	Rh	45	102.91
Dysprosium	Dy	66	162.50	Roentgenium	Rg	111	272 ^a
Einsteinium	Es	99	252.08 ^a	Rubidium	Rb	37	85.47
Erbium	Er	68	167.26	Ruthenium	Ru	44	101.07
Europium	Eu	63	151.96	Rutherfordium	Rf	104	261.11 ^a
Fermium	Fm	100	257.10 ^a	Samarium	Sm	62	150.36
Flerovium	Fl	114	289 ^a	Scandium	Sc	21	44.96
Fluorine	F	9	19.00	Seaborgium	Sg	106	266.12 ^a
Francium	Fr	87	223.02 ^a	Selenium	Se	34	78.97
Gadolinium	Gd	64	157.25	Silicon	Si	14	28.09
Gallium	Ga	31	69.72	Silver	Ag	47	107.87
Germanium	Ge	32	72.63	Sodium	Na	11	22.99
Gold	Au	79	196.97	Strontium	Sr	38	87.62
Hafnium	Hf	72	178.49	Sulfur	S	16	32.06
Hassium	Hs	108	269.13 ^a	Tantalum	Ta	73	180.95
Helium	He	2	4.003	Technetium	Tc	43	98 ^a
Holmium	Ho	67	164.93	Tellurium	Te	52	127.60
Hydrogen	H	1	1.008	Tennessine	Ts	117	294 ^a
Indium	In	49	114.82	Terbium	Tb	65	158.93
Iodine	I	53	126.90	Thallium	Tl	81	204.38
Iridium	Ir	77	192.22	Thorium	Th	90	232.04
Iron	Fe	26	55.85	Thulium	Tm	69	168.93
Krypton	Kr	36	83.80	Tin	Sn	50	118.71
Lanthanum	La	57	138.91	Titanium	Ti	22	47.87
Lawrencium	Lr	103	262.11 ^a	Tungsten	W	74	183.84
Lead	Pb	82	207.2	Uranium	U	92	238.03
Lithium	Li	3	6.94	Vanadium	V	23	50.94
Livermorium	Lv	116	292 ^a	Xenon	Xe	54	131.293
Lutetium	Lu	71	174.97	Ytterbium	Yb	70	173.05
Magnesium	Mg	12	24.31	Yttrium	Y	39	88.91
Manganese	Mn	25	54.94	Zinc	Zn	30	65.38
Meitnerium	Mt	109	268.14 ^a	Zirconium	Zr	40	91.22

^aMass of longest-lived or most important isotope.

Main groups		Transition metals										Main groups						
1A ^a		2A		3B	4B	5B	6B	7B	8B			1B	3A	4A	5A	6A	7A	8A
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	18
H 1.008	He 4.003	Li 6.94	Be 9.012	B 10.81	C 12.01	N 14.01	O 16.00	F 19.00	Ne 20.18	Na 22.99	Mg 24.31	Al 26.98	Si 28.09	P 30.97	S 32.06	Cl 35.45	Ar 39.95	Kr 83.80
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
K 39.10	Ca 40.08	Sc 44.96	Ti 47.87	V 50.94	Cr 52.00	Mn 54.94	Fe 55.85	Co 58.93	Ni 58.69	Cu 63.55	Zn 65.38	Ga 69.72	Ge 72.63	As 74.92	Se 78.97	Br 79.90	Kr 83.80	Rb 85.47
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
Rb 85.47	Sr 87.62	Y 88.91	Zr 91.22	Nb 92.91	Mo 95.95	Tc [98]	Ru 101.07	Rh 102.91	Pd 106.42	Ag 107.87	Cd 112.41	In 114.82	Sn 118.71	Sb 121.76	Te 127.60	I 126.90	Xe 131.29	Cs 132.91
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
Cs 132.91	Ba 137.33	La 138.91	Hf 178.49	Ta 180.95	W 183.84	Re 186.21	Os 190.23	Ir 192.22	Pt 195.08	Au 196.97	Hg 200.59	Tl 204.38	Pb 207.2	Bi 208.98	Po [208.98]	At [209.99]	Rn [222.02]	Fr [223.02]
87	88	89	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119
Fr [223.02]	Ra [226.03]	Ac [227.03]	Rf [261.11]	Db [262.11]	Sg [266.12]	Bh [264.12]	Hs [269.13]	Mt [268.14]	Ds [271]	Rg [272]	Cn [285]	Nh [284]	Fl [289]	Mc [289]	Lv [292]	Ts [294]	Og [294]	Uu [295]
Lanthanide series		58	59	60	61	62	63	64	65	66	67	68	69	70	71			
		Ce 140.12	Pr 140.91	Nd 144.24	Pm [145]	Sm 150.36	Eu 151.96	Gd 157.25	Tb 158.93	Dy 162.50	Ho 164.93	Er 167.26	Tm 168.93	Yb 173.05	Lu 174.97			
Actinide series		90	91	92	93	94	95	96	97	98	99	100	101	102	103			
		Th 232.04	Pa 231.04	U 238.03	Np [237.05]	Pu [244.06]	Am [243.06]	Cm [247.07]	Bk [247.07]	Cf [251.08]	Es [252.08]	Fm [257.10]	Md [258.10]	No [259.10]	Lr [262.11]			

^aThe labels on top (1A, 2A, etc.) are common American usage. The labels below these (1, 2, etc.) are those recommended by the International Union of Pure and Applied Chemistry.

Atomic masses in brackets are the masses of the longest-lived or most important isotope of radioactive elements.

This page is intentionally left blank

Principles of
Chemistry
A MOLECULAR APPROACH

This page is intentionally left blank

FOURTH EDITION

Principles of Chemistry

A MOLECULAR APPROACH
GLOBAL EDITION



Nivaldo J. Tro



Pearson Education Limited
KAO Two
KAO Park
Hockham Way
Harlow
Essex
CM17 9SR
United Kingdom

and Associated Companies throughout the world

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

© Pearson Education Limited, 2021

The rights 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, 4th Edition, ISBN 978-0-13-489574-1 by Nivaldo J. Tro, published by Pearson Education © 2020.

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. For information regarding permissions, request forms, and the appropriate contacts within the Pearson Education Global Rights and Permissions department, please visit www.pearsoned.com/permissions.

This eBook is a standalone product and may or may not include all assets that were part of the print version. It also does not provide access to other Pearson digital products like MyLab and Mastering. The publisher reserves the right to remove any material in this eBook at any time.

British Library Cataloguing-in-Publication Data

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

ISBN 10: 1-292-34888-7

ISBN 13: 978-1-292-34888-9

eBook ISBN 13: 978-1-292-34894-0

Typeset by SPi Global

About the Author



Nivaldo Tro has been teaching college Chemistry since 1990 and is currently teaching at Santa Barbara City College. 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. Professor Tro has been awarded grants from the American Chemical Society Petroleum Research Fund, the Research Corporation, and the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. 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, and being outdoors with his family.

*To Michael, Ali,
Kyle, and Kaden*

Brief Contents

1	Matter, Measurement, and Problem Solving	42
2	Atoms and Elements	90
3	Molecules and Compounds	132
4	Chemical Reactions and Chemical Quantities	180
5	Introduction to Solutions and Aqueous Reactions	208
6	Gases	252
7	Thermochemistry	304
8	The Quantum-Mechanical Model of the Atom	352
9	Periodic Properties of the Elements	392
10	Chemical Bonding I: The Lewis Model	434
11	Chemical Bonding II: Molecular Shapes, Valence Bond Theory, and Molecular Orbital Theory	478
12	Liquids, Solids, and Intermolecular Forces	536
13	Solids and Modern Materials	582
14	Solutions	620
15	Chemical Kinetics	672
16	Chemical Equilibrium	724
17	Acids and Bases	772
18	Aqueous Ionic Equilibrium	828
19	Free Energy and Thermodynamics	888
20	Electrochemistry	938
21	Radioactivity and Nuclear Chemistry	988
Appendix I	Common Mathematical Operations in Chemistry	A-1
Appendix II	Useful Data	A-5
Appendix III	Answers to Selected Exercises	A-15
Appendix IV	Answers to In-Chapter Practice Problems	A-45
	Glossary	G-1
	Photo and Text Credits	C-1
	Index	I-1



Interactive Media Contents in Mastering Chemistry

KEY CONCEPT VIDEOS (KCVs)

- 1.1 Atoms and Molecules
- 1.3 Classifying Matter
- 1.6 Units and Significant Figures
- 1.7 Significant Figures in Calculations
- 1.8 Solving Chemical Problems
- 2.3 Atomic Theory
- 2.6 Subatomic Particles and Isotope Symbols
- 2.7 The Periodic Law and the Periodic Table
- 2.9 The Mole Concept
- 3.5 Naming Ionic Compounds
- 3.6 Naming Molecular Compounds
- 4.2 Writing and Balancing Chemical Equations
- 4.3 Reaction Stoichiometry
- 4.4 Limiting Reactant, Theoretical Yield, and Percent Yield
- 5.2 Solution Concentration
- 5.5 Reactions in Solutions
- 6.3 Simple Gas Laws and Ideal Gas Law
- 6.6 Mixtures of Gases and Partial Pressures
- 6.8 Kinetic Molecular Theory
- 7.3 The First Law of Thermodynamics
- 7.4 Heat Capacity
- 7.6 The Change in Enthalpy for a Chemical Reaction
- 7.9 Determining the Enthalpy of Reaction from Standard Enthalpies of Formation
- 8.2 The Nature of Light
- 8.4 The Wave Nature of Matter
- 8.5A Quantum Mechanics and the Atom: Orbitals and Quantum Numbers
- 8.5B Atomic Spectroscopy
- 9.3 Electron Configurations
- 9.4 Writing an Electron Configuration Based on an Element's Position on the Periodic Table
- 9.6 Periodic Trends in the Size of Atoms and Effective Nuclear Charge
- 10.5 The Lewis Model for Chemical Bonding
- 10.6 Electronegativity and Bond Polarity
- 10.7 Writing Lewis Structures for Molecular Compounds
- 10.8 Resonance and Formal Charge
- 10.9 Exceptions to the Octet Rule and Expanded Octets
- 11.2 VSEPR Theory
- 11.3 VSEPR Theory: The Effect of Lone Pairs
- 11.5 Molecular Shape and Polarity
- 11.6 Valence Bond Theory
- 11.7 Valence Bond Theory: Hybridization
- 12.3 Intermolecular Forces
- 12.5 Vaporization and Vapor Pressure
- 12.7 Heating Curve for Water
- 12.8 Phase Diagrams
- 13.3 Unit Cells: Simple Cubic, Body-Centered Cubic, and Face-Centered Cubic
- 14.4 Solution Equilibrium and the Factors Affecting Solubility
- 14.5 Solution Concentration: Molarity, Molality, Parts by Mass and Volume, Mole Fraction
- 14.6 Colligative Properties
- 15.2 The Rate of a Chemical Reaction
- 15.3 The Rate Law for a Chemical Reaction
- 15.4 The Integrated Rate Law
- 15.5 The Effect of Temperature on Reaction Rate
- 15.6 Reaction Mechanisms
- 16.3 The Equilibrium Constant
- 16.7 The Reaction Quotient
- 16.8 Finding Equilibrium Concentrations from Initial Concentrations
- 16.9 Le Châtelier's Principle
- 17.3 Definitions of Acids and Bases
- 17.4 Acid Strength and the Acid Ionization Constant
- 17.5 The pH Scale
- 17.6 Finding the $[\text{H}_3\text{O}^+]$ and pH of Strong and Weak Acid Solutions
- 17.8 The Acid-Base Properties of Ions and Salts
- 18.2A Buffers
- 18.2B Finding pH and pH Changes in Buffer Solutions
- 18.4A The Titration of a Strong Acid with a Strong Base
- 18.4B The Titration of a Weak Acid and a Strong Base
- 19.3 Entropy and the Second Law of Thermodynamics
- 19.6 The Effect of ΔH , ΔS , and T on Reaction Spontaneity
- 19.7 Standard Molar Entropies
- 20.3 Voltaic Cells
- 20.4 Standard Electrode Potentials
- 20.5 Cell Potential, Free Energy, and the Equilibrium Constant
- 21.3 Types of Radioactivity

INTERACTIVE WORKED EXAMPLES (IWEs)

- 1.5 Determining the Number of Significant Figures in a Number
- 1.6 Significant Figures in Calculations
- 1.8 Unit Conversion
- 1.9 Unit Conversions Involving Units Raised to a Power
- 1.10 Density as a Conversion Factor
- 1.12 Problems with Equations
- 2.3 Atomic Numbers, Mass Numbers, and Isotope Symbols
- 2.5 Atomic Mass
- 2.8 The Mole Concept—Converting between Mass and Number of Atoms
- 2.9 The Mole Concept
- 3.3 Writing Formulas for Ionic Compounds
- 3.11 Using the Nomenclature Flowchart to Name Compounds
- 3.13 The Mole Concept—Converting between Mass and Number of Molecules
- 3.15 Using Mass Percent Composition as a Conversion Factor
- 3.16 Chemical Formulas as Conversion Factors
- 3.18 Obtaining an Empirical Formula from Experimental Data
- 3.21 Determining an Empirical Formula from Combustion Analysis
- 4.2 Balancing Chemical Equations
- 4.3 Balancing Chemical Equations Containing a Polyatomic Ion
- 4.4 Stoichiometry
- 4.6 Limiting Reactant and Theoretical Yield
- 5.1 Calculating Solution Concentration
- 5.2 Using Molarity in Calculations
- 5.3 Solution Dilution
- 5.4 Solution Stoichiometry
- 5.5 Predicting Whether an Ionic Compound Is Soluble
- 5.6 Writing Equations for Precipitation Reactions
- 5.9 Writing Equations for Acid–Base Reactions Involving a Strong Acid
- 5.11 Acid–Base Titration
- 5.13 Assigning Oxidation States
- 6.5 Ideal Gas Law I
- 6.7 Density
- 6.8 Molar Mass of a Gas
- 6.10 Partial Pressures and Mole Fractions
- 6.11 Collecting Gases over Water
- 6.12 Gases in Chemical Reactions
- 6.15 Graham’s Law of Effusion
- 7.2 Temperature Changes and Heat Capacity
- 7.3 Thermal Energy Transfer
- 7.5 Measuring ΔE_{rxn} in a Bomb Calorimeter
- 7.7 Stoichiometry Involving ΔH
- 7.8 Measuring ΔH_{rxn} in a Coffee-Cup Calorimeter
- 7.9 Hess’s Law
- 7.11 $\Delta H_{\text{rxn}}^{\circ}$ and Standard Enthalpies of Formation
- 8.2 Photon Energy
- 8.3 Wavelength, Energy, and Frequency
- 8.5 Quantum Numbers I
- 8.7 Wavelength of Light for a Transition in the Hydrogen Atom
- 9.2 Writing Orbital Diagrams
- 9.4 Writing Electron Configurations from the Periodic Table
- 9.5 Atomic Size
- 9.6 Electron Configurations and Magnetic Properties for Ions
- 9.8 First Ionization Energy
- 10.4 Writing Lewis Structures
- 10.6 Writing Lewis Structures for Polyatomic Ions
- 10.7 Writing Resonance Structures
- 10.8 Assigning Formal Charges
- 10.9 Drawing Resonance Structures and Assigning Formal Charge for Organic Compounds
- 10.10 Writing Lewis Structures for Compounds Having Expanded Octets
- 10.11 Calculating ΔH_{rxn} from Bond Energies
- 11.1 VSEPR Theory and the Basic Shapes
- 11.2 Predicting Molecular Geometries
- 11.4 Predicting the Shape of Larger Molecules
- 11.5 Determining Whether a Molecule Is Polar
- 11.8 Hybridization and Bonding Scheme
- 11.10 Molecular Orbital Theory
- 12.1 Dipole–Dipole Forces
- 12.2 Hydrogen Bonding
- 12.3 Using the Heat of Vaporization in Calculations
- 12.5 Using the Two-Point Form of the Clausius–Clapeyron Equation to Predict the Vapor Pressure at a Given Temperature
- 13.3 Relating Unit Cell Volume, Edge Length, and Atomic Radius
- 13.4 Relating Density to Crystal Structure
- 14.2 Henry’s Law
- 14.3 Using Parts by Mass in Calculations
- 14.4 Calculating Concentrations
- 14.5 Converting between Concentration Units
- 14.6 Calculating the Vapor Pressure of a Solution Containing a Nonelectrolyte and Nonvolatile Solute
- 14.9 Boiling Point Elevation
- 14.12 Calculating the Vapor Pressure of a Solution Containing an Ionic Solute
- 15.1 Expressing Reaction Rates
- 15.2 Determining the Order and Rate Constant of a Reaction
- 15.4 The First-Order Integrated Rate Law: Determining the Concentration of a Reactant at a Given Time
- 15.8 Using the Two-Point Form of the Arrhenius Equation
- 15.9 Reaction Mechanisms
- 16.1 Expressing Equilibrium Constants for Chemical Equations

- 16.3 Relating K_p and K_c
- 16.5 Finding Equilibrium Constants from Experimental Concentration Measurements
- 16.7 Predicting the Direction of a Reaction by Comparing Q and K
- 16.8 Finding Equilibrium Concentrations When You Know the Equilibrium Constant and All but One of the Equilibrium Concentrations of the Reactants and Products
- 16.9 Finding Equilibrium Concentrations from Initial Concentrations and the Equilibrium Constant
- 16.12 Finding Equilibrium Concentrations from Initial Concentrations in Cases with a Small Equilibrium Constant
- 16.14 The Effect of a Concentration Change on Equilibrium
- 17.1 Identifying Brønsted–Lowry Acids and Bases and Their Conjugates
- 17.3 Calculating pH from $[H_3O^+]$ or $[OH^-]$
- 17.5 Finding the $[H_3O^+]$ of a Weak Acid Solution
- 17.7 Finding the pH of a Weak Acid Solution in Cases Where the x is *small* Approximation Does Not Work
- 17.8 Finding the Equilibrium Constant from pH
- 17.9 Finding the Percent Ionization of a Weak Acid
- 17.12 Finding the $[OH^-]$ and pH of a Weak Base Solution
- 17.14 Determining the pH of a Solution Containing an Anion Acting as a Base
- 17.16 Determining the Overall Acidity or Basicity of Salt Solutions
- 18.2 Calculating the pH of a Buffer Solution as an Equilibrium Problem and with the Henderson–Hasselbalch Equation
- 18.3 Calculating the pH Change in a Buffer Solution after the Addition of a Small Amount of Strong Acid or Base
- 18.4 Using the Henderson–Hasselbalch Equation to Calculate the pH of a Buffer Solution Composed of a Weak Base and Its Conjugate Acid
- 18.6 Strong Acid–Strong Base Titration pH Curve
- 18.7 Weak Acid–Strong Base Titration pH Curve
- 18.8 Calculating Molar Solubility from K_{sp}
- 18.12 Predicting Precipitation Reactions by Comparing Q and K_{sp}
- 19.2 Calculating ΔS for a Change of State
- 19.3 Calculating Entropy Changes in the Surroundings
- 19.4 Calculating Gibbs Free Energy Changes and Predicting Spontaneity from ΔH and ΔS
- 19.5 Calculating Standard Entropy Changes (ΔS_{rxn}°)
- 19.6 Calculating the Standard Change in Free Energy for a Reaction Using $\Delta G_{rxn}^\circ = \Delta H_{rxn}^\circ - T\Delta S_{rxn}^\circ$
- 19.10 Calculating ΔG_{rxn} under Nonstandard Conditions
- 19.11 The Equilibrium Constant and ΔG_{rxn}°
- 20.2 Half-Reaction Method of Balancing Aqueous Redox Equations in Acidic Solution
- 20.3 Balancing Redox Reactions Occurring in Basic Solution
- 20.4 Calculating Standard Potentials for Electrochemical Cells from Standard Electrode Potentials of the Half-Reactions
- 20.6 Relating ΔG° and E_{cell}°
- 21.1 Writing Nuclear Equations for Alpha Decay
- 21.2 Writing Nuclear Equations for Beta Decay, Positron Emission, and Electron Capture
- 21.4 Radioactive Decay Kinetics
- 21.5 Radiocarbon Dating

Contents

PREFACE 23

1 Matter, Measurement, and Problem Solving 42

- 1.1 Atoms and Molecules 43
- 1.2 The Scientific Approach to Knowledge 45
 - THE NATURE OF SCIENCE** *Thomas S. Kuhn and Scientific Revolutions* 47
- 1.3 The Classification of Matter 47
 - The States of Matter: Solid, Liquid, and Gas 48
 - Classifying Matter by Composition: Elements, Compounds, and Mixtures 49
 - Separating Mixtures 50
- 1.4 Physical and Chemical Changes and Physical and Chemical Properties 51
- 1.5 Energy: A Fundamental Part of Physical and Chemical Change 54
- 1.6 The Units of Measurement 55
 - Standard Units 56
 - The Meter: A Measure of Length 56
 - The Kilogram: A Measure of Mass 56
 - The Second: A Measure of Time 56
 - The Kelvin: A Measure of Temperature 57
 - Prefix Multipliers 59
 - Derived Units: Volume and Density 59
 - Volume 60
 - Density 60
 - Calculating Density 61
 - CHEMISTRY AND MEDICINE** *Bone Density* 62
- 1.7 The Reliability of a Measurement 62
 - Counting Significant Figures 64
 - Exact Numbers 64
 - Significant Figures in Calculations 65
 - Precision and Accuracy 67
 - CHEMISTRY IN YOUR DAY** *Integrity in Data Gathering* 68
- 1.8 Solving Chemical Problems 68
 - Converting from One Unit to Another 68
 - General Problem-Solving Strategy 70
 - Units Raised to a Power 72
 - Order-of-Magnitude Estimations 73
 - Problems Involving an Equation 74
- 1.9 Analyzing and Interpreting Data 75
 - Identifying Patterns in Data 75
 - Interpreting Graphs 76

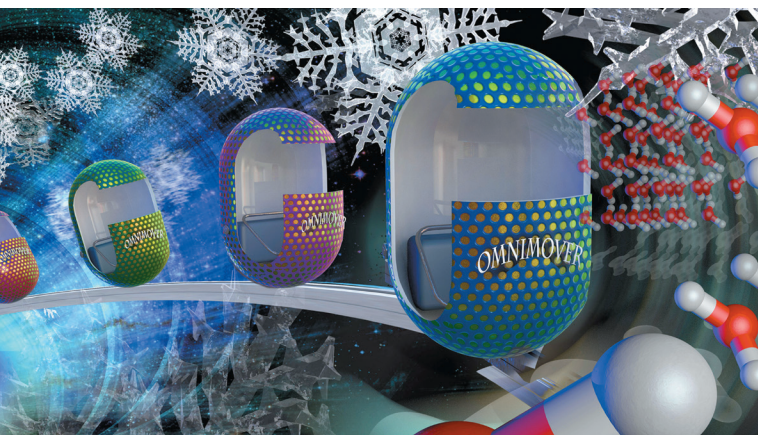
CHAPTER IN REVIEW Self-Assessment Quiz 78 Terms 79
Concepts 80 Equations and Relationships 80
Learning Outcomes 80

EXERCISES Review Questions 81 Problems by Topic 81
Cumulative Problems 85 Challenge Problems 87
Conceptual Problems 87 Questions for Group Work 88
Data Interpretation and Analysis 88 Answers to Conceptual Connections 89

2 Atoms and Elements 90



- 2.1 Brownian Motion: Atoms Confirmed 91
- 2.2 Early Ideas about the Building Blocks of Matter 93
- 2.3 Modern Atomic Theory and the Laws That Led to It 93
 - The Law of Conservation of Mass 93
 - The Law of Definite Proportions 94
 - The Law of Multiple Proportions 95
 - John Dalton and the Atomic Theory 96
 - CHEMISTRY IN YOUR DAY** *Atoms and Humans* 96
- 2.4 The Discovery of the Electron 97
 - Cathode Rays 97
 - Millikan's Oil Drop Experiment: The Charge of the Electron 98
- 2.5 The Structure of the Atom 99
- 2.6 Subatomic Particles: Protons, Neutrons, and Electrons in Atoms 101
 - Elements: Defined by Their Numbers of Protons 102
 - Isotopes: When the Number of Neutrons Varies 103
 - Ions: Losing and Gaining Electrons 105
 - CHEMISTRY IN YOUR DAY** *Where Did Elements Come From?* 106
- 2.7 Finding Patterns: The Periodic Law and the Periodic Table 107
 - Modern Periodic Table Organization 108
 - Ions and the Periodic Table 110
 - CHEMISTRY AND MEDICINE** *The Elements of Life* 111
- 2.8 Atomic Mass: The Average Mass of an Element's Atoms 111
 - Mass Spectrometry: Measuring the Mass of Atoms and Molecules 112
 - CHEMISTRY IN YOUR DAY** *Evolving Atomic Masses* 114



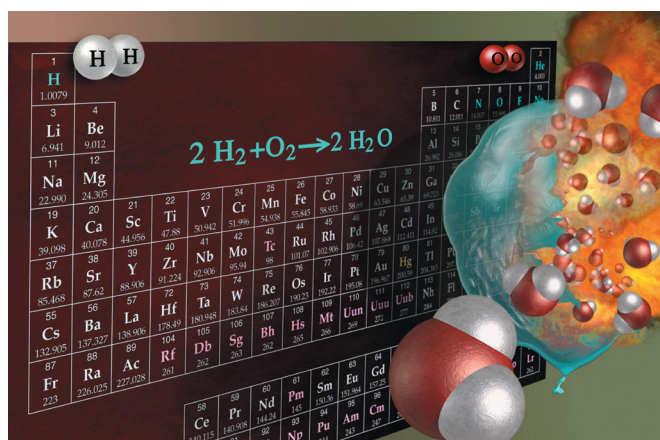
2.9 Molar Mass: Counting Atoms by Weighing Them 115

The Mole: A Chemist's "Dozen" 115
 Converting between Number of Moles and Number of Atoms 116
 Converting between Mass and Amount (Number of Moles) 117

CHAPTER IN REVIEW Self-Assessment Quiz 120 Terms 121
 Concepts 122 Equations and Relationships 122
 Learning Outcomes 123

EXERCISES Review Questions 123 Problems by Topic 124
 Cumulative Problems 127 Challenge Problems 128
 Conceptual Problems 129 Questions for Group Work 130
 Data Interpretation and Analysis 130 Answers to Conceptual
 Connections 131

3 Molecules and Compounds 132



3.1 Hydrogen, Oxygen, and Water 133

3.2 Chemical Bonds 135

Ionic Bonds 135 Covalent Bonds 136

3.3 Representing Compounds: Chemical Formulas and Molecular Models 136

Types of Chemical Formulas 136
 Molecular Models 138

3.4 An Atomic-Level View of Elements and Compounds 138

3.5 Ionic Compounds: Formulas and Names 142

Writing Formulas for Ionic Compounds 142 Naming
 Ionic Compounds 143 Naming Binary Ionic Compounds
 Containing a Metal That Forms Only One Type of
 Cation 144 Naming Binary Ionic Compounds Containing
 a Metal That Forms More Than One Kind of
 Cation 145 Naming Ionic Compounds Containing
 Polyatomic Ions 146 Hydrated Ionic Compounds 147

3.6 Molecular Compounds:

Formulas and Names 148

Naming Molecular Compounds 148 Naming Acids 149
 Naming Binary Acids 150 Naming Oxyacids 150

CHEMISTRY IN THE ENVIRONMENT Acid Rain 150

3.7 Summary of Inorganic Nomenclature 151

3.8 Formula Mass and the Mole Concept for Compounds 153

Molar Mass of a Compound 153 Using Molar Mass to
 Count Molecules by Weighing 153

3.9 Composition of Compounds 155

Mass Percent Composition as a Conversion Factor 156

Conversion Factors from Chemical Formulas 158

CHEMISTRY AND MEDICINE Methylmercury in Fish 160

3.10 Determining a Chemical Formula from Experimental Data 160

Determining Molecular Formulas for Compounds 162

Combustion Analysis 163

3.11 Organic Compounds 165

Hydrocarbons 166 Functionalized Hydrocarbons 167

CHAPTER IN REVIEW Self-Assessment Quiz 169 Terms 170

Concepts 170 Equations and Relationships 171

Learning Outcomes 171

EXERCISES Review Questions 171 Problems by

Topic 172 Cumulative Problems 176 Challenge

Problems 177 Conceptual Problems 177 Questions for Group

Work 178 Data Interpretation and Analysis 178 Answers to

Conceptual Connections 178

4 Chemical Reactions and Chemical Quantities 180

4.1 Climate Change and the Combustion of Fossil Fuels 181

4.2 Writing and Balancing Chemical Equations 183

4.3 Reaction Stoichiometry: How Much Carbon Dioxide? 187

Making Pizza: The Relationships among Ingredients 187

Making Molecules: Mole-to-Mole Conversions 188

Making Molecules: Mass-to-Mass Conversions 188

4.4 Stoichiometric Relationships: Limiting Reactant, Theoretical Yield, Percent Yield, and Reactant in Excess 191

Calculating Limiting Reactant, Theoretical Yield, and

Percent Yield 193 Calculating Limiting Reactant,

Theoretical Yield, and Percent Yield from Initial

Reactant Masses 194

4.5 Three Examples of Chemical Reactions: Combustion, Alkali Metals, and Halogens 197

Combustion Reactions 197 Alkali Metal Reactions 198

Halogen Reactions 198

CHAPTER IN REVIEW Self-Assessment Quiz 200 Terms 201

Concepts 201 Equations and Relationships 201

Learning Outcomes 201

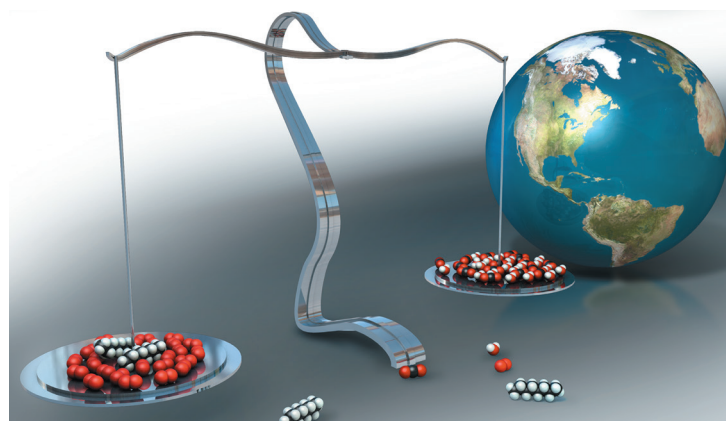
EXERCISES Review Questions 202 Problems by Topic 202

Cumulative Problems 205 Challenge Problems 206 Conceptual

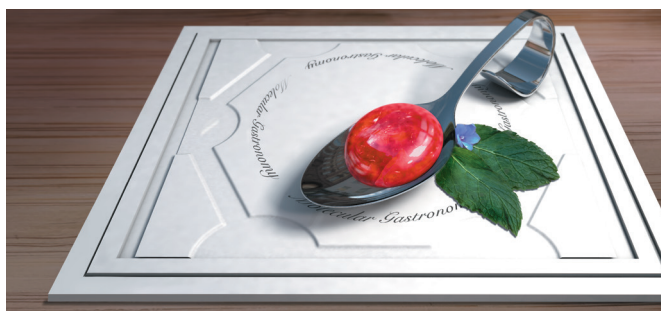
Problems 206 Questions for Group Work 207 Data

Interpretation and Analysis 207 Answers to Conceptual

Connections 207



5 Introduction to Solutions and Aqueous Reactions 208



- 5.1 Molecular Gastronomy and the Spherified Cherry 209
- 5.2 Solution Concentration 210
Solution Concentration 210 Using Molarity in Calculations 212 Solution Dilution 213
- 5.3 Solution Stoichiometry 215
- 5.4 Types of Aqueous Solutions and Solubility 217
Electrolyte and Nonelectrolyte Solutions 217
The Solubility of Ionic Compounds 219
- 5.5 Precipitation Reactions 221
- 5.6 Representing Aqueous Reactions: Molecular, Ionic, and Net Ionic Equations 225
- 5.7 Acid–Base Reactions 227
Acid–Base Reactions 227 Acid–Base Titrations 231
- 5.8 Gas-Evolution Reactions 233
- 5.9 Oxidation–Reduction Reactions 235
Oxidation States 236 Identifying Redox Reactions 238 The Activity Series: Predicting Whether a Redox Reaction Is Spontaneous 240

CHEMISTRY IN YOUR DAY Bleached Blonde 241

CHAPTER IN REVIEW Self-Assessment Quiz 243 Terms 244
Concepts 244 Equations and Relationships 245
Learning Outcomes 245

EXERCISES Review Questions 246 Problems by Topic 246
Cumulative Problems 248 Challenge Problems 249
Conceptual Problems 249 Questions for Group Work 250
Data Interpretation and Analysis 250 Answers to Conceptual Connections 251

6 Gases 252

- 6.1 Supersonic Skydiving and the Risk of Decompression 253
- 6.2 Pressure: The Result of Molecular Collisions 254
Pressure Units 255 The Manometer: A Way to Measure Pressure in the Laboratory 256
CHEMISTRY AND MEDICINE Blood Pressure 257
- 6.3 The Simple Gas Laws: Boyle's Law, Charles's Law, and Avogadro's Law 257
Boyle's Law: Volume and Pressure 258
Charles's Law: Volume and Temperature 260

CHEMISTRY IN YOUR DAY Extra-Long Snorkels 261
Avogadro's Law: Volume and Amount (in Moles) 263

- 6.4 The Ideal Gas Law 264
- 6.5 Applications of the Ideal Gas Law: Molar Volume, Density, and Molar Mass of a Gas 267
Molar Volume at Standard Temperature and Pressure 267
Density of a Gas 268 Molar Mass of a Gas 269
- 6.6 Mixtures of Gases and Partial Pressures 270
Deep-Sea Diving and Partial Pressures 273
Collecting Gases over Water 275
- 6.7 Gases in Chemical Reactions: Stoichiometry Revisited 277
Molar Volume and Stoichiometry 278
ANALYZING AND INTERPRETING DATA Good News about Our Nation's Air Quality 280
- 6.8 Kinetic Molecular Theory: A Model for Gases 280
How Kinetic Molecular Theory Explains Pressure and the Simple Gas Laws 281 Kinetic Molecular Theory and the Ideal Gas Law 282 Temperature and Molecular Velocities 284
- 6.9 Mean Free Path, Diffusion, and Effusion of Gases 287
- 6.10 Real Gases: The Effects of Size and Intermolecular Forces 288
The Effect of the Finite Volume of Gas Particles 289
The Effect of Intermolecular Forces 290 Van der Waals Equation 291 Real Gases 291

CHAPTER IN REVIEW Self-Assessment Quiz 292 Terms 293
Concepts 293 Equations and Relationships 294
Learning Outcomes 294

EXERCISES Review Questions 295 Problems by Topic 295
Cumulative Problems 299 Challenge Problems 301
Conceptual Problems 302 Questions for Group Work 302
Data Interpretation and Analysis 302 Answers to Conceptual Connections 303



7 Thermochemistry 304

- 7.1 Chemical Hand Warmers 305
- 7.2 The Nature of Energy: Key Definitions 306
Types of Energy 306 Energy Conservation and Energy Transfer 307 Units of Energy 307
- 7.3 The First Law of Thermodynamics: There Is No Free Lunch 309
Internal Energy 309
CHEMISTRY IN YOUR DAY Redheffer's Perpetual Motion Machine 309
Heat and Work 312



7.4 Quantifying Heat and Work 314

Heat 314 Temperature Changes and Heat Capacity 314 Thermal Energy Transfer 316 Work: Pressure–Volume Work 318

7.5 Measuring ΔE for Chemical Reactions: Constant-Volume Calorimetry 320

7.6 Enthalpy: The Heat Evolved in a Chemical Reaction at Constant Pressure 323

Exothermic and Endothermic Processes: A Molecular View 325 Stoichiometry Involving ΔH : Thermochemical Equations 325

7.7 Constant-Pressure Calorimetry: Measuring ΔH_{rxn} 327

7.8 Relationships Involving ΔH_{rxn} 328

7.9 Determining Enthalpies of Reaction from Standard Enthalpies of Formation 331

Standard States and Standard Enthalpy Changes 331 Calculating the Standard Enthalpy Change for a Reaction 333

7.10 Energy Use and the Environment 336

Energy Consumption 336 Environmental Problems Associated with Fossil Fuel Use 337 Air Pollution 337 Global Climate Change 338

CHEMISTRY IN THE ENVIRONMENT Renewable Energy 340

CHAPTER IN REVIEW Self-Assessment Quiz 341 Terms 342 Concepts 342 Equations and Relationships 343 Learning Outcomes 343

EXERCISES Review Questions 344 Problems by Topic 344 Cumulative Problems 348 Challenge Problems 349 Conceptual Problems 350 Questions for Group Work 350 Data Interpretation and Analysis 351 Answers to Conceptual Connections 351

8 The Quantum-Mechanical Model of the Atom 352

8.1 Schrödinger's Cat 353

8.2 The Nature of Light 354

The Wave Nature of Light 355 The Electromagnetic Spectrum 357

CHEMISTRY AND MEDICINE Radiation Treatment for Cancer 359

Interference and Diffraction 359 The Particle Nature of Light 360

8.3 Atomic Spectroscopy and the Bohr Model 364

CHEMISTRY IN YOUR DAY Atomic Spectroscopy, a Bar Code for Atoms 366

8.4 The Wave Nature of Matter: The de Broglie Wavelength, the Uncertainty Principle, and Indeterminacy 367

The de Broglie Wavelength 369 The Uncertainty Principle 370 Indeterminacy and Probability Distribution Maps 371

8.5 Quantum Mechanics and the Atom 373

Solutions to the Schrödinger Equation for the Hydrogen Atom 373 Atomic Spectroscopy Explained 376

8.6 The Shapes of Atomic Orbitals 379

s Orbitals ($l = 0$) 379 p Orbitals ($l = 1$) 382 d Orbitals ($l = 2$) 382 f Orbitals ($l = 3$) 382 The Phase of Orbitals 383 The Shape of Atoms 384

CHAPTER IN REVIEW Self-Assessment Quiz 384 Terms 385 Concepts 385 Equations and Relationships 386 Learning Outcomes 386

EXERCISES Review Questions 386 Problems by Topic 387 Cumulative Problems 388 Challenge Problems 389 Conceptual Problems 390 Questions for Group Work 390 Data Interpretation and Analysis 391 Answers to Conceptual Connections 391



9 Periodic Properties of the Elements 392

9.1 Nerve Signal Transmission 393

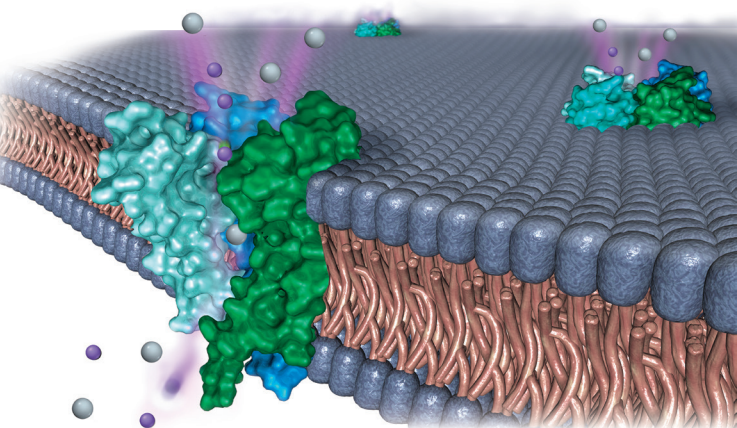
9.2 The Development of the Periodic Table 394

9.3 Electron Configurations: How Electrons Occupy Orbitals 395

Electron Spin and the Pauli Exclusion Principle 396 Sublevel Energy Splitting in Multielectron Atoms 396 Coulomb's Law 397 Shielding 398 Penetration 398 Electron Spatial Distributions and Sublevel Splitting 398 Electron Configurations for Multielectron Atoms 400

9.4 Electron Configurations, Valence Electrons, and the Periodic Table 403

Orbital Blocks in the Periodic Table 404 Writing an Electron Configuration for an Element from Its Position in the Periodic Table 405 The Transition and Inner Transition Elements 406



- 9.5 The Explanatory Power of the Quantum-Mechanical Model** 407
- 9.6 Periodic Trends in the Size of Atoms and Effective Nuclear Charge** 408
Effective Nuclear Charge 410 Atomic Radii and the Transition Elements 411
- 9.7 Ions: Electron Configurations, Magnetic Properties, Ionic Radii, and Ionization Energy** 413
Electron Configurations and Magnetic Properties of Ions 413 Ionic Radii 415 Ionization Energy 417 Trends in First Ionization Energy 417 Exceptions to Trends in First Ionization Energy 419 Trends in Second and Successive Ionization Energies 420
- 9.8 Electron Affinities and Metallic Character** 421
Electron Affinity 421 Metallic Character 422
- 9.9 Periodic Trends Summary** 425

CHAPTER IN REVIEW Self-Assessment Quiz 425 Terms 426 Concepts 426 Equations and Relationships 427 Learning Outcomes 427

EXERCISES Review Questions 428 Problems by Topic 429 Cumulative Problems 430 Challenge Problems 431 Conceptual Problems 432 Questions for Group Work 432 Data Interpretation and Analysis 433 Answers to Conceptual Connections 433

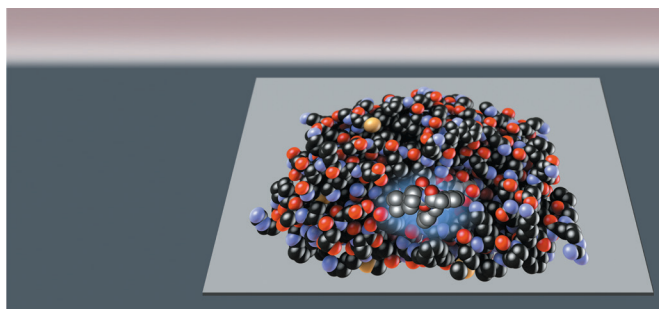
10 Chemical Bonding I: The Lewis Model 434

- 10.1 Bonding Models and AIDS Drugs** 435
- 10.2 Types of Chemical Bonds** 436
- 10.3 Representing Valence Electrons with Dots** 438
- 10.4 Ionic Bonding: Lewis Symbols and Lattice Energies** 439
Ionic Bonding and Electron Transfer 439 Lattice Energy: The Rest of the Story 440 The Born–Haber Cycle 440 Trends in Lattice Energies: Ion Size 443 Trends in Lattice Energies: Ion Charge 443 Ionic Bonding: Models and Reality 444
CHEMISTRY AND MEDICINE *Ionic Compounds in Medicine* 445

- 10.5 Covalent Bonding: Lewis Structures** 446
Single Covalent Bonds 446 Double and Triple Covalent Bonds 446 Covalent Bonding: Models and Reality 447
- 10.6 Electronegativity and Bond Polarity** 448
Electronegativity 449 Bond Polarity, Dipole Moment, and Percent Ionic Character 450
- 10.7 Lewis Structures of Molecular Compounds and Polyatomic Ions** 452
Writing Lewis Structures for Molecular Compounds 452 Writing Lewis Structures for Polyatomic Ions 454
- 10.8 Resonance and Formal Charge** 454
Resonance 454 Formal Charge 456
- 10.9 Exceptions to the Octet Rule: Odd-Electron Species, Incomplete Octets, and Expanded Octets** 459
Odd-Electron Species 460 Incomplete Octets 460
CHEMISTRY IN THE ENVIRONMENT *Free Radicals and the Atmospheric Vacuum Cleaner* 461 Expanded Octets 462
- 10.10 Bond Energies and Bond Lengths** 464
Bond Energy 464 Using Average Bond Energies to Estimate Enthalpy Changes for Reactions 465 Bond Lengths 466
- 10.11 Bonding in Metals: The Electron Sea Model** 467
CHEMISTRY IN THE ENVIRONMENT *The Lewis Structure of Ozone* 468

CHAPTER IN REVIEW Self-Assessment Quiz 469 Terms 470 Concepts 470 Equations and Relationships 471 Learning Outcomes 471

EXERCISES Review Questions 472 Problems by Topic 472 Cumulative Problems 474 Challenge Problems 476 Conceptual Problems 476 Questions for Group Work 476 Data Interpretation and Analysis 477 Answers to Conceptual Connections 477



11 Chemical Bonding II: Molecular Shapes, Valence Bond Theory, and Molecular Orbital Theory 478

- 11.1 Morphine: A Molecular Imposter** 479
- 11.2 VSEPR Theory: The Five Basic Shapes** 480
Two Electron Groups: Linear Geometry 481
Three Electron Groups: Trigonal Planar Geometry 481
Four Electron Groups: Tetrahedral Geometry 481
Five Electron Groups: Trigonal Bipyramidal Geometry 483
Six Electron Groups: Octahedral Geometry 483



11.3 VSEPR Theory: The Effect of Lone Pairs 484
Four Electron Groups with Lone Pairs 484 Five Electron Groups with Lone Pairs 486 Six Electron Groups with Lone Pairs 487

11.4 VSEPR Theory: Predicting Molecular Geometries 489
Representing Molecular Geometries on Paper 491 Predicting the Shapes of Larger Molecules 491

11.5 Molecular Shape and Polarity 492
Vector Addition 494

CHEMISTRY IN YOUR DAY *How Soap Works* 496

11.6 Valence Bond Theory: Orbital Overlap as a Chemical Bond 497

11.7 Valence Bond Theory: Hybridization of Atomic Orbitals 499
 sp^3 Hybridization 500 sp^2 Hybridization and Double Bonds 502

CHEMISTRY IN YOUR DAY *The Chemistry of Vision* 506

sp Hybridization and Triple Bonds 506 sp^3d and sp^3d^2 Hybridization 508 Writing Hybridization and Bonding Schemes 509

11.8 Molecular Orbital Theory: Electron Delocalization 512

Linear Combination of Atomic Orbitals (LCAOs) 513
Period Two Homonuclear Diatomic Molecules 517
Second-Period Heteronuclear Diatomic Molecules 522
Polyatomic Molecules 524

CHAPTER IN REVIEW Self-Assessment Quiz 525 Terms 526
Concepts 526 Equations and Relationships 526
Learning Outcomes 527

EXERCISES Review Questions 527 Problems by Topic 528 Cumulative Problems 530 Challenge Problems 532 Conceptual Problems 533 Questions for Group Work 533 Data Interpretation and Analysis 534 Answers to Conceptual Connections 534

12 Liquids, Solids, and Intermolecular Forces 536

12.1 Water, No Gravity 537

12.2 Solids, Liquids, and Gases: A Molecular Comparison 538
Differences between States of Matter 538
Changes between States 540

12.3 Intermolecular Forces: The Forces That Hold Condensed States Together 541
Dispersion Force 542 Dipole–Dipole Force 544
Hydrogen Bonding 547 Ion–Dipole Force 549
CHEMISTRY AND MEDICINE *Hydrogen Bonding in DNA* 550

12.4 Intermolecular Forces in Action: Surface Tension, Viscosity, and Capillary Action 551
Surface Tension 551 Viscosity 553
CHEMISTRY IN YOUR DAY *Viscosity and Motor Oil* 553
Capillary Action 553

12.5 Vaporization and Vapor Pressure 554
The Process of Vaporization 554 The Energetics of Vaporization 556 Vapor Pressure and Dynamic Equilibrium 557 Temperature Dependence of Vapor Pressure and Boiling Point 559 The Clausius–Clapeyron Equation 560 The Critical Point: The Transition to an Unusual State of Matter 563

12.6 Sublimation and Fusion 564
Sublimation 564 Fusion 565 Energetics of Melting and Freezing 565

12.7 Heating Curve for Water 566

12.8 Phase Diagrams 569
The Major Features of a Phase Diagram 569 Navigation within a Phase Diagram 570 The Phase Diagrams of Other Substances 571

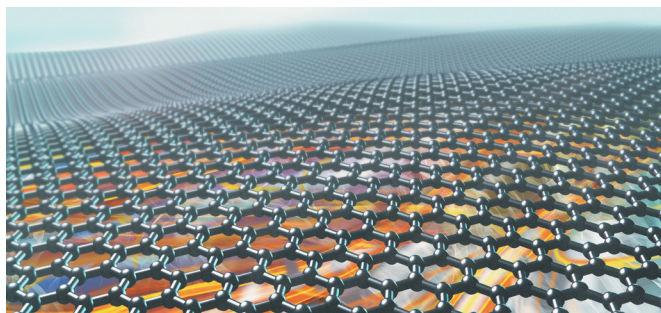
12.9 Water: An Extraordinary Substance 571
CHEMISTRY IN THE ENVIRONMENT *Water Pollution* 573

CHAPTER IN REVIEW Self-Assessment Quiz 573 Terms 574
Concepts 574 Equations and Relationships 575
Learning Outcomes 575

EXERCISES Review Questions 576 Problems by Topic 576 Cumulative Problems 579 Challenge Problems 579 Conceptual Problems 580 Questions for Group Work 580 Data Interpretation and Analysis 581 Answers to Conceptual Connections 581



13 Solids and Modern Materials 582



- 13.1 Friday Night Experiments: The Discovery of Graphene** 583
- 13.2 X-Ray Crystallography** 584
- 13.3 Unit Cells and Basic Structures** 587
Cubic Unit Cells 587 Closest-Packed Structures 593
- 13.4 The Fundamental Types of Crystalline Solids** 594
Molecular Solids 595
CHEMISTRY IN YOUR DAY *Chocolate, An Edible Material* 596
Ionic Solids 597 Atomic Solids 597
- 13.5 The Structures of Ionic Solids** 598
- 13.6 Network Covalent Atomic Solids: Carbon and Silicates** 600
Carbon 600 Silicates 603
- 13.7 Ceramics, Cement, and Glass** 603
Ceramics 603 Cement 604 Glass 605
- 13.8 Semiconductors and Band Theory** 605
Molecular Orbitals and Energy Bands 605 Doping: Controlling the Conductivity of Semiconductors 607
- 13.9 Polymers and Plastics** 607
CHEMISTRY IN YOUR DAY *Kevlar* 610

CHAPTER IN REVIEW Self-Assessment Quiz 611
Terms 612 Concepts 612 Equations and Relationships 613
Learning Outcomes 613

EXERCISES Review Questions 613 Problems by Topic 614 Cumulative Problems 617 Challenge Problems 618 Conceptual Problems 618 Questions for Group Work 618 Data Interpretation and Analysis 619 Answers to Conceptual Connections 619

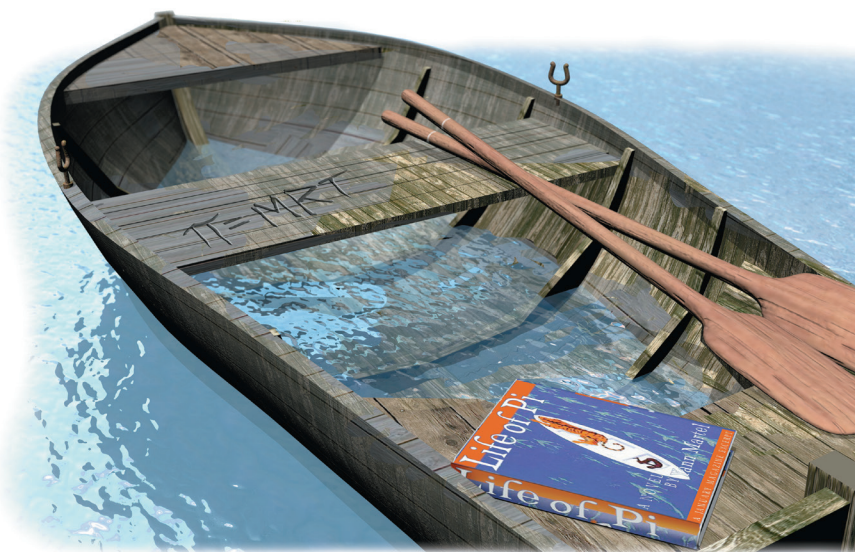
14 Solutions 620

- 14.1 Thirsty Solutions: Why You Shouldn't Drink Seawater** 621
- 14.2 Types of Solutions and Solubility** 623
Nature's Tendency toward Mixing: Entropy 624
The Effect of Intermolecular Forces 624

- 14.3 Energetics of Solution Formation** 628
Energy Changes in Solution Formation 628 Aqueous Solutions and Heats of Hydration 630
- 14.4 Solution Equilibrium and Factors Affecting Solubility** 631
The Temperature Dependence of the Solubility of Solids 633 Factors Affecting the Solubility of Gases in Water 633
- 14.5 Expressing Solution Concentration** 636
CHEMISTRY IN THE ENVIRONMENT *Lake Nyos* 636
Molarity 637 Molality 638 Parts by Mass and Parts by Volume 638 Using Parts by Mass (or Parts by Volume) in Calculations 639 Mole Fraction and Mole Percent 640
CHEMISTRY IN THE ENVIRONMENT *The Dirty Dozen* 640
- 14.6 Colligative Properties: Vapor Pressure Lowering, Freezing Point Depression, Boiling Point Elevation, and Osmotic Pressure** 643
Vapor Pressure Lowering 644 Vapor Pressures of Solutions Containing a Volatile (Nonelectrolyte) Solute 647
Freezing Point Depression and Boiling Point Elevation 650
CHEMISTRY IN YOUR DAY *Antifreeze in Frogs* 653
Osmotic Pressure 653
- 14.7 Colligative Properties of Strong Electrolyte Solutions** 655
Strong Electrolytes and Vapor Pressure 656
Colligative Properties and Medical Solutions 657
- 14.8 Colloids** 658

CHAPTER IN REVIEW Self-Assessment Quiz 661 Terms 662
Concepts 662 Equations and Relationships 663
Learning Outcomes 663

EXERCISES Review Questions 664 Problems by Topic 665
Cumulative Problems 668 Challenge Problems 669
Conceptual Problems 670 Questions for Group Work 670
Data Interpretation and Analysis 671 Answers to Conceptual Connections 671





15 Chemical Kinetics 672

- 15.1 Catching Lizards** 673
- 15.2 The Rate of a Chemical Reaction** 674
Definition of Reaction Rate 674 Measuring Reaction Rates 678
- 15.3 The Rate Law: The Effect of Concentration on Reaction Rate** 679
The Three Common Reaction Orders ($n = 0, 1,$ and 2) 679
Determining the Order of a Reaction 680 Reaction Order for Multiple Reactants 682
- 15.4 The Integrated Rate Law: The Dependence of Concentration on Time** 684
The Integrated Rate Law 684 The Half-Life of a Reaction 688
- 15.5 The Effect of Temperature on Reaction Rate** 692
The Arrhenius Equation 692 The Activation Energy, Frequency Factor, and Exponential Factor 693 Arrhenius Plots: Experimental Measurements of the Frequency Factor and the Activation Energy 694 The Collision Model: A Closer Look at the Frequency Factor 697
- 15.6 Reaction Mechanisms** 698
Rate Laws for Elementary Steps 699 Rate-Determining Steps and Overall Reaction Rate Laws 700 Mechanisms with a Fast Initial Step 701
- 15.7 Catalysis** 703
Homogeneous and Heterogeneous Catalysis 705
Enzymes: Biological Catalysts 706
CHEMISTRY AND MEDICINE *Enzyme Catalysis and the Role of Chymotrypsin in Digestion* 708

CHAPTER IN REVIEW Self-Assessment Quiz 709 Terms 711
Concepts 711 Equations and Relationships 712
Learning Outcomes 712

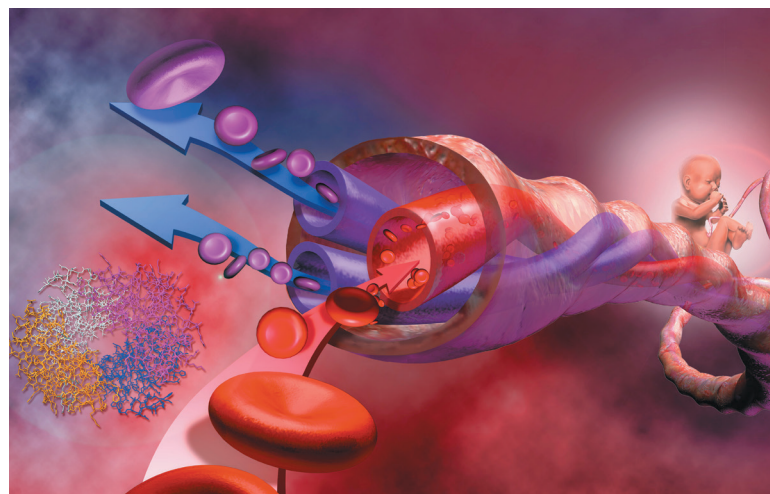
EXERCISES Review Questions 712 Problems by Topic 713
Cumulative Problems 718 Challenge Problems 720 Conceptual Problems 721 Questions for Group Work 722 Data Interpretation and Analysis 722 Answers to Conceptual Connections 723

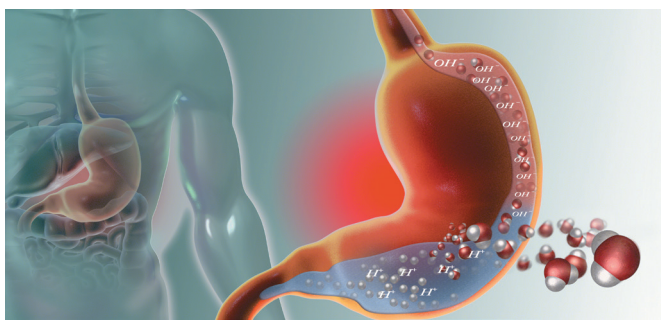
16 Chemical Equilibrium 724

- 16.1 Fetal Hemoglobin and Equilibrium** 725
- 16.2 The Concept of Dynamic Equilibrium** 727
- 16.3 The Equilibrium Constant (K)** 730
Expressing Equilibrium Constants for Chemical Reactions 730
The Significance of the Equilibrium Constant 731
CHEMISTRY AND MEDICINE *Life and Equilibrium* 732
Relationships between the Equilibrium Constant and the Chemical Equation 733
- 16.4 Expressing the Equilibrium Constant in Terms of Pressure** 734
Relationship Between K_p and K_c 735 Units of K 736
- 16.5 Heterogeneous Equilibria: Reactions Involving Solids and Liquids** 737
- 16.6 Calculating the Equilibrium Constant from Measured Equilibrium Concentrations** 738
- 16.7 The Reaction Quotient: Predicting the Direction of Change** 741
- 16.8 Finding Equilibrium Concentrations** 743
Finding Equilibrium Concentrations from the Equilibrium Constant and All but One of the Equilibrium Concentrations of the Reactants and Products 744
Finding Equilibrium Concentrations from the Equilibrium Constant and Initial Concentrations or Pressures 745
Simplifying Approximations in Working Equilibrium Problems 749
- 16.9 Le Châtelier's Principle: How a System at Equilibrium Responds to Disturbances** 753
The Effect of a Concentration Change on Equilibrium 754
The Effect of a Volume (or Pressure) Change on Equilibrium 756 The Effect of a Temperature Change on Equilibrium 758

CHAPTER IN REVIEW Self-Assessment Quiz 760 Terms 761
Concepts 761 Equations and Relationships 762
Learning Outcomes 762

EXERCISES Review Questions 763 Problems by Topic 764
Cumulative Problems 767 Challenge Problems 769
Conceptual Problems 769 Questions for Group Work 770
Data Interpretation and Analysis 770 Answers to Conceptual Connections 771



17 Acids and Bases 772

- 17.1 Heartburn** 773
- 17.2 The Nature of Acids and Bases** 774
- 17.3 Definitions of Acids and Bases** 776
The Arrhenius Definition 776 The Brønsted–Lowry Definition 777
- 17.4 Acid Strength and the Acid Ionization Constant (K_a)** 779
Strong Acids 779 Weak Acids 780 The Acid Ionization Constant (K_a) 781
- 17.5 Autoionization of Water and pH** 782
The pH Scale: A Way to Quantify Acidity and Basicity 784
pOH and Other p Scales 785
CHEMISTRY AND MEDICINE *Ulcers* 786
- 17.6 Finding the $[H_3O^+]$ and pH of Strong and Weak Acid Solutions** 787
Strong Acids 787 Weak Acids 787 Percent Ionization of a Weak Acid 792 Mixtures of Acids 793
- 17.7 Base Solutions** 796
Strong Bases 796 Weak Bases 796
Finding the $[OH^-]$ and pH of Basic Solutions 798
CHEMISTRY AND MEDICINE *What's in My Antacid?* 800
- 17.8 The Acid–Base Properties of Ions and Salts** 800
Anions as Weak Bases 801 Cations as Weak Acids 804
Classifying Salt Solutions as Acidic, Basic, or Neutral 805
- 17.9 Polyprotic Acids** 807
Finding the pH of Polyprotic Acid Solutions 808 Finding the Concentration of the Anions for a Weak Diprotic Acid Solution 810
- 17.10 Acid Strength and Molecular Structure** 812
Binary Acids 812 Oxyacids 813
- 17.11 Lewis Acids and Bases** 814
Molecules That Act as Lewis Acids 814 Cations That Act as Lewis Acids 815
- 17.12 Acid Rain** 815
Effects of Acid Rain 816 Acid Rain Legislation 817

CHAPTER IN REVIEW Self-Assessment Quiz 817 Terms 818
Concepts 818 Equations and Relationships 819
Learning Outcomes 820

EXERCISES Review Questions 820 Problems by Topic 821
Cumulative Problems 824 Challenge Problems 826 Conceptual Problems 826 Questions for Group Work 826 Data Interpretation and Analysis 826 Answers to Conceptual Connections 827

18 Aqueous Ionic Equilibrium 828

- 18.1 The Danger of Antifreeze** 829
- 18.2 Buffers: Solutions That Resist pH Change** 830
Calculating the pH of a Buffer Solution 832 The Henderson–Hasselbalch Equation 833 Calculating pH Changes in a Buffer Solution 836 The Stoichiometry Calculation 836 The Equilibrium Calculation 836
Buffers Containing a Base and Its Conjugate Acid 840
- 18.3 Buffer Effectiveness: Buffer Range and Buffer Capacity** 841
Relative Amounts of Acid and Base 841 Absolute Concentrations of the Acid and Conjugate Base 842
Buffer Range 843
CHEMISTRY AND MEDICINE *Buffer Effectiveness in Human Blood* 844
Buffer Capacity 844
- 18.4 Titrations and pH Curves** 845
The Titration of a Strong Acid with a Strong Base 846
The Titration of a Weak Acid with a Strong Base 850
The Titration of a Weak Base with a Strong Acid 855
The Titration of a Polyprotic Acid 856
Indicators: pH-Dependent Colors 856
- 18.5 Solubility Equilibria and the Solubility Product Constant** 859
 K_{sp} and Molar Solubility 859
CHEMISTRY IN YOUR DAY *Hard Water* 861
 K_{sp} and Relative Solubility 862 The Effect of a Common Ion on Solubility 862 The Effect of pH on Solubility 864
- 18.6 Precipitation** 865
Selective Precipitation 866
- 18.7 Qualitative Chemical Analysis** 868
Group 1: Insoluble Chlorides 869 Group 2: Acid-Insoluble Sulfides 869 Group 3: Base-Insoluble Sulfides and Hydroxides 870 Group 4: Insoluble Phosphates 870 Group 5: Alkali Metals and NH_4^+ 870
- 18.8 Complex Ion Equilibria** 871
The Effect of Complex Ion Equilibria on Solubility 873
The Solubility of Amphoteric Metal Hydroxides 874

CHAPTER IN REVIEW Self-Assessment Quiz 875 Terms 876
Concepts 876 Equations and Relationships 877
Learning Outcomes 877

EXERCISES Review Questions 878 Problems by Topic 879
Cumulative Problems 884 Challenge Problems 885 Conceptual Problems 885 Questions for Group Work 886
Data Interpretation and Analysis 886 Answers to Conceptual Connections 887



19 Free Energy and Thermodynamics 888



- 19.1 Cold Coffee and Dead Universes** 889
- 19.2 Spontaneous and Nonspontaneous Processes** 890
- 19.3 Entropy and the Second Law of Thermodynamics** 892
Entropy 894 The Entropy Change upon the Expansion of an Ideal Gas 896
- 19.4 Entropy Changes Associated with State Changes** 898
Entropy and State Change: The Concept 899 Entropy and State Changes: The Calculation 900
- 19.5 Heat Transfer and Changes in the Entropy of the Surroundings** 902
The Temperature Dependence of ΔS_{surr} 903
Quantifying Entropy Changes in the Surroundings 903
- 19.6 Gibbs Free Energy** 905
The Effect of ΔH , ΔS , and T on Spontaneity 906
- 19.7 Entropy Changes in Chemical Reactions: Calculating $\Delta S_{\text{rxn}}^{\circ}$** 909
Defining Standard States and Standard Entropy Changes 909 Standard Molar Entropies (S°) and the Third Law of Thermodynamics 909 Calculating the Standard Entropy Change ($\Delta S_{\text{rxn}}^{\circ}$) for a Reaction 913
- 19.8 Free Energy Changes in Chemical Reactions: Calculating $\Delta G_{\text{rxn}}^{\circ}$** 913
Calculating Standard Free Energy Changes with $\Delta G_{\text{rxn}}^{\circ} = \Delta H_{\text{rxn}}^{\circ} - T\Delta S_{\text{rxn}}^{\circ}$ 914 Calculating $\Delta G_{\text{rxn}}^{\circ}$ with Tabulated Values of Free Energies of Formation 915
CHEMISTRY IN YOUR DAY Making a Nonspontaneous Process Spontaneous 917
Calculating $\Delta G_{\text{rxn}}^{\circ}$ for a Stepwise Reaction from the Changes in Free Energy for Each of the Steps 917
Why Free Energy Is “Free” 918
- 19.9 Free Energy Changes for Nonstandard States: The Relationship between $\Delta G_{\text{rxn}}^{\circ}$ and ΔG_{rxn}** 920
Standard versus Nonstandard States 920 The Free Energy Change of a Reaction under Nonstandard Conditions 920 Standard Conditions 920
Equilibrium Conditions 921 Other Nonstandard Conditions 922
- 19.10 Free Energy and Equilibrium: Relating $\Delta G_{\text{rxn}}^{\circ}$ to the Equilibrium Constant (K)** 923
The Relationship between $\Delta G_{\text{rxn}}^{\circ}$ and K 923 The Temperature Dependence of the Equilibrium Constant 925

CHAPTER IN REVIEW Self-Assessment Quiz 926 Terms 927
Concepts 927 Equations and Relationships 928
Learning Outcomes 928

EXERCISES Review Questions 929 Problems by Topic 930
Cumulative Problems 933 Challenge Problems 934 Conceptual
Problems 935 Questions for Group Work 935 Data
Interpretation and Analysis 936 Answers to Conceptual
Connections 936

20 Electrochemistry 938

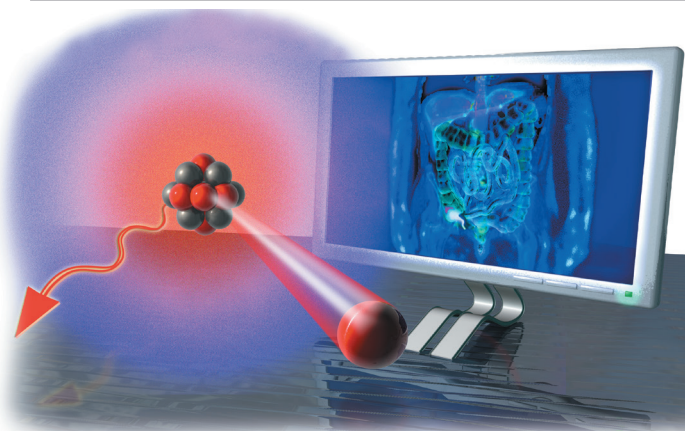
- 20.1 Lightning and Batteries** 939
- 20.2 Balancing Oxidation–Reduction Equations** 940
- 20.3 Voltaic (or Galvanic) Cells: Generating Electricity from Spontaneous Chemical Reactions** 943
The Voltaic Cell 944 Current and Potential Difference 945 Anode, Cathode, and Salt Bridge 946
Electrochemical Cell Notation 947
- 20.4 Standard Electrode Potentials** 947
Predicting the Spontaneous Direction of an Oxidation–Reduction Reaction 952 Predicting Whether a Metal Will Dissolve in Acid 955
- 20.5 Cell Potential, Free Energy, and the Equilibrium Constant** 955
The Relationship between ΔG° and E_{cell}° 956
The Relationship between E_{cell}° and K 958
- 20.6 Cell Potential and Concentration** 959
Cell Potential under Nonstandard Conditions: The Nernst Equation 959 Concentration Cells 962
CHEMISTRY AND MEDICINE Concentration Cells in Human Nerve Cells 964
- 20.7 Batteries: Using Chemistry to Generate Electricity** 964
Dry-Cell Batteries 964 Lead–Acid Storage Batteries 965 Other Rechargeable Batteries 966
Fuel Cells 967
CHEMISTRY IN YOUR DAY The Fuel-Cell Breathalyzer 968
- 20.8 Electrolysis: Driving Nonspontaneous Chemical Reactions with Electricity** 968
Predicting the Products of Electrolysis 971 Stoichiometry of Electrolysis 974
- 20.9 Corrosion: Undesirable Redox Reactions** 975
Corrosion of Iron 976 Preventing the Corrosion of Iron 977

CHAPTER IN REVIEW Self-Assessment Quiz 978 Terms 979
Concepts 979 Equations and Relationships 980
Learning Outcomes 980

EXERCISES Review Questions 981 Problems by Topic 981
Cumulative Problems 985 Challenge Problems 986 Conceptual
Problems 986 Questions for Group Work 986 Data
Interpretation and Analysis 987 Answers to Conceptual
Connections 987



21 Radioactivity and Nuclear Chemistry 988



- 21.1 Diagnosing Appendicitis** 989
- 21.2 The Discovery of Radioactivity** 990
- 21.3 Types of Radioactivity** 991
Alpha (α) Decay 992 Beta (β) Decay 993 Gamma (γ)
Ray Emission 994 Positron Emission 994 Electron
Capture 995
- 21.4 The Valley of Stability: Predicting the Type of Radioactivity** 996
Magic Numbers 998 Radioactive Decay Series 998
- 21.5 Detecting Radioactivity** 999
- 21.6 The Kinetics of Radioactive Decay and Radiometric Dating** 1000
The Integrated Rate Law 1002 Radiocarbon Dating:
Using Radioactivity to Measure the Age of Fossils and
Artifacts 1003
CHEMISTRY IN YOUR DAY *Radiocarbon Dating and the
Shroud of Turin* 1005
Uranium/Lead Dating 1005 The Age of Earth 1006
- 21.7 The Discovery of Fission: The Atomic Bomb and Nuclear Power** 1007
The Manhattan Project 1007 Nuclear Power: Using
Fission to Generate Electricity 1009 Problems with
Nuclear Power 1010

- 21.8 Converting Mass to Energy: Mass Defect and Nuclear Binding Energy** 1011
Mass Defect and Nuclear Binding Energy 1011
The Nuclear Binding Energy Curve 1013
- 21.9 Nuclear Fusion: The Power of the Sun** 1013
- 21.10 Nuclear Transmutation and Transuranium Elements** 1014
- 21.11 The Effects of Radiation on Life** 1016
Acute Radiation Damage 1016 Increased Cancer Risk 1016
Genetic Defects 1016 Measuring Radiation Exposure
and Dose 1017
- 21.12 Radioactivity in Medicine and Other Applications** 1018
Diagnosis in Medicine 1019 Radiotherapy in
Medicine 1020 Other Applications 1020

CHAPTER IN REVIEW Self-Assessment Quiz 1021 Terms 1022
Concepts 1022 Equations and Relationships 1023
Learning Outcomes 1023

EXERCISES Review Questions 1024 Problems by Topic 1024
Cumulative Problems 1026 Challenge Problems 1027 Conceptual
Problems 1028 Questions for Group Work 1028 Data Interpretation
and Analysis 1029 Answers to Conceptual Connections 1029

- Appendix I** Common Mathematical Operations
in Chemistry A-1
- Appendix II** Useful Data A-5
- Appendix III** Answers to Selected Exercises A-15
- Appendix IV** Answers to In-Chapter Practice
Problems A-45

Glossary G-1

Photo and Text Credits C-1

Index I-1

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 some day. Although these are good reasons, I would like to 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* to 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 behavior of matter is 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 dependence of the world we *can* see on 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 create 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 hair spray 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 hair spray depleting the ozone layer and thereby leading to global warming, the chlorofluorocarbons that deplete ozone have been banned from hair spray 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 some day, but 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 understanding 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 previous editions. You helped to make this book one of the most popular general chemistry textbooks in the world. 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 the direct result of your input, as well as my own experience using the book in my general chemistry courses. If you have reviewed content or have contacted me directly, you will likely see your suggestions reflected in the changes I have made. Thank you.

Higher education in science is changing. Foremost among those changes is a shift toward *active learning*. A flood of recent studies has demonstrated that General Chemistry students learn better when they are active in the learning process. However, implementing active learning can be a difficult and time-consuming process. One of my main goals in this revision is to give you, the professor, a range of tools to easily implement active learning in your class. My goal is

simple: *I want to make it easy for you to engage your students in active learning before class, during class, and after class.*

- **BEFORE CLASS** Although the term *active learning* has been applied mainly to in-class learning, the main idea—that *we learn better when we are actively engaged*—applies to all of learning. I have developed two main tools to help students prepare for class in an active way. The first tool is a complete library of 3- to 6-minute *Key Concept Videos (KCVs)* that, with this edition, span virtually all of the key concepts in a general chemistry course. The videos introduce a key concept and encourage active learning because they stop in the middle and pose a question that must be answered before the video continues playing. Each video also has an associated follow-up question that can be assigned using Mastering Chemistry. You can assign a video before each one of your classes to get your students thinking about the concepts for that day. A second tool for use before class is *active reading*. Each chapter in the book now contains 10–12 *Conceptual Connection* questions. These questions are assignable in Mastering Chemistry, and contain wrong answer feedback. Instead of passively reading the assigned material with no accountability, you can now encourage your students to engage in *active reading*, in which they read a bit and then answer a question that probes their comprehension and gives them immediate feedback.
- **DURING CLASS** By delivering some content through key concept videos and active reading before class, you can make room in your lecture to pose questions to your students that make the class experience active as well. This book features two main tools for in-class use. The first tool is *Learning Catalytics*, which allows you to pose many different types of questions to your students during class. Instead of passively listening to your lecture, students interact with the concepts you present through questions you pose. Your students can answer the questions individually, or you can pair them with a partner or small group. A second tool for in-class use is the *Questions for Group Work*. These questions appear in the end-of-chapter material and are specifically designed to be answered in small groups.
- **AFTER CLASS** Active learning can continue after class with two additional tools. The first is another library of 3- to 6-minute videos called *Interactive Worked Examples (IWEs)*. Each IWE video walks a student through the solution to a chemistry problem. Like the KCVs, the IWE video stops in the middle and poses a question that must be answered before the video continues playing. Each video also has an associated follow-up problem that can be assigned using Mastering Chemistry. The second tool for after (or outside of) class active learning is *Active Exam Preparation*. Research studies suggest that students who take a pretest before an exam do better on the exam, especially if the pretest contains immediate feedback. Each chapter in this book contains a *Self-Assessment Quiz* that

you can use to easily make a pretest for any of your exams. The *Self-Assessment Quizzes* are assignable in Mastering Chemistry, and contain wrong answer feedback. Simply choose the questions that you want from each of the quizzes that span the chapters on your exam, and you can create an assignable pretest that students can use to actively prepare for your exams.

Although we have added many active learning tools to this edition and made other changes as well, the book's goal 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. My own courses are populated with students with a range of backgrounds and abilities in chemistry. The challenge of successful teaching, in my opinion, is 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 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 and yet can be used and understood by any student willing to put in the necessary effort.

Principles of Chemistry: A Molecular Approach is first and foremost 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 the 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, I use images

to deepen the student's insight into chemistry. In developing chemical principles, multipart images help 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. In this edition, the art program has been thoroughly revised in two major ways. First, navigation of the more complex figures has been reoriented to track from left to right whenever possible. Second, figure captions have been migrated into the image itself as an "author voice" that explains the image and guides the reader through it. The resulting images are rich with information but also clear and quickly understood.

Fourth, *Principles of Chemistry: A Molecular Approach* is a "big-picture" book. At the beginning of each chapter, a short paragraph helps students to see the key relationships between the different topics they are learning. Through a 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. This philosophy is also integral to the *Key Concept Videos*, which concisely reinforce student appreciation of the core concepts in each chapter.

Lastly, *Principles of Chemistry: A Molecular Approach* is a book that delivers the depth of coverage faculty want. We do not have to cut corners and water down the material in order to get our students interested. We have to meet them where they are, challenge them to the highest level of achievement, and support them with enough pedagogy to allow them to succeed.

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 contact me with any questions or comments about the book.

Nivaldo J. Tro
nivatro@gmail.com

What's New in This Edition?

The book has been extensively revised and contains more small changes than can be detailed here. The most significant changes to the book and its supplements are listed below:

- **NEW INTERACTIVE VIDEOS** I have added 16 new *Key Concept Videos (KCVs)* and 24 new *Interactive Worked*

Examples (IWEs) to the media package that accompanies the book. *The video library now contains nearly 200 interactive videos.* These tools are designed to help professors engage their students in active learning.

- **NEW IN-CHAPTER QUESTIONS WITH FEEDBACK** I have added approximately 67 new *Conceptual Connection* questions throughout the book and have changed the format to multiple choice (with wrong answer feedback in Mastering Chemistry). Each chapter now has 10–12 of these assignable questions. These questions transform the reading process from passive to active and hold students accountable for reading assignments.
- **NEW MISSED THIS? FEATURE** I have added a new feature called *MISSED THIS?* to the *Self-Assessment Quizzes* and to the *Problems by Topic* section of the end-of-chapter problems. This feature lists the resources that students can use to learn how to answer the question or solve the problem. The resources include chapter sections to read, *Key Concept Videos (KCVs)* to watch, and *Interactive Worked Examples (IWEs)* to view. Students often try to solve an assigned question or problem before doing any reading or reviewing; they seek resources only *after* they have missed the question or problem. The *MISSED THIS?* feature guides them to reliable resources that provide just-in-time instruction.
- **NEW FOR PRACTICE FEEDBACK** I have enhanced 64 of the in-chapter *For Practice* problems (which immediately follow an in-chapter worked example) with feedback that can be accessed through Mastering Chemistry.
- **REVISED ART PROGRAM** The art program has been extensively revised. Navigation of the more complex figures has been reoriented to track from left to right, and many figure captions have been broken up and have been moved into the image itself as an "author voice" that explains the image and guides the reader through it.
- **REVISED DATA INTERPRETATION AND ANALYSIS QUESTIONS** The *Data Interpretation and Analysis* questions that accompany each chapter have been extensively revised to make them clearer and more accessible to students.
- **NEW SECTION ON DATA INTERPRETATION AND ANALYSIS** I have added a new section to Chapter 1 (Section 1.9) on the general topic of analyzing and interpreting data. This section introduces the skills required to address many of the revised data interpretation and analysis questions.
- **NEW HOW TO . . . FEATURE** All guidance for essential skills such as problem-solving techniques, drawing Lewis structures, and naming compounds is now presented in a consistent, step-by-step numbered list called *How To*...
- **REVISED CHAPTER 4** Chapter 4 in the previous edition covered both stoichiometry and chemical reactions in solution. In this edition, this content has been

expanded slightly and has been divided into two more focused chapters, so that Chapter 4 is now focused on stoichiometry and Chapter 5 on chemical reactions in solution. This new organization lessens the cognitive load for students and allows each chapter to be more direct and focused. All subsequent chapters have been renumbered accordingly.

- **NEW ACTIVITY SERIES CONTENT** I added a new subsection to Section 5.9 entitled *The Activity Series: Predicting Whether a Redox Reaction Is Spontaneous*. The new section includes new figures, tables, and a new worked example.
- **NEW READY-TO-GO LEARNING MODULES** These online modules offer students easy access to the best Tro content in Mastering Chemistry without needing to have it assigned.
- **NEW TWO-TIER OBJECTIVES** A system of two-tier objectives is being applied to the text and to the Mastering Chemistry assets. The two tiers are Learning Objectives, or LOs, and Enabling Objectives, or EOs. The LOs are broad, high-level objectives that summarize the overall learning goal, while the EOs are the building block skills that enable students to achieve the LO. The learning objectives are given in the Learning Outcomes table at the end of the chapter.
- **REVISED DATA** All the data throughout the book have been updated to reflect the most recent measurements available. These updates include Figure 4.2: *Carbon Dioxide in the Atmosphere*; Figure 4.3: *Global Temperatures*; the unnumbered figure in Section 7.10 of *U.S. Energy Consumption*; Figure 7.12: *Energy Consumption by Source*; Table 7.6: *Changes in National Average Pollutant Levels, 1990–2016*; Figure 15.19: *Ozone Depletion in the Antarctic Spring*; Figure 17.15: *Sources of U.S. Energy*; Figure 17.16: *Acid Rain*; and Figure 17.18: *U.S. Sulfur Dioxide Pollutant Levels*.
- **REVISED CHAPTER OPENERS** Many chapter-opening sections and (or) the corresponding art—including Chapters 1, 3, 4, 5, 6, 7, 10, 11, 18, 19, and 20—have been replaced or modified.

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. Terry is a great editor and friend. He gives me the right balance of freedom and direction and always supports me in my endeavors. Thanks, Terry, for all you have done for me and for general chemistry courses throughout the world. Thanks also to Matt Walker, my new developmental editor on this project. Matt is creative, organized, and extremely competent. He has made significant contributions to this revision and has helped me with the many tasks that must be simultaneously addressed and developed during a revision as significant as this one. Matt, I hope this is only the beginning of

a long and fruitful collaboration. I also owe a special debt of gratitude to Barbara Yien and Laura Southworth. Barbara was involved in many parts of content development, and Laura played a critical role in the revision of the art program. Many thanks to the both of you!

Thanks also to my media editor, Paula Iborra. Paula has been instrumental in helping me craft and develop the Key Concept Videos, Interactive Worked Examples, and other media content that accompany this text. Gracias, Paula.

I am also grateful to Harry Misthos, who helped with organizing reviews, as well as numerous other tasks associated with keeping the team running smoothly. I am also grateful to Jeanne Zalesky, Editor-in-Chief for Physical Sciences. She has supported me and my projects and allowed me to succeed. Thanks also to Adam Jaworski, who oversees science courseware at Pearson. I am grateful to have his wise and steady, yet innovative, hand at the wheel, especially during the many changes that are happening within educational publishing. I am also grateful to my marketing managers, Chris Barker and Elizabeth Bell. Chris and I go way back and have worked together in many different ways. Chris, thanks for all you do to promote my books. Elizabeth is a marketing manager extraordinaire. She has endless energy and ideas for marketing this book. I have enjoyed working with her over the last several years and wish to congratulate her on the recent birth of her first child. Congratulations, Elizabeth! I continue to owe a special word of thanks to Glenn and Meg Turner of Burrston House, ideal collaborators whose contributions to the first edition of the book were extremely important and much appreciated. Quade Paul, who makes my ideas come alive with his art, has been with us from the beginning, and I owe a special debt of gratitude to him. I am also grateful to Maria Guglielmo Walsh and Elise Lansdon for their creativity and hard work in crafting the design of this text. Finally, I would like to thank Beth Sweeten and the rest of the Pearson production team. They are a first-class operation—this text has benefited immeasurably from their talents and hard work. I also thank Francesca Monaco and her coworkers 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 over many projects, and to Eric Schrader for his exemplary photo research. And of course, I am continually grateful for Paul Corey, with whom I have now worked for over 18 years and 16 projects. 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 those who have supported me personally while working on this book. First on that list is my wife, Ann. Her patience and love for me are beyond description, and without her, this book would never have been

written. 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; and my nephews and nieces, Germain, Danny, Lisette, Sara, and Kenny. These are the people with whom I celebrate life.

I am especially grateful to Michael Tro, who put in many hours proofreading my manuscript, working problems and quiz questions, and organizing appendices. Michael, you are amazing—it is my privilege to have you work with me on this project.

I would like to thank all of the general chemistry students who have been in my classes throughout my 29 years as a professor. You have taught me much about teaching that is now in this book.

Lastly, I am indebted to the many reviewers, listed on the following pages, 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. I am particularly grateful to Corey Beck who has played an important role in developing the objectives for this edition. I am also grateful to the accuracy of reviewers who tirelessly checked page proofs for correctness.

Reviewers of the Fourth Edition

Vanessa Castleberry, *Baylor University*
 Andrew Frazer, *University of Central Florida*
 Alton Hassell, *Baylor University*
 Barry Lavine, *Oklahoma State University*
 Diana Leung, *The University of Alabama*
 Lauren McMills, *Ohio University*
 David Perdian, *Broward College*
 Daniele Ramella, *Temple University*
 Shuai Sun, *University of Kansas*
 Dennis Taylor, *Clemson University*
 Tara Todd, *Vanderbilt University*

Reviewers of Previous Editions

Patricia G. Amateis, *Virginia Tech*
 Margaret R. Asirvatham, *University of Colorado*
 Paul Badger, *Robert Morris University*
 Monica H. Baloga, *Florida Institute of Technology*
 Rebecca Barlag, *Ohio University*
 Mufeed M. Basti, *North Carolina Agricultural & Technological State University*
 Amy E. Beilstein, *Centre College*
 Donald Bellew, *The University of New Mexico*
 Maria Benavides, *University of Houston, Downtown*
 Kyle A. Beran, *University of Texas of the Permian Basin*
 Thomas Bertolini, *University of Southern California*
 Christine V. Bilicki, *Pasadena City College*
 Silas C. Blackstock, *The University of Alabama*
 Robert E. Blake, *Texas Tech University*
 Angela E. Boerger, *Loyola University Chicago*
 Robert S. Boikess, *Rutgers University*
 Paul Brandt, *North Central College*
 Michelle M. Brooks, *College of Charleston*
 Gary Buckley, *Cameron University*
 Joseph H. Bularzik, *Purdue University, Calumet*
 Cindy M. Burkhardt, *Radford University*
 Andrew E. Burns, *Kent State University at Stark*

Kim C. Calvo, *The University of Akron*
 Stephen C. Carlson, *Lansing Community College*
 David A. Carter, *Angelo State University*
 Ferman Chavez, *Oakland University*
 Eric G. Chesloff, *Villanova University*
 Ted Clark, *The Ohio State University*
 William M. Cleaver, *The University of Vermont*
 Charles T. Cox Jr., *Georgia Institute of Technology*
 J. Ricky Cox, *Murray State University*
 Samuel R. Cron, *Arkansas State University*
 Guy Crundwell, *Central Connecticut State University*
 Darwin B. Dahl, *Western Kentucky University*
 Robert F. Dias, *Old Dominion University*
 Daniel S. Domin, *Tennessee State University*
 Bonnie Dixon, *University of Maryland*
 Alan D. Earhart, *Southeast Community College*
 Jack Eichler, *University of California, Riverside*
 Amina K. El-Ashmawy, *Collin College*
 Joseph P. Ellison, *United States Military Academy at West Point*
 Joseph M. Eridon, *Central New Mexico Community College*
 Deborah B. Exton, *The University of Oregon*
 William A. Faber, *Grand Rapids Community College*
 Michael Ferguson, *Honolulu Community College*
 Maria C. Fermin-Ennis, *Gordon College*
 Oscar Navarro Fernandez, *University of Hawaii at Manoa*
 Jan Florian, *Loyola University Chicago*
 Andy Frazer, *University of Central Florida*
 Candice E. Fulton, *Midwestern State University*
 Ron Garber, *California State University at Long Beach*
 Carlos D. Garcia, *The University of Texas at San Antonio*
 Eric S. Goll, *Brookdale Community College*
 Robert A. Gossage, *Acadia University*
 Pierre Y. Goueth, *Santa Monica College*
 Thomas J. Greenbowe, *Iowa State University*
 Victoria Guarisco, *Middle Georgia State University*
 Christin Gustafson, *Illinois Central College*
 Jason A. Halfen, *University of Wisconsin-Eau Claire*
 Nathan Hammer, *University of Mississippi*
 Michael D. Hampton, *University of Central Florida*
 Tamara Hanna, *Texas Tech University*
 Lois Hansen-Polcar, *Cuyahoga Community College-Western Campus*
 Tony Hascall, *Northern Arizona University*
 Elda Hegmann, *Kent State University*
 Monte L. Helm, *Fort Lewis College*
 David E. Henderson, *Trinity College*
 Susan K. Henderson, *Quimmipiac University*
 Peter M. Hierl, *The University of Kansas*
 Paula Hjorth-Gustin, *San Diego Mesa College*
 Angela Hoffman, *University of Portland*
 Todd A. Hopkins, *Butler University*
 Byron E. Howell, *Tyler Junior College*
 Ralph Isovitsch, *Xavier University of Louisiana*
 Kenneth C. Janda, *University of California, Irvine*
 Milt Johnston, *University of South Florida*
 Jason A. Kautz, *University of Nebraska-Lincoln*
 Catherine A. Keenan, *Chaffey College*
 Steven W. Keller, *University of Missouri*
 Resa Kelly, *San Jose State University*
 Chulsung Kim, *Georgia Gwinnett College*
 Louis J. Kirschenbaum, *University of Rhode Island*
 Mark Knecht, *University of Kentucky*
 Bette Kreuz, *University of Michigan-Dearborn*
 Sergiy Kryatov, *Tufts University*
 Richard H. Langley, *Stephen F. Austin State University*
 Clifford B. Lemaster, *Boise State University*
 Sarah Lievens, *University of California, Davis*
 Robley Light, *Florida State University*
 Adam List, *Vanderbilt University*
 Christopher Lovallo, *Mount Royal University*
 Eric Malina, *University of Nebraska-Lincoln*
 Benjamin R. Martin, *Texas State University*
 Lydia J. Martinez-Rivera, *University of Texas at San Antonio*
 Marcus T. McEllistrem, *University of Wisconsin-Eau Claire*
 Danny G. McGuire, *Cameron University*
 Charles W. McLaughlin, *University of Nebraska, Lincoln*
 Curt L. McLendon, *Saddleback College*
 Lauren McMills, *Ohio University*

Robert C. McWilliams, *United States Military Academy*
 Behnoush Memari, *Broward College*
 David H. Metcalf, *University of Virginia*
 Ray Mohseni, *East Tennessee State University*
 Elisabeth A. Morlino, *University of the Sciences, Philadelphia*
 Nancy Mullins, *Florida State College at Jacksonville*
 James E. Murphy, *Santa Monica College*
 Maria C. Nagan, *Truman State University*
 Edward J. Neth, *University of Connecticut*
 Aric Opdahl, *University of Wisconsin La Crosse*
 Kenneth S. Overway, *Bates College*
 Greg Owens, *University of Utah*
 Naresh Pandya, *University of Hawaii*
 George Papadantonakis, *The University of Illinois at Chicago*
 Gerard Parkin, *Columbia University*
 Jessica Parr, *University of Southern California*
 Yasmin Patell, *Kansas State University*
 Tom Pentecost, *Grand Valley State University*
 David Perdian, *Broward College*
 Glenn A. Petrie, *Central Missouri State*
 Norbert J. Pienta, *University of Iowa*
 Louis H. Pignolet, *University of Minnesota*
 Jerry Poteat, *Georgia Perimeter College*
 Valerie Reeves, *University of New Brunswick*
 Dawn J. Richardson, *Colin College*
 Thomas G. Richmond, *University of Utah*
 Dana L. Richter-Egger, *University of Nebraska*
 Jason Ritchie, *University of Mississippi*
 Christopher P. Roy, *Duke University*
 A. Timothy Royappa, *University of West Florida*
 Stephen P. Ruis, *American River College*
 Raymond Sadeghi, *The University of Texas at San Antonio*
 Alan E. Sadurski, *Ohio Northern University*
 Thomas W. Schleich, *University of California, Santa Cruz*
 Rod Schoonover, *CA Polytechnic State University*
 Mark Schraf, *West Virginia University*
 John Selegue, *University of Kentucky*
 Tom Selegue, *Pima Community College, West*
 Susan Shadle, *Boise State University*
 Anju H. Sharma, *Stevens Institute of Technology*
 Sherril A. Soman, *Grand Valley State University*
 Michael S. Sommer, *University of Wyoming*
 Jie S. Song, *University of Michigan, Flint*
 Clarissa Sorensen, *Central New Mexico Community College*
 Mary Kay Sorenson, *University of Wisconsin, Milwaukee*
 Stacy E. Sparks, *University of Texas, Austin*
 Richard Spinney, *Ohio State University*
 William H. Steel, *York College of Pennsylvania*
 Vinodhkumar Subramaniam, *East Carolina University*
 Jerry Suits, *University of Northern Colorado*
 Tamar Y. Susskind, *Oakland Community College*
 Uma Swamy, *Florida International University*
 Ryan Sweeder, *Michigan State University*
 Dennis Taylor, *Clemson University*
 Jacquelyn Thomas, *Southwestern College*
 Kathleen Thrush Shaginaw, *Villanova University*
 Lydia Tien, *Monroe Community College*
 David Livingstone Toppen, *California State University Northridge*
 Marcy Towns, *Purdue University*
 Harold Trimm, *Broome Community College*
 Frank Tsung, *Boston College*
 Laura VanDorn, *University of Arizona*
 Susan Varkey, *Mount Royal College*
 Ramaiyer Venkatraman, *Jackson State University*
 John B. Vincent, *University of Alabama, Tuscaloosa*
 Kent S. Voelkner, *Lake Superior College*
 Sheryl K. Wallace, *South Plains College*
 Wayne E. Wesolowski, *University of Arizona*
 Sarah E. West, *Notre Dame University*
 John Wiginton, *University of Mississippi*
 Kurt J. Winkelmann, *Florida Institute of Technology*
 Troy D. Wood, *University of Buffalo*
 Servet M. Yatin, *Quincy College*
 Kazushige Yokoyama, *SUNY Geneseo*
 Lin Zhu, *IUPUI*

Chapter 13, Solids and Modern Materials, Advisory Board

Michael Burand, *Oregon State University*
 Christopher Collison, *Rochester Institute of Technology*
 Jordan Fantini, *Denison University*
 Melissa Hines, *Cornell University*
 Raymond Schaak, *Penn State University*
 Jennifer Shanoski, *Merritt College*
 Jim Zubricky, *University of Toledo*

Focus Group Participants

We would like to thank the following professors for contributing their valuable time to meet with the author and the publishing team in order to provide a meaningful perspective on the most important challenges they face in teaching general chemistry. They gave us insight into creating a general chemistry text that successfully responds to those challenges.

Focus Group 13

Kim Cortes, *Kennesaw State University*
 Patrick Daubenmire, *Loyola University - Chicago*
 Michael Dianovsky, *South Dakota State University*
 Deborah Exton, *University of Oregon*
 Joel Goldberg, *University of Vermont*
 Edith Preciosa Kippenhan, *University of Toledo*
 Thomas Mullen, *University of North Florida*
 Tricia Shepherd, *St. Edward's University*

Focus Groups 1–12

Corey Beck, *Ohio University*
 Jennifer Duis, *Northern Arizona University*
 Alton Hassell, *Baylor University*
 Tina Huang, *University of Illinois*
 Amy Irwin, *Monroe Community College*
 Maria Korolev, *University of Florida*
 Jennifer Schwartz Poehlmann, *Stanford University*
 John Selegue, *University of Kentucky*
 Sarah Siegel, *Gonzaga University*
 Jeff Statler, *University of Utah*
 Michael R. Abraham, *University of Oklahoma*
 Ramesh D. Arasasingham, *University of California, Irvine*
 James A. Armstrong, *City College of San Francisco*
 Silas C. Blackstock, *University of Alabama*
 Roberto A. Bogomolni, *University of California, Santa Cruz*
 Stacey Brydges, *University of California San Diego*
 Kenneth Capps, *Central Florida Community College*
 Stephen C. Carlson, *Lansing Community College*
 Charles E. Carraher, *Florida Atlantic University*
 Kenneth Caswell, *University of South Florida*
 Robert Craig Taylor, *Oakland University*
 Darwin B. Dahl, *Western Kentucky University*
 Mohammed Daoudi, *University of Central Florida*
 Kate Deline, *College of San Mateo*
 Stephanie Dillon, *Florida State University*
 Ralph C. Dougherty, *Florida State University*
 William Eck, *University of Wisconsin, Marshfield/Wood County*
 Robert J. Eierman, *University of Wisconsin, Eau Claire*
 Amina K. El-Ashmawy, *Collin County Community College*
 William A. Faber, *Grand Rapids Community College*
 Richard W. Frazee, *Rowan University*
 Barbara A. Gage, *Prince George's Community College*
 Simon Garrett, *California State University, Northridge*
 Raymond F. Glienna, *Glendale Community College*
 Eric S. Goll, *Brookdale Community College*
 Pierre Y. Goueth, *Santa Monica College*

W. Tandy Grubbs, *Stetson University*
 Jerome E. Haky, *Florida Atlantic University*
 Jason A. Halfen, *University of Wisconsin, Eau Claire*
 John A. W. Harkless, *Howard University*
 Paul I. Higgs, *Barry University*
 Norris W. Hoffman, *University of South Alabama*
 Tony Holland, *Wallace Community College*
 Todd A. Hopkins, *Butler University*
 Moheb Ishak, *St. Petersburg College, St. Petersburg*
 Kamal Ismail, *CUNY, Bronx Community College*
 Greg M. Jorgensen, *American River College*
 Sharon K. Kapica, *County College of Morris*
 Jason Kautz, *University of Nebraska, Lincoln*
 Mark Kearley, *Florida State University*
 Catherine A. Keenan, *Chaffey College*
 Steven W. Keller, *University of Missouri, Columbia*
 Ellen Kime-Hunt, *Riverside Community College, Riverside Campus*
 Peter J. Krieger, *Palm Beach Community College, Lake Worth*
 Roy A. Lacey, *State University of New York, Stony Brook*
 David P. Licata, *Coastline Community College*
 Michael E. Lipschutz, *Purdue University*
 Patrick M. Lloyd, *CUNY, Kingsborough Community College*
 Boon H. Loo, *Towson University*
 James L. Mack, *Fort Valley State University*
 Jeanette C. Madea, *Broward Community College, North*
 Joseph L. March, *University of Alabama, Birmingham*
 Jack F. McKenna, *St. Cloud State University*
 Curtis L. McLendon, *Saddleback College*
 Dianne Meador, *American River College*
 David Metcalf, *University of Virginia*
 John A. Milligan, *Los Angeles Valley College*
 Alice J. Monroe, *St. Petersburg College, Clearwater*
 Elisabeth A. Morlino, *University of the Sciences, Philadelphia*
 Heino Nitsche, *University of California at Berkeley*
 Pedro Patino, *University of Central Florida*
 Jeremy Perotti, *Nova Southeastern University*
 Norbert J. Pienta, *University of Iowa*
 Jayashree Ranga, *Salem State University*
 Cathrine E. Reck, *Indiana University*
 Thomas Ridgway, *University of Cincinnati*
 Jil Robinson, *Indiana University*
 Richard Rosso, *St. John's University*
 Steven Rowley, *Middlesex County College*
 Benjamin E. Rusiloski, *Delaware Valley College*
 Karen Sanchez, *Florida Community College, Jacksonville*
 David M. Sarno, *CUNY, Queensborough Community College*

Reva A. Savkar, *Northern Virginia Community College*
 Thomas W. Schleich, *University of California, Santa Cruz*
 Donald L. Siegel, *Rutgers University, New Brunswick*
 Mary L. Sohn, *Florida Institute of Technology*
 Sherril Soman-Williams, *Grand Valley State University*
 Allison Soult, *University of Kentucky*
 Louise S. Sowers, *Richard Stockton College of New Jersey*
 Anne Spuches, *East Carolina University*
 William H. Steel, *York College of Pennsylvania*
 Uma Swamy, *Florida International University*
 Richard E. Sykora, *University of South Alabama*
 Galina G. Talanova, *Howard University*
 Claire A. Tessier, *University of Akron*
 Kathleen Thrush Shaginaw, *Villanova University*
 John Vincent, *University of Alabama*
 Gary L. Wood, *Valdosta State University*
 Servet M. Yatin, *Quincy College*
 James Zubricky, *University of Toledo*

Acknowledgments for the Global Edition

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

Contributors

Mathew Akerman, *University of KwaZulu-Natal*
 James Brady, *The University of Auckland*
 Mark Lynch, *University of Southern Queensland*
 Katherine Stevens, *The University of Adelaide*
 Bheki Xulu, *University of KwaZulu-Natal*

Reviewers

Burkhard Kirste, *Freie Universität Berlin*
 Jakob "SciFox" Lauth, *University of Applied Sciences, Aachen*
 Sadhna Mathura, *University of the Witwatersrand*
 Nor Saadah Mohd Yusof, *University of Malaya*
 Toon Peters, *Zuyd Hogeschool*
 Susan Pyke, *Flinders University*

Actively Engage Students to Become Expert Problem Solvers and Critical Thinkers

Nivaldo Tro's *Principles of Chemistry: A Molecular Approach* presents chemistry visually through multi-level images—macroscopic, molecular, and symbolic representations—to help students see the connections between the world they see around them, the atoms and molecules that compose the world, and the formulas they write down on paper. The **4th Edition** pairs digital, pedagogical innovation with insights from learning design and educational research to create an active, integrated, and easy-to-use framework. The new edition introduces a fully integrated book and media package that streamlines course setup, actively engages students in becoming expert problem solvers, and makes it possible for professors to teach the general chemistry course easily and effectively.

