

Chemistry A Molecular Approach

THIRD EDITION

Nivaldo J.Tro



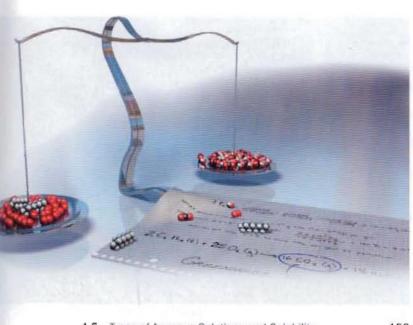
Contents

ref	ace	xix		54 80
1			U	C English
T	Matter, Measurement, and			
	Problem Solving xx	xviii		
1.1	Atoms and Molecules	1		
1.2	The Scientific Approach to Knowledge	3		
	THE NATURE OF SCIENCE: Thomas S. Kuhn and			
	Scientific Revolutions	5		
1.3	The Classification of Matter	5		
	The States of Matter: Solid, Liquid, and Gas 5 Classifying Matter according to Its Composition: Elements, Compounds, and Mixtures 7 Separating Mixtures 8			
1.4	Physical and Chemical Changes and Physical			
	and Chemical Properties	9	2.3	Modern Atomic Theory and the Laws That Led to It
1.5	Energy: A Fundamental Part of Physical and	**		The Law of Conservation of Mass 47 The Law
	Chemical Change	12		of Definite Proportions 48 The Law of Multiple
1.6	The Units of Measurement The Standard Units 13 The Meter: A Measure of	13		Proportions 49 John Dalton and the Atomic Theory 50
	Length 14 The Kilogram: A Measure of			CHEMISTRY IN YOUR DAY: Atoms and Humans
	Mass 14 The Second: A Measure of Time 14		2.4	The Discovery of the Electron
	The Kelvin: A Measure of Temperature 15 Prefix Multipliers 17 Derived Units: Volume and Density 17 Calculating Density 18			Cathode Rays 51 Millikan's Oil Drop Experiment The Charge of the Electron 52
	CHEMISTRY AND MEDICINE: Bone Density	20	2.5	The Structure of the Atom
1.7	The Reliability of a Measurement	20	2.6	Subatomic Particles: Protons, Neutrons, and
	Counting Significant Figures 22 Exact Numbers 22 Significant Figures in Calculations 23 Precision and Accuracy 25			Electrons in Atoms Elements: Defined by Their Numbers of Protons 56 Isotopes: When the Number of Neutro
	CHEMISTRY IN YOUR DAY: Integrity in Data Gathering	26		Varies 58 Ions: Losing and Gaining Electrons 5 CHEMISTRY IN YOUR DAY: Where Did Elements
1.8	Solving Chemical Problems	27		Come From?
	Converting from One Unit to Another 27 General Problem-Solving Strategy 28 Units Raised to a Power 30 Order-of-Magnitude Estimations 31			
	Problems Involving an Equation 32			
	CHAPTER IN REVIEW	34		
	Self-Assessment Quiz 34 Key Terms 35 Key Concepts 35 Key Equations and Relationships 36 Key Learning Outcomes 36			
	EXERCISES Review Questions 36 Problems by Topic 37 Cumulative Problems 41 Challenge Problems 42 Conceptual Problems 42 Answers to Conceptual Connections 43	36		
2	Atoms and Elements	44		
0.1	Constituting the second of the			
2.1	Imaging and Moving Individual Atoms	45		
, ,	Larly Ideas about the Building Dicele of Motter	17		The state of the s

xiv	Contents					
16.5	Solubility Equilibria and the Solubili	ty Product Constant	783	17.5	Gibbs Free Energy	828
	K _{sp} and Molar Solubility 783				The Effect of ΔH , ΔS , and T on Spontaneity 829	
	CHEMISTRY IN YOUR DAY: Hard Wa	ter	785	17.6	Entropy Changes in Chemical Reactions:	
	K _{sp} and Relative Solubility 786 Common Ion on Solubility 786 on Solubility 788				Calculating ΔS ^o _{ton} Standard Molar Entropies (S ^o) and the Third Law of Thermodynamics 832	832
16.6	Precipitation Selective Precipitation 790		789	17.7	Free Energy Changes in Chemical Reactions: Calculating ΔG_{cm}°	836
16.7	Qualitative Chemical Analysis Group 1: Insoluble Chlorides 793 Insoluble Sulfides 793 Group 3 Sulfides and Hydroxides 794 G Phosphates 794 Group 5: Alkal NH ₄ 794	: Base-Insoluble roup 4: Insoluble	792		Calculating Standard Free Energy Changes with $\Delta G_{\text{TXN}}^{\circ} = \Delta H_{\text{TXN}}^{\circ} - T\Delta S_{\text{TXN}}^{\circ}$ 836 Calculating $\Delta G_{\text{TXN}}^{\circ}$ with Tabulated Values of Free Energies of Formation 838 CHEMISTRY IN YOUR DAY: Making a Nonspontaneous Process Spontaneous	
16.8	Complex Ion Equilibria The Effect of Complex Ion Equili Solubility 797 The Solubility of		795		Calculating $\Delta G_{\text{cut}}^{\circ}$ for a Stepwise Reaction from the Changes in Free Energy for Each of the Steps 840 Why Free Energy Is "Free" 841	
	Hydroxides 798		700	17.8	Free Energy Changes for Nonstandard States:	0.40
	CHAPTER IN REVIEW Self Assessment Quiz 799 Key Key Concepts 801 Key Equation	s and	799		The Relationship between ΔG_{DR}^{o} and ΔG_{DR} The Free Energy Change of a Reaction under Nonstandard Conditions 843	842
	Relationships 801 Key Learning EXERCISES	Outcomes 801	อกว	17.9	Free Energy and Equilibrium: Relating $\Delta G_{\text{txn}}^{\circ}$	
	Review Questions 803 Problem Cumulative Problems 808 Chal	lenge Problems 809	803		to the Equilibrium Constant (K) The Temperature Dependence of the Equilibrium Constant 847	845
1	Conceptual Problems 810 Answ Connections 810	vers to Conceptual			CHAPTER IN REVIEW Self Assessment Quiz 848 Key Terms 849 Key Concepts 850 Key Equations and Relationships 850 Key Learning Outcomes 851	848
1	Free Energy and				EXERCISES	852
	Thermodynamics	8	312		Review Questions 852 Problems by Topic 852	002
17.1	Nature's Heat Tax: You Can't Win and You Can't Break Even	1	813		Cumulative Problems 855 Challenge Problems 85 Conceptual Problems 858 Answers to Conceptual Connections 858	7
17.2	Spontaneous and Nonspontaneous	Processes	814			
17.3	Entropy and the Second Law of Ther	modynamics	817	1	Q	
	Entropy 818 The Entropy Chan a Change in State 822	ge Associated with		10.1		860
17.4	Heat Transfer and Changes in the En	tropy of		18.1	Pulling the Plug on the Power Grid	861
	The Temperature Dependence of a		824	18.2 18.3	Balancing Oxidation-Reduction Equations Voltaic (or Galvanic) Cells: Generating Electricity from Spontaneous Chemical Reactions	862 865
	Quantifying Entropy Changes in t Surroundings 826	ne			Electrochemical Cell Notation 869	000
	and the same			18.4	Standard Electrode Potentials	870
					Predicting the Spontaneous Direction of an Oxidation Reduction Reaction 874 Predicting Whether a Meta Will Dissolve in Acid 877	
				18.5	Cell Potential, Free Energy, and the Equilibrium Constant The Relationship between ΔG° and E°_{cell} 878 The Relationship between E°_{cell} and K 880	877
				18.6	Cell Potential and Concentration	881
					Concentration Cells 884	
					CHEMISTRY AND MEDICINE: Concentration Cells in Human Nerve Cells	886

Formulas 112

Solution Stoichiometry 156



4.5	Types of Aqueous Solutions and Solubility Electrolyte and Nonelectrolyte Solutions 159	158
	The Solubility of Ionic Compounds 160	
4.6	Precipitation Reactions	162
4.7	Representing Aqueous Reactions: Molecular, Ionic, and	
	Complete Ionic Equations	166
4.8	Acid-Base and Gas-Evolution Reactions	168
	Acid–Base Reactions 168 Gas-Evolution Reactions 173	
4.9	Oxidation-Reduction Reactions	175
	Oxidation States 176 Identifying Redox	
	Reactions 179 Combustion Reactions 182	
	CHEMISTRY IN YOUR DAY: Bleached Blonde	181
	CHAPTER IN REVIEW	182
	Self Assessment Quiz 182 Key Terms 183	
	Key Concepts 184 Key Equations and	
	Relationships 184 Key Learning Outcomes 185	
	EXERCISES	186
	Review Questions 186 Problems by Topic 186	
	Cumulative Problems 190 Challenge Problems 191	
	Conceptual Problems 192 Answers to Conceptual	
	Connections 193	

3	Gases	194
5.1	Breathing: Putting Pressure to Work	195
5.2	Pressure: The Result of Molecular Collisions	196
	Pressure Units 197 The Manometer: A Way to Measure Pressure in the Laboratory 198 CHEMISTRY AND MEDICINE: Blood Pressure	199
5.3	The Simple Gas Laws: Boyle's Law, Charles's Law, and Avogadro's Law	199
	Boyle's Law: Volume and Pressure 200 Charles's	

	CHEMISTRY IN YOUR DAY: Extra-Long Snorkels	203
	Avogadro's Law: Volume and Amount (in Moles) 205	
5.4	The Ideal Gas Law	206
5.5	Applications of the Ideal Gas Law: Molar Volume, Density, and Molar Mass of a Gas	209
	Molar Volume at Standard Temperature and Pressure 209 Density of a Gas 210 Molar Mass of a Gas 211	
5.6	Mixtures of Gases and Partial Pressures	213
	Deep-Sea Diving and Partial Pressures 215 Collecting Gases over Water 217	
5.7	Gases in Chemical Reactions:	
	Stoichiometry Revisited	219
	Molar Volume and Stoichiometry 221	
5.8	Kinetic Molecular Theory: A Model for Gases	222
	Kinetic Molecular Theory and the Ideal Gas Law 224 Temperature and Molecular Velocities 226	
5.9	Mean Free Path, Diffusion, and Effusion of Gases	229
5.10	Real Gases: The Effects of Size and	
	Intermolecular Forces	230
	The Effect of the Finite Volume of Gas Particles 230	
	The Effect of Intermolecular Forces 232 Van der Waals Equation 233 Real Gases 233	
	CHAPTER IN REVIEW	234
	Self Assessment Quiz 234 Key Terms 235	
	Key Concepts 235 Key Equations and	
	Relationships 236 Key Learning Outcomes 237	000
	EXERCISES Review Questions 238 Problems by Topic 238	238
	Cumulative Problems 242 Challenge Problems 244	
	Conceptual Problems 244 Answers to Conceptual Connections 245	



O	Thermochemistry	246		
6.1	Chemical Hand Warmers	247		
6.2	The Nature of Energy: Key Definitions Units of Energy 250	248		羅
6.3	The First Law of Thermodynamics: There Is No Free Lunch	250		
	CHEMISTRY IN YOUR DAY: Redheffer's Perpetual Motion Machine Internal Energy 251	251	No.	
6.4	Quantifying Heat and Work Heat 256 Work: Pressure-Volume Work 260	256		
6.5	Measuring ΔE for Chemical Reactions: Constant-Volume Calorimetry	262		25
6.6	Enthalpy: The Heat Evolved in a Chemical Reaction at Constant Pressure	265		
	Exothermic and Endothermic Processes: A Molecula View 267 Stoichiometry Involving ΔH: Thermochemical Equations 267	r	7	T- 0
6.7		269		The Qua
6.8		271		of the At
6.9	Determining Enthalpies of Reaction from Standard	211	7.1	Schrödinger
0.0	Enthalpies of Formation	273	7.2	The Nature
	Standard States and Standard Enthalpy Changes 273 Calculating the Standard Enthalpy Change for a Reaction 275			The Wave Spectrum
3.10	Energy Use and the Environment	279		for Cancer
	Energy Consumption 279 Environmental Problems	,		The Parti
	Associated with Fossil Fuel Use 280		7.3	Atomic Spe
	Air Pollution 280 Global Climate Change 281			CHEMISTRY
	CHEMISTRY IN THE ENVIRONMENT: Renewable Energy	282		a Bar Code
	CHAPTER IN REVIEW	283	7.4	The Wave N
	Self Assessment Quiz 283 Key Terms 284 Key Concepts 285 Key Equations and Relationships 285 Key Learning Outcomes 286	203		The de B Principle
	EXERCISES	287		Distributi
	Review Questions 287 Problems by Topic 287	201	7.5	Quantum M
	Cumulative Problems 291 Challenge Problems 292 Conceptual Problems 293 Answer to Conceptual Connections 293	s		Solutions Hydroger Explained
			7.6	The Shapes
	Toll 1			s Orbitals d Orbitals
Ę.,				The Phase
ÄΛ		1		CHAPTER IN Self Asse
5 V	A PORTOR OF THE PROPERTY OF TH	1		Key Cone
		1		Relations





7	The Quantum-Mechanical Model	
		294
7.1	Schrödinger's Cat	295
7.2	The Nature of Light	296
	The Wave Nature of Light 296 The Electromagnetic Spectrum 299 Interference and Diffraction 301	
	CHEMISTRY AND MEDICINE: Radiation Treatment	
	for Cancer	300
	The Particle Nature of Light 302	
7.3	Atomic Spectroscopy and the Bohr Model	306
	CHEMISTRY IN YOUR DAY: Atomic Spectroscopy,	
	a Bar Code for Atoms	308
7.4	The Wave Nature of Matter: The de Broglie Wavelength, the Uncertainty Principle, and Indeterminacy	309
	The de Broglie Wavelength 310 The Uncertainty Principle 311 Indeterminacy and Probability Distribution Maps 313	
7.5	Quantum Mechanics and the Atom	315
	Solutions to the Schrödinger Equation for the Hydrogen Atom 315 Atomic Spectroscopy Explained 318	
7.6	The Shapes of Atomic Orbitals	321
	s Orbitals $(l=0)$ 321 p Orbitals $(l=1)$ 325 d Orbitals $(l=2)$ 325 f Orbitals $(l=3)$ 326 The Phase of Orbitals 326 The Shape of Atoms 327	
	CHAPTER IN REVIEW	327
	Self Assessment Quiz 327 Key Terms 328 Key Concepts 328 Key Equations and	
	Relationships 329 Key Learning Outcomes 329	
	EXERCISES Province Counting 220 People of Province 220	329
	Review Questions 329 Problems by Topic 330 Cumulative Problems 331 Challenge Problems 332 Conceptual Problems 333 Answers to Conceptual Connections 333	

8	Periodic Properties of the Elements	334		• •
8.1	Nerve Signal Transmission	335	- 25	0
8.2	The Development of the Periodic Table	336	S. Carlot	
8.3	Electron Configurations: How Electrons Occupy Orbitals	337		
	Electron Spin and the Pauli Exclusion Principle 338 Sublevel Energy Splitting in Multielectron Atoms 338 Electron Configurations for Multielectron Atoms 342			
8.4	Electron Configurations, Valence Electrons, and the Periodic Table	345		
	Orbital Blocks in the Periodic Table 346 Writing an Electron Configuration for an Element from Its Position in the Periodic Table 347 The Transition and Inner Transition Elements 348			·
8.5	The Explanatory Power of the Quantum- Mechanical Model	349	9.4	Ionic Bonding: Lewis Symbols and Lattice Energies Ionic Bonding and Electron Transfer 384 Lattice
8.6	Periodic Trends in the Size of Atoms and			Energy: The Rest of the Story 386 The Born-Haber
	Effective Nuclear Charge	350		Cycle 386 Trends in Lattice Energies: Ion Size 388 Trends in Lattice Energies: Ion
	Effective Nuclear Charge 352 Atomic Radii and the	e		Charge 388 Ionic Bonding: Models and Reality 389
0 7	Transition Elements 353			CHEMISTRY AND MEDICINE: Ionic Compounds
8.7	Ions: Electron Configurations, Magnetic Properties, Ionic Radii, and Ionization Energy	355		in Medicine
	Electron Configurations and Magnetic Properties of Ions 355 Ionic Radii 357 Ionization Energy 359 Trends in First Ionization Energy 359 Exceptions to Trends in First Ionization Energy 362		9.5	Covalent Bonding: Lewis Structures Single Covalent Bonds 391 Double and Triple Covalent Bonds 392 Covalent Bonding: Models and Reality 392
	Trends in Second and Successive Ionization		9.6	Electronegativity and Bond Polarity
	Energies 362			Electronegativity 394 Bond Polarity, Dipole
8.8	Electron Affinities and Metallic Character	363		Moment, and Percent Ionic Character 396
	Electron Affinity 363 Metallic Character 364		9.7	Lewis Structures of Molecular Compounds and Polyatomic lons
8.9	Some Examples of Periodic Chemical Behavior:	266		Writing Lewis Structures for Molecular
	The Alkali Metals, the Halogens, and the Noble Gases The Alkali Metals (Group 1A) 367 The Halogens (Group 7A) 368	366		Compounds 398 Writing Lewis Structures for Polyatomic Ions 400
	CHEMISTRY AND MEDICINE: Potassium lodide in		9.8	Resonance and Formal Charge
	Radiation Emergencies	370		Resonance 400 Formal Charge 403
	The Noble Gases (Group 8A) 370		9.9	Exceptions to the Octet Rule: Odd-Electron Species,
	CHAPTER IN REVIEW	371		Incomplete Octets, and Expanded Octets
1	Self Assessment Quiz 371 Key Terms 372 Key Concepts 372 Key Equations and Relationships 373 Key Learning Outcomes 373			Odd-Electron Species 406 Incomplete Octets 406
	EXERCISES Review Questions 374 Problems by Topic 375 Cumulative Problems 377 Challenge Problems 379 Conceptual Problems 379 Answers to Conceptual Connections 379	374 8	1	
9	Chemical Bonding I: The Lewis Model	380		THE WAR

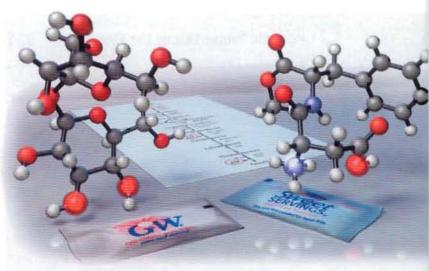
9.1 Bonding Models and AIDS Drugs

9.3 Representing Valence Electrons with Dots

Types of Chemical Bonds

X	Contents	
	CHEMISTRY IN THE ENVIRONMENT: Free Radicals	
	and the Atmospheric Vacuum Cleaner Expanded Octets 408	407
9.10	Bond Energies and Bond Lengths	409
	Bond Energy 410 Using Average Bond Energies to Estimate Enthalpy Changes for Reactions 411 Bond Lengths 412	
9.11	Bonding in Metals: The Electron Sea Model CHEMISTRY IN THE ENVIRONMENT: The Lewis	413
	Structure of Ozone	414
	CHAPTER IN REVIEW Self Assessment Quiz 415 Key Terms 416 Key Concepts 416 Key Equations and Relationships 417 Key Learning Outcomes 418	415
	EXERCISES	418
	Review Questions 418 Problems by Topic 419 Cumulative Problems 421 Challenge Problems 42 Conceptual Problems 423 Answers to Conceptual Connections 423	2
11	0	
1	Chemical Bonding II: Molecular	
	Shapes, Valence Bond Theory, and	
	Molecular Orbital Theory	424
10.1	Artificial Sweeteners: Fooled by Molecular Shape	425
10.2	VSEPR Theory: The Five Basic Shapes	426
	Two Electron Groups: Linear Geometry 426 Three Electron Groups: Trigonal Planar Geometry 427 Four Electron Groups: Tetrahedral Geometry 427 Five Electron Groups: Trigonal Bipyramidal Geometry 429 Six Electron Groups: Octahedral Geometry 429	
10.3	VSEPR Theory: The Effect of Lone Pairs	430
	Four Electron Groups with Lone Pairs 430 Five Electron Groups with Lone Pairs 432 Six Electron Groups with Lone Pairs 433	
10.4	VSEPR Theory: Predicting Molecular Geometries	435
	Representing Molecular Geometries on Paper 437 Predicting the Shapes of Larger Molecules 437	
10.5	Molecular Shape and Polarity Vector Addition 440	438
	CHEMISTRY IN YOUR DAY: How Soap Works	442
10.6	Valence Bond Theory: Orbital Overlap as	
	a Chemical Bond	443
10.7	Valence Bond Theory: Hybridization of Atomic Orbitals	445
	 sp³ Hybridization 446 sp² Hybridization and Doul Bonds 448 	
	CHEMISTRY IN YOUR DAY: The Chemistry of Vision	452
	sp Hybridization and Triple Bonds 452 sp ³ d and sp ³ d ² Hybridization 454	
10.0	Writing Hybridization and Bonding Schemes 455	AEO
10.8	Molecular Orbital Theory: Electron Delocalization Linear Combination of Atomic Orbitals (LCAO) 459 Period Two Homonuclear Diatomic Molecules 463 Second-Period Heteronuclear Diatomic Molecules 469 Polyatomic	458

Molecules 470

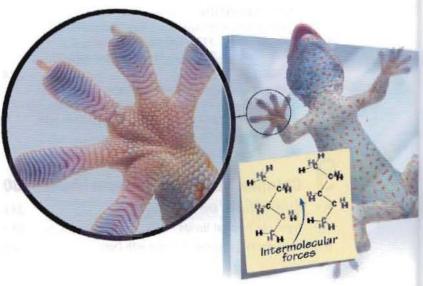


471
474

Liquids, Solids, and Intermolecular **Forces** 482

482 11.1 Climbing Geckos and Intermolecular Forces 11.2 Solids, Liquids, and Gases: A Molecular Comparison 484 Changes between States 486 11.3 Intermolecular Forces: The Forces That Hold Condensed 487 States Together Dispersion Force 487 Dipole-Dipole Force 490 Hydrogen Bonding 492

Ion-Dipole Force 494



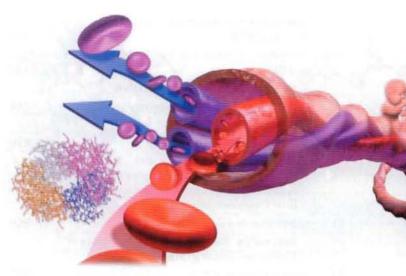
xi

	CHEMISTRY AND MEDICINE: Hydrogen Bonding in DNA	496			_^
11.4	Intermolecular Forces in Action: Surface Tension, Viscos and Capillary Action		1		Y
	Surface Tension 497 Viscosity 498			The state of the s	
	CHEMISTRY IN YOUR DAY: Viscosity and Motor Oil Capillary Action 499	498	-		4
11.5	Vaporization and Vapor Pressure	499		The state of the s	
	The Process of Vaporization 499 The Energetics of Vaporization 500 Vapor Pressure and Dynamic Equilibrium 502 The Critical Point: The Transition to an Unusual State of Matter 508				1
11.6	Sublimation and Fusion Sublimation 509 Fusion 510 Energetics of Melting and Freezing 510	509	3		
11.7	Heating Curve for Water	511	U		
11.8	Phase Diagrams	513	- 3	191	
	The Major Features of a Phase Diagram 513 Navigation within a Phase Diagram 514 The Phase Diagrams of Other Substances 515		*	relli 1	0
11.9	Water: An Extraordinary Substance	516			
	CHEMISTRY IN THE ENVIRONMENT: Water Pollution	517			
11.10	Crystalline Solids: Determining Their Structure by X-Ray Crystallography	518	12.5	Expressing Solution Concentration	559
11.11	Crystalline Solids: Unit Cells and Basic Structures Closest-Packed Structures 524	520	12.0	CHEMISTRY IN THE ENVIRONMENT: Lake Nyos	560
11.12	Crystalline Solids: The Fundamental Types Molecular Solids 527 Ionic Solids 527 Atomic Solids 528	526		Molarity 560 Molality 562 Parts by Mass and Parts by Volume 562 Mole Fraction and Mole Percent 563	F.0.4
11 13	Crystalline Solids: Band Theory	530	12.6		564
11.10	Doping: Controlling the Conductivity of Semiconductors 531	550	12.6	Colligative Properties: Vapor Pressure Lowering, Freezing Point Depression, Boiling Point Elevation, and Osmotic Pressure	567
	CHAPTER IN REVIEW Self Assessment Quiz 532 Key Terms 533 Key Concepts 533 Key Equations and Relationships 534 Key Learning Outcomes 534	532		Vapor Pressure Lowering 567 Vapor Pressures of Solutions Containing a Volatile (Nonelectrolyte) Solute 571 Freezing Point Depression and Boiling Point Elevation 574	
	EXERCISES	535		CHEMISTRY IN YOUR DAY: Antifreeze in Frogs	577
	Review Questions 535 Problems by Topic 536			Osmotic Pressure 577	
	Cumulative Problems 540 Challenge Problems 54 Conceptual Problems 542 Answers to Conceptual Connections 542		12.7	Colligative Properties of Strong Electrolyte Solutions Strong Electrolytes and Vapor Pressure 580 Colligative Properties and Medical Solutions 581	579
NI			12.8	Colloids	582
\mathbf{L}_{i}	Solutions	544		CHAPTER IN REVIEW	585
				Self Assessment Quiz 585 Key Terms 586	
12.1	Thirsty Solutions: Why You Shouldn't Drink Seawater	544		Key Concepts 586 Key Equations and Relationships 587 Key Learning Outcomes 587	
12.2	Types of Solutions and Solubility Nature's Tendency toward Mixing: Entropy 547 The Effect of Intermolecular Forces 548	546			588
12.3	Energetics of Solution Formation	551		Cumulative Problems 592 Challenge Problems 593	
	Aqueous Solutions and Heats of Hydration 553	001		Conceptual Problems 594 Answers to Conceptual	
12.4	Solution Equilibrium and Factors Affecting Solubility	555		Problems 594	
	The Temperature Dependence of the Solubility of Solids 556 Factors Affecting the Solubility of Gase				

in Water 557

1	3 Chemical Kinetics	596
13.1	Catching Lizards	597
13.2	The Rate of a Chemical Reaction Measuring Reaction Rates 602	598
13.3	The Rate Law: The Effect of Concentration on Reaction Rate Determining the Order of a Reaction 604	603
13.4	Reaction Order for Multiple Reactants 606 The Integrated Rate Law: The Dependence of Concentration on Time The Half-Life of a Reaction 612	607
13.5	The Effect of Temperature on Reaction Rate Arrhenius Plots: Experimental Measurements of the Frequency Factor and the Activation Energy 618 The Collision Model: A Closer Look at the Frequency Factor 620	615
13.6	Reaction Mechanisms Rate Laws for Elementary Steps 623 Rate-Determining Steps and Overall Reaction Rate Laws 623 Mechanisms with a Fast Initial Step 625	622
13.7	Catalysis	627
	Homogeneous and Heterogeneous Catalysis 629 Enzymes: Biological Catalysts 631	
	CHEMISTRY AND MEDICINE: Enzyme Catalysis and the Role of Chymotrypsin in Digestion	632
	CHAPTER IN REVIEW Self Assessment Quiz 633 Key Terms 635 Key Concepts 635 Key Equations and	633
	Relationships 636 Key Learning Outcomes 636 EXERCISES	637
	Review Questions 637 Problems by Topic 638 Cumulative Problems 643 Challenge Problems 645 Conceptual Problems 646 Answers to Conceptual Connections 647	5





1	Chemical Equilibrium	648
14.1	Fetal Hemoglobin and Equilibrium	649
14.2	The Concept of Dynamic Equilibrium	651
14.3	The Equilibrium Constant (K)	653
14.5	Expressing Equilibrium Constants for Chemical Reactions 654 The Significance of the Equilibrium Constant 655 Relationships between the Equilibrium Constant and the Chemical Equation 656	
	CHEMISTRY AND MEDICINE: Life and Equilibrium	656
14.4	Expressing the Equilibrium Constant in Terms of	
	Pressure	658
	Units of K 660	
14.5	Heterogeneous Equilibria: Reactions Involving Solids and Liquids	661
14.6	Calculating the Equilibrium Constant from Measured Equilibrium Concentrations	662
14.7	The Reaction Quotient: Predicting the Direction of	
	Change	665
14.8	Finding Equilibrium Concentrations	667
	Finding Equilibrium Concentrations from the Equilibrium Constant and All but One of the Equilibrium Concentrations of the Reactants and Products 668 Finding Equilibrium Concentrations from the Equilibrium Constant and Initial Concentrations or Pressures 669 Simplifying Approximations in Working Equilibrium Problems 673	
14.9	Le Châtelier's Principle: How a System at Equilibrium	
	Responds to Disturbances	677
	The Effect of a Concentration Change on Equilibrium 678 The Effect of a Volume (or Pressure) Change on Equilibrium 680 The Effect of a Temperature Change on Equilibrium 682	
	CHAPTER IN REVIEW Self Assessment Quiz 684 Key Terms 685 Key Concepts 685 Key Equations and Relationships 686 Key Learning Outcomes 686	684

xiii

The Titration of a Strong Acid with a Strong Base 770 The Titration of a Weak Acid with a Strong Base 773 The Titration of a Weak Base with a Strong Acid 779 The Titration of a Polyprotic Acid 779 Indicators:

pH-Dependent Colors 780

	Cumulative Problems 692 Challenge Problems 692 Conceptual Problems 694 Answers to Conceptual Connections 695)4		5 6 Neutral 8	9
1	Acids and Bases	696			
15.1	Heartburn	697		135	
15.2	The Nature of Acids and Bases	698			
15.3	Definitions of Acids and Bases	700			
	The Arrhenius Definition 700 The Brønsted-Lown Definition 701	У		PH scan	0
15.4	Acid Strength and the Acid Ionization Constant (K _a) Strong Acids 703 Weak Acids 704 The Acid Ionization Constant (K _a) 705	703		1x2	
15.5	Autoionization of Water and pH	706		Aller and Aller	
	The pH Scale: A Way to Quantify Acidity and				
	Basicity 708 pOH and Other p Scales 709	740	15.11	Lewis Acids and Bases	738
15.6	CHEMISTRY AND MEDICINE: Ulcers	710		Molecules That Act as Lewis Acids 738 Cations	
15.6	Finding the [H ₃ O [*]] and pH of Strong and Weak Acid Solutions	711		That Act as Lewis Acids 739	
	Strong Acids 711 Weak Acids 711 Percent Ionization of a Weak Acid 716 Mixtures of Acids 717		15.12	Effects of Acid Rain 740 Acid Rain Legislation 741	739 741
15.7	Base Solutions		Self Assessment Quiz 741 Key Terms 742		
	Strong Bases 720 Weak Bases 720 Finding the [OH*] and pH of Basic Solutions 722			Key Concepts 743 Key Equations and Relationships 744 Key Learning Outcomes 744 EXERCISES	745
	CHEMISTRY AND MEDICINE: What's in My Antacid?	724		Review Questions 745 Problems by Topic 745	745
15.8	The Acid-Base Properties of lons and Salts			Cumulative Problems 749 Challenge Problems 750	
	Anions as Weak Bases 725 Cations as Weak Acids 728 Classifying Salt Solutions as Acidic, Basic, or Neutral 729		Conceptual Problems 751 Answers to Conceptual Connections 751		
15.9	Polyprotic Acids	731	1	C	
	Finding the pH of Polyprotic Acid Solutions 732		T	Aqueous Ionic Equilibrium 7	752
	Finding the Concentration of the Anions for a Weak		16.1		753
15 10	Diprotic Acid Solution 734	736		Comment Constant Designation (Constant)	754
15.10	Acid Strength and Molecular Structure Binary Acids 736 Oxyacids 737	130		Calculating the pH of a Buffer Solution 756	
				The Henderson–Hasselbalch Equation 757 Calculating pH Changes in a Buffer Solution 760 Buffers Containing a Base and Its Conjugate Acid 764	
j	To min	JV A	16.3	Buffer Effectiveness: Buffer Range and Buffer Capacity	765
		7		Relative Amounts of Acid and Base 765 Absolute Concentrations of the Acid and Conjugate Base 766 Buffer Range 767	
	1			CHEMISTRY AND MEDICINE: Buffer Effectiveness	
					768
				Buffer Capacity 768	7.00
-			16.4	Titrations and pH Curves	769

687

3 Acid

EXERCISES

Review Questions 687 Problems by Topic 688