# **Contents in Brief**

Prologue 1

- 1 Structure and Bonding 7
- 2 Acids and Bases 58
- 3 Introduction to Organic Molecules and Functional Groups 86
- 4 Alkanes 120
- 5 Stereochemistry 166
- 6 Understanding Organic Reactions 205
- 7 Alkyl Halides and Nucleophilic Substitution 238
- 8 Alkyl Halides and Elimination Reactions 288
- 9 Alcohols, Ethers, and Epoxides 324
- 10 Alkenes 372
- 11 Alkynes 416
- 12 Oxidation and Reduction 444
- 13 Mass Spectrometry and Infrared Spectroscopy 483
- 14 Nuclear Magnetic Resonance Spectroscopy 514
- 15 Radical Reactions 558
- 16 Conjugation, Resonance, and Dienes 593
- 17 Benzene and Aromatic Compounds 630
- 18 Reactions of Aromatic Compounds 665
- 19 Carboxylic Acids and the Acidity of the O-H Bond 718
- 20 Introduction to Carbonyl Chemistry; Organometallic Reagents; Oxidation and Reduction 753
- 21 Aldehydes and Ketones—Nucleophilic Addition 807
- 22 Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 859
- 23 Substitution Reactions of Carbonyl Compounds at the  $\alpha$  Carbon 915
- 24 Carbonyl Condensation Reactions 954
- 25 Amines 988
- 26 Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 1042
- 27 Pericyclic Reactions 1069
- 28 Carbohydrates 1098
- 29 Amino Acids and Proteins 1148
- 30 Lipids 1194
- 31 Synthetic Polymers 1225
  - Appendices A-1
  - Glossary G-1
  - Credits C-1
  - Index I-1

# Contents

Preface xiii Acknowledgments xxi List of *How To's* xxiv List of Mechanisms xxvi List of Selected Applications xxix

### Prologue 1

What Is Organic Chemistry?1Some Representative Organic Molecules2Organic Chemistry in the Marine Environment4

8

#### **1** Structure and Bonding

- 1.1 The Periodic Table 8
- 1.2 Bonding 11
- 1.3 Lewis Structures 13
- 1.4 Isomers 18
- 1.5 Exceptions to the Octet Rule 18
- 1.6 Resonance 19
- 1.7 Determining Molecular Shape 24
- 1.8 Drawing Organic Structures 29
- 1.9 Hybridization 34
- 1.10 Ethane, Ethylene, and Acetylene 38
- 1.11 Bond Length and Bond Strength 43
- 1.12 Electronegativity and Bond Polarity 45
- 1.13 Polarity of Molecules 47
- 1.14 ∟-Dopa—A Representative Organic Molecule 48
   Key Concepts 49
   Problems 51

#### 2 Acids and Bases 58

2.1 Brønsted–Lowry Acids and Bases 59



- 2.2 Reactions of Brønsted–Lowry Acids and Bases 60
- 2.3 Acid Strength and pK<sub>a</sub> 62
- 2.4 Predicting the Outcome of Acid-Base Reactions 65
- 2.5 Factors That Determine Acid Strength 66
- 2.6 Common Acids and Bases 76

- **2.7** Aspirin 76
- 2.8 Lewis Acids and Bases 77Key Concepts 79Problems 80

## Introduction to Organic Molecules and Functional Groups 86



- 3.1 Functional Groups 87
- 3.2 An Overview of Functional Groups 88
- 3.3 Intermolecular Forces 92
- 3.4 Physical Properties 96
- 3.5 Application: Vitamins 102
- 3.6 Application of Solubility: Soap 104
- 3.7 Application: The Cell Membrane 105
- 3.8 Functional Groups and Reactivity 108
- **3.9** Biomolecules 110 Key Concepts 111 Problems 113

#### 4 Alkanes 120

- 4.1 Alkanes—An Introduction 121
- 4.2 Cycloalkanes 125
- 4.3 An Introduction to Nomenclature 125
- 4.4 Naming Alkanes 126
- 4.5 Naming Cycloalkanes 132
- 4.6 Common Names 134
- 4.7 Fossil Fuels 135
- 4.8 Physical Properties of Alkanes 136
- 4.9 Conformations of Acyclic Alkanes—Ethane 137
- 4.10 Conformations of Butane 141
- 4.11 An Introduction to Cycloalkanes 144
- 4.12 Cyclohexane 145
- 4.13 Substituted Cyclohexanes 148
- **4.14** Oxidation of Alkanes 154
- **4.15** Lipids—Part 1 156 Key Concepts 158 Problems 160

#### 5 Stereochemistry 166

- 5.1 Starch and Cellulose 167
- The Two Major Classes of 5.2 Isomers 169
- 5.3 Looking Glass Chemistry—Chiral and Achiral Molecules 170
- 5.4 Stereogenic Centers 173
- 5.5 Stereogenic Centers in Cyclic Compounds 176
- 5.6 Labeling Stereogenic Centers with *R* or *S* 178
- 5.7 Diastereomers 183
- 5.8 Meso Compounds 185
- 5.9 R and S Assignments in Compounds with Two or More Stereogenic Centers 187
- 5.10 Disubstituted Cycloalkanes 187
- 5.11 Isomers—A Summary 189
- 5.12 Physical Properties of Stereoisomers 190
- 5.13 Chemical Properties of Enantiomers 195 Key Concepts 197 Problems 198

## **6** Understanding Organic Reactions 205



- Writing Equations for Organic 6.1 Reactions 206
- 6.2 Kinds of Organic Reactions 207
- 6.3 Bond Breaking and Bond Making 209
- 6.4 Bond Dissociation Energy 212
- 6.5 Thermodynamics 216
- Enthalpy and Entropy 218 6.6
- 6.7 Energy Diagrams 220
- Energy Diagram for a Two-Step Reaction 6.8 Mechanism 222
- 6.9 Kinetics 225
- 6.10 Catalysts 228
- 6.11 Enzymes 229 Key Concepts 230 Problems 232

## 7 Alkyl Halides and Nucleophilic Substitution 238

- Introduction to Alkyl 7.1 Halides 239
- 7.2 Nomenclature 240
- 7.3 Physical Properties 241
- 7.4 Interesting Alkyl Halides 242

- 7.5 The Polar Carbon–Halogen Bond 244
- 7.6 General Features of Nucleophilic Substitution 245
- 7.7 The Leaving Group 246
- 7.8 The Nucleophile 248
- 7.9 Possible Mechanisms for Nucleophilic Substitution 252
- 7.10 Two Mechanisms for Nucleophilic Substitution 253
- 7.11 The S<sub>N</sub>2 Mechanism 254
- 7.12 Application: Useful S<sub>N</sub>2 Reactions 260
- The S<sub>N</sub>1 Mechanism 262 7.13
- 7.14 Carbocation Stability 266
- 7.15 The Hammond Postulate 268
- 7.16 Application: S<sub>N</sub>1 Reactions, Nitrosamines, and Cancer 271
- When Is the Mechanism  $S_N 1$  or  $S_N 2$ ? 272 7.17
- Vinyl Halides and Aryl Halides 277 7.18
- 7.19 Organic Synthesis 278 Key Concepts 280 Problems 281
  - 8 **Alkyl Halides** and Elimination Reactions 288



- 8.1 General Features of Elimination 289
- 8.2 Alkenes—The Products of Elimination Reactions 291
- 8.3 The Mechanisms of Flimination 294
- 8.4 The E2 Mechanism 295
- The Zaitsev Rule 299 8.5
- 8.6 The E1 Mechanism 301
- 8.7 S<sub>N</sub>1 and E1 Reactions 304
- 8.8 Stereochemistry of the E2 Reaction 305
- 8.9 When Is the Mechanism E1 or E2? 309
- E2 Reactions and Alkyne Synthesis 310 8.10
- 8.11 When Is the Reaction  $S_N 1$ ,  $S_N 2$ , E1, or E2? 311 Key Concepts 315 Problems 317

#### 9 Alcohols, Ethers, and **Epoxides** 324

- 9.1 Introduction 325
- 9.2 Structure and Bonding 326
- Nomenclature 327 9.3







- 9.4 Physical Properties 330
- 9.5 Interesting Alcohols, Ethers, and Epoxides 331
- 9.6 Preparation of Alcohols, Ethers, and Epoxides 334
- 9.7 General Features—Reactions of Alcohols, Ethers, and Epoxides 336
- 9.8 Dehydration of Alcohols to Alkenes 338
- 9.9 Carbocation Rearrangements 341
- 9.10 Dehydration Using POCl<sub>3</sub> and Pyridine 344
- Conversion of Alcohols to Alkyl Halides 9.11 with HX 345
- 9.12 Conversion of Alcohols to Alkyl Halides with SOCl<sub>2</sub> and PBr<sub>3</sub> 349
- 9.13 Tosylate—Another Good Leaving Group 352
- 9.14 Reaction of Ethers with Strong Acid 355
- 9.15 Reactions of Epoxides 357
- 9.16 Application: Epoxides, Leukotrienes, and Asthma 361
- 9.17 Application: Benzo[a]pyrene, Epoxides, and Cancer 363 Key Concepts 363 Problems 365

#### **10** Alkenes 372

- 10.1 Introduction 373
- 10.2 Calculating Degrees of Unsaturation 374
- 10.3 Nomenclature 376
- 10.4 Physical Properties 380
- 10.5 Interesting Alkenes 380
- 10.6 Lipids—Part 2 382
- 10.7 Preparation of Alkenes 384
- 10.8 Introduction to Addition Reactions 385
- 10.9 Hydrohalogenation—Electrophilic Addition of HX 386
- 10.10 Markovnikov's Rule 389
- 10.11 Stereochemistry of Electrophilic Addition of HX 391
- 10.12 Hydration—Electrophilic Addition of Water 394
- 10.13 Halogenation—Addition of Halogen 395
- **10.14** Stereochemistry of Halogenation 396
- 10.15 Halohydrin Formation 398
- 10.16 Hydroboration–Oxidation 401
- 10.17 Keeping Track of Reactions 406
- 10.18 Alkenes in Organic Synthesis 407 Key Concepts 409 Problems 410

#### 11 Alkynes 416

- Introduction 417 11.1
- 11.2 Nomenclature 418
- 11.3 Physical Properties 419
- 11.4 Interesting Alkynes 420
- Preparation of Alkynes 421 11.5
- 11.6 Introduction to Alkyne Reactions 422
- Addition of Hydrogen Halides 424 11.7
- Addition of Halogen 426 11.8
- 11.9 Addition of Water 427
- 11.10 Hydroboration-Oxidation 429
- 11.11 Reaction of Acetylide Anions 431
- 11.12 Synthesis 434 Key Concepts 437

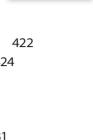
Problems 438

#### 12 Oxidation and **Reduction 444**

- 12.1 Introduction 445
- 12.2 Reducing Agents 446
- 12.3 Reduction of Alkenes 447
- 12.4 Application: Hydrogenation of Oils 450
- 12.5 Reduction of Alkynes 452
- **12.6** The Reduction of Polar C–X σ Bonds 455
- 12.7 Oxidizing Agents 456
- 12.8 Epoxidation 458
- 12.9 Dihydroxylation 461
- **12.10** Oxidative Cleavage of Alkenes 463
- 12.11 Oxidative Cleavage of Alkynes 465
- 12.12 Oxidation of Alcohols 466
- 12.13 Green Chemistry 469
- 12.14 Application: The Oxidation of Ethanol 470
- 12.15 Sharpless Epoxidation 471 Key Concepts 474 Problems 476

#### 13 Mass Spectrometry and Infrared Spectroscopy 483

- Mass Spectrometry 484 13.1
- 13.2 Alkyl Halides and the M + 2 Peak 488
- 13.3 Fragmentation 489
- Other Types of Mass Spectrometry 492 13.4







vii



Penicillin

- 13.5 Electromagnetic Radiation 494
- 13.6 Infrared Spectroscopy 496
- 13.7 IR Absorptions 498
- 13.8 IR and Structure Determination 505 Key Concepts 507 Problems 508
- 14 Nuclear Magnetic Resonance Spectroscopy 514



- 14.1 An Introduction to NMR Spectroscopy 515
- **14.2** <sup>1</sup>H NMR: Number of Signals 518
- 14.3 <sup>1</sup>H NMR: Position of Signals 522
- **14.4** The Chemical Shift of Protons on *sp*<sup>2</sup> and *sp* Hybridized Carbons 525
- 14.5 <sup>1</sup>H NMR: Intensity of Signals 527
- 14.6 <sup>1</sup>H NMR: Spin–Spin Splitting 529
- 14.7 More Complex Examples of Splitting 533
- 14.8 Spin–Spin Splitting in Alkenes 536
- 14.9 Other Facts About <sup>1</sup>H NMR Spectroscopy 538
- **14.10** Using <sup>1</sup>H NMR to Identify an Unknown 541
- 14.11 <sup>13</sup>C NMR Spectroscopy 543
- **14.12** Magnetic Resonance Imaging (MRI) 547 Key Concepts 548 Problems 549

#### 15 Radical Reactions 558

- 15.1 Introduction 559
- **15.2** General Features of Radical Reactions 560
- 15.3 Halogenation of Alkanes 562
- 15.4 The Mechanism of Halogenation 563
- 15.5 Chlorination of Other Alkanes 566
- 15.6 Chlorination Versus Bromination 566
- **15.7** Halogenation as a Tool in Organic Synthesis 570
- **15.8** The Stereochemistry of Halogenation Reactions 570
- **15.9** Application: The Ozone Layer and CFCs 573
- **15.10** Radical Halogenation at an Allylic Carbon 574
- **15.11** Application: Oxidation of Unsaturated Lipids 577
- **15.12** Application: Antioxidants 578
- **15.13** Radical Addition Reactions to Double Bonds 579

**15.14** Polymers and Polymerization 582 *Key Concepts* 585 *Problems* 586

## 16 Conjugation, Resonance, and Dienes 593

- 16.1 Conjugation 594
- **16.2** Resonance and Allylic Carbocations 596
- 16.3 Common Examples of Resonance 597
- 16.4 The Resonance Hybrid 599
- **16.5** Electron Delocalization, Hybridization, and Geometry 600
- 16.6 Conjugated Dienes 601
- 16.7 Interesting Dienes and Polyenes 602
- **16.8** The Carbon–Carbon σ Bond Length in 1,3-Butadiene 603
- 16.9 Stability of Conjugated Dienes 604
- **16.10** Electrophilic Addition: 1,2- Versus 1,4-Addition 606
- 16.11 Kinetic Versus Thermodynamic Products 608
- 16.12 The Diels-Alder Reaction 610
- **16.13** Specific Rules Governing the Diels–Alder Reaction 612
- 16.14 Other Facts About the Diels-Alder Reaction 616
- 16.15 Conjugated Dienes and Ultraviolet Light 619Key Concepts 621Problems 623
- 17 Benzene and Aromatic Compounds 630
- 17.1 Background 631
- 17.2 The Structure of Benzene 632
- 17.3 Nomenclature of Benzene Derivatives 634
- 17.4 Spectroscopic Properties 636
- 17.5 Interesting Aromatic Compounds 637
- 17.6 Benzene's Unusual Stability 639
- 17.7 The Criteria for Aromaticity—Hückel's Rule 640
- 17.8 Examples of Aromatic Compounds 643
- 17.9 What Is the Basis of Hückel's Rule? 650
- **17.10** The Inscribed Polygon Method for Predicting Aromaticity 653
- 17.11 Buckminsterfullerene—Is it Aromatic? 655Key Concepts 656Problems 657



## **18** Reactions of Aromatic Compounds 665

- **18.1** Electrophilic Aromatic Substitution 666
- 18.2 The General Mechanism 667
- 18.3 Halogenation 669
- 18.4 Nitration and Sulfonation 670
- **18.5** Friedel–Crafts Alkylation and Friedel–Crafts Acylation 672
- 18.6 Substituted Benzenes 678
- **18.7** Electrophilic Aromatic Substitution of Substituted Benzenes 681
- **18.8** Why Substituents Activate or Deactivate a Benzene Ring 684
- 18.9 Orientation Effects in Substituted Benzenes 686
- **18.10** Limitations on Electrophilic Substitution Reactions with Substituted Benzenes 690
- 18.11 Disubstituted Benzenes 692
- 18.12 Synthesis of Benzene Derivatives 694
- 18.13 Nucleophilic Aromatic Substitution 695
- 18.14 Halogenation of Alkyl Benzenes 699
- **18.15** Oxidation and Reduction of Substituted Benzenes 701
- 18.16 Multistep Synthesis 705 Key Concepts 708 Problems 710
- 19 Carboxylic Acids and the Acidity of the O–H Bond 718



700

- 19.1 Structure and Bonding 719
- 19.2 Nomenclature 720
- **19.3** Physical Properties 723
- 19.4 Spectroscopic Properties 724
- **19.5** Interesting Carboxylic Acids 725
- **19.6** Aspirin, Arachidonic Acid, and Prostaglandins 726
- 19.7 Preparation of Carboxylic Acids 728
- **19.8** Reactions of Carboxylic Acids—General Features 729
- **19.9** Carboxylic Acids—Strong Organic Brønsted– Lowry Acids 730
- **19.10** Inductive Effects in Aliphatic Carboxylic Acids 734
- 19.11 Substituted Benzoic Acids 735
- 19.12 Extraction 738

- 19.13 Sulfonic Acids 741
  19.14 Amino Acids 741
  Key Concepts 744
  Problems 745
- 20 Introduction to Carbonyl Chemistry; Organometallic Reagents; Oxidation and Reduction 753
- Ż
- 20.1 Introduction 754
- 20.2 General Reactions of Carbonyl Compounds 755
- **20.3** A Preview of Oxidation and Reduction 758
- 20.4 Reduction of Aldehydes and Ketones 760
- **20.5** The Stereochemistry of Carbonyl Reduction 762
- 20.6 Enantioselective Carbonyl Reductions 763
- **20.7** Reduction of Carboxylic Acids and Their Derivatives 766
- 20.8 Oxidation of Aldehydes 771
- 20.9 Organometallic Reagents 771
- **20.10** Reaction of Organometallic Reagents with Aldehydes and Ketones 775
- **20.11** Retrosynthetic Analysis of Grignard Products 778
- 20.12 Protecting Groups 781
- **20.13** Reaction of Organometallic Reagents with Carboxylic Acid Derivatives 783
- **20.14** Reaction of Organometallic Reagents with Other Compounds 786
- **20.15**  $\alpha$ , $\beta$ -Unsaturated Carbonyl Compounds 788
- 20.16 Summary—The Reactions of Organometallic Reagents 791
- 20.17 Synthesis 792 Key Concepts 795 Problems 798

### 21 Aldehydes and Ketones—Nucleophilic Addition 807



- 21.2 Nomenclature 809
- 21.3 Physical Properties 812
- 21.4 Spectroscopic Properties 813
- 21.5 Interesting Aldehydes and Ketones 815
- 21.6 Preparation of Aldehydes and Ketones 816





#### x Contents

- **21.7** Reactions of Aldehydes and Ketones—General Considerations 818
- **21.8** Nucleophilic Addition of H<sup>-</sup> and R<sup>-</sup>—A Review 821
- 21.9 Nucleophilic Addition of CN 823
- 21.10 The Wittig Reaction 825
- 21.11 Addition of 1° Amines 830
- 21.12 Addition of 2° Amines 833
- 21.13 Addition of H<sub>2</sub>O—Hydration 835
- 21.14 Addition of Alcohols—Acetal Formation 837
- 21.15 Acetals as Protecting Groups 841
- 21.16 Cyclic Hemiacetals 842
- 21.17 An Introduction to Carbohydrates 845 Key Concepts 846 Problems 849

## 22 Carboxylic Acids and Their Derivatives— Nucleophilic Acyl Substitution 859



- 22.1 Introduction 860
- 22.2 Structure and Bonding 862
- 22.3 Nomenclature 864
- 22.4 Physical Properties 868
- 22.5 Spectroscopic Properties 869
- 22.6 Interesting Esters and Amides 871
- **22.7** Introduction to Nucleophilic Acyl Substitution 873
- 22.8 Reactions of Acid Chlorides 876
- 22.9 Reactions of Anhydrides 878
- 22.10 Reactions of Carboxylic Acids 880
- 22.11 Reactions of Esters 885
- 22.12 Application: Lipid Hydrolysis 887
- 22.13 Reactions of Amides 890
- 22.14 Application: The Mechanism of Action of β-Lactam Antibiotics 891
- 22.15 Summary of Nucleophilic Acyl Substitution Reactions 892
- 22.16 Natural and Synthetic Fibers 893
- 22.17 Biological Acylation Reactions 895
- 22.18 Nitriles 897

```
Key Concepts 902
Problems 905
```

## Substitution Reactions of Carbonyl Compounds at the α Carbon 915

- 23.1 Introduction 916
- 23.2 Enols 917
- 23.3 Enolates 919
- 23.4 Enolates of Unsymmetrical Carbonyl Compounds 925
- **23.5** Racemization at the  $\alpha$  Carbon 927
- **23.6** A Preview of Reactions at the  $\alpha$  Carbon 928
- **23.7** Halogenation at the  $\alpha$  Carbon 928
- 23.8 Direct Enolate Alkylation 933
- 23.9 Malonic Ester Synthesis 936
- 23.10 Acetoacetic Ester Synthesis 940 Key Concepts 943 Problems 945

## 24 Carbonyl Condensation Reactions 954

- 24.1 The Aldol Reaction 955
- 24.2 Crossed Aldol Reactions 960
- 24.3 Directed Aldol Reactions 963
- 24.4 Intramolecular Aldol Reactions 965
- 24.5 The Claisen Reaction 967
- 24.6 The Crossed Claisen and Related Reactions 969
- 24.7 The Dieckmann Reaction 971
- 24.8 The Michael Reaction 972
- 24.9 The Robinson Annulation 974 Key Concepts 978 Problems 979

#### 25 Amines 988

- 25.1 Introduction 989
- 25.2 Structure and Bonding 989
- 25.3 Nomenclature 991
- 25.4 Physical Properties 993
- 25.5 Spectroscopic Properties 994
- 25.6 Interesting and Useful Amines 995
- 25.7 Preparation of Amines 998
- 25.8 Reactions of Amines—General Features 1005
- 25.9 Amines as Bases 1005



Motrin

Motrii

- **25.10** Relative Basicity of Amines and Other Compounds 1007
- 25.11 Amines as Nucleophiles 1014
- 25.12 Hofmann Elimination 1016
- 25.13 Reaction of Amines with Nitrous Acid 1020
- 25.14 Substitution Reactions of Aryl Diazonium Salts 1022
- 25.15 Coupling Reactions of Aryl Diazonium Salts 1026
- 25.16 Application: Synthetic Dyes 1028
- **25.17** Application: Sulfa Drugs 1030 Key Concepts 1031 Problems 1034

#### 26 Carbon–Carbon Bond– Forming Reactions in Organic Synthesis 1042



- 26.1 Coupling Reactions of Organocuprate Reagents 1043
- 26.2 Suzuki Reaction 1046
- 26.3 Heck Reaction 1050
- 26.4 Carbenes and Cyclopropane Synthesis 1052
- 26.5 Simmons–Smith Reaction 1055
- 26.6 Metathesis 1056 Key Concepts 1061 Problems 1062

27.1

#### 27 Pericyclic Reactions 1069



- Types of Pericyclic Reactions 1070
- 27.2 Molecular Orbitals 1071
- 27.3 Electrocyclic Reactions 1074
- 27.4 Cycloaddition Reactions 1081
- 27.5 Sigmatropic Rearrangements 1085
- 27.6 Summary of Rules for Pericyclic Reactions 1090 Key Concepts 1091 Problems 1092

#### **28** Carbohydrates 1098

- 28.1 Introduction 1099
- 28.2 Monosaccharides 1100
- 28.3 The Family of D-Aldoses 1106
- 28.4 The Family of D-Ketoses 1108



- 28.5 Physical Properties of Monosaccharides 1108
- 28.6 The Cyclic Forms of Monosaccharides 1109
- 28.7 Glycosides 1115
- **28.8** Reactions of Monosaccharides at the OH Groups 1119
- **28.9** Reactions at the Carbonyl Group—Oxidation and Reduction 1120
- **28.10** Reactions at the Carbonyl Group—Adding or Removing One Carbon Atom 1123
- **28.11** The Fischer Proof of the Structure of Glucose 1126
- 28.12 Disaccharides 1129
- 28.13 Polysaccharides 1132
- **28.14** Other Important Sugars and Their Derivatives 1134

Key Concepts 1139 Problems 1141

#### 29 Amino Acids and Proteins 1148



- 29.1 Amino Acids 1149
- 29.2 Synthesis of Amino Acids 1152
- **29.3** Separation of Amino Acids 1155
- 29.4 Enantioselective Synthesis of Amino Acids 1159
- 29.5 Peptides 1160
- 29.6 Peptide Sequencing 1165
- 29.7 Peptide Synthesis 1168
- 29.8 Automated Peptide Synthesis 1173
- 29.9 Protein Structure 1175
- **29.10** Important Proteins 1182 Key Concepts 1185 Problems 1187

#### **30** Lipids 1194

- 30.1 Introduction 1195
- 30.2 Waxes 1196
- 30.3 Triacylglycerols 1197
- 30.4 Phospholipids 1201
- 30.5 Fat-Soluble Vitamins 1204
- 30.6 Eicosanoids 1205
- **30.7** Terpenes 1208
- **30.8** Steroids 1214 Key Concepts 1219 Problems 1220



#### 31 Synthetic Polymers 1225

- 31.1 Introduction 1226
- **31.2** Chain-Growth Polymers—Addition Polymers 1227
- **31.3** Anionic Polymerization of Epoxides 1234
- **31.4** Ziegler–Natta Catalysts and Polymer Stereochemistry 1235
- 31.5 Natural and Synthetic Rubbers 1237
- **31.6** Step-Growth Polymers—Condensation Polymers 1238
- 31.7 Polymer Structure and Properties 1243
- 31.8 Green Polymer Synthesis 1244
- **31.9** Polymer Recycling and Disposal 1247 Key Concepts 1250 Problems 1251



- Appendix A pK<sub>a</sub> Values for Selected Compounds A-1
- Appendix B Nomenclature A-3
- Appendix C Bond Dissociation Energies for Some Common Bonds  $[A-B \rightarrow A \cdot + \cdot B]$  A-7
- Appendix D Reactions that Form Carbon–Carbon Bonds A-8
- Appendix E Characteristic IR Absorption Frequencies A-9
- Appendix F Characteristic NMR Absorptions A-10
- Appendix G General Types of Organic Reactions A-12
- Appendix H How to Synthesize Particular Functional Groups A-14

Glossary G-1 Credits C-1 Index I-1