

BASIC PRINCIPLES OF  
ORGANIC  
CHEMISTRY

JOHN D. ROBERTS

MARJORIE C. CASERIO

## PREFACE

**P**ROGRESS IN organic chemistry is like that of a forest fire—fastest when fanned by the winds of new ideas; brightest when passing through heavily wooded virgin areas. Although organic chemistry is more than 150 years old, its fire rages faster and brighter than ever, as the result of a veritable hurricane of new theoretical concepts and experimental techniques from other areas of science. The new ideas are leading to a new kind of organic chemist, one who is versed in all the disciplines of chemistry from chemical physics to chemical biology and who may be called an organic chemist solely because he happens to work on the chemistry of carbon compounds.

The gradual recognition that physical chemical principles are vital to the understanding and improvement of synthetic reactions has helped more than anything else to broaden the outlook of organic chemists. One of the pioneers in this respect was Professor Howard J. Lucas of the California Institute of Technology—whose text, *Organic Chemistry*, published in 1935, made the first real attempt to suffuse thermodynamics and quantum mechanics into the teaching of elementary organic chemistry. This textbook was very much ahead of its time—so much so that no other book published in the intervening years has gone quite so far, particularly in the application of thermodynamics to organic chemistry.

The present text owes much to Professor Lucas, because it was originally conceived as a revision of the second edition of his *Organic Chemistry* and follows a somewhat similar order of presentation, as well as placing a similar emphasis on thermochemistry as an aid to the understanding of organic reactions. This emphasis should be of general value in undergraduate education because the gradual shift of teaching in elementary physical chemistry toward quantum mechanics and statistical mechanics has tended to displace the study of many applications of thermodynamics from the undergraduate chemistry curriculum.

Much has been said and written about possible orders of presentation of topics in elementary organic chemistry texts. Whether or not to mix aliphatic and aromatic chemistry, whether or not to go heavily into organic structural theory before discussing reactions—these and similar questions

have been subjected to serious debate without any clear decision (if one is indeed possible). The approach in this book has been an intermediate one which takes cognizance of the fact that it is difficult, if not impossible, to teach everything at once and that a certain degree of repetition is helpful to the learning process. Thus, we cover electronic theory of organic chemistry lightly in Chapter 1 (Lewis structures), extensively in Chapter 5 (atomic orbital models), extensively again in Chapter 9 (the resonance method and rudiments of molecular orbital theory), somewhat in Chapter 28 (molecular orbital theory) and finally lightly in Chapter 31 (bonding between carbon and elements such as silicon, boron, and phosphorus).

At each juncture, the intention has been to introduce only as many new ideas as important for the subject at hand. As a result, Chapters 6 and 7 cover the basic physical and chemical properties of alkenes, yet do not cover the methods by which alkenes are prepared simply because the reactions involved could not be properly understood at this juncture. A reaction index is provided, however, to enable the student to refer quickly to the various reactions by which types of compounds are synthesized.

We cannot claim that there is much that is revolutionary or original about the format or arrangement of our book and yet we believe there is an element of newness about the way we have approached the subject, with unceasing effort to test both traditional and current concepts to see if they really ring true when hit hard. Sometimes, a sort of schizophrenia has resulted, because we have not been able to decide which of two different theoretical treatments is more useful. Usually, we have not made clearcut decisions to accept or reject, but have presented the alternatives. This may be unsettling for elementary students expecting, for example, a consistent treatment of bond angles, in terms of either hybridization or electron repulsion (Chapter 5); or of unsaturated compounds, in terms of either the resonance method or molecular orbital theory (Chapters 9 and 28). We regret this, but the fact is we couldn't make up our own minds on how best to handle these subjects.

The present book is a large one—not so much because of the amount of factual material covered, but perhaps more because of the detail in which many basic ideas are discussed. In some cases, such as with hemiacetal and acetal formation (Chapter 14), the discussion is considerably longer than the synthetic importance of reactions themselves would warrant; however, such discussions have been given in detail because they illustrate principles of broad importance—in the case cited, of the factors governing acid- and base-catalyzed additions to carbonyl groups. Still, the number of topics is large and an instructor with limited time for presentation of an elementary organic course may well find himself in the position of having a small appetite at a sumptuous buffet supper. This is not a problem unique to our book. At least, we have made an attempt to solve it by following the suggestion of Dr. Christian E. Kaslow, that each important topic be assigned a section

number, so that an instructor pressed for time, or wishing to ignore some of our alternative treatments, can quickly and easily plan and assign an appropriate table d'hôte menu for his students.

Two features of the book seem to call for special comment. First, the exercises, of which there are many—not only at the ends of the chapters but also integrated into the text. None of these exercises is of the "Write twelve reactions of aldehydes" type. Such questions may well provide useful review but our concept of the purpose of exercises was different. We hoped to make the students think, make them scour the text for clues, and, in many cases, lead them into areas rather beyond those explicitly covered in the text. Some of the exercises may be exasperating to instructor and student alike because they do not have well-defined, precise answers. However, such exercises often have the advantage of helping to stimulate classroom discussions. There are many more exercises than a student could be expected to work in a year course, but here, again, the idea has been to provide the instructor with a wide range of possible choices. The tables of synthetic reactions contained in many of the chapters and the special reaction-type index should be useful aids to solving the exercises pertaining to organic syntheses.

The other feature of the book which seems to merit separate discussion is the emphasis on applications of the various forms of spectroscopy to problems in organic chemistry. Chapter 2 is particularly controversial in this respect—some reviewers liked it, some thought it belonged in an appendix, and some believed it had no place at all in an elementary text. The importance of spectroscopic methods to structural analysis of organic compounds cannot be questioned. Despite the qualms of the older generation in this respect, it really is the proper thing to take spectra before determining the melting point of a new compound—vastly more information can be obtained thereby. However, this does not mean that instruction in spectroscopic methods is necessary or even desirable in elementary organic courses. There is always a limit to how much material can be covered and an argument can be made for possible pedagogical disadvantages to teaching subjects which may be of no very immediate value to the student.

The material on spectroscopy is available in Chapter 2 and in parts of later chapters—to be used or not at the discretion of the instructor. We see no important difficulties with omitting all of it, if the instructor so desires, except possibly in the latter part of Chapter 28 (which covers some of the recent developments in organic photochemistry). If spectroscopy is covered, the student should be given to understand that it is not necessary for him to grasp all the material in Chapter 2 at once. Rather, he should expect to enhance his ability to comprehend and use spectroscopic methods by returning to this chapter for study and reference material as new applications are encountered with the different classes of compounds. The extensive use we have made of nuclear magnetic resonance spectroscopy may seem to reflect

too much of our own research interests. Nonetheless, we feel this requires no apology because, for qualitative analysis, n.m.r. spectroscopy is usually quite superior to infrared spectroscopy and has the further advantage of being much easier to understand.

This book is not only designed as an introductory text for the student of organic chemistry; it aims also to reach the chemistry major, graduate student, and research man alike—to whom we intend it to serve as a useful reference text. It is the sixth revision and extension of a handful of mimeographed lecture supplements compiled in 1954. Many of our colleagues and friends have contributed to its improvement over the ensuing ten years. At the early stages, Dr. Verner Schomaker was particularly helpful in guiding the presentation of thermochemistry (Chapter 3) and of the resonance method (Chapter 9). At a later stage, Professor Christian E. Kaslow made a very large number of valuable suggestions as the result of using the fifth edition in a summer course at the University of Indiana. Very detailed and helpful reviews of the whole manuscript were provided by Professor Douglas E. Applequist, Henry E. Baumgarten, and William K. Noyce. Many helpful suggestions with respect to particular chapters were also made by Drs. E. R. Buchman and L. H. Klee and Professors Virgil Boekelheide, Kenneth N. Harmon, Carl Niemann, and John H. Richards.

The early printed editions and most of the IBM art work in the present book were skillfully typed by Mrs. Joy Yamashita; Mrs. Birgitta Isaacson provided valuable assistance with the art work, proof, and corrections; and Mrs. Beatrice Wulf typed the cards for the 9000 entries of the index.

We shall be grateful for suggestions for improvements on matters of fact, interpretation, or presentation.

JOHN D. ROBERTS

MARJORIE C. CASERIO

*Pasadena, California*  
*March 1964*

# CONTENTS

	<b>PREFACE</b>	<b>vii</b>
<b>Chapter 1</b>	<b>STRUCTURE, IDENTIFICATION, AND NOMENCLATURE</b>	<b>3</b>
1-1	Bonding in Carbon Compounds	3
1-2	Structural Organic Chemistry	6
1-3	Bond Angles and Ball-and-Stick Models	10
1-4	Rotational Conformations	11
1-5	Space-Filling Models	13
1-6	Identification and Structure Determination	13
1-7	Nomenclature of Organic Compounds	22
<b>Chapter 2</b>	<b>SPECTROSCOPY OF ORGANIC MOLECULES</b>	<b>27</b>
2-1	Line Spectra	28
2-2	Microwave Spectroscopy	29
2-3	Infrared Spectroscopy	29
2-4	Raman Spectroscopy	35
2-5	Electronic Spectra of Organic Molecules	39
2-6	Nuclear Magnetic Resonance Spectroscopy	43
2-7	Mass Spectrometry	58
<b>Chapter 3</b>	<b>ALKANES</b>	<b>63</b>
3-1	Nomenclature	63
3-2	Physical Properties of Alkanes—Concept of Homology	70
3-3	Spectroscopic Properties of Alkanes	72
		<b>xi</b>

	<b>Chemical Reactions of Alkanes</b>	<b>75</b>
3-4	Combustion of Alkanes	75
3-5	Estimation of Heats of Combustion. Bond Energies	75
3-6	Further Comments on Bond Energies	78
3-7	Halogenation of Alkanes and General Problems Regarding Organic Synthesis	80
3-8	Practice of Halogenation	91
3-9	Nitration of Alkanes	95
<b>Chapter 4</b>	<b>CYCLOALKANES</b>	<b>99</b>
4-1	Nomenclature	99
4-2	Physical Properties of Cycloalkanes	100
4-3	Spectroscopic Properties of Cycloalkanes	101
4-4	Conformations of Cycloalkanes	103
4-5	Strain in Cycloalkane Rings	111
4-6	Chemical Properties	113
4-7	<i>Cis-Trans</i> Isomerism of Substituted Cycloalkanes	115
4-8	Polycycloalkanes	118
4-9	Conformations of Decalin	120
<b>Chapter 5</b>	<b>BONDING IN ORGANIC MOLECULES.</b>	
	<b>ATOMIC ORBITAL MODELS</b>	<b>125</b>
5-1	Hydrogen-like Atomic Orbitals	125
5-2	Bond Formation Using Atomic Orbitals	129
5-3	Directed Covalent Bonds	130
5-4	Hybrid Bond Orbitals	134
5-5	Atomic Orbital Models of Organic Compounds	136
5-6	Bond Orbitals for Atoms Carrying Unshared Electron Pairs	141
5-7	Interelectronic Repulsion and Bond Angles	143
<b>Chapter 6</b>	<b>ALKENES I. STRUCTURE, SPECTRA, AND STEREoisomerism</b>	<b>147</b>
6-1	Nomenclature	147
6-2	Physical Properties of Alkenes	150

6-3	Spectroscopic Properties of Alkenes	150
6-4	The Structure of Ethylene	157
6-5	<i>Cis-Trans</i> Isomerism	158
6-6	Determination of Configuration of <i>Cis-Trans</i> Isomers	160
6-7	Determination of Dipole Moments	162

**Chapter 7 ALKENES II. REACTIONS OF CARBON-CARBON**

**DOUBLE BONDS 169**

7-1	Additions to Alkenes. Electrophilic and Nucleophilic Reagents	169
7-2	Hydrogenation of Alkenes: Heterogeneous Catalysis	171
7-3	Heats of Hydrogenation	173
7-4	Electrophilic Addition to Alkenes	175
7-5	Orientation in Addition to Alkenes	182
7-6	Additions of Unsymmetrical Reagents Opposite to Markownikoff's Rule	188
7-7	Addition of Boron Hydrides to Alkenes	190
7-8	Oxidation of Alkenes	191
7-9	Polymerization of Alkenes	195
7-10	Alkylation of Alkenes	199
7-11	Synthesis of Organic Compounds	201

**Chapter 8 ALKYNES 209**

8-1	Nomenclature	210
8-2	Physical Properties of Alkynes	211
8-3	Spectroscopic Properties of Alkynes	211
8-4	Acetylene	214
8-5	Addition Reactions of Alkynes	216
8-6	1-Alkynes as Acids	220

**Chapter 9 THE RESONANCE METHOD AND SOME OF ITS APPLICATIONS. THE MOLECULAR-ORBITAL APPROACH 227**

9-1	Electron-Pair Bonds	227
9-2	The Benzene Problem	228



9-3	An Atomic-Orbital Model of Benzene	231
9-4	Electron-Pairing Schemes—The Resonance Method	232
9-5	Further Comments on the Resonance Method	234
9-6	Rules for Use of the Resonance Method	235
9-7	Stabilization and Resonance Energy	243
9-8	Bond Lengths and Double-Bond Character	247
9-9	Resonance and Absorption Spectra	248
9-10	Molecular Orbital Theory	251
<b>Chapter 10</b>	<b>BIFUNCTIONAL COMPOUNDS. ALKADIENES</b>	<b>257</b>
10-1	Functional Groups as an Aid to the Classification of Organic Compounds	257
10-2	Alkadienes	260
10-3	1,3- or Conjugated Dienes	260
10-4	1,4-Cycloaddition Reactions of Dienes: The Diels-Alder Reaction	262
10-5	1,2-Cycloaddition of Dienes	269
10-6	Polymerization of Conjugated Dienes	270
10-7	1,2-Dienes, Allenes	273
<b>Chapter 11</b>	<b>NUCLEOPHILIC DISPLACEMENT AND ELIMINATION REACTIONS. ALKYL, CYCLO-ALKYL, ALKENYL, AND ALKYNYL HALIDES</b>	<b>281</b>
11-1	Organic Derivatives of Inorganic Compounds	281
11-2	Alcohol and Alkyl Halide Nomenclature	283
11-3	Ether Nomenclature	285
11-4	Carboxylic Acid Nomenclature	285
11-5	The Use of Greek Letters to Denote Substituent Positions	286
11-6	Single- or Multiple-Word Names	286
	<b>Nucleophilic Displacement Reactions</b>	<b>287</b>
11-7	General Considerations	287
11-8	Thermochemistry of Displacement Reactions	291
11-9	Mechanisms of $S_N$ Displacements	292
11-10	Stereochemistry of $S_N2$ Displacements	295

11-11	Stereochemistry of $S_N1$ Reactions	298
11-12	Structural and Solvent Effects in $S_N$ Reactions	299
	<b>Elimination Reactions</b>	<b>306</b>
11-13	The E2 Reaction	309
11-14	The E1 Reaction	312
11-15	Stereochemistry of Elimination Reactions	315
	<b>Alkyl, Alkenyl, and Cycloalkyl Halides</b>	<b>320</b>
11-16	Alkyl Halides	320
11-17	Alkenyl Halides	321
11-18	Cycloalkyl Halides	329
11-19	Polyhalogen Compounds	329
11-20	Fluorinated Alkanes	332
<b>Chapter 12</b>	<b>ORGANOMETALLIC COMPOUNDS</b>	<b>341</b>
12-1	General Properties of Organometallic Compounds	342
12-2	Preparation of Organometallic Compounds	345
12-3	Organomagnesium Compounds	348
12-4	Reactions of Grignard Reagents	350
12-5	Organosodium and Organolithium Compounds	364
12-6	Zinc Alkyls—The Reformatsky Reaction	364
12-7	Commercial Applications of Organometallic Compounds	365
12-8	Electrophilic Displacement Reactions at Carbon	366
<b>Chapter 13</b>	<b>ALCOHOLS AND ETHERS</b>	<b>375</b>
13-1	Nomenclature of Carbonyl Compounds	376
13-2	Physical Properties of Alcohols—Hydrogen Bonding	378
13-3	Spectroscopic Properties of Alcohols—Hydrogen Bonding	380
13-4	Preparation of Alcohols	382
	<b>Chemical Reactions of Alcohols</b>	<b>384</b>
13-5	Reactions Involving the O—H Bond	384
13-6	Reactions Involving the C—O Bond of Alcohols	391
13-7	Oxidation of Alcohols	400

13-8	Polyhydric Alcohols	405
13-9	Unsaturated Alcohols	406
	<b>Ethers</b>	<b>407</b>
13-10	Types and Reactions of Simple Ethers	407
13-11	Cyclic Ethers	410
13-12	Oxiranes	411
<b>Chapter 14</b>	<b>ALDEHYDES AND KETONES. REACTIONS AT THE CARBONYL GROUP</b>	<b>427</b>
14-1	Preparation of Aldehydes and Ketones	427
14-2	Carbonyl Groups of Aldehydes and Ketones	432
14-3	Some Typical Carbonyl Addition Reactions	438
14-4	Condensations of Carbonyl Compounds with $\text{RNH}_2$ Derivatives	449
14-5	Hydrogen Halide Addition and Replacement by Halogen	453
14-6	Reduction of Carbonyl Compounds	455
14-7	Oxidation of Carbonyl Compounds	460
14-8	The Cannizzaro Reaction	461
<b>Chapter 15</b>	<b>ALDEHYDES AND KETONES. REACTIONS INVOLVING THE SUBSTITUENT GROUPS; UNSATURATED AND POLYCARBONYL COMPOUNDS</b>	<b>473</b>
15-1	Halogenation of Aldehydes and Ketones	473
15-2	Reactions of Enolate Anions	479
15-3	Enamines	486
	<b>Unsaturated Carbonyl Compounds</b>	<b>488</b>
15-4	$\alpha,\beta$ -Unsaturated Aldehydes and Ketones	488
15-5	Ketenes	491
	<b>Polycarbonyl Compounds</b>	<b>495</b>
15-6	1,2-Dicarbonyl Compounds	495
15-7	1,3-Dicarbonyl Compounds	496

<b>Contents</b>		<b>xvii</b>
15-8	1,4-Dicarbonyl Compounds	499
15-9	Tricarbonyl Compounds	500
<b>Chapter 16</b>	<b>CARBOXYLIC ACIDS AND DERIVATIVES</b>	<b>507</b>
	<b>Physical Properties of Carboxylic Acids</b>	<b>509</b>
16-1	Hydrogen Bonding	509
16-2	Spectra of Carboxylic Acids	511
	<b>Chemical Properties of Carboxylic Acids</b>	<b>513</b>
16-3	Dissociation of Carboxylic Acids	514
16-4	Reactions at the Carbonyl Carbon of Carboxylic Acids	518
16-5	Decarboxylation of Carboxylic Acids	523
16-6	Reactions at the Alpha Carbons of Carboxylic Acids	526
	<b>Functional Derivatives of Carboxylic Acids</b>	<b>528</b>
16-7	Reactions at the Carbonyl Carbon	530
16-8	Reactions at the Alpha Carbons of Carboxylic Acid Derivatives	536
	<b>Reactions of Unsaturated Carboxylic Acids and Their Derivatives</b>	<b>544</b>
16-9	Migration of the Double Bond	544
16-10	Double-Bond Addition Reactions	545
	<b>Dicarboxylic Acids</b>	<b>549</b>
16-11	Acidic Properties of Dicarboxylic Acids	551
16-12	Thermal Behavior of Dicarboxylic Acids	551
16-13	Derivatives of Dicarboxylic Acids	552
<b>Chapter 17</b>	<b>OPTICAL ISOMERISM</b>	<b>569</b>
17-1	Plane-Polarized Light and the Origin of Optical Rotation	569
17-2	Specific Rotation	572
17-3	Optically Active Compounds with Asymmetric Carbon Atoms	573

17-4	Optically Active Compounds Having No Asymmetric Carbon Atoms	581
17-5	Absolute and Relative Configuration	588
17-6	Optical Rotatory Dispersion	595
17-7	Separation or Resolution of Enantiomers	597
17-8	Asymmetric Synthesis and Asymmetric Induction	599
17-9	Racemization	603
<b>Chapter 18</b>	<b>CARBOHYDRATES</b>	<b>611</b>
18-1	Classification of Carbohydrates	612
18-2	The Structure and Properties of D-Glucose	616
18-3	Projection Formulas for Carbohydrates	619
18-4	Conformations of Carbohydrates	622
18-5	Conventions for Indicating Ring Size of Mono-saccharides	622
18-6	Configuration and Molecular Rotation Relationships	623
18-7	Mutarotation	625
18-8	Derivatives of Glucose	625
18-9	Glycosides	629
18-10	Disaccharides	631
18-11	Polysaccharides	635
18-12	Vitamin C	638
<b>Chapter 19</b>	<b>ORGANIC NITROGEN COMPOUNDS. AMINES, AMIDES, NITRILES. NITRO, AZO, DIAZO, AND RELATED COMPOUNDS</b>	<b>641</b>
	<b>Derivatives of Ammonia</b>	<b>642</b>
19-1	Types and Nomenclature of Amines	642
19-2	Physical and Spectroscopic Properties of Amines	644
19-3	Stereochemistry of Amines	648
19-4	Amines as Acids and Bases	650
19-5	Methods for the Preparation of Amines	652
19-6	Reactions of Amines	664
19-7	Oxidation of Amines	670

	<b>Amides</b>	<b>674</b>
19-8	Physical and Spectral Characteristics of Amides	674
19-9	Syntheses of Amides	681
19-10	Hydrolysis of Amides	681
	<b>Nitriles, Isocyanides, and Isocyanates</b>	<b>682</b>
19-11	Nitriles	682
19-12	Isocyanides	684
19-13	Isocyanates	685
	<b>Nitroso and Nitro Compounds</b>	<b>687</b>
19-14	Nitroso Compounds	687
19-15	Nitro Compounds	687
	<b>Some Compounds with N—N Bonds</b>	<b>691</b>
19-16	Hydrazines	691
19-17	Azo Compounds	692
19-18	Diazo Compounds	693
19-19	Azides	696
<b>Chapter 20</b>	<b>AMINO ACIDS, PEPTIDES, PROTEINS, AND ENZYMES</b>	<b>701</b>
20-1	Types of Biologically Important Amino Acids	701
20-2	Synthesis of $\alpha$ -Amino Acids	702
20-3	The Acid-Base Properties of Amino Acids	706
20-4	Analysis of Amino Acids	708
20-5	Lactams	712
20-6	Peptides and Proteins	715
20-7	Protein Structures	723
20-8	Enzymes	727
20-9	Coenzymes	730
20-10	Biosynthesis of Proteins	732
20-11	The Structure of DNA	732
<b>Chapter 21</b>	<b>ORGANOSULFUR COMPOUNDS</b>	<b>745</b>
21-1	Types and Nomenclature of Organosulfur Compounds	747
21-2	Thiols	747

21-3	Alkyl Sulfides	755
21-4	Sulfoxides and Sulfones	758
21-5	Sulfenic, Sulfinic, and Sulfonic Acids	760
<b>Chapter 22</b>	<b>ARENES. ELECTROPHILIC AROMATIC SUBSTITUTION</b>	<b>767</b>
22-1	Nomenclature of Arenes	768
22-2	Physical Properties of Arenes	771
22-3	Spectroscopic Properties of Arenes	772
	<b>Reactions of Aromatic Hydrocarbons</b>	<b>783</b>
22-4	Electrophilic Aromatic Substitution	783
22-5	Effect of Substituents on Reactivity and Orientation in Electrophilic Aromatic Substitution	799
22-6	Aromatic Substitution by Metalation	810
22-7	Substitution Reactions of Polynuclear Aromatic Hydrocarbons	810
22-8	Addition Reactions of Arenes	815
22-9	Oxidation Reactions	817
22-10	Sources and Uses of Aromatic Hydrocarbons	819
22-11	Nonbenzenoid Aromatic Compounds	825
<b>Chapter 23</b>	<b>ARYL HALOGEN COMPOUNDS. NUCLEO- PHILIC AROMATIC SUBSTITUTION</b>	<b>837</b>
23-1	Physical Properties of Aryl Halogen Compounds	838
23-2	Preparation of Aryl Halides	840
23-3	Reactions of Aryl Halides	843
23-4	Polyvalent Iodine Compounds	853
<b>Chapter 24</b>	<b>ARYL NITROGEN COMPOUNDS</b>	<b>861</b>
	<b>Aromatic Nitro Compounds</b>	<b>862</b>
24-1	Synthesis of Nitro Compounds	862
24-2	Reduction of Aromatic Nitro Compounds	867
24-3	The Benzidine Rearrangement and Related Reactions	871

24-4	Polynitro Compounds	874
24-5	Charge-Transfer ( $\pi$ ) Complexes	874
	<b>Aromatic Amines</b>	<b>879</b>
24-6	Synthesis and General Properties	879
24-7	Oxidation of Aromatic Amines	883
24-8	Aromatic Amines with Nitrous Acid	885
	<b>Diazonium Salts</b>	<b>887</b>
24-9	Preparation and General Properties	887
24-10	Replacement Reactions of Diazonium Salts	888
24-11	Reactions of Diazonium Compounds Which Occur without Loss of Nitrogen	892
<b>Chapter 25</b>	<b>ARYL OXYGEN COMPOUNDS</b>	<b>901</b>
25-1	Synthesis and Physical Properties of Phenols	901
25-2	Some Chemical Properties of Phenols	905
25-3	Polyhydric Phenols	916
	<b>Quinones</b>	<b>919</b>
25-4	Reduction of Quinones	920
25-5	Photographic Developers	922
25-6	Addition Reactions of Quinones	923
25-7	Vitamin K <sub>1</sub>	924
25-8	Phenylcyclobutadienoquinones	925
25-9	Tropolones and Related Compounds	926
<b>Chapter 26</b>	<b>AROMATIC SIDE-CHAIN DERIVATIVES</b>	<b>933</b>
	<b>Preparation of Aromatic Side-Chain Compounds</b>	<b>933</b>
26-1	Aromatic Carboxylic Acids	933
26-2	Preparation of Side-Chain Aromatic Halogen Compounds	935
26-3	Side-Chain Compounds Derived from Arylmethyl Halides	937
26-4	Preparation of Aromatic Side-Chain Compounds by Ring Substitution	939



	<b>Properties of Aromatic Side-Chain Derivatives</b>	<b>942</b>
26-5	Arylmethyl Halides. Stable Carbonium Ions, Carbanions, and Free Radicals	942
26-6	Aromatic Aldehydes	947
26-7	Natural Occurrence and Uses of Aromatic Side- Chain Derivatives	951
26-8	Correlation between Structure and Reactivity in Aromatic Side-Chain Derivatives	954
26-9	Electron Paramagnetic Resonance Spectroscopy	963
<b>Chapter 27</b>	<b>HETEROCYCLIC AROMATIC COMPOUNDS</b>	<b>967</b>
27-1	Nomenclature of Heterocyclic Ring Systems	968
	<b>Monohetero Ring Systems</b>	<b>974</b>
27-2	Some Derivatives of Furan, Pyrrole, Thiophene, and Pyridine	974
27-3	Aromatic Character of Unsaturated Heterocycles	979
27-4	Chemical Properties of Pyrrole, Furan, Thiophene, and Pyridine	983
27-5	Synthesis of Pyrroles, Furans, and Thiophenes	996
27-6	Derivatives of Pyrrole, Furan, and Pyridine	1002
	<b>Polyhetero Ring Systems</b>	<b>1005</b>
27-7	Imidazole and Pyrazole	1006
27-8	Oxazole	1008
27-9	Pyrimidine	1008
27-10	Purine and Pteridine	1010
27-11	Synthesis of Polyhetero Ring Systems by 1,3-Cyclo- addition	1011
	<b>Heterocyclic Natural Products</b>	<b>1016</b>
27-12	Natural Products Related to Pyrrole	1016
27-13	Natural Products Related to Indoles	1018
27-14	Natural Products Related to Pyridine, Quinoline, and Isoquinoline	1021
27-15	Natural Products Related to Pyrimidine	1022
27-16	Natural Products Related to Purine	1023