

---

**Volume 12:  
Five-Membered Heterenes with Two Nitrogen  
or Phosphorus Atoms**

	<b>Preface</b> .....	V
	<b>Volume Editor's Preface</b> .....	VII
	<b>Table of Contents</b> .....	XI
	<b>Introduction</b>	
	R. Neier .....	1
12.1	<b>Product Class 1: Pyrazoles</b>	
	B. Stanovnik and J. Svete .....	15
12.2	<b>Product Class 2: 1<i>H</i>- and 2<i>H</i>-Indazoles</b>	
	W. Stadlbauer .....	227
12.3	<b>Product Class 3: Imidazoles</b>	
	M. R. Grimmett .....	325
12.4	<b>Product Class 4: Benzimidazoles</b>	
	M. R. Grimmett .....	529
12.5	<b>Product Class 5: Azaindolizines with Two Nitrogen Atoms in the Five-Membered Ring</b>	
	G. Hajos and Z. Riedl .....	613
12.6	<b>Product Class 6: Azaphospholes and Azarsoles</b>	
	A. Schmidpeter and K. Karaghiosoff .....	679
12.7	<b>Product Class 7: Diphospholes</b>	
	F. Mathey .....	705
	<b>Keyword Index</b> .....	719
	<b>Author Index</b> .....	741
	<b>Abbreviations</b> .....	791

## Table of Contents

	<b>Introduction</b>	
	R. Neier	
	<b>Introduction</b> .....	1
<b>12.1</b>	<b>Product Class 1: Pyrazoles</b>	
	B. Stanovnik and J. Svete	
<b>12.1</b>	<b>Product Class 1: Pyrazoles</b> .....	15
<b>12.1.1</b>	Synthesis by Ring-Closure Reactions .....	21
<b>12.1.1.1</b>	By Formation of One N—C and Two C—C Bonds .....	21
<b>12.1.1.1.1</b>	Fragments N—N—C, C, and C .....	21
<b>12.1.1.1.1.1</b>	Method 1: From [(Aryldiazenyl)(methoxycarbonyl)methylene]triphenyl- phosphoranes and Dichlorocarbene .....	21
<b>12.1.1.2</b>	By Formation of Two N—C Bonds .....	22
<b>12.1.1.2.1</b>	Fragments C—C—C and N—N .....	22
<b>12.1.1.2.1.1</b>	From 1,3-Dicarbonyl Compounds (and Acetals Thereof) and Hydrazines .....	22
<b>12.1.1.2.1.1.1</b>	Method 1: From <i>O,O</i> -Acetals of 1,3-Dicarbonyl Compounds and Hydrazines .....	23
<b>12.1.1.2.1.1.1.1</b>	Variation 1: From Malonaldehyde Acetals and Hydrazines .....	23
<b>12.1.1.2.1.1.1.2</b>	Variation 2: From 3,3-Dialkoxyalkan-1-ones and Hydrazines .....	24
<b>12.1.1.2.1.1.2</b>	Method 2: From Malonaldehyde and Derivatives and Hydrazines .....	25
<b>12.1.1.2.1.1.3</b>	Method 3: From $\beta$ -Oxoaldehydes and Hydrazines .....	25
<b>12.1.1.2.1.1.3.1</b>	Variation 1: From Carbonyl Compounds and Alkyl Formate Followed by Reaction with Hydrazine Hydrate .....	26
<b>12.1.1.2.1.1.4</b>	Method 4: From $\beta$ -Diketones and Hydrazines .....	28
<b>12.1.1.2.1.1.4.1</b>	Variation 1: From 2-Hydroxyimino-1,3-dicarbonyl Compounds and Hydrazines .....	32
<b>12.1.1.2.1.1.4.2</b>	Variation 2: From 2-Acetoxy-1,3-dicarbonyl Compounds and Hydrazines ..	33
<b>12.1.1.2.1.1.4.3</b>	Variation 3: From Tetracarbonyl Compounds and Hydrazines .....	33
<b>12.1.1.2.1.1.5</b>	Method 5: From $\beta$ -Diketones and Acylhydrazines .....	34
<b>12.1.1.2.1.1.6</b>	Method 6: From 2-Arylazo-1,3-dicarbonyl Compounds and Acylhydrazines	35
<b>12.1.1.2.1.1.7</b>	Method 7: From 3-Oxocarboxylic Acids and Hydrazines .....	36
<b>12.1.1.2.1.1.7.1</b>	Variation 1: From 3-Oxocarboxylic Acids and 1-Alkyl-1-nitrosohydrazines ..	41
<b>12.1.1.2.1.1.7.2</b>	Variation 2: From 3-Oxocarbothioic Esters or 3-Oxocarbothioamides and Hydrazine .....	41
<b>12.1.1.2.1.1.8</b>	Method 8: From 3-Oxocarboxylic Acid Derivatives and Acylhydrazines ...	42
<b>12.1.1.2.1.1.9</b>	Method 9: From $\alpha$ -Cyano Ketones and Hydrazines .....	43
<b>12.1.1.2.1.1.9.1</b>	Variation 1: From $\alpha$ -Cyano- $\alpha$ -( <i>N</i> -methylanilino) Ketones and Hydrazines ..	44

12.1.1.2.1.1.9.2	Variation 2:	From $\alpha$ -Cyano Ketones and Semicarbazides and Thiosemicarbazides	44
12.1.1.2.1.1.9.3	Variation 3:	From $\alpha$ -Cyano Ketones and Arylsulfonylhydrazides	45
12.1.1.2.1.1.9.4	Variation 4:	From $\alpha$ -Cyano- $\alpha$ -hydroxyimino Ketones and Hydrazines	46
12.1.1.2.1.1.10	Method 10:	From Malonic Acid Derivatives and Hydrazines	46
12.1.1.2.1.1.10.1	Variation 1:	From Malonic Acid Derivatives and Arylhydrazines	47
12.1.1.2.1.1.10.2	Variation 2:	From Malonic Acid Derivatives and 1-Acetyl-2-arylhydrazines	47
12.1.1.2.1.1.10.3	Variation 3:	From Malonic Acid Anilide Esters and Arylhydrazines	48
12.1.1.2.1.1.10.4	Variation 4:	From Thiomalonic Acid <i>O,O</i> -Dialkyl Esters and Hydrazine	48
12.1.1.2.1.1.11	Method 11:	From Cyanoacetic Acid Esters and Hydrazine	49
12.1.1.2.1.1.11.1	Variation 1:	From Alkyl [Alkoxy(imino)methyl]acetates and Arylhydrazine	50
12.1.1.2.1.1.11.2	Variation 2:	From Malononitriles and Its Derivatives and Hydrazine	51
12.1.1.2.1.1.12	Method 12:	From Propanediimidic Esters and Hydrazine	52
12.1.1.2.1.1.12.1	Variation 1:	From 2-Substituted Malononitriles and Hydrazine	52
12.1.1.2.1.1.13	Method 13:	From Alk-2-en-1-ones and Hydrazine	53
12.1.1.2.1.1.13.1	Variation 1:	From 2-Acryloyloxiranes and Hydrazine	53
12.1.1.2.1.1.13.2	Variation 2:	From 2-Substituted Alk-2-en-1-ones and Hydrazine	54
12.1.1.2.1.1.13.3	Variation 3:	From 1,2-Disubstituted 3-(Dimethylamino)prop-2-en-1-ones and Hydrazine	55
12.1.1.2.1.1.13.4	Variation 4:	From 2-Acryloyl-3-(dimethylamino)prop-2-enoates and Hydrazine	57
12.1.1.2.1.1.13.5	Variation 5:	From Alkyl 2-Acyl-3-alkoxyprop-2-enoates and Hydrazine	57
12.1.1.2.1.1.13.6	Variation 6:	From 3-Haloalk-2-en-1-ones and Hydrazine	60
12.1.1.2.1.1.13.7	Variation 7:	From 3-(Alkylsulfanyl)-2-[(alkylsulfanyl)methyl]alk-2-en-1-ones and Hydrazine	60
12.1.1.2.1.1.13.8	Variation 8:	From Acylketene <i>O,N</i> -Acetals or <i>N,S</i> -Acetals and Hydrazine	61
12.1.1.2.1.1.13.9	Variation 9:	From 3,3-Bis(methylsulfanyl)prop-2-en-1-ones and Hydrazine	62
12.1.1.2.1.1.14	Method 14:	From Acrylic Acid Derivatives and Hydrazine	64
12.1.1.2.1.1.15	Method 15:	From 3,3-Diamino-2-nitroprop-2-enethioamides and Hydrazine	65
12.1.1.2.1.1.15.1	Variation 1:	From 3-Aminoprop-2-enethioamide and Hydrazine	66
12.1.1.2.1.1.16	Method 16:	From Prop-2-enenitriles and Hydrazine	67
12.1.1.2.1.1.16.1	Variation 1:	From Prop-2-enenitriles and Hydrazides or Thiohydrazides	67
12.1.1.2.1.1.16.2	Variation 2:	From (Alkoxyethylene)malononitriles and Hydrazine	68
12.1.1.2.1.1.16.3	Variation 3:	From (Aminomethylene)malononitriles and Hydrazine	70
12.1.1.2.1.1.16.4	Variation 4:	From 3-(Alkylsulfanyl)acrylonitriles and Hydrazine	70
12.1.1.2.1.1.16.5	Variation 5:	From 2-Haloacrylonitriles and Hydrazine	71
12.1.1.2.1.1.16.6	Variation 6:	From 3-Haloacrylonitriles and Hydrazine	72
12.1.1.2.1.1.16.7	Variation 7:	From 2,3-Dihalofumaritriles and Hydrazine	72
12.1.1.2.1.1.16.8	Variation 8:	From Cyanoketene <i>N,S</i> -Acetals or <i>S,S</i> -Acetals and Hydrazine	73
12.1.1.2.1.1.16.9	Variation 9:	From Tetracyanoethene and Hydrazine	76
12.1.1.2.1.1.17	Method 17:	From Alk-2-yn-1-ones and Hydrazine	77
12.1.1.2.1.1.18	Method 18:	From Alk-2-ynenitriles and Hydrazine	79
12.1.1.2.1.1.19	Method 19:	From 1,3-Dienes, Alk-1-en-3-yne, or Alka-1,3-diyne and Hydrazine	79
12.1.1.2.1.1.20	Method 20:	From Active Methylene Compounds and Diazonium Salts	80
12.1.1.2.1.1.20.1	Variation 1:	From Active Methylene Compounds and Tosyl Azide	82

12.1.1.2.1.2	From Other Compounds and Hydrazine	82
12.1.1.2.1.2.1	Method 1: From Haloalkenes, Hydroxyalkenes, Hydroxyalkynes, or Halo-, Hydroxy-, and Aminocarbonyl Compounds and Hydrazine	82
12.1.1.2.1.2.2	Method 2: From Nitroalkanes or 1-Nitroalkenes and Hydrazine	83
12.1.1.2.1.2.2.1	Variation 1: From 1,1-Dinitroalkanes and Hydrazine	83
12.1.1.2.1.2.2.2	Variation 2: From 1,3-Dinitroalkanes and Hydrazine	84
12.1.1.3	By Formation of One N—C and One C—C Bond	84
12.1.1.3.1	Fragments N—N—C and C—C	84
12.1.1.3.1.1	From Diazo Compounds by 1,3-Dipolar Cycloadditions	84
12.1.1.3.1.1.1	Method 1: From Diazoalkanes and Alkynes	84
12.1.1.3.1.1.1.1	Variation 1: From Furanosylalkynes or 1-Diazo-1-furanosylalkanes	87
12.1.1.3.1.1.2	Method 2: From Diazoalkanes and Alkenes Followed by Elimination	88
12.1.1.3.1.1.3	Method 3: From Disubstituted Diazoalkanes and Alkynes	90
12.1.1.3.1.1.4	Method 4: From 2-Diazocarbonyl Compounds and Alkynes	91
12.1.1.3.1.1.5	Method 5: From Alkenes and Diazocarbonyl Compounds Followed by Elimination	91
12.1.1.3.1.1.6	Method 6: From Dimethyl Diazomalonate and Dimethyl Malonate	92
12.1.1.3.1.2	From Nitrile Imines	92
12.1.1.3.1.2.1	Method 1: From Nitrile Imines and Alkynes	92
12.1.1.3.1.2.2	Method 2: From Nitrile Imines and Alkenes with a Leaving Group at the 3-Position	93
12.1.1.3.1.2.2.1	Variation 1: From Nitrile Imines and 1,3-Dicarbonyl Compounds	94
12.1.1.3.1.2.2.2	Variation 2: From 1-Perfluoroalkyl-1,3-dicarbonyl Compounds and Hydrazonoyl Halides	94
12.1.1.3.1.2.2.3	Variation 3: From Ketene Aminals and Nitrile Imines	95
12.1.1.3.1.2.2.4	Variation 4: From Hydrazonoyl Halides and Phosphoranes	96
12.1.1.3.1.3	From Hydrazones and 1,2-Dicarbonyl Compounds	97
12.1.1.3.1.4	From Arylhydrazones and $\beta$ -Oxo Esters	98
12.1.1.3.1.5	From Arylhydrazones and Dimethyl Acetylenedicarboxylate	98
12.1.1.3.2	Fragments N—N—C—C and C	99
12.1.1.3.2.1	Method 1: From Hydrazones or Azines by Vilsmeier–Haack Reaction	99
12.1.1.3.2.2	Method 2: From Aldehydes and Tosylhydrazones of (Dialkoxyphosphoryl)acetaldehydes	99
12.1.1.3.2.2.1	Variation 1: From Aldehydes and Alkylated Tosylhydrazono Phosphonates	100
12.1.1.3.2.3	Method 3: From Hydrazones and Carboxylic Acid Derivatives	101
12.1.1.3.2.3.1	Variation 1: From Hydrazones and Aroyl Chloride	104
12.1.1.3.2.4	Method 4: From Arylhydrazones of Active Methylene Compounds and $\alpha$ -Halocarbonyl Compounds and Chloroacetonitrile	105
12.1.1.3.2.5	Method 5: From Hydrazones and (Dichloromethylene)dimethylammonium Chloride	105
12.1.1.3.2.6	Method 6: From Benzoin Phenylhydrazones and Aldehydes	106
12.1.1.3.2.7	Method 7: From Monohydrazones of 1,2-Dicarbonyl Compounds and Diethyl [(Ethylsulfanyl)methyl]phosphonate	106

12.1.1.3.2.8	Method 8: From Phenylhydrazones and <i>N</i> -Aryltrifluoroacetimidoyl Iodides .....	107
12.1.1.4	By Formation of One N—N Bond .....	108
12.1.1.4.1	Fragment N—C—C—N .....	108
12.1.1.4.1.1	Method 1: From 1,3-Dioximes .....	108
12.1.1.4.1.2	Method 2: From $\beta$ -Aminothiocinnamic Acid Anilide .....	109
12.1.1.4.1.3	Method 3: From <i>N</i> ,3-Diaryl-3-iminoprop-1-enamines .....	109
12.1.1.5	By Formation of One N—C Bond .....	110
12.1.1.5.1	Fragments N—N—C—C and C .....	110
12.1.1.5.1.1	Method 1: From Hydrazones of Alkane-1,3-diones .....	110
12.1.1.5.1.1.1	Variation 1: From Hydrazones of 1,1-Dialkoxy-3-oxoalkanes .....	110
12.1.1.5.1.1.2	Variation 2: From Arylhydrazones of Methyl Ketones by Acylation of the Methyl Group .....	111
12.1.1.5.1.2	Method 2: From 3-Halo-1-hydrazonoacetones .....	112
12.1.1.5.1.3	Method 3: From Alk-1-enylhydrazones .....	113
12.1.1.5.1.4	Method 4: From 3-(2-Alkylidenehydrazino)propanenitriles .....	113
12.1.1.5.1.5	Method 5: From 2-Cyano-3-(2-alkylhydrazino)- or 2-Cyano-3-(2-arylhydrazino)but-2-enethioamides .....	114
12.1.1.5.1.6	Method 6: From [3-(Ethoxycarbonyl)-3-hydrazono-2-oxopropyl]di- methylsulfonium Salts .....	114
12.1.1.5.1.7	Method 7: From 3-Hydrazonoalkanoic Acid Derivatives .....	115
12.1.1.5.1.8	Method 8: From Alk-2-ynohydrazides .....	116
12.1.1.5.1.9	Method 9: From Azines .....	116
12.1.1.5.1.9.1	Variation 1: From Symmetrical Acrolein Azines with Leaving Groups at 3-Position .....	117
12.1.1.5.1.9.2	Variation 2: From Phosphonium-Substituted Azines .....	117
12.1.1.5.1.10	Method 10: From 3-Diazoalk-1-enes .....	118
12.1.1.5.1.11	Method 11: From 3,3-Disubstituted Alk-2-en-1-one Tosylhydrazones .....	119
12.1.1.5.1.12	Method 12: From 1,3-Substituted 3-Arylhydrazonoprop-1-enes by Oxidative Cyclization .....	120
12.1.1.6	By Formation of One C—C Bond .....	121
12.1.1.6.1	Fragment C—N—N—C—C .....	121
12.1.1.6.1.1	Method 1: From Mono(methylhydrazones) or Mono{[(alkoxycarbonyl)methyl]hydrazones} of 1,2-Dicarbonyl Compounds .....	121
12.1.1.6.1.2	Method 2: From Mono(acylhydrazones) of 1,3-Dicarbonyl Compounds ..	122
12.1.1.6.1.3	Method 3: From Cinnamaldehyde (2-Phosphoniovinyl)hydrazone Halides	123
12.1.2	Synthesis by Ring Transformation .....	124
12.1.2.1	Ring Enlargement .....	124
12.1.2.1.1	From Three-Membered Hetero- and Carbocycles .....	124
12.1.2.1.1.1	Method 1: Synthesis from Cyclopropanes .....	124
12.1.2.1.1.2	Method 2: Synthesis from Oxiranes .....	125
12.1.2.1.1.3	Method 3: Synthesis from Thiirene 1,1-Dioxides .....	126

12.1.2.1.1.3.1	Variation 1: By Addition of Diazoalkane	126
12.1.2.1.1.3.2	Variation 2: By Addition of Nitrile Imine	126
12.1.2.1.1.4	Method 4: Synthesis from Aziridines	127
12.1.2.1.2	From Four-Membered Heterocycles	128
12.1.2.1.2.1	Method 1: Synthesis from 1,3-Dithietanes	128
12.1.2.2	Retention of Ring Size	128
12.1.2.2.1	Method 1: Synthesis from Furans	128
12.1.2.2.1.1	Variation 1: From 3-(Diethoxymethyl)-2-ethoxytetrahydrofuran	128
12.1.2.2.1.2	Variation 2: From Furan-2,4(3 <i>H</i> ,5 <i>H</i> )-ones or 4-Hydroxyfuran-2(5 <i>H</i> )-ones	129
12.1.2.2.1.3	Variation 3: From 3,4-Bis(arylhydrazono)dihydrofuran-2(3 <i>H</i> )-ones	130
12.1.2.2.1.4	Variation 4: From 3-Acyldihydrofuran-2(3 <i>H</i> )-ones	130
12.1.2.2.1.5	Variation 5: From 2-(Arylmethylene)furan-2(3 <i>H</i> )-ones	132
12.1.2.2.1.6	Variation 6: From Furan-3(2 <i>H</i> )-ones	132
12.1.2.2.1.7	Variation 7: From 2-Alkoxy- or 2-Hydroxyfuran-3(2 <i>H</i> )-ones	133
12.1.2.2.2	Method 2: Synthesis from Pyrroles	134
12.1.2.2.2.1	Variation 1: From 2-(Dicyanomethylene)pyrrolidines	134
12.1.2.2.2.2	Variation 2: From 5-Substituted 2-Oxopyrrolidine-3-carbaldehydes	135
12.1.2.2.2.3	Variation 3: From 3-[(Dimethylamino)methylene]pyrrolidin-2-one	135
12.1.2.2.3	Method 3: Synthesis from Isoxazoles	136
12.1.2.2.3.1	Variation 1: From Isoxazoles and Hydrazines	136
12.1.2.2.3.2	Variation 2: From Isoxazolium Salts and Hydrazines	137
12.1.2.2.3.3	Variation 3: From 3,5-Disubstituted Isoxazoles by Reductive Cleavage of the O–N Bond Followed by Treatment with Hydrazine	138
12.1.2.2.4	Method 4: Synthesis from Oxazoles	138
12.1.2.2.4.1	Variation 1: From Oxazole-4-carbohydrazides	138
12.1.2.2.4.2	Variation 2: From 2-(Dicyanomethylene)oxazolidine	139
12.1.2.2.4.3	Variation 3: From 4-[(Dimethylamino)methylene]oxazol-5(4 <i>H</i> )-ones	139
12.1.2.2.5	Method 5: Synthesis from Isothiazoles	140
12.1.2.2.6	Method 6: Synthesis from Thiazoles	140
12.1.2.2.7	Method 7: Synthesis from Imidazoles	141
12.1.2.2.7.1	Variation 1: From 2-(Aroylmethylene)imidazolidines	141
12.1.2.2.7.2	Variation 2: From 3-Amino-1-methylbenzimidazolium Salts	142
12.1.2.2.8	Method 8: Synthesis from 1,2,3-Oxadiazolium-5-olates (Sydnones)	143
12.1.2.2.9	Method 9: Synthesis from 1,2,4-Oxadiazoles	143
12.1.2.2.10	Method 10: Synthesis from 1,3,4-Oxadiazoles	144
12.1.2.2.10.1	Variation 1: From 1,3,4-Oxadiazolium-2-olates (Isosydnones)	144
12.1.2.2.10.2	Variation 2: From 1,3,4-Oxadiazol-2-ylacetones	145
12.1.2.2.11	Method 11: Synthesis from 1,2,3-Thiadiazoles	146
12.1.2.2.12	Method 12: Synthesis from 1,2,3-Triazoles	147
12.1.2.2.13	Method 13: Synthesis from Tetrazoles	147
12.1.2.3	Ring Contraction	148
12.1.2.3.1	From Six-Membered Rings	148
12.1.2.3.1.1	Method 1: Synthesis from Pyrans	148
12.1.2.3.1.1.1	Variation 1: From Pyranones and Benzopyranone	148
12.1.2.3.1.1.2	Variation 2: From 2 <i>H</i> -Pyran-4(3 <i>H</i> )-ones	150

12.1.2.3.1.1.3	Variation 3:	From 3-Acetyldihydro-2 <i>H</i> -pyran-2,4(3 <i>H</i> )-diones	151
12.1.2.3.1.2	Method 2:	Synthesis from Pyridines	152
12.1.2.3.1.3	Method 3:	Synthesis from 1,3-Dioxanes	152
12.1.2.3.1.4	Method 4:	Synthesis from 1,3-Oxazines	153
12.1.2.3.1.5	Method 5:	Synthesis from Pyridazines	154
12.1.2.3.1.5.1	Variation 1:	From 2-Substituted 5,6-Diphenyl-2,3-dihydropyridazine	154
12.1.2.3.1.5.2	Variation 2:	From 2-Substituted 4-Chloro-, 4-Hydroxy-, 4-Alkoxy-, and 4-(Alkylsulfanyl)pyridazin-3(2 <i>H</i> )-ones	154
12.1.2.3.1.6	Method 6:	Synthesis from Pyrimidines	155
12.1.2.3.1.6.1	Variation 1:	From Pyrimidines and Hydrazine Hydrate	155
12.1.2.3.1.6.2	Variation 2:	From 1-Aryl-5-bromo-6-methylpyrimidine-2,4(1 <i>H</i> ,3 <i>H</i> )-diones	156
12.1.2.3.1.7	Method 7:	Synthesis from 1,2,6-Thiadiazines	156
12.1.2.3.1.7.1	Variation 1:	From 1,2,6-Thiadiazines by Extrusion of Sulfur	156
12.1.2.3.1.7.2	Variation 2:	From 1,2,6-Thiadiazines and Hydrazine Hydrate	157
12.1.2.3.1.8	Method 8:	Synthesis from 1,3,4-Thiadiazines	158
12.1.2.3.1.9	Method 9:	Synthesis from Tetrazines	158
12.1.2.3.2		From Seven-Membered Rings	159
12.1.2.3.2.1	Method 1:	Synthesis from 1 <i>H</i> -1,5-Diazepines	159
12.1.2.3.2.2	Method 2:	Synthesis from 1,3,4-Thiadiazepines	160
12.1.3		Aromatization	160
12.1.3.1		By Dehydrogenation	160
12.1.3.1.1	Method 1:	With <i>p</i> -Chloranil	160
12.1.3.1.2	Method 2:	With Bromine	161
12.1.3.1.3	Method 3:	With Lead(IV) Acetate	162
12.1.3.1.4	Method 4:	With Iodobenzene Diacetate	163
12.1.3.2		By Elimination	163
12.1.3.2.1	Method 1:	By Dehydration of 4,5-Dihydropyrazol-4-ols	163
12.1.3.2.1.1	Variation 1:	By Dehydration of 2-(Arylsulfonyl)-Substituted 2,3-Dihydro- pyrazol-5-ols and 2,3-Dihydropyrazol-5-amines	164
12.1.3.2.1.2	Variation 2:	By Dehydration of 4-(Phenylsulfonyl)-4,5-dihydropyrazole Derivatives	165
12.1.3.2.1.3	Variation 3:	By Elimination of Benzamide from Methyl 3-(Benzoylamino)- 4,5-dihydro-3 <i>H</i> -pyrazole-3-carboxylate Derivatives	165
12.1.3.2.2	Method 2:	Aromatization by Cleavage of the Alkylidene Structural Element	166
12.1.3.3		By Rearrangement	168
12.1.4		Synthesis by Substituent Modification	168
12.1.4.1		Substitution of Existing Substituents	168
12.1.4.1.1		Of Hydrogen	168
12.1.4.1.1.1	Method 1:	Deuteration of Pyrazoles	168
12.1.4.1.1.2	Method 2:	Metalation of Pyrazoles	169
12.1.4.1.1.3	Method 3:	C-Acylation and C-Alkylation	170
12.1.4.1.1.3.1	Variation 1:	C-Acylation with Acyl Halides	170

12.1.4.1.1.3.2	Variation 2:	C-Acylation with Acetic Anhydride	171
12.1.4.1.1.3.3	Variation 3:	C-Acylation with Oxalyl Chloride	171
12.1.4.1.1.3.4	Variation 4:	C-Alkylation at Position 4	173
12.1.4.1.1.3.5	Variation 5:	C-Alkylation at Position 5	173
12.1.4.1.1.4	Method 4:	Halogenation	174
12.1.4.1.1.4.1	Variation 1:	Halogenation of 1,3-Disubstituted 1 <i>H</i> -Pyrazol-5-ols at Position 4	174
12.1.4.1.1.5	Method 5:	Nitration	176
12.1.4.1.1.5.1	Variation 1:	C-Nitration of Pyrazoles with Nitric Acid	176
12.1.4.1.1.5.2	Variation 2:	C-Nitration of Pyrazoles with Acyl Nitrates	177
12.1.4.1.1.6	Method 6:	Nitrosation	177
12.1.4.1.2		Of Carbon Functionalities	178
12.1.4.1.2.1	Method 1:	Decarboxylation	178
12.1.4.1.2.2	Method 2:	N-Dealkylation	179
12.1.4.1.3		Of Heteroatoms	180
12.1.4.1.3.1		Substitution of Halogen	180
12.1.4.1.3.1.1	Method 1:	Lithiation	180
12.1.4.1.3.1.2	Method 2:	With Anionic Nucleophiles	183
12.1.4.1.3.1.3	Method 3:	With Ammonia and Amines	184
12.1.4.1.3.1.3.1	Variation 1:	With Ammonia and Amines in the Presence of Copper Powder or Copper(I) Bromide (Ullmann Reaction)	185
12.1.4.1.3.2		Substitution of Oxygen Functional Groups	185
12.1.4.1.3.3		Substitution of Nitrogen Functional Groups	187
12.1.4.2		Addition Reactions	188
12.1.4.2.1		Addition of Organic Groups	188
12.1.4.2.1.1		N-Acylation	188
12.1.4.2.1.1.1	Method 1:	With Carboxylic Anhydrides	188
12.1.4.2.1.1.2	Method 2:	With Acyl Chlorides	189
12.1.4.2.1.1.3	Method 3:	With Diazo Ketones	191
12.1.4.2.1.2		N-Arylation	191
12.1.4.2.1.2.1	Method 1:	With Aryl Halides	191
12.1.4.2.1.3		N-Alkylation	192
12.1.4.2.1.3.1	Method 1:	N-Alkylation with Alkyl Halides	192
12.1.4.2.1.3.2	Method 2:	N-Alkylation by Michael Addition	193
12.1.4.2.1.3.2.1	Variation 1:	N-Cyanomethylation with Acrylonitrile	194
12.1.4.2.1.4		Synthesis of Pyrazolium Compounds by Protonation	195
12.1.4.2.1.5		Synthesis of Pyrazolium Compounds by Quarternization	195
12.1.4.2.2		Addition of Heteroatoms	196
12.1.4.2.2.1	Method 1:	N-Nitration of N-Unsubstituted Pyrazoles	196
12.1.4.2.2.2	Method 2:	Synthesis of Pyrazolium Compounds by N-Oxidation	197



12.1.4.3	Modification of Substituents .....	198
12.1.4.3.1	Modification of Carbon Functional Groups .....	198
12.1.4.3.1.1	Method 1: Reduction of 4-Alkylidenepyrazol-5(4 <i>H</i> )-ones .....	198
12.1.4.3.1.2	Method 2: Hydrolysis of the Trifluoroacetyl Group to the Carboxy Group .....	198
12.1.4.3.1.3	Method 3: Aromatization by 1,4-Addition to 4-Benzylidene-4 <i>H</i> -pyrazoles .....	199
12.1.4.3.1.4	Method 4: Oxidation of Alkyl Group .....	200
12.1.4.3.2	Modification of Heterofunctional Groups .....	200
12.1.4.3.2.1	Modification of Hydroxy Groups .....	200
12.1.4.3.2.1.1	Method 1: Acylation of the Hydroxy Group .....	200
12.1.4.3.2.1.2	Method 2: Alkylation of the Hydroxy Group .....	201
12.1.4.3.2.2	Modification of the Nitro Group .....	202
12.1.4.3.2.3	Modification of the Amino Group .....	202
12.1.4.3.2.3.1	Method 1: Acylation of the Amino Group .....	202
12.1.4.4	Cross-Coupling Reactions of Metalated Pyrazole Derivatives .....	203
12.1.4.4.1	Cross-Coupling Reactions at Position 4 .....	203
12.1.4.4.2	Cross-Coupling Reactions at Position 5 .....	203
12.1.4.4.2.1	Method 1: From 5-Lithio-1-(4-methoxybenzyl)-1 <i>H</i> -pyrazole and Electrophiles .....	203
12.1.4.4.2.2	Method 2: Palladium-Catalyzed Cross Coupling of [1-(Benzyloxy)-1 <i>H</i> -pyrazol-5-yl]zinc Chloride with Electrophiles .....	205
<b>12.2</b>	<b>Product Class 2: 1<i>H</i>- and 2<i>H</i>-Indazoles</b> W. Stadlbauer	
<b>12.2</b>	<b>Product Class 2: 1<i>H</i>- and 2<i>H</i>-Indazoles .....</b>	<b>227</b>
12.2.1	Synthesis by Ring-Closure Reactions .....	230
12.2.1.1	By Annulation to an Arene .....	230
12.2.1.1.1	By Formation of One N—N and One N—C Bond .....	230
12.2.1.1.1.1	Fragments N—Arene—C and N .....	230
12.2.1.1.1.1.1	Method 1: From 2-Alkylanilines by Diazotization .....	230
12.2.1.1.1.1.2	Method 2: From 2-Alkylanilines by Nitrosation .....	232
12.2.1.1.1.1.3	Method 3: From 2-Acylanilines by Diazotization and Reductive Cyclization .....	233
12.2.1.1.1.1.4	Method 4: From 1-Acyl-2-nitroarenes and Amines .....	234
12.2.1.1.2	By Formation of Two N—C Bonds .....	234
12.2.1.1.2.1	Fragments Arene—C and N—N .....	235
12.2.1.1.2.1.1	Method 1: From 1-Acyl-2-haloarenes and Hydrazine .....	235
12.2.1.1.2.1.2	Method 2: From 1-Acyl-2-hydroxy- or 1-Acyl-2-aminoarenes and Hydrazines .....	236

12.2.1.1.2.1.3	Method 3: From 1-Acyl-2-azidoarenes and Hydrazines	237
12.2.1.1.2.1.4	Method 4: From 2-Acylcyclohexanones and Hydrazines	237
12.2.1.1.3	By Formation of One N—C and One C—C Bond	238
12.2.1.1.3.1	Fragments N—N—Arene and C	239
12.2.1.1.3.1.1	Method 1: From Phenylhydrazines and Carbonic Acid Derivatives	239
12.2.1.1.3.1.2	Method 2: From Azobenzenes and a C1 Fragment via Metal Complexes	239
12.2.1.1.3.1.3	Method 3: From Azobenzenes and C1 Fragments Such as Methanol or Carbenes	240
12.2.1.1.3.2	Fragments Arene and N—N—C	241
12.2.1.1.3.2.1	Method 1: From Cyclohexanediones, Benzoquinones, or Arynes and Hydrazones	241
12.2.1.1.3.2.2	Method 2: From Benzoquinones or Arynes with Diazoalkanes	242
12.2.1.1.4	By Formation of One N—N Bond	243
12.2.1.1.4.1	Fragment N—Arene—C—N	243
12.2.1.1.4.1.1	Method 1: From 2-Acyl-1-aminoarenes	243
12.2.1.1.4.1.2	Method 2: From 2-Acyl-1-azidoarenes	243
12.2.1.1.4.1.3	Method 3: From 2-Aminoalkyl- or 2-Acyl-1-nitroarenes	245
12.2.1.1.5	By Formation of One N—C Bond	246
12.2.1.1.5.1	Fragment N—N—Arene—C	247
12.2.1.1.5.1.1	Method 1: From 2-Carboxy- or 2-Acyl-1-hydrazinobenzenes	247
12.2.1.1.5.1.2	Method 2: From 2-Acyl- or 2-Alkyl-1-azidoarenes	248
12.2.1.1.5.1.3	Method 3: From 2-Acyl- or 2-Alkyl-1-azoarenes	249
12.2.1.1.5.2	Fragment N—N—C—Arene	249
12.2.1.1.5.2.1	Method 1: From 2-Halobenzohydrazides or 2-Halobenzoylhydrazones	249
12.2.1.1.5.2.2	Method 2: From 2-Azidobenzohydrazides or 2-Azidobenzoylhydrazones	250
12.2.1.1.5.2.3	Method 3: From 2-(Nitrobenzoyl)hydrazones	251
12.2.1.1.5.2.4	Method 4: From Benzohydrazides and Hydrazones of Aldehydes and Ketones	251
12.2.1.1.6	By Formation of One C—C Bond	252
12.2.1.1.6.1	Fragment Arene—N—N—C	252
12.2.1.1.6.1.1	Method 1: From (2-Alkylidenehydrazino)arenes	252
12.2.1.1.6.1.2	Method 2: From (2-Alkylidenehydrazino)arenes by Rearrangement	253
12.2.1.1.6.1.3	Method 3: From Carbamic Acid Azides by Curtius Rearrangement	253
12.2.1.2	By Annulation to the Heterocyclic Ring	254
12.2.1.2.1	By Formation of Two C—C Bonds	254
12.2.1.2.1.1	Fragments Pyrazole—C—C and C—C	254
12.2.1.2.1.1.1	Method 1: From 4-Vinylpyrazoles and Dienophiles	254
12.2.1.2.1.2	Fragments C—Pyrazole—C and C—C	255
12.2.1.2.1.2.1	Method 1: From 4,5-Dimethylene-4,5-dihydro-1 <i>H</i> -pyrazoles and Dienophiles	255

12.2.1.2.1.2.2	Method 2: From Pyrazole-4,5-dicarbaldehyde and Oxalaldehyde	256
12.2.1.2.1.3	Fragments Pyrazole—C and C—C—C	256
12.2.1.2.1.3.1	Method 1: From 4-Formylpyrazoles and Diethyl Succinate	256
12.2.1.2.1.3.2	Method 2: From 3-Methylpyrazoles and $\alpha$ -Oxo Ketenes	256
12.2.1.2.2	By Formation of One C—C Bond	257
12.2.1.2.2.1	Fragment C—C—Pyrazole—C—C	257
12.2.1.2.2.1.1	Method 1: From 3,4-Diphenylpyrazoles	257
12.2.2	Synthesis by Ring Transformation	258
12.2.2.1	Ring Enlargement	258
12.2.2.1.1	Method 1: Of a Three-Membered Carbocycle	258
12.2.2.1.2	Method 2: Of a Four-Membered Heterocycle	259
12.2.2.1.3	Method 3: Of a Five-Membered Carbocycle	259
12.2.2.2	Formal Exchange of Ring Members with Retention of the Ring Size	260
12.2.2.2.1	Method 1: Rearrangement of Indoles to Indazoles	261
12.2.2.2.2	Method 2: Rearrangement of 1,2-Isoxazoles or 1,2,4-Oxadiazoles	264
12.2.2.3	Ring Contraction	266
12.2.2.3.1	Method 1: Of a Six-Membered Heterocycle	266
12.2.2.3.2	Method 2: Of a Seven-Membered Heterocycle	268
12.2.2.3.3	Method 3: Of a Seven-Membered Carbocycle	269
12.2.3	Aromatization	269
12.2.3.1	Method 1: Aromatization of the Five-Membered Heterocycle	269
12.2.3.2	Method 2: Aromatization of the Six-Membered Carbocycle	270
12.2.4	Synthesis by Substituent Modification	271
12.2.4.1	Addition Reactions	272
12.2.4.1.1	Addition of Organic Groups	272
12.2.4.1.1.1	Method 1: Formation of Indazolium Salts by N-Alkylation	272
12.2.4.1.1.2	Method 2: Introduction of a 1-Hydroxyalkyl Group by Addition of 1 <i>H</i> -Indazole to Aldehydes	273
12.2.4.1.1.3	Method 3: Introduction of Alkyl or Alkenyl Groups by Addition of Indazole to Alkenes or Alkynes	274
12.2.4.1.1.4	Method 4: Annulation of a Ring System by Addition to the Heterocyclic Ring	275
12.2.4.1.2	Addition of Heteroatoms	277
12.2.4.1.2.1	Method 1: By Oxidation	277
12.2.4.1.2.2	Method 2: Reduction (Hydrogenation) of the Benzo Ring	277
12.2.4.2	Substitution of Existing Substituents	278
12.2.4.2.1	Of Hydrogen	278
12.2.4.2.1.1	Method 1: Deuterium Exchange	278
12.2.4.2.1.2	Method 2: Halogenation	278
12.2.4.2.1.3	Method 3: Alkoxylation	279

12.2.4.2.1.4	Method 4:	Sulfonation	279
12.2.4.2.1.5	Method 5:	Nitration	280
12.2.4.2.1.6	Method 6:	Azo Coupling	281
12.2.4.2.1.7	Method 7:	Amination	282
12.2.4.2.1.8	Method 8:	Phosphorylation	283
12.2.4.2.1.9	Method 9:	Alkylation	283
12.2.4.2.1.10	Method 10:	Arylation	286
12.2.4.2.1.11	Method 11:	Glycosylation	287
12.2.4.2.1.12	Method 12:	Acylation and Carboxylation	289
12.2.4.2.1.13	Method 13:	Metalation	292
12.2.4.2.2		Of Metals	293
12.2.4.2.2.1	Method 1:	Alkylation of Sodium and Silver Salts	294
12.2.4.2.2.2	Method 2:	Glycosylation of 1-(Trimethylsilyl)-1 <i>H</i> -indazoles	294
12.2.4.2.2.3	Method 3:	Acylation of Silver Salts	295
12.2.4.2.3		Of Carbon Functionalities	295
12.2.4.2.3.1	Method 1:	Dealkylation	295
12.2.4.2.3.2	Method 2:	Dearylation	296
12.2.4.2.3.3	Method 3:	Deacylation and Decarboxylation	297
12.2.4.2.4		Of Heteroatoms	299
12.2.4.2.4.1	Method 1:	Removal or Exchange of Halogen Atoms	299
12.2.4.2.4.2	Method 2:	Removal or Exchange of Hydroxy Groups	300
12.2.4.2.4.3	Method 3:	Removal or Exchange of Amino and Diazo Groups	301
12.2.4.2.5		Modification of Substituents	303
12.2.4.2.5.1	Method 1:	Modification of Hydroxy Groups	303
12.2.4.2.5.2	Method 2:	Modification of Amino and Diazo Groups	304
12.2.4.2.5.3	Method 3:	Modification of Azido Groups	305
12.2.4.2.5.4	Method 4:	Modification of Nitro Groups	306
12.2.4.2.5.5	Method 5:	Modification of Alkyl Groups	307
12.2.4.2.5.6	Method 6:	Modification of Carbonyl Groups	307
12.2.4.2.6		Rearrangement of Substituents	308
12.2.4.2.6.1	Method 1:	Rearrangement of 2 <i>H</i> -Indazoles into 1 <i>H</i> -Indazoles	308
12.2.4.2.6.2	Method 2:	Rearrangement of 2-Nitro-2 <i>H</i> -indazoles into 3-Nitro-1 <i>H</i> -indazoles	309
12.2.4.2.6.3	Method 3:	Rearrangement 1,1-Dialkylindazolium-3-olates into 3-Alkoxy-1-alkyl-1 <i>H</i> -indazoles and 1,2-Dialkyl-1 <i>H</i> -indazol- 3(2 <i>H</i> )-ones	309
12.2.4.2.6.4	Method 4:	Rearrangement of 1,2-Diacetyl-1 <i>H</i> -indazol-3(2 <i>H</i> )-one into 1-Acetyl-1 <i>H</i> -indazol-3-yl Acetate	310
12.2.4.2.6.5	Method 5:	Rearrangement of 3 <i>H</i> -Indazoles into 1 <i>H</i> -Indazoles	310

<b>12.3</b>	<b>Product Class 3: Imidazoles</b> M. R. Grimmett	
<b>12.3</b>	<b>Product Class 3: Imidazoles</b> .....	325
<b>12.3.1</b>	Synthesis by Ring-Closure Reactions .....	331
<b>12.3.1.1</b>	By Formation of Four N—C Bonds .....	331
<b>12.3.1.1.1</b>	Fragments C—C, C, and Two N Fragments .....	331
<b>12.3.1.1.1.1</b>	Method 1: Combination of an Alkene, Carbon Monoxide, and Ammonia	331
<b>12.3.1.1.1.2</b>	Method 2: Reaction of an $\alpha$ -Dicarbonyl Compound with an Aldehyde and an Amino Source .....	332
<b>12.3.1.1.1.2.1</b>	Variation 1: Reactions Involving Ammonia, Ammonium Acetate, or a Primary Amine .....	332
<b>12.3.1.1.1.2.2</b>	Variation 2: Use of Hydroxylamine in Place of Ammonia or Amines; 1-Hydroxyimidazoles and 1-Hydroxyimidazole 3-Oxides .....	335
<b>12.3.1.1.1.3</b>	Method 3: Reaction of an $\alpha$ -Hydroxycarbonyl Reagent with an Aldehyde and Ammonia (or an Amine) .....	336
<b>12.3.1.1.1.3.1</b>	Variation 1: Use of Reducing Carbohydrates .....	336
<b>12.3.1.1.1.3.2</b>	Variation 2: Use of Acyloins and Derivatives .....	337
<b>12.3.1.1.1.4</b>	Method 4: The Maquenne Synthesis .....	338
<b>12.3.1.1.1.5</b>	Method 5: Miscellaneous Procedures .....	339
<b>12.3.1.2</b>	By Formation of Three N—C Bonds .....	339
<b>12.3.1.2.1</b>	Fragments N—C, C—C, and N .....	339
<b>12.3.1.2.1.1</b>	Method 1: The Bredereck Synthesis .....	339
<b>12.3.1.2.1.1.1</b>	Variation 1: Use of Formamide .....	340
<b>12.3.1.2.1.1.2</b>	Variation 2: Use of Higher Amides .....	342
<b>12.3.1.2.1.2</b>	Method 2: Reaction of $\alpha$ -Hydroxy Ketones with an Imidate and Ammonia	342
<b>12.3.1.2.1.3</b>	Method 3: Preparation of 1-Amino-1 <i>H</i> -imidazole-2(3 <i>H</i> )-thiones from $\alpha$ -Halo Ketones, Thiocyanate, and a Monosubstituted Hydrazine .....	342
<b>12.3.1.2.1.4</b>	Method 4: Preparation of 1-Hydroxyimidazoles from Acetonitrile, an Alkene, and a Nitrosonium Salt .....	343
<b>12.3.1.2.2</b>	Fragments N—C—C, N, and C .....	343
<b>12.3.1.2.2.1</b>	Method 1: Cyclization of an $\alpha$ -Hydroxyimino Ketone, an Aldehyde, and Ammonia (or an Amine) .....	344
<b>12.3.1.2.2.2</b>	Method 2: Cyclization of an $\alpha$ -Aminonitrile, an Orthoformate, and a Primary Amine .....	344
<b>12.3.1.3</b>	By Formation of Two N—C Bonds and One C—C Bond .....	345
<b>12.3.1.3.1</b>	Fragments N—C, N—C, and C .....	345
<b>12.3.1.3.1.1</b>	Method 1: Reactions of (Nitromethyl)arene Dianions with Aryl Cyanides	345
<b>12.3.1.3.1.2</b>	Method 2: Metal—Carbonyl Induced Cyclization of Benzylamine with Carbon Tetrachloride .....	347
<b>12.3.1.4</b>	By Formation of Two N—C Bonds .....	347

12.3.1.4.1	Fragments N—C—N and C—C	347
12.3.1.4.1.1	Method 1: Reactions of Amidines with $\alpha$ -Hydroxy- or $\alpha$ -Halocarbonyl Compounds	347
12.3.1.4.1.2	Method 2: Reactions of Guanidines with $\alpha$ -Functionalized Ketones	351
12.3.1.4.1.3	Method 3: Reactions of Ureas and Thioureas with $\alpha$ -Functionalized Carbonyl Compounds	353
12.3.1.4.1.4	Method 4: Reactions of Functionalized Alkenes with Amidines, Guanidines, and Ureas	354
12.3.1.4.1.5	Method 5: Reactions of 2-Cyanoepoxides with Amidines or Guanidines	358
12.3.1.4.1.6	Method 6: Reaction of Aminonitrines or Aminooximes with Propiolate Esters	359
12.3.1.4.1.7	Method 7: Use of "Betmip"; Reaction of Iminophosphoranes with $\alpha$ -Diketones	360
12.3.1.4.1.8	Method 8: Miscellaneous Procedures	361
12.3.1.4.2	Fragments N—C—C and N—C	361
12.3.1.4.2.1	Method 1: Reaction of an $\alpha$ -Aminocarbonyl Compound with a Cyanate, Thiocyanate, Isocyanate, or Isothiocyanate	362
12.3.1.4.2.2	Method 2: Reaction of an $\alpha$ -Aminocarbonyl Compound with Cyanamide	365
12.3.1.4.2.3	Method 3: Reactions of $\alpha$ -Aminocarbonyl Compounds with Other N—C Reagents	366
12.3.1.4.2.4	Method 4: Reactions of Imidates with Aminomalononitrile	369
12.3.1.4.2.5	Method 5: Reaction of <i>N</i> -Isopropylacetoneitrilium Chloroferrate with Amino Acid Esters	369
12.3.1.4.2.6	Method 6: Synthesis of Imidazole-4-thiols and Imidazole-2-carboxylates from $\alpha$ -Oxothioamides	370
12.3.1.4.2.7	Method 7: Formation of Imidazoles, 1-Hydroxyimidazoles, and Imidazole <i>N</i> -Oxides from $\alpha$ -Hydroxyimino Ketones	370
12.3.1.4.2.8	Method 8: Reactions of 1,2-Diimines with Aldoximes	372
12.3.1.4.2.9	Method 9: Miscellaneous Procedures	373
12.3.1.4.3	Fragments N—C—C—N and C	374
12.3.1.4.3.1	Method 1: Reactions of 1,2-Diaminoalkenes with Carbonyl Reagents	374
12.3.1.4.3.2	Method 2: Reactions of 1,2-Diaminoalkanes with Carbon Reagents	375
12.3.1.4.3.3	Method 3: Cyclizations Involving 1,2-Diimines	377
12.3.1.4.3.4	Method 4: Syntheses Based on the Use of Diaminomaleonitrile	378
12.3.1.4.3.5	Method 5: Reactions of $\alpha$ -Aminonitriles with Aldehydes or Ortho Esters	380
12.3.1.4.3.6	Method 6: Reactions of Aminoacetimidamides or Their Oximes with Aldehydes or Ortho Esters	380
12.3.1.4.3.7	Method 7: Synthesis of Imidazole <i>N</i> -Oxides or 1-Hydroxyimidazoles from $\alpha$ -Hydroxyamino Oximes and Aldehydes	381
12.3.1.4.3.8	Method 8: Syntheses Based on the Pinner Salt	382
12.3.1.4.3.9	Method 9: From 2-Amino-3-azidoacrylates	383
12.3.1.4.4	Fragments C—N—C—C and N	384
12.3.1.4.4.1	Method 1: Reactions of Alkyl <i>N</i> -( $\alpha$ -Cyanoalkyl)imidates with Primary Amines or Hydrazines	384
12.3.1.4.4.2	Method 2: Reactions of $\alpha$ -Acylamino Ketones with Primary Amines	386

12.3.1.4.4.3	Method 3:	Reactions of 2-Azabuta-1,3-dienes with Amines or Hydrazines	387
12.3.1.4.4.4	Method 4:	Reactions of <i>N</i> -Alkenylformamides with Formamide	390
12.3.1.4.4.5	Method 5:	Reactions of Acylketene <i>N,S</i> -Acetals with Nitrosoaryl Reagents	390
12.3.1.5		By Formation of One N—C and One C—C Bond	391
12.3.1.5.1		Fragments C—N—C and N—C	391
12.3.1.5.1.1	Method 1:	Reaction of Methyl Isocyanides with an Aldimine	392
12.3.1.5.1.1.1	Variation 1:	Use of Tosylmethyl Isocyanide	392
12.3.1.5.1.1.2	Variation 2:	Use of Benzotriazol-1-ylmethyl Isocyanide	396
12.3.1.5.1.2	Method 2:	Reactions of Tosylmethyl Isocyanide with Imidoyl Chlorides	397
12.3.1.5.1.3	Method 3:	Reactions of Tosylmethyl Isocyanide with <i>N</i> -Hetaryl-Substituted Imidates	398
12.3.1.5.1.4	Method 4:	Reactions of Tosylmethyl Isocyanide with Isothiocyanates	398
12.3.1.5.1.5	Method 5:	Reactions of Tosylmethyl Isocyanide Dianions with Nitriles	399
12.3.1.5.1.6	Method 6:	Reactions of Related Isocyanides with Nitriles	399
12.3.1.5.1.7	Method 7:	Reactions of <i>N</i> -(Tosylmethyl)imidic Thioesters with Aldimines	400
12.3.1.5.1.8	Method 8:	Reactions of Tosylmethyl Isocyanide with an Aldehyde and an Amine	401
12.3.1.5.1.9	Method 9:	Reaction of the Enolate of Ethyl Isocyanoacetate with an Isothiourea	402
12.3.1.5.1.10	Method 10:	1,3-Dipolar Cycloadditions of Mesoionic Oxazolones	403
12.3.1.5.1.11	Method 11:	Self-Condensations of <i>C</i> -Aryl- <i>N</i> -methyl Nitrones	404
12.3.1.5.1.12	Method 12:	Cycloadditions of Aldimine Anions to Nitriles	404
12.3.1.5.1.13	Method 13:	Cycloaddition of Imines and 2-Azaallenyl Radical Cations	405
12.3.1.5.1.14	Method 14:	Cycloaddition of Isocyanoacetate to Nitriles	406
12.3.1.5.1.15	Method 15:	Cyclization of Methyl Isothiocyanate	407
12.3.1.5.1.16	Method 16:	Cycloaddition of Aryl Chloro- <i>N</i> -(4-nitrobenzyl)thioformimidates and Ethyl Cyanoformate	407
12.3.1.5.1.17	Method 17:	Cycloadditions of Gold's Salt	408
12.3.1.5.1.18	Method 18:	Condensation of Cyanodithioimidocarbonates with $\alpha$ -Amino Esters	408
12.3.1.5.2		Fragments N—C—N—C and C	408
12.3.1.6		By Formation of One N—C Bond	408
12.3.1.6.1		Fragment N—C—C—N—C	408
12.3.1.6.1.1	Method 1:	The Wallach Synthesis	409
12.3.1.6.1.2	Method 2:	Ring Closures of Acylated Glycines or the Related (Formamido)acetamides	410
12.3.1.6.1.3	Method 3:	Cyclization of <i>N</i> -Monoacylated 1,2-Diaminoalkenes	411
12.3.1.6.1.4	Method 4:	Cyclizations Based on <i>N</i> <sup>2</sup> -[2-(Acylamino)vinyl]imidamides	415
12.3.1.6.1.5	Method 5:	Cyclization of $\alpha$ -Acylamino Schiff Bases	416
12.3.1.6.1.6	Method 6:	Ring Closure of Formylglycine Amidines	418
12.3.1.6.1.7	Method 7:	Cyclization of Schiff Bases of Diaminomaleonitrile	418
12.3.1.6.1.8	Method 8:	Oxidation of Schiff Bases of 2,3-Diamino-3-cyanoacrylamides	420
12.3.1.6.1.9	Method 9:	Reaction of 3-(Dimethylamino)-2-isocyanoacrylates with Alkyl or Aryl Halides	420

12.3.1.6.1.10	Method 10:	Photochemical Transformations of Diaminomaleonitrile	421
12.3.1.6.1.11	Method 11:	Ring Closure of <i>N</i> -Alkylidene-1-cyanoalkylamine <i>N</i> -Oxides	421
12.3.1.6.1.12	Method 12:	Thermal Rearrangement of 1-(Trifluoroacetyl)alkan-1-one Hydrazones	422
12.3.1.6.1.13	Method 13:	Cyclization of 2-Isocyanoalkanenitriles	423
12.3.1.6.1.14	Method 14:	Synthesis of Imidazole-4- and Imidazole-5-thiols from Thioamides	424
12.3.1.6.1.15	Method 15:	Photochemical Cyclization of Nitrile Ylides	425
12.3.1.6.2		Fragment N—C—N—C—C	426
12.3.1.6.2.1	Method 1:	Cyclization of Suitably Functionalized Amidines	426
12.3.1.6.2.2	Method 2:	Cyclization of Functionalized Guanidines	432
12.3.1.6.2.3	Method 3:	Reduction of Schiff Bases of Amidines	433
12.3.1.6.2.4	Method 4:	Cyclization of Amidinium Salts and Amidines Made from Diaminomaleonitrile	433
12.3.1.6.2.5	Method 5:	Cyclization of Amidrazones Derived from Diaminomaleonitrile	438
12.3.1.6.2.6	Method 6:	Cyclizations of Functionalized Ureas and Thioureas	438
12.3.1.6.2.7	Method 7:	Cyclization of Ureido Esters	439
12.3.1.6.2.8	Method 8:	Cyclization of $\alpha$ -Cyanoalkyl Cyanamides	440
12.3.1.6.2.9	Method 9:	Miscellaneous Procedures	441
12.3.1.7		By Formation of One C—C Bond	442
12.3.1.7.1		Fragment C—N—C—N—C	442
12.3.1.7.1.1	Method 1:	Ring Closure of <i>N</i> <sup>1</sup> -Ethoxycarbonylmethyl- and <i>N</i> <sup>1</sup> -Benzoyl-Substituted <i>N</i> <sup>2</sup> -Cyanofornimidamides	442
12.3.1.7.1.2	Method 2:	Cyclization of <i>N</i> <sup>2</sup> -Cyano- <i>N</i> <sup>1</sup> -(cyanomethyl)formimidamides and Related Isothioureas	444
12.3.1.7.1.3	Method 3:	Cyclization of 2-Azavinamidinium Salts	445
12.3.2		Synthesis by Ring Transformation	446
12.3.2.1		Ring Enlargement	446
12.3.2.1.1	Method 1:	Ring Enlargement of Azirines by Reaction with Nitriles	446
12.3.2.1.2	Method 2:	Ring Expansion of Azetidines	447
12.3.2.2		From Five-Membered Heterocycles	447
12.3.2.2.1	Method 1:	Photochemical Rearrangement of Pyrazoles	448
12.3.2.2.2	Method 2:	Oxidation of Benzimidazoles	448
12.3.2.2.3	Method 3:	From 1,2,4-Triazolium Salts	448
12.3.2.2.4	Method 4:	From Tetrazoles	449
12.3.2.2.4.1	Variation 1:	Photolysis of 1-Vinyltetrazoles	449
12.3.2.2.4.2	Variation 2:	Reactions of Tetrazolium Salts with Bases	451
12.3.2.2.5	Method 5:	From Isoxazoles	451
12.3.2.2.6	Method 6:	From Oxazoles	452
12.3.2.2.6.1	Variation 1:	Heating with a Nitrogen Source	452
12.3.2.2.6.2	Variation 2:	Action of Heat on 2-Oxo-2,3-dihydrooxazole-3-carboxamides	453
12.3.2.2.6.3	Variation 3:	Reaction of Oxazolium Salts with Amines	453
12.3.2.2.7	Method 7:	From Thiazoles	454



12.3.2.2.7.1	Variation 1: Rearrangement of Thiazol-5-amines	454
12.3.2.2.7.2	Variation 2: From Thiazole <i>N</i> -Oxides	454
12.3.2.2.8	Method 8: From Oxa- or Thiadiazoles	454
12.3.2.3	Ring Contraction	454
12.3.2.3.1	From Six-Membered Heterocycles	455
12.3.2.3.1.1	Method 1: From Pyrimidines	455
12.3.2.3.1.1.1	Variation 1: Action of Strong Bases on Chloropyrimidines	455
12.3.2.3.1.1.2	Variation 2: Pyrolysis of Azidopyrimidines	455
12.3.2.3.1.1.3	Variation 3: Base-Catalyzed Rearrangement of 5-(Acylamino)pyrimidin-4(3 <i>H</i> )-ones	456
12.3.2.3.1.2	Method 2: From Pyrazines	457
12.3.2.3.1.2.1	Variation 1: Pyrolysis of 2-Azidopyrazines	457
12.3.2.3.1.2.2	Variation 2: Photolysis of Pyrazine Derivatives	459
12.3.2.3.1.2.3	Variation 3: Action of Strong Bases on Chloropyrazines	459
12.3.2.3.1.3	Method 3: From Other Six-Membered Heterocycles	459
12.3.2.3.1.4	Method 4: From Seven-Membered Heterocycles	459
12.3.3	Aromatization	459
12.3.3.1	Method 1: Oxidation by Manganate or Permanganate	460
12.3.3.2	Method 2: Use of Active Manganese Dioxide	460
12.3.3.3	Method 3: Catalytic Dehydrogenation	460
12.3.4	Synthesis by Substituent Modification	461
12.3.4.1	Addition Reactions	461
12.3.4.1.1	Method 1: Protonation	461
12.3.4.1.2	Method 2: Addition of Metal Groups	462
12.3.4.1.3	Method 3: Addition of Organic Groups	462
12.3.4.1.4	Method 4: Addition of Heteroatom Groups	464
12.3.4.2	Substitution of Existing Substituents on Carbon	464
12.3.4.2.1	Of Hydrogen	464
12.3.4.2.1.1	Method 1: Substitution by Hydrogen or Deuterium	465
12.3.4.2.1.2	Method 2: Substitution by a Metal	466
12.3.4.2.1.3	Method 3: Substitution by Alkyl Groups	467
12.3.4.2.1.4	Method 4: Substitution by Hydroxyalkyl Groups	468
12.3.4.2.1.5	Method 5: Substitution by Other Substituted Alkyl Groups	469
12.3.4.2.1.6	Method 6: Substitution by Aryl Groups	469
12.3.4.2.1.7	Method 7: Substitution by Acyl and Aroyl Groups	469
12.3.4.2.1.8	Method 8: Substitution by Carboxy Groups	470
12.3.4.2.1.9	Method 9: Substitution by Halogens	470
12.3.4.2.1.10	Method 10: Substitution by Oxygen Groups	472
12.3.4.2.1.11	Method 11: Substitution by Sulfur Groups	472
12.3.4.2.1.12	Method 12: Substitution by Nitrogen Groups	473
12.3.4.2.2	Of Metals	473
12.3.4.2.2.1	Method 1: Substitution by Hydrogen or Deuterium	474
12.3.4.2.2.2	Method 2: Transmetalation	474

12.3.4.2.2.3	Method 3:	Substitution by Alkyl Groups	474
12.3.4.2.2.4	Method 4:	Substitution by Alkenyl Groups	476
12.3.4.2.2.5	Method 5:	Substitution by Substituted Alkyl Groups	476
12.3.4.2.2.6	Method 6:	Substitution by Aryl Groups	477
12.3.4.2.2.7	Method 7:	Substitution by Acyl and Aroyl Groups	477
12.3.4.2.2.8	Method 8:	Substitution by Carboxy Groups	479
12.3.4.2.2.9	Method 9:	Substitution by a Cyano Group	479
12.3.4.2.2.10	Method 10:	Substitution by Silyl and Stannyl Groups	480
12.3.4.2.2.11	Method 11:	Substitution by Halogens	480
12.3.4.2.2.12	Method 12:	Substitution by Oxygen or Sulfur Groups	482
12.3.4.2.2.13	Method 13:	Substitution by Nitrogen or Phosphorus Groups	482
12.3.4.2.3		Of Carbon Functionalities	483
12.3.4.2.4		Of Heteroatom Groups	484
12.3.4.2.4.1	Method 1:	Substitution of Halogen	484
12.3.4.2.4.1.1	Variation 1:	Reduction	484
12.3.4.2.4.1.2	Variation 2:	Metal–Halogen Exchange	484
12.3.4.2.4.1.3	Variation 3:	By an Organic Group	485
12.3.4.2.4.1.4	Variation 4:	By Another Halogen	486
12.3.4.2.4.1.5	Variation 5:	By an Oxygen or Sulfur Species	486
12.3.4.2.4.1.6	Variation 6:	By a Nitrogen Function	487
12.3.4.2.4.2	Method 2:	Substitution of Oxygen Groups	487
12.3.4.2.4.3	Method 3:	Substitution of Nitrogen Groups	487
12.3.4.3		Substitution of Existing Substituents on Nitrogen	488
12.3.4.3.1		Of Hydrogen	488
12.3.4.3.1.1	Method 1:	Substitution by Hydrogen or Deuterium	488
12.3.4.3.1.2	Method 2:	Substitution by Metals	488
12.3.4.3.1.3	Method 3:	Substitution by Alkyl and Substituted Alkyl Groups	489
12.3.4.3.1.4	Method 4:	Substitution by Alkenyl Groups	492
12.3.4.3.1.5	Method 5:	Substitution by Aryl Groups	492
12.3.4.3.1.6	Method 6:	Substitution by Acyl or Aroyl Groups	494
12.3.4.3.1.7	Method 7:	Substitution by a Nitrile Group	495
12.3.4.3.1.8	Method 8:	Substitution by Silyl Groups	495
12.3.4.3.1.9	Method 9:	Substitution by Chalcogen Groups	496
12.3.4.3.1.10	Method 10:	Replacement by a Nitro Group	496
12.3.4.3.2		Of Metals	497
12.3.4.3.3		Of Organic Groups	497
12.3.4.3.3.1	Method 1:	Substitution of Alkyl or Aryl Groups	497
12.3.4.3.3.2	Method 2:	Substitution of Acyl or Aroyl Groups	497
12.3.4.3.4		Of Heteroatom Groups	498
12.3.4.4		Modification of Carbon Substituents	498
12.3.4.4.1		Organic Groups	498
12.3.4.4.1.1	Method 1:	Reactions That Involve a Full or Partial Carbanion at the $\alpha$ -Carbon	499

---

12.3.4.4.1.1	Variation 1:	Metalation .....	499
12.3.4.4.1.2	Variation 2:	Carbanion Condensations .....	500
12.3.4.4.1.3	Variation 3:	Halogenation .....	500
12.3.4.4.1.4	Variation 4:	Oxidation .....	500
12.3.4.4.1.2	Method 2:	Addition Reactions of Unsaturated Carbon Groups .....	500
12.3.4.4.1.3	Method 3:	Reactions of Aryl Groups .....	500
12.3.4.4.1.4	Method 4:	Nucleophilic Substitutions and Eliminations of Haloalkyl Groups .....	501
12.3.4.4.1.5	Method 5:	Reactions of Hydroxyalkyl Groups .....	501
12.3.4.4.1.6	Method 6:	Reactions of Aldehyde and Ketone Groups .....	501
12.3.4.4.1.7	Method 7:	Reactions of Carboxy Groups .....	502
12.3.4.4.1.8	Method 8:	Reactions of Nitrile Groups .....	503
12.3.4.4.2		Chalcogen Groups .....	503
12.3.4.4.2.1	Method 1:	Removal of Sulfur Groups .....	503
12.3.4.4.2.2	Method 2:	Alkylation, Arylation, and Acylation .....	503
12.3.4.4.2.3	Method 3:	Oxidation of Sulfur Groups .....	504
12.3.4.4.3		Nitrogen Groups .....	504
12.3.4.4.3.1	Method 1:	Reactions of Amino Groups .....	504
12.3.4.4.3.2	Method 2:	Reactions of Nitroso Groups .....	505
12.3.4.4.3.3	Method 3:	Reactions of Nitro Groups .....	505
12.3.4.5		Modification of Substituents on Nitrogen Substituents .....	505
12.3.4.5.1		Organic Groups .....	505
12.3.4.5.1.1	Method 1:	Alkyl Groups .....	505
12.3.4.5.1.2	Method 2:	Unsaturated Carbon Groups .....	506
12.3.4.5.1.3	Method 3:	Aryl Groups .....	507
12.3.4.5.1.4	Method 4:	Acyl and Aroyl Groups .....	507
12.3.4.5.1.5	Method 5:	Carboxy Groups .....	508
12.3.4.5.1.6	Method 6:	<i>N</i> -Oxides and <i>N</i> -Hydroxy Species .....	508
12.3.4.5.1.7	Method 7:	Sulfur Groups .....	509
12.3.4.5.1.8	Method 8:	Nitrogen and Phosphorus Groups .....	509
12.3.4.5.1.8.1	Variation 1:	Amino Groups .....	509
12.3.4.5.1.8.2	Variation 2:	Nitro Groups .....	510
12.3.4.5.1.8.3	Variation 3:	Phosphorus Groups .....	510
12.3.4.5.1.9	Method 9:	Halogen Groups .....	510
12.3.4.6		Rearrangement of Substituents .....	510
12.3.4.6.1	Method 1:	Photolytic and Thermolytic Rearrangements of 1-Alkylimidazoles .....	510
12.3.4.6.2	Method 2:	Rearrangement of 1-Acylimidazoles .....	511
12.3.4.6.3	Method 3:	Dimroth Rearrangement .....	511
12.3.4.6.4	Method 4:	Rearrangement of 1-Nitroimidazoles .....	511
12.3.4.6.5	Method 5:	Miscellaneous .....	512

<b>12.4</b>	<b>Product Class 4: Benzimidazoles</b> M. R. Grimmett	
<b>12.4</b>	<b>Product Class 4: Benzimidazoles</b> .....	529
<b>12.4.1</b>	Synthesis by Ring-Closure Reactions .....	534
<b>12.4.1.1</b>	By Annulation to an Arene .....	535
<b>12.4.1.1.1</b>	By Formation of Two N—C Bonds .....	535
<b>12.4.1.1.1.1</b>	With Formation of 1—2 and 2—3 Bonds .....	535
<b>12.4.1.1.1.1.1</b>	Method 1: Reaction of 1,2-Diaminoarenes with Carbonic Acid Analogues .....	535
<b>12.4.1.1.1.1.2</b>	Method 2: Reaction of 1,2-Diaminoarenes with Carboxylic Acids and Derivatives .....	536
<b>12.4.1.1.1.1.2.1</b>	Variation 1: Reaction with Monocarboxylic Acids .....	536
<b>12.4.1.1.1.1.2.2</b>	Variation 2: Reactions with Dicarboxylic Acids .....	540
<b>12.4.1.1.1.1.2.3</b>	Variation 3: Reactions with Carboxylic Acid Derivatives .....	541
<b>12.4.1.1.1.1.3</b>	Method 3: Reaction of 1,2-Diaminoarenes with Imidates .....	541
<b>12.4.1.1.1.1.4</b>	Method 4: Via Palladium-Catalyzed Carbonylation of Iodobenzene .....	543
<b>12.4.1.1.1.1.5</b>	Method 5: Reactions of Aldehydes with 1,2-Diaminoarenes .....	544
<b>12.4.1.1.1.1.6</b>	Method 6: Reactions of Ketones with 1,2-Diaminoarenes .....	545
<b>12.4.1.1.1.1.7</b>	Method 7: Reactions of $\beta$ -Diketones or $\beta$ -Oxo Esters with 1,2-Diaminoarenes .....	546
<b>12.4.1.1.1.1.8</b>	Method 8: Reactions of Unsaturated Species with 1,2-Diaminoarenes ...	547
<b>12.4.1.1.1.1.9</b>	Method 9: Reactions of Hydrogen Cyanide Derivatives with 1,2-Diaminoarenes .....	548
<b>12.4.1.1.1.1.10</b>	Method 10: Reactions of 1,2-Diaminoarenes with Alcohols .....	550
<b>12.4.1.1.1.1.11</b>	Method 11: Miscellaneous Cyclizations Involving 1,2-Diaminoarenes .....	550
<b>12.4.1.1.1.1.12</b>	Method 12: Reactions of 2-Nitroanilines with Carbon Synthons .....	551
<b>12.4.1.1.1.1.12.1</b>	Variation 1: Reactions with Carboxylic Acids and Derivatives .....	551
<b>12.4.1.1.1.1.12.2</b>	Variation 2: Reactions with Alcohols .....	552
<b>12.4.1.1.1.1.12.3</b>	Variation 3: Reactions with Carbonic Acid Derivatives .....	553
<b>12.4.1.1.1.1.12.4</b>	Variation 4: Reactions with Aldehydes Forming Benzimidazole <i>N</i> -Oxides	553
<b>12.4.1.1.1.1.12.5</b>	Variation 5: Reactions with Alkyl Halides .....	553
<b>12.4.1.1.1.1.13</b>	Method 13: Reaction of Benzo-1,2-quinone Dioximes with Aldehydes ...	554
<b>12.4.1.1.1.2</b>	By Reaction of a Guanidine with a 1,2-Dicarbonyl Species .....	554
<b>12.4.1.1.1.2.1</b>	Method 1: Reaction of an <i>o</i> -Quinone with a Guanidine .....	554
<b>12.4.1.1.2</b>	By Formation of One N—C Bond .....	555
<b>12.4.1.1.2.1</b>	With Formation of 1—2 or 2—3 Bonds .....	555
<b>12.4.1.1.2.1.1</b>	Method 1: Cyclization of 1-(Acylamino)- or 1-(Aroylamino)-2-aminoarenes .....	555
<b>12.4.1.1.2.1.2</b>	Method 2: Cyclization of Acylated or Aroylated 2-Aminophenylhydrazines .....	557
<b>12.4.1.1.2.1.3</b>	Method 3: Reductive Cyclization of <i>N</i> -Acyl-2-nitroanilines .....	558
<b>12.4.1.1.2.1.3.1</b>	Variation 1: Formation of 1- and 2-Substituted and 1,2-Disubstituted Benzimidazoles .....	558

12.4.1.1.2.1.3.2	Variation 2:	Formation of Benzimidazole <i>N</i> -Oxides	559
12.4.1.1.2.1.4	Method 4:	Cyclization of Activated <i>N</i> -Alkyl- or <i>N</i> -Alkenyl-2-nitroanilines to Benzimidazole <i>N</i> -Oxides	560
12.4.1.1.2.1.5	Method 5:	Cyclization of 2-Aminophenylhydrazones of Aldehydes	562
12.4.1.1.2.1.6	Method 6:	Cyclization of Diacylated 1,2-Diaminoarenes and Related Derivatives	562
12.4.1.1.2.1.7	Method 7:	Cyclizations of 1,2-Diisocyanatoarenes and Their Sulfur Analogues	563
12.4.1.1.2.1.8	Method 8:	Cyclization of 2-Aminoaryl Azides	563
12.4.1.1.2.1.9	Method 9:	Cyclization of Schiff Bases of 1,2-Diaminoarenes or 2-Nitroanilines	564
12.4.1.1.2.1.10	Method 10:	Thermolysis of Schiff Bases of 2-Azidoanilines	565
12.4.1.1.2.1.11	Method 11:	Cyclization of <i>N</i> -(2-Aminoaryl)- or <i>N</i> -(2-Nitroaryl)ureas (or -thioureas)	565
12.4.1.1.2.1.12	Method 12:	Cyclization of an <i>O</i> -Aroyl-2-aminobenzamide Oxime	567
12.4.1.1.2.1.13	Method 13:	Reductive Cyclization of <i>N</i> -Cyano-2-nitroanilines	567
12.4.1.1.2.1.14	Method 14:	Conversion of <i>N,N</i> -Disubstituted 2-Nitroanilines into Benzimidazoles and Their <i>N</i> -Oxides	568
12.4.1.1.2.1.15	Method 15:	Conversion of <i>N</i> <sup>1</sup> , <i>N</i> <sup>1</sup> -Disubstituted 1,2-Diaminoarenes into Benzimidazoles	569
12.4.1.1.2.1.15.1	Variation 1:	Acid-Catalyzed Cyclizations	569
12.4.1.1.2.1.15.2	Variation 2:	Oxidative Cyclizations	570
12.4.1.1.2.1.16	Method 16:	Ring Closure of 1-(2-Nitroaryl)-4,5-dihydro-1 <i>H</i> -1,2,3-triazoles	571
12.4.1.1.2.2		With Formation of 1–5 or 3–4 Bonds	571
12.4.1.1.2.2.1	Method 1:	Cyclization of Arylamidines or Arylguanidines	572
12.4.1.1.2.2.1.1	Variation 1:	Direct Cyclization of Amidines or Guanidines	572
12.4.1.1.2.2.1.2	Variation 2:	Pyrolysis of Oxadiazolones	573
12.4.1.1.2.2.2	Method 2:	Cyclization of Arylureas and Arylthioureas	573
12.4.1.2		By Annulation to the Heterocyclic Ring	574
12.4.1.2.1		By Formation of Two C–C Bonds	574
12.4.1.2.2		By Formation of One C–C Bond	574
12.4.2		Synthesis by Ring Transformation	575
12.4.2.1		From Benzo Five-Membered Ring Heterocycles	575
12.4.2.1.1	Method 1:	From Indazoles	575
12.4.2.1.2	Method 2:	From Benzoxazoles	575
12.4.2.1.3	Method 3:	From Benzofuroxans	575
12.4.2.2		Ring Contraction	577
12.4.2.2.1	Method 1:	From Quinoxalines	577
12.4.2.2.1.1	Variation 1:	Action of Strong Bases on 2-Haloquinoxalines	577
12.4.2.2.1.2	Variation 2:	Ring Contractions of Quinoxaline <i>N</i> -Oxides	578
12.4.2.2.2	Method 2:	Miscellaneous Ring Contractions	578
12.4.3		Aromatization	578

<b>12.4.4</b>	Synthesis by Substituent Modification .....	579
<b>12.4.4.1</b>	Addition Reactions .....	579
<b>12.4.4.1.1</b>	Addition of Hydrogen .....	580
<b>12.4.4.1.2</b>	Addition of Metals .....	580
<b>12.4.4.1.3</b>	Addition of Organic Groups .....	580
<b>12.4.4.1.4</b>	Addition of Heteroatoms .....	580
<b>12.4.4.2</b>	Substitution of Existing Substituents on Carbon .....	581
<b>12.4.4.2.1</b>	Of Hydrogen .....	581
<b>12.4.4.2.1.1</b>	Method 1: Substitution by Hydrogen or Deuterium .....	581
<b>12.4.4.2.1.2</b>	Method 2: Substitution by a Metal .....	581
<b>12.4.4.2.1.3</b>	Method 3: Substitution by Alkyl, Aryl, and Substituted Alkyl Groups .....	582
<b>12.4.4.2.1.4</b>	Method 4: Substitution by Acyl or Aryl Groups .....	584
<b>12.4.4.2.1.5</b>	Method 5: Substitution by Halogens .....	584
<b>12.4.4.2.1.6</b>	Method 6: Substitution by Chalcogen Groups .....	585
<b>12.4.4.2.1.7</b>	Method 7: Substitution by Nitrogen Groups .....	586
<b>12.4.4.2.1.7.1</b>	Variation 1: Amination .....	586
<b>12.4.4.2.1.7.2</b>	Variation 2: Nitration .....	587
<b>12.4.4.2.2</b>	Of Metals .....	588
<b>12.4.4.2.3</b>	Of Carbon Functionalities .....	589
<b>12.4.4.2.3.1</b>	Method 1: Substitution by Amino Groups .....	589
<b>12.4.4.2.3.2</b>	Method 2: Substitution by Hydrogen (Decarboxylation) .....	589
<b>12.4.4.2.4</b>	Of Heteroatoms .....	589
<b>12.4.4.2.4.1</b>	Method 1: Substitution of Halogen .....	590
<b>12.4.4.2.4.1.1</b>	Variation 1: Reduction .....	590
<b>12.4.4.2.4.1.2</b>	Variation 2: Electrophilic Displacement .....	590
<b>12.4.4.2.4.1.3</b>	Variation 3: Nucleophilic Displacement .....	590
<b>12.4.4.2.4.2</b>	Method 2: Substitution of Chalcogen Groups .....	591
<b>12.4.4.2.4.3</b>	Method 3: Substitution of Nitrogen Groups .....	591
<b>12.4.4.3</b>	Substitution of Existing Substituents on Nitrogen .....	592
<b>12.4.4.3.1</b>	Of Hydrogen .....	592
<b>12.4.4.3.1.1</b>	Method 1: Substitution by Alkyl, Substituted Alkyl, and Unsaturated Carbon Groups .....	592
<b>12.4.4.3.1.2</b>	Method 2: Substitution by Aryl Groups .....	593
<b>12.4.4.3.1.3</b>	Method 3: Substitution by Acyl Groups .....	593
<b>12.4.4.3.1.4</b>	Method 4: Substitution by Silyl Groups .....	594
<b>12.4.4.3.1.5</b>	Method 5: Substitution by Chalcogens .....	594
<b>12.4.4.3.1.6</b>	Method 6: Substitution by Nitrogen and Phosphorus Groups .....	594
<b>12.4.4.3.2</b>	Of Metals .....	594
<b>12.4.4.3.3</b>	Of Carbon Functionalities .....	594
<b>12.4.4.3.4</b>	Of Heteroatoms .....	594

12.4.4.4	Modification of Substituents on a Ring Carbon	595
12.4.4.4.1	Organic Groups	595
12.4.4.4.1.1	Method 1: Reactions That Involve a Full or Partial Carbanion at the $\alpha$ -Carbon	595
12.4.4.4.1.2	Method 2: Oxidation of Alkyl Groups	597
12.4.4.4.1.3	Method 3: Reactions of Carboxy Groups	597
12.4.4.4.2	Oxygen and Sulfur Functions	597
12.4.4.4.3	Nitrogen Functions	598
12.4.4.4.3.1	Method 1: Alkylation and Acylation of Amino Groups	598
12.4.4.4.3.2	Method 2: Diazotization of Amino Groups	598
12.4.4.4.3.3	Method 3: Oxidation of Amino Groups	598
12.4.4.4.3.4	Method 4: Reduction of Nitro Groups	598
12.4.4.4.3.5	Method 5: Reactions of Azido Groups	599
12.4.4.5	Modification of Substituents on a Ring Nitrogen	599
12.4.4.5.1	Organic Groups	599
12.4.4.5.1.1	Method 1: Alkyl Groups	599
12.4.4.5.1.2	Method 2: Unsaturated Carbon Groups	599
12.4.4.5.1.3	Method 3: Oxygen Groups	600
12.4.4.5.1.4	Method 4: Amino Groups	600
12.4.4.6	Rearrangement of Substituents	601
<b>12.5</b>	<b>Product Class 5: Azaindolizines with Two Nitrogen Atoms in the Five-Membered Ring</b> G. Hajos and Z. Riedl	
<b>12.5</b>	<b>Product Class 5: Azaindolizines with Two Nitrogen Atoms in the Five-Membered Ring</b>	613
<b>12.5.1</b>	<b>Product Subclass 1: Imidazo[1,2-<math>\sigma</math>]pyridines</b>	613
<b>12.5.1.1</b>	Synthesis by Ring-Closure Reactions	614
12.5.1.1.1	Method 1: Reaction of Pyridin-2-amine with Bifunctional Reagents	614
12.5.1.1.1.1	Variation 1: Reaction of Pyridin-2-amine Derivatives with $\alpha$ -Halo Oxo Compounds	614
12.5.1.1.1.2	Variation 2: Reaction of Pyridin-2-amine Derivatives with $\alpha$ -Dioxo Compounds	617
12.5.1.1.1.3	Variation 3: Transformation of Pyridin-2-amines with $\alpha$ -Oxocarboxylic Acid Derivatives	617
12.5.1.1.2	Method 2: Ring Closures Starting from N-Substituted Pyridin-2-amines	618
12.5.1.1.3	Method 3: Dipolar Cyclization	620
12.5.1.1.3.1	Variation 1: 1,5-Dipolar Cyclization	620
12.5.1.1.3.2	Variation 2: 1,3-Dipolar Cyclization	622
12.5.1.1.4	Method 4: Miscellaneous Procedures	622

12.5.1.2	Synthesis by Substituent Modification	624
12.5.1.2.1	Method 1: Electrophilic Substitution	624
12.5.1.2.2	Method 2: Substitution via Lithiation	625
12.5.1.2.3	Method 3: Introduction of Elements of the Third Row of the Periodic Table	626
12.5.1.2.4	Method 4: Nucleophilic Substitution	627
12.5.1.2.5	Method 5: Interconversion of Substituents	628
12.5.1.2.6	Method 6: Quaternization	628
12.5.2	<b>Product Subclass 2: Aza Analogues of Imidazo[1,2-<i>a</i>]pyridines Containing Additional Nitrogen Atoms in the Six-Membered Ring</b>	629
12.5.2.1	Synthesis by Ring-Closure Reactions	630
12.5.2.1.1	Method 1: Reaction of $\alpha$ -Aminoazines with Bifunctional Reagents	630
12.5.2.1.1.1	Variation 1: Reaction of $\alpha$ -Aminoazines with $\alpha$ -Halo Oxo Reagents	630
12.5.2.1.1.2	Variation 2: Reaction of $\alpha$ -Aminodiazines with $\alpha$ -Dioxo Compounds	635
12.5.2.1.1.3	Variation 3: Reaction of $\alpha$ -Aminoazines with $\alpha$ -Oxocarboxylic Acid Derivatives	635
12.5.2.1.2	Method 2: Ring Closure of Functionalized $\alpha$ -(Alkylamino)azines	636
12.5.2.1.3	Method 3: Miscellaneous Procedures	637
12.5.2.2	Synthesis by Substituent Modification	638
12.5.2.2.1	Method 1: Electrophilic Substitution	638
12.5.2.2.2	Method 2: Substitution via Lithiation	640
12.5.2.2.3	Method 3: Nucleophilic Substitution	641
12.5.2.2.4	Method 4: Oxidation of the Ring Nitrogen Atom	642
12.5.2.2.5	Method 5: Reduction	642
12.5.2.2.6	Method 6: Ring Transformation	642
12.5.3	<b>Product Subclass 3: Imidazo[1,5-<i>a</i>]pyridines</b>	643
12.5.3.1	Synthesis by Ring-Closure Reactions	643
12.5.3.1.1	Method 1: Ring Closure Starting from 2-(Aminomethyl)pyridine Derivatives	643
12.5.3.1.1.1	Variation 1: Ring Closures of 2-[(Acylamino)methyl]pyridines	643
12.5.3.1.1.2	Variation 2: Cyclization of 2-Pyridylglycine Esters with Oxo Compounds	645
12.5.3.1.2	Method 2: 1,3-Dipolar Cyclization	646
12.5.3.1.3	Method 3: Reactions with Carbenes	646
12.5.3.1.4	Method 4: Miscellaneous Procedures	646
12.5.3.2	Synthesis by Substituent Modification	648
12.5.3.2.1	Method 1: Electrophilic Substitution	648
12.5.3.2.2	Method 2: Substitution via Lithiation	650
12.5.4	<b>Product Subclass 4: Aza Analogues of Imidazo[1,5-<i>a</i>]pyridines Containing Additional Nitrogen Atoms in the Six-Membered Ring</b>	651
12.5.4.1	Synthesis by Ring-Closure Reactions	651
12.5.4.1.1	Method 1: Ring Closure Starting from 2-(Aminomethyl)diazine Derivatives	651



12.5.4.1.2	Method 2:	1,3-Dipolar Cyclization	653
12.5.4.1.3	Method 3:	Ring Closure of 2-(Aminoalkyl)pyrazines using Carbon Disulfide	653
12.5.4.2		Synthesis by Substituent Modification	654
12.5.4.2.1	Method 1:	Electrophilic Substitution	654
12.5.4.2.2	Method 2:	Nucleophilic Substitution	655
12.5.4.2.3	Method 3:	Oxidation	656
12.5.5		<b>Product Subclass 5: Pyrazolo[1,5-<i>a</i>]pyridines</b>	656
12.5.5.1		Synthesis by Ring-Closure Reactions	657
12.5.5.1.1	Method 1:	Ring Closure of $\beta$ -Aminoalkylpyridines by Oxidation	657
12.5.5.1.2	Method 2:	Ring Closure by Cyclocondensation	657
12.5.5.1.3	Method 3:	1,3-Dipolar Cycloaddition	658
12.5.5.1.4	Method 4:	1,5-Dipolar Cyclization	661
12.5.5.1.5	Method 5:	Ring Closure Including Ring Transformation	663
12.5.5.2		Synthesis by Substituent Modification	665
12.5.5.2.1	Method 1:	Electrophilic Substitution	665
12.5.5.2.2	Method 2:	Substitution via Lithiation	666
12.5.6		<b>Product Subclass 6: Aza Analogues of Pyrazolo[1,5-<i>a</i>]pyridines Containing Additional Nitrogen Atoms in the Six-Membered Ring</b>	667
12.5.6.1		Synthesis by Ring-Closure Reactions	667
12.5.6.1.1	Method 1:	1,3-Dipolar Cycloaddition	667
12.5.6.1.2	Method 2:	Simultaneous Formation of the Five- and Six-Membered Rings	668
12.5.6.1.3	Method 3:	Ring Closure Including Ring Transformation	669
12.5.6.2		Synthesis by Substituent Modification	670
12.5.6.2.1	Method 1:	Electrophilic Substitution	670
12.5.6.2.2	Method 2:	Palladium-Catalyzed Coupling	671
12.5.6.2.3	Method 3:	Reduction	672
12.6		<b>Product Class 6: Azaphospholes and Azarsoles</b> A. Schmidpeter and K. Karaghiosoff	
12.6		<b>Product Class 6: Azaphospholes and Azarsoles</b>	679
12.6.1		<b>Product Subclass 1: 1<i>H</i>-1,2-Azaphospholes</b>	679
12.6.1.1		Synthesis by Ring-Closure Reactions	680
12.6.1.1.1		By Formation of One N—P and One P—C Bond	680
12.6.1.1.1.1	Method 1:	Cyclocondensation of $\beta$ -Methylene Ketimines with Phosphorus Trichloride or Tribromide and a Base	680
12.6.1.2		Synthesis from Other Heterocycles	680
12.6.1.2.1		By Formation of One N—C and One C—C Bond	680

12.6.1.2.1.1	Method 1: Cycloaddition of 1-Aza-2-phospha-4-vanada(V)cyclobutenes and Alkynes .....	680
12.6.1.2.2	By Formation of One P—C and One C—C Bond .....	681
12.6.1.2.2.1	Method 1: Cycloaddition of 1 <i>H</i> -1,3,2-Diazaphospholes and Alkynes .....	681
12.6.1.2.3	By Formation of One C—C Bond .....	681
12.6.1.2.3.1	Method 1: Flash-Vacuum Pyrolysis of 3-Aryl-1,2,3,4-triazaphospholes .....	681
12.6.2	<b>Product Subclass 2: Monocyclic 1<i>H</i>-1,3-Azaphospholes and 1<i>H</i>-1,3-Azarsoles</b> .....	682
12.6.2.1	Synthesis by Ring-Closure Reactions .....	683
12.6.2.1.1	By Formation of Two P—C Bonds .....	683
12.6.2.1.1.1	Method 1: [4 + 1] Cyclocondensation of <i>N</i> -[Chloro(phenyl)methylene]- <i>N</i> -(2-oxo-1,2-diphenylethyl)benzenaminium Chloride with Tris(trimethylsilyl)phosphine .....	683
12.6.2.1.1.1.1	Variation 1: From Ethenediamines and Phosphorus Trichloride .....	683
12.6.2.1.1.1.2	Variation 2: From 4,5-Dihydrooxazolium Bromides and 4,5-Dihydrothiazolium Bromides .....	684
12.6.2.1.1.2	Method 2: Phosphorus–Oxygen Exchange in Oxazolium Compounds by the Action of Tris(trimethylsilyl)phosphine .....	685
12.6.2.1.2	By Formation of One P—C and One C—C Bond .....	686
12.6.2.1.2.1	Method 1: [3 + 2]-Cycloaddition/Reversion Reactions with Phosphaalkynes and Phosphaalkenes .....	686
12.6.3	<b>Product Subclass 3: 1<i>H</i>-1,3-Benzazaphospholes and 1<i>H</i>-1,3-Benzazarsoles</b> .....	688
12.6.3.1	Synthesis by Ring-Closure Reactions .....	689
12.6.3.1.1	By Formation of One N—C and One P—C Bond .....	689
12.6.3.1.1.1	Method 1: [4 + 1] Cyclocondensation of 2-Phosphinophenylamines and 2-Arsinophenylamines with Carbonyl Compounds .....	689
12.6.3.1.2	By Formation of Two P—C or Two As—C Bonds .....	692
12.6.3.1.2.1	Method 1: [4 + 1] Cyclocondensation of [ <i>N</i> -(2-Lithiophenyl)-2,2-dimethylpropanimidoyl]lithium with <i>tert</i> -Butylphosphonous Dichloride or <i>tert</i> -Butylarsonous Dichloride .....	692
12.6.4	<b>Product Subclass 4: [1,3]Azaphospholo[1,2-<i>a</i>]pyridines and Related Compounds</b> .....	692
12.6.4.1	Synthesis by Ring-Closure Reactions .....	693
12.6.4.1.1	By Formation of Two P—C or As—C Bonds .....	694
12.6.4.1.1.1	Method 1: Oxygen–Phosphorus or Oxygen–Arsenic Exchange in Oxazolo[3,2- <i>a</i> ]pyridin-4-ium Salts with Tris(trimethylsilyl)phosphine or Tris(trimethylsilyl)arsine .....	694

<b>12.6.5</b>	<b>Product Subclass 5: [1,3]Azaphospholo[1,5-<math>\alpha</math>]pyridines and Related Compounds</b> .....	694
<b>12.6.5.1</b>	Synthesis by Ring-Closure Reactions .....	696
<b>12.6.5.1.1</b>	By Formation of Two P—C Bonds .....	696
<b>12.6.5.1.1.1</b>	Method 1: [4 + 1] Cyclocondensation of Cycloiminium Salts with Phosphorus Trichloride .....	696
<b>12.6.5.1.1.2</b>	Method 2: [3 + 2] Cycloaddition of Pyridinium and Related Ylides with Phosphaalkynes .....	699
<b>12.6.5.1.1.3</b>	Method 3: [1,5] Electrocyclization of Pyridinium Ylides .....	700
<b>12.7</b>	<b>Product Class 7: Diphospholes</b> F. Mathey	
<b>12.7</b>	<b>Product Class 7: Diphospholes</b> .....	705
<b>12.7.1</b>	<b>Product Subclass 1: 1,2-Diphospholes</b> .....	705
<b>12.7.1.1</b>	Method 1: Alkylation of 1,2-Diphospholides .....	705
<b>12.7.2</b>	<b>Product Subclass 2: 1,2-Diphospholides</b> .....	706
<b>12.7.2.1</b>	Method 1: From Diylides .....	706
<b>12.7.2.2</b>	Method 2: From 1,2-Dihydrophosphetes .....	707
<b>12.7.2.3</b>	Method 3: From Phosponium Salts by Ring Closure .....	708
<b>12.7.3</b>	<b>Product Subclass 3: 1,3-Diphospholes</b> .....	708
<b>12.7.3.1</b>	Method 1: From Phosphaalkynes .....	709
<b>12.7.3.2</b>	Method 2: From 1,3-Diphospholides .....	709
<b>12.7.3.3</b>	Method 3: From 1,2-Bis(phosphino)arenes by Ring Closure .....	710
<b>12.7.4</b>	<b>Product Subclass 4: 1,3-Diphospholides</b> .....	710
<b>12.7.4.1</b>	Method 1: From Phosphaalkynes .....	710
<b>12.7.4.2</b>	Method 2: From 1,2-Dihydro-1,2-diphosphetes .....	711
<b>12.7.4.3</b>	Method 3: From 1,2-Bis(phosphino)arenes by Ring Closure .....	713
<b>12.7.5</b>	<b>Product Subclass 5: <math>\eta^5</math>-Diphospholyl Complexes</b> .....	714
<b>12.7.5.1</b>	Method 1: From Metal-1,2-Diphosphaallyl Complexes by Ring Closure ..	715
<b>12.7.5.2</b>	Method 2: From Phosphaalkynes .....	716
<b>12.7.5.3</b>	Method 3: From Diphospholides .....	716
	<b>Keyword Index</b> .....	719
	<b>Author Index</b> .....	741
	<b>Abbreviations</b> .....	791