

Organic Reaction Mechanisms

A Step by Step Approach

Second Edition

MICHAEL EDENBOROUGH



Contents

Preface to the First Edition	xi
Preface to the Second Edition	xiii
Part I: Basic Principles	1
1 Introduction	3
1.1 The aims of this book	3
1.2 What is organic chemistry?	4
1.3 Organic synthesis	5
1.4 Organic mechanisms	6
1.5 Two examples	6
1.6 The structure of this book	11
2 Electron Counting	13
2.1 Introduction	13
2.2 Atoms	13
2.3 Uncharged molecules	19
2.4 Molecules with whole charges	22
2.5 Summary of electron counting	31
3 Bond Polarisation and Fission	35
3.1 Introduction	35
3.2 Partially charged species	35
3.3 Bond fission	39

Contents

3.4 Isolated multiple bonds	42
3.5 Conjugated multiple bonds	46
3.6 Summary of bond polarisation and fission	51
4 Shapes of Molecules	53
4.1 Introduction	53
4.2 Types of bonding	54
4.3 Tetrahedral geometry	56
4.4 Trigonal planar geometry	62
4.5 Linear geometry	68
4.6 Further examples	70
4.7 Summary of shapes of molecules	76
5 Stabilisation of Charged Species	79
5.1 Introduction	79
5.2 Inductive effects	80
5.2.1 Charged hydrocarbon species	80
5.2.2 Charged non-hydrocarbon species	85
5.3 Mesomeric effects	85
5.3.1 Charged hydrocarbon species	85
5.3.2 Charged non-hydrocarbon species	88
5.4 Degree of s orbital character	92
5.5 d orbital involvement	93
5.6 Aromatic character	94
5.7 Hydrogen bonding	98
5.8 Steric effects	99
5.9 Summary of stabilisation of charged species	101
6 Thermodynamic and Kinetic Effects	103
6.1 Introduction	103
6.2 Thermodynamic effects	105
6.2.1 General considerations	105
6.2.2 Enthalpy effects	107
6.2.3 Entropy effects	110
6.3 Kinetic effects	111
6.3.1 Forcing reactions	111
6.3.2 Ring formation	113
6.3.3 Abstraction of protons	115
6.4 Catalysis	116
6.4.1 General considerations	116
6.4.2 Acid/base catalysis	117
6.5 Summary of thermodynamic and kinetic effects	118
7 Acid/Base Characteristics	121
7.1 Introduction	121

7.2 Definitions of acids and bases	122
7.2.1 Arrhenius	122
7.2.2 Brönsted–Lowry	122
7.2.3 Lewis	129
7.2.4 Cady–Elsey	130
7.3 Electrophilic and nucleophilic properties	131
7.4 External factors	134
7.5 Summary of acid/base characteristics	136
 Part II: Mechanisms	 139
 8 Introduction to Mechanisms	 141
8.1 Preliminary considerations	141
8.2 Summary of introduction to mechanisms	143
 9 Nucleophilic Substitution Reactions	 145
9.1 Introduction	145
9.2 Substitution at a saturated carbon	146
9.2.1 Introduction	146
9.2.2 Unimolecular substitution	148
9.2.3 Bimolecular substitution	152
9.2.4 Intramolecular substitution	157
9.2.5 Formation and cleavage of three-membered rings	161
9.3 Substitution at an unsaturated carbon	164
9.3.1 S _N 1 mechanism	164
9.3.2 S _N 2 mechanism	165
9.3.3 Tetrahedral mechanism	165
9.3.4 Ester hydrolysis	167
9.4 Summary of nucleophilic substitution reactions	170
 10 Electrophilic Substitution Reactions	 175
10.1 Introduction	175
10.2 Aromatic substitution	176
10.2.1 Arenium ion mechanism	176
10.2.2 Orientation and reactivity of monosubstituted benzene rings	181
10.2.3 <i>Ortho/para</i> ratio	184
10.2.4 Multiple substitutions	186
10.3 Aliphatic substitution	187
10.4 Summary of electrophilic substitution reactions	191
 11 Radical Substitution Reactions	 195
11.1 Introduction	195
11.2 Photochlorination of methane	195

Contents

11.3 Reactivity and structure	200
11.4 Neighbouring group assistance	203
11.5 Further examples of radical reactions	204
11.6 Summary of radical substitution reactions	211
12 Addition Reactions to Carbon/Carbon Multiple Bonds	213
12.1 Introduction	213
12.2 Cyclic addition	215
12.2.1 Heterogeneous catalytic hydrogenation	215
12.2.2 Other <i>syn</i> -addition reactions	216
12.2.3 Pericyclic reactions	218
12.3 Electrophilic addition	222
12.3.1 Addition of a symmetrical molecule	222
12.3.2 Rate of addition	228
12.3.3 Orientation of addition	230
12.3.4 Some other electrophilic additions	233
12.4 Radical addition	236
12.5 Nucleophilic addition	237
12.6 Conjugate addition	239
12.7 Summary of addition reactions to carbon/carbon multiple bonds	242
13 Addition Reactions to Carbon/Oxygen Double Bonds	245
13.1 Introduction	245
13.2 Structure and reactivity	245
13.3 Hydration	248
13.4 Other addition reactions	251
13.5 Addition of carbon nucleophiles	254
13.5.1 Cyanide, alkynyl and alkyl anions	254
13.5.2 Carbonyl stabilised carbon anions	256
13.6 Stereochemical consequences	264
13.7 Conjugate addition	266
13.8 Summary of addition reactions to carbon/oxygen double bonds	267
14 Elimination Reactions	271
14.1 Introduction	271
14.2 Bimolecular 1,2-elimination reactions	273
14.2.1 <i>Anti</i> -elimination reactions	273
14.2.2 <i>Syn</i> -elimination reactions	280
14.3 Unimolecular 1,2-elimination reactions	282
14.4 1,1-Elimination reactions	287
14.5 Pyrolytic elimination reactions	288

14.6 γ -Elimination and extrusion reactions	291
14.7 Summary of elimination reactions	292
15 Sequential Addition/Elimination Reactions	297
15.1 Introduction	297
15.2 Addition/elimination reactions	298
15.2.1 Carbon/carbon double bonds	298
15.2.2 Carbon/oxygen double bonds	300
15.3 Elimination/addition reactions	305
15.4 Summary of sequential addition/elimination reactions	307
16 Rearrangement and Fragmentation Reactions	309
16.1 Introduction	309
16.2 Carbon/carbon rearrangements	310
16.2.1 Allylic rearrangements	310
16.2.2 Whitmore 1,2-shifts	312
16.3 Carbon/nitrogen rearrangements	318
16.4 Carbon/oxygen rearrangements	321
16.5 Fragmentation reactions	322
16.6 Summary of rearrangement and fragmentation reactions	325
17 Redox Reactions	329
17.1 Introduction	329
17.2 Reduction reactions	330
17.2.1 Electron donors	330
17.2.2 Hydride anion donors	334
17.3 Oxidation reactions	336
17.4 Disproportionation reactions	341
17.5 Summary of redox reactions	344
Part III: Appendices	347
18 Glossary	349
19 Abbreviations	399
19.1 Atomic, group and molecular abbreviations	399
19.2 Mechanistic abbreviations	401
19.3 Reaction type abbreviations	403
20 Molecular Notations	405
20.1 Non-structural notations	405
20.1.1 Empirical formula	405
20.1.2 Molecular formula	405

Contents

20.2 Two-dimensional structural notations	406
20.2.1 Dot and cross	406
20.2.2 Line notation	407
20.2.3 Expanded line notation	408
20.2.4 Stick notation	409
20.2.5 Two-dimensional skeletal notation	409
20.3 Three-dimensional structural notations	412
20.3.1 Haworth notation	412
20.3.2 Three-dimensional skeletal notation	412
20.3.3 Stereo projection	413
20.3.4 Sawhorse projection	414
20.3.5 Newman projection	415
20.3.6 Fischer projection	415
21 Stereochemical Terminology	417
21.1 Introduction	417
21.2 Structural isomerism	418
21.2.1 Skeletal isomerism	420
21.2.2 Positional isomerism	421
21.2.3 Functional isomerism	423
21.2.4 Tautomeric isomerism	423
21.2.5 Meta isomerism	424
21.3 Stereoisomerism	425
21.3.1 Optical isomerism	427
21.3.2 Geometrical isomerism	432
21.3.3 Conformers	436
22 Oxidation Numbers	441
22.1 Introduction	441
22.2 Oxidation numbers in ionic species	441
22.3 Oxidation numbers in covalent species	443
23 Skeletal Index	447
23.1 Hydrocarbon compounds	447
23.2 Oxygen containing compounds	452
23.3 Nitrogen containing compounds	459
23.4 Nitrogen and oxygen containing compounds	465
23.5 Sulphur containing compounds	470
23.6 Phosphorus containing compounds	472
Index	473