
Catalysts for Fine
Chemical Synthesis

Volume 1

Hydrolysis, Oxidation and Reduction

Edited by

Stan M Roberts and Geraldine Poignant
University of Liverpool, UK



JOHN WILEY & SONS, LTD

Catalysts for Fine Chemical Synthesis

Volume 1

Catalysts for Fine Chemical Synthesis

Series Editors

Stan M Roberts, Ivan V Kozhevnikov and Eric Derouane

University of Liverpool, UK

Forthcoming Volumes

Catalysts for Fine Chemical Synthesis Volume 2

Catalysis by Polyoxometalates

Ivan V Kozhevnikov

University of Liverpool, UK

ISBN 0 471 62381 4

Catalysts for Fine Chemical Synthesis Volume 3

Edited by Eric Derouane

University of Liverpool, UK

ISBN 0 471 49054 7

Catalysts for Fine
Chemical Synthesis

Volume 1

Hydrolysis, Oxidation and Reduction

Edited by

Stan M Roberts and Geraldine Poignant
University of Liverpool, UK



JOHN WILEY & SONS, LTD

Copyright © 2002 John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester,
West Sussex PO19 8SQ, England

Telephone (+44) 1243 779777

Email (for orders and customer service enquiries): cs-books@wiley.co.uk

Visit our Home Page on www.wileyurope.com or www.wiley.com

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except under the terms of the Copyright, Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency Ltd, 90 Tottenham Court Road, London W1T 4LP, UK, without the permission in writing of the Publisher. Requests to the Publisher should be addressed to the Permissions Department, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, or emailed to permreq@wiley.co.uk, or faxed to (+44) 1243 770571.

This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the Publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Other Wiley Editorial Offices

John Wiley & Sons Inc., 111 River Street,
Hoboken, NJ 07030, USA

Jossey-Bass, 989 Market Street,
San Francisco, CA 94103-1741, USA

Wiley-VCH Verlag GmbH,
Boschstr. 12, D-69469 Weinheim, Germany

John Wiley & Sons Australia Ltd, 33 Park Road, Milton,
Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop # 02-01,
Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 22 Worcester Road,
Etobicoke, Ontario, Canada M9W 1L1

Library of Congress Cataloging-in-Publication Data

Hydrolysis, oxidation, and reduction / edited by Stan M. Roberts and Geraldine Poignant.
p. cm—(Catalysts for fine chemical synthesis; v. 1)

Includes bibliographical references and index.

ISBN 0-471-49850-5 (acid-free paper)

1. Enzymes—Biotechnology.
2. Organic compounds—Synthesis.
3. Hydrolysis.
4. Oxidation-reduction reaction. I. Roberts, Stanley M. II. Poignant, Geraldine. III. Series.

TP248.65.E59 H98 2002

660'.28443—dc21

2002072357

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 0 471 98123 0

Typeset in 10/12pt Times by Kolam Information Services Pvt Ltd, Pondicherry, India.

Printed and bound in Great Britain by Antony Rowe Ltd, Chippenham, Wiltshire.

This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

Contents

| | |
|--|-----------|
| Series Preface | xiii |
| Preface to Volume 1 | xv |
| Abbreviations | xvii |
| PART I: REVIEW | 1 |
| 1 The Integration of Biotransformations into the Catalyst Portfolio | 3 |
| 1.1 Hydrolysis of esters, amides, nitriles and oxiranes | 4 |
| 1.2 Reduction reactions | 9 |
| 1.2.1 Reduction of carbonyl compounds | 10 |
| 1.2.2 Reduction of alkenes | 13 |
| 1.3 Oxidative transformations | 17 |
| 1.4 Carbon–carbon bond-forming reactions | 26 |
| 1.5 Conclusions | 37 |
| References | 39 |
| PART II: PROCEDURES | 47 |
| 2 General Information. | 49 |
| 3 Asymmetric Epoxidation | 51 |
| 3.1 Introduction. | 51 |
| References | 52 |
| 4 Epoxidation of α, β-Unsaturated Carbonyl Compounds | 55 |
| 4.1 Non-asymmetric epoxidation | 55 |
| 4.2 Asymmetric epoxidation using poly-D-leucine | 56 |
| 4.2.1 Synthesis of leucine N-carboxyanhydride | 57 |
| 4.2.2 Synthesis of immobilized poly-D-leucine | 58 |

| | | |
|----------|---|-----------|
| 4.2.3 | Asymmetric epoxidation of (<i>E</i>)-benzylideneacetophenone | 59 |
| 4.2.4 | Conclusion | 61 |
| 4.3 | Asymmetric epoxidation using chiral modified diethylzinc | 61 |
| 4.3.1 | Epoxidation of 2- <i>isobutylidene</i> -1-tetralone | 62 |
| 4.3.2 | Conclusion | 64 |
| 4.4 | Asymmetric epoxidation of (<i>E</i>)- benzylideneacetophenone using the La-(<i>R</i>)-BINOL-Ph ₃ PO/cumene hydroperoxide system <i>K. Daikai, M. Kamaura and J. Inanaga</i> | 66 |
| 4.4.1 | Merits of the system | 68 |
| | References | 69 |
| 5 | Epoxidation of Allylic Alcohols | 71 |
| 5.1 | Non-asymmetric epoxidation | 72 |
| 5.2 | Asymmetric epoxidation using a chiral titanium complex. | 73 |
| 5.2.1 | Epoxidation of cinnamyl alcohol. | 74 |
| 5.2.2 | Epoxidation of (<i>E</i>) -2-methyl-3-phenyl-2-propenol | 76 |
| 5.2.3 | Epoxidation of (<i>E</i>)-2-hexen-1-ol | 78 |
| 5.2.4 | Conclusion | 81 |
| 5.3 | Asymmetric epoxidation of (<i>E</i>)-undec-2-en-1-ol using poly(octamethylene tartrate) <i>D.C. Sherrington, J.K. Karjalainen and O.E.O. Hormi</i> | 81 |
| 5.3.1 | Synthesis of branched poly (octamethylene-L-(+)-tartrate). | 81 |
| 5.3.2 | Asymmetric epoxidation of (<i>E</i>)-undec-2-en-1-ol | 82 |
| | References | 86 |
| 6 | Epoxidation of Unfunctionalized Alkenes and α, β-Unsaturated Esters. | 87 |
| 6.1 | Asymmetric epoxidation of disubstituted <i>Z</i> -alkenes using a chiral salen–manganese complex | 88 |
| 6.1.1 | Epoxidation of (<i>Z</i>)-methyl styrene | 89 |
| 6.1.2 | Epoxidation of (<i>Z</i>)-ethyl cinnamate | 91 |
| 6.1.3 | Conclusion | 93 |
| 6.2 | Asymmetric epoxidation of disubstituted <i>E</i> -alkenes using a D-fructose based catalyst | 94 |
| 6.2.1 | Epoxidation of (<i>E</i>)-stilbene | 95 |
| 6.2.2 | Conclusion | 97 |

| | | |
|----------|--|------------|
| 6.3 | Enantioselective epoxidation of (<i>E</i>)- β -methylstyrene by D_2 -symmetric chiral <i>trans</i> -dioxoruthenium (VI) porphyrins <i>Rui Zhang, Wing-Yiu Yu and Chi-Ming Che</i> | 98 |
| 6.3.1 | Preparation of the <i>trans</i> -dioxoruthenium(VI) complexes with D_2 -symmetric porphyrins (H_2L^{1-3}) | 98 |
| 6.3.2 | Enantioselective epoxidation of (<i>E</i>)- β -methylstyrene | 99 |
| 6.3.3 | Conclusion | 100 |
| | References | 101 |
| 7 | Asymmetric Hydroxylation and Aminohydroxylation | 103 |
| 7.1 | Asymmetric aminohydroxylation of 4-methoxystyrene <i>P.O'Brien, S.A. Osborne and D.D. Parker</i> | 103 |
| 7.1.1 | Conclusion | 105 |
| 7.2 | Asymmetric dihydroxylation of (1-cyclohexenyl)acetonitrile <i>Jean-Michel Vatèle</i> | 105 |
| 7.2.1 | (<i>R,R</i>)-(1,2-Dihydroxycyclohexyl)acetonitrile acetonide | 107 |
| 7.2.2 | Conclusion | 108 |
| | References | 108 |
| 8 | Asymmetric Sulfoxidation | 109 |
| 8.1 | Asymmetric oxidation of sulfides and kinetic resolution of sulfoxides <i>Laura Palombi and Arrigo Scettri</i> | 109 |
| 8.1.1 | Asymmetric oxidation of 4-bromothioanisole | 109 |
| 8.1.2 | Kinetic resolution of racemic 4-bromophenyl methyl sulfoxide | 111 |
| | References | 113 |
| 9 | Asymmetric Reduction of Ketones Using Organometallic Catalysts | 115 |
| 9.1 | Introduction | 115 |
| 9.2 | Asymmetric hydrogenation using a metal catalyst: [Ru(<i>S</i>)-BiNAP]. | 117 |
| 9.3 | Asymmetric transfer hydrogenation of β -ketoesters <i>Kathelyne Everaere, Jean-François Carpentier, André Mortreux and Michel Bulliard</i> | 121 |
| 9.4 | (<i>S,S</i>)-1,2-bis(<i>tert</i> -Butylmethylphosphino)ethane (BisP*): Synthesis and use as a ligand <i>T. Imamoto</i> | 123 |
| 9.4.1 | Synthesis of BisP* | 123 |

| | | |
|-----------|--|------------|
| 9.4.2 | Synthesis of 1,2-bis(<i>tert</i> -butylmethylphosphino)ethaneruthenium bromide (BisP*–Ru) | 125 |
| 9.4.3 | Synthesis of (<i>R</i>)-(–)-methyl 3-hydroxypentanoate using (BisP*–Ru) | 126 |
| 9.5 | (1 <i>S</i> ,3 <i>R</i> ,4 <i>R</i>)-2-Azanorborylmethanol, an efficient ligand for ruthenium-catalysed asymmetric transfer hydrogenation of aromatic ketones <i>Diego A. Alonso and Pher G. Andersson</i> | 127 |
| 9.5.1 | Synthesis of ethyl(1 <i>S</i> ,3 <i>R</i> ,4 <i>R</i>)-2-[(<i>S</i>)-1-phenylethylamino]-2-azabicyclo[2.2.1]hept-5-ene-3-carboxylate | 129 |
| 9.5.2 | Synthesis of (1 <i>S</i> ,3 <i>R</i> ,4 <i>R</i>)-3-hydroxymethyl-2-azabicyclo[2.2.1]heptane | 131 |
| 9.5.3 | Ruthenium-catalysed asymmetric transfer hydrogenation of acetophenone | 133 |
| | References | 134 |
| 10 | Asymmetric Reduction of Ketones Using Bakers' Yeast | 137 |
| 10.1 | Bakers' yeast reduction of ethyl acetoacetate | 137 |
| 10.2 | Enantioselective synthesis of <i>cis</i> - <i>N</i> -carbobenzyloxy-3-hydroxyproline ethyl ester <i>Mukund P. Sibi and James W. Christensen</i> | 140 |
| 10.2.1 | Immobilization of bakers' yeast | 140 |
| 10.2.2 | Bakers' yeast reduction of <i>cis</i> - <i>N</i> -carbobenzyloxy-3-ketoproline ethyl ester | 140 |
| | References | 142 |
| 11 | Asymmetric Reduction of Ketones Using Nonmetallic Catalysts. | 143 |
| 11.1 | Introduction | 143 |
| 11.2 | Oxazaborolidine borane reduction of acetophenone | 146 |
| 11.3 | Oxazaphosphinamide borane reduction of chloroacetophenone | 148 |
| 11.4 | Asymmetric reduction of chloroacetophenone using a sulfoximine catalyst | 151 |
| 11.4.1 | Preparation of β -hydroxysulfoximine borane | 151 |
| 11.4.2 | Reduction of chloroacetophenone using the sulfoximine borane | 153 |
| 11.4.3 | Summary | 155 |
| 11.5 | Asymmetric reduction of bromoketone catalysed by <i>cis</i> -aminoindanol oxazaborolidine <i>Chris H. Senanayake, H. Scott Wilkinson and Gerald J. Tanoury.</i> | 157 |

| | | |
|--------|--|-----|
| 11.5.1 | Synthesis of aminoindanol oxazaborolidine . . . | 157 |
| 11.5.2 | Asymmetric reduction of 2-bromo- (3-nitro-4-benzyloxy)acetophenone | 157 |
| 11.5.3 | Conclusions | 159 |
| 11.5.4 | Stereoselective reduction of 2,3-butadione monoxime trityl ether | 161 |
| 11.5.5 | Stereoselective reduction of methyl 3-oxo-2-trityloxyiminostearate | 163 |
| 11.5.6 | Stereoselective reduction of 1 -(<i>tert</i> -butyldimethylsilyloxy)-3-oxo-2- trityloxyiminooctadecane | 164 |
| 11.6 | Enantioselective reduction of ketones using N-arylsulfonyl oxazaborolidines <i>Mukund P. Sibi, Pingrong Liu and Gregory R. Cook.</i> . . . | 166 |
| 11.6.1 | Synthesis of N-(2-pyridinesulfonyl)-1-amino- 2-indanol | 166 |
| 11.6.2 | Asymmetric reduction of a prochiral ketone (chloroacetophenone) | 167 |
| 11.7 | Reduction of ketones using amino acid anions as catalyst and hydrosilane as oxidant <i>Michael A. Brook</i> | 169 |
| | References | 172 |

| | | |
|-----------|---|------------|
| 12 | Asymmetric Hydrogenation of Carbon–Carbon Double Bonds Using Organometallic Catalysts | 175 |
| 12.1 | Introduction | 176 |
| 12.2 | Hydrogenation of dimethyl itaconate using [Rh(<i>S,S</i>)-Me-BPE] | 177 |
| 12.3 | Hydrogenation of an α -amidoacrylate using [Rh(<i>R,R</i>)-Me-DuPHOS] | 179 |
| 12.4 | Hydrogenation of an α -amidoacrylate using [Rh(B[3.2.0]DPO)] complexes | 180 |
| 12.4.1 | Preparation of (COD) ₂ Rh ⁺ BF ₄ ⁻ | 180 |
| 12.4.2 | Preparation of the bisphosphinite ligand | 182 |
| 12.4.3 | Asymmetric reduction of α -acetamido cinnamic acid | 184 |
| 12.5 | Hydrogenation of enol carbonates and 4-methylene-N-acyloxazolidinone using [Rh(<i>R</i>)-BiNAP] complexes | 186 |
| | <i>P.H. Dixneuf, C. Bruneau and P. Le Gendre</i> | |
| 12.5.1 | Synthesis of (<i>S</i>)-4,4,5-trimethyl-1, 3-dioxolane-2-one | 186 |
| 12.5.2 | Synthesis of (<i>S</i>)-2-methyl-2,3-butanediol | 187 |

| | | |
|--------|---|-----|
| 12.5.3 | Preparation of optically active N-acyloxazolidinones | 188 |
| 12.5.4 | Synthesis of (<i>R</i>)- <i>N</i> -propionyl-4,5,5-trimethyl-1, 3-oxazolidin-2-one. | 189 |
| 12.6 | Enantioselective ruthenium-catalyzed hydrogenation of vinylphosphonic acids <i>Virginie Ratovelomanana-Vidal, Jean-Pierre Genêt</i> | 190 |
| 12.6.1 | Synthesis of chiral Ru(II) catalysts | 190 |
| 12.6.2 | Asymmetric hydrogenation of vinylphosphonic acids carrying a phenyl substituent at C ₂ | 191 |
| 12.6.3 | Asymmetric reduction of a vinylphosphonic acid carrying a naphthyl substituent at C ₂ | 192 |
| 12.6.4 | Scope of the hydrogenation reaction | 193 |
| 12.7 | Synthesis of a cylindrically chiral diphosphine and asymmetric hydrogenation of dehydroamino acids <i>Jahyo Kang and Jun Hee Lee</i> | 194 |
| 12.7.1 | Preparation of (<i>R,R</i>)-1,1'-bis(α -hydroxypropyl) ferrocene | 195 |
| 12.7.2 | Preparation of (<i>R,R</i>)-1,1'-bis [α -(dimethylamino)propyl]ferrocene | 196 |
| 12.7.3 | Preparation of (<i>R,R</i> , _p <i>S</i> , _p <i>S</i>)-1,1'-bis [α -(dimethylamino)propyl]-2,2'-bis (diphenyl-phosphino)ferrocene | 197 |
| 12.7.4 | Preparation of (<i>R,R</i> , _p <i>S</i> , _p <i>S</i>)-1,1'-bis [α -acetoxypropyl]-2,2'- bis(diphenyl-phosphino)ferrocene | 198 |
| 12.7.5 | Preparation of (_p <i>S</i> , _p <i>S</i>)-1, 1'-bis (diphenylphosphino)-2,2'-bis(1-ethylpropyl) ferrocene [(<i>S,S</i>)-3-Pt-FerroPHOS] | 199 |
| 12.7.6 | Preparation of [(COD)Rh(_p <i>S</i> , _p <i>S</i>)-1, 1'-bis(diphenylphosphino)-2,2'-bis (1-ethylpropyl)ferrocene] ⁺ BF ₄ ⁻ | 200 |
| 12.7.7 | Asymmetric hydrogenation of α -acetamido cinnamic acid. | 201 |
| 12.8 | Synthesis and application of diamino FERRIPHOS as ligand for enantioselective Rh-catalysed preparation of chiral α -amino acids <i>Matthias Lotz, Juan J. Almena Perea and Paul Knochel</i> | 202 |
| 12.8.1 | Synthesis of 1,1'-di(benzoyl)ferrocene | 202 |
| 12.8.2 | Synthesis of (<i>S,S</i>)-1,1'-bis (α -hydroxyphenylmethyl)ferrocene | 204 |
| 12.8.3 | Synthesis of (<i>S,S</i>)-1,1'-bis (α -acetoxyphenylmethyl)ferrocene | 205 |

| | | |
|-----------|--|------------|
| 12.8.4 | Synthesis of (<i>S,S</i>)-1,1'-bis(α -N,N-dimethylaminophenylmethyl)ferrocene | 206 |
| 12.8.5 | Synthesis of (α <i>S</i> , α' <i>S</i>)-1,1'-bis(α -N,N-dimethylaminophenylmethyl)-(<i>R,R</i>)-1,1'-bis(diphenylphosphino)ferrocene | 207 |
| 12.8.6 | Asymmetric hydrogenation of methyl-(<i>Z</i>)-3-phenyl-2-methyl-carboxamido-2-propenoate using (<i>S</i>)-(<i>R</i>)-diamino FERRIPHOS as chiral ligand | 209 |
| | References | 210 |
| 13 | Employment of Catalysts Working in Tandem | 213 |
| 13.1 | A one-pot sequential asymmetric hydrogenation utilizing Rh(I)- and Ru(II)-catalysts <i>Takayuki Doi and Takashi Takahashi</i> | 213 |
| 13.1.1 | Synthesis of ethyl (<i>Z</i>)-4-acetamido-3-oxo-5-phenyl-4-pentenoate | 213 |
| 13.1.2 | Asymmetric hydrogenation of ethyl 4-acetamido-3-oxo-5-phenyl-4-pentenoate | 214 |
| | References | 217 |
| | Index | 219 |

Catalysts for Fine Chemical Synthesis

Series Preface

During the early-to-mid 1990s we published a wide range of protocols, detailing the use of biotransformations in synthetic organic chemistry. The procedures were first published in the form of a loose-leaf laboratory manual and, recently, all the protocols have been collected together and published in book form (*Preparative Biotransformations*, Wiley-VCH, 1999).

Over the past few years the employment of enzymes and whole cells to carry out selected organic reactions has become much more commonplace. Very few research groups would now have any reservations about using commercially available biocatalysts such as lipases. Biotransformations have become accepted as powerful methodologies in synthetic organic chemistry.

Perhaps less clear to a newcomer to a particular area of chemistry is *when* to use biocatalysis as a key step in a synthesis, and when it is better to use one of the alternative non-natural catalysts that may be available. Therefore we set out to extend the objective of *Preparative Biotransformations*, so as to cover the whole panoply of catalytic methods available to the synthetic chemist, incorporating biocatalytic procedures where appropriate.

In keeping with the earlier format we aim to provide the readership with sufficient practical details for the preparation and successful use of the relevant catalyst. Coupled with these specific examples, a selection of the products that may be obtained by a particular technology will be reviewed.

In the different volumes of this new series we will feature catalysts for oxidation and reduction reactions, hydrolysis protocols and catalytic systems for carbon-carbon bond formation *inter alia*. Many of the catalysts featured will be chiral, given the present day interest in the preparation of single-enantiomer fine chemicals. When appropriate, a catalyst type that is capable of a wide range of transformations will be featured. In these volumes the amount of practical data that is described will be proportionately less, and attention will be focused on the past uses of the system and its future potential.

Newcomers to a particular area of catalysis may use these volumes to validate their techniques, and, when a choice of methods is available, use the background information better to delineate the optimum strategy to try to accomplish a previously unknown conversion.

**S.M. ROBERTS
I. KOZHEVNIKOV
E. DEROUANE
LIVERPOOL, 2002**

Preface for Volume 1: Hydrolysis, Oxidation and Reduction

A REVIEW OF NATURAL AND NON-NATURAL CATALYSTS IN SYNTHETIC ORGANIC CHEMISTRY: PRACTICAL TIPS FOR SOME IMPORTANT OXIDATION AND REDUCTION REACTIONS

In this volume we indicate some of the different natural and non-natural catalysts for hydrolysis, oxidation, reduction and carbon–carbon bond forming reactions leading to optically active products. Literature references are given to assist the reader to pertinent reviews. The list of references is not in the least comprehensive and is meant to be an indicator rather than an exhaustive compilation. It includes references up to mid-1999 together with a handful of more recent reports.

The later sections of the book deal with the actual laboratory use of catalysts for asymmetric reduction and oxidation reactions. Most of the protocols describe non-natural catalysts principally because many of the corresponding biological procedures were featured in the sister volume *Preparative Biotransformations*. As in this earlier book, we have spelt out the procedures in great detail, giving where necessary, helpful tips and, where appropriate, clear warnings of toxicity, fire hazards, etc.

Many of the procedures have been validated in the Liverpool laboratories (by GP). Other protocols were kindly submitted by colleagues from the USA, Japan, the UK and mainland Europe. The names of the contributors are given at the start of the corresponding protocol. These descriptions of the recipes also contain references to the literature. In these cases the references point the reader to the more practical aspects of the topic and are meant to complement rather than repeat the references given in the first, overview chapter.

Some of the practicals describe the use of similar catalysts and/or catalysts that accomplish the same task. This has been done purposely to try to get the best match between the substrate described and the one being considered by an interested reader. Moreover when catalysts can be compared, this has been done. Sometimes a guide is given as to what *we* found to be the most useful system in our hands. In this context, it is important to note that, except for polyleucine-catalysed oxidations and the use of a bicyclic bisphosphinite for asymmetric hydrogenation, the Liverpool group had no previous experience in

using the catalysts described herein; we approached the experiments carried out in Liverpool as newcomers in the field.

Thus for the first volume in this series we have performed a selection of oxidation and reduction reactions, arguably some of the most important transformations of these two types, mainly employing non-natural catalysts. In other volumes of this work other catalysts for oxidation and reduction will be featured and, of equal importance, the use of preferred catalysts for carbon-carbon bond formation will be described. In the first phase, therefore, this series will seek to explore the ‘pros and cons’ of using many, if not most, well-documented catalysts and we will endeavour to report our findings in a non-partisan manner.

We truly hope these procedures will be really valuable for fellow chemists trying out a new catalyst system for the first time. Feedback and further hints and tips would be most welcome.

**G. POIGNANT
S.M. ROBERTS
LIVERPOOL, 2002**

Abbreviations

| | |
|-----------------------------|--|
| Ac | acetyl |
| Ar | aryl |
| b.p. | boiling point |
| BSA | <i>N,O</i> -bis-(trimethylsilyl)-acetamide |
| Bu | butyl |
| cat | catalyst |
| CLAMPS | cross-linked aminomethylpolystyrene |
| DBU | 1,8-diazabicyclo[5.4.0]undec-7-ene |
| DEPT | diethyl tartrate |
| DIPT | diisopropyl tartrate |
| DMAP | 4-dimethylaminopyridine |
| DMM | dimethoxymethane |
| DMSO | dimethyl sulfoxide |
| EDTA | ethylenediaminetetraacetic acid |
| ee | enantiomeric excess |
| eq | equivalent |
| Et | ethyl |
| GC | gas chromatography |
| HPLC | high pressure liquid chromatography |
| ID | internal diameter |
| IR | infrared (spectroscopy) |
| L | ligand |
| lit. | literature |
| M | metal |
| m.p. | melting point |
| MCPBA } <i>m</i> -CPBA } | <i>meta</i> -chloroperbenzoic acid |
| Me | methyl |
| MTPA | methoxy- α -(trifluoromethyl)phenylacetyl |
| NMR | nuclear magnetic resonance |
| Ph | phenyl |
| Pr | propyl |
| psi | pounds per square inch |
| r.p.m. | rotation per minutes |
| R_f | retention factor |
| R_t | retention time |

| | |
|------|----------------------------------|
| TBHP | <i>tert</i> -butyl hydroperoxide |
| THF | tetrahydrofuran |
| TLC | thin layer chromatography |
| TMS | tetramethylsilane |
| UHP | urea–hydrogen peroxide |
| UV | ultraviolet |
| v:v | volume per unit volume |

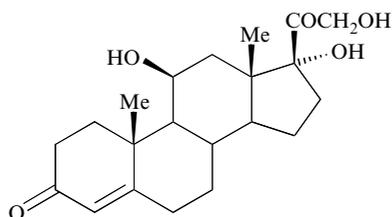
Part I Review

1 The Integration of Biotransformations into the Catalyst Portfolio

CONTENTS

| | | |
|-------|---|----|
| 1.1 | HYDROLYSIS OF ESTERS, AMIDES, NITRILES AND OXIRANES | 4 |
| 1.2 | REDUCTION REACTIONS | 9 |
| 1.2.1 | Reduction of carbonyl compounds | 10 |
| 1.2.2 | Reduction of alkenes | 13 |
| 1.3 | OXIDATIVE TRANSFORMATIONS | 17 |
| 1.4 | CARBON-CARBON BOND-FORMING REACTIONS | 26 |
| 1.5 | CONCLUSIONS | 37 |
| | REFERENCES | 39 |

The science of biotransformations has been investigated since the days of Pasteur^[1]. However, progress in the use of enzymes and whole cells in synthetic organic chemistry was relatively slow until the 1950s, when the use of microorganisms to modify the steroid nucleus was studied in industry and academic laboratories^[2]. Thus conversions such as the transformation of 17 α -acetoxy-11-deoxycortisol into cortisol (hydrocortisone) (**1**), using the microorganism



(1)

Curvularia lunata to introduce the 11 β -hydroxy group directly, helped to revive interest in the application of biological catalysis to problems in synthetic organic chemistry. The momentum was continued by Charles Sih, J. Bryan Jones, George Whitesides and others, until, by the mid-1980s, biocatalysis

was being accepted as a powerful method, especially for the production of optically active products^[3]. At this time the whole field was given another boost by Alexander Klivanov at the MIT who showed emphatically (but not for the first time) that some enzymes (especially lipases) could function in organic solvents, thus broadening the substrate range to include water-insoluble substances^[4].

For a while, in the early 1990s, the interest in the use of enzymes in organic synthesis increased at an almost exponential rate and two-volume works were needed even to summarize developments in the field^[5]. Now, at the turn of the century, it is abundantly clear that the science of biotransformations has a significant role to play in the area of preparative chemistry; however, it is, by no stretch of the imagination, a panacea for the synthetic organic chemist. Nevertheless, biocatalysis is the method of choice for the preparation of some classes of optically active materials. In other cases the employment of man-made catalysts is preferred. In this review, a comparison will be made of the different methods available for the preparation of various classes of chiral compounds^[6].

Obviously, in a relatively small work such as this it is not possible to be comprehensive. Preparations of bulk, achiral materials (e.g. simple oxiranes such as ethylene oxide) involving key catalytic processes will not be featured. Only a handful of representative examples of preparations of optically inactive compounds will be given, since the emphasis in the main body of this book, i.e. the experimental section, is on the preparation of chiral compounds. The focus on the preparation of compounds in single enantiomer form reflects the much increased importance of these compounds in the fine chemical industry (e.g. for pharmaceuticals, agrichemicals, fragrances, flavours and the suppliers of intermediates for these products).

The text of this short review article will be broken down into the following sections:

1. Hydrolysis of esters, amides, nitriles and oxiranes
2. Reduction reactions
3. Oxidative transformations
4. Carbon-carbon bond forming reactions.

In each of these areas the relative merits of biocatalysis versus other catalytic methodologies will be assessed. Note that the text is given an asterisk (*) when mention is made of a catalyst for a reduction or oxidation reaction that is featured in the later experimental section of this book.

1.1 HYDROLYSIS OF ESTERS, AMIDES, NITRILES AND OXIRANES

The enantioselective hydrolysis of racemic esters to give optically active acids and/or alcohols (Figure 1.1) is a well established protocol using esterases or lipases. In general, esterases from microorganisms or animal sources (such as