

Methods in Enzymology

Volume 331

Hyperthermophilic Enzymes *Part B*

EDITED BY

Michael W. W. Adams

THE UNIVERSITY OF GEORGIA
ATHENS, GEORGIA

Robert M. Kelly

NORTH CAROLINA STATE UNIVERSITY
RALEIGH, NORTH CAROLINA



ACADEMIC PRESS

San Diego London Boston New York Sydney Tokyo Toronto

This book is printed on acid-free paper. (∞)

Copyright © 2001 by ACADEMIC PRESS

All Rights Reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

The appearance of the code at the bottom of the first page of a chapter in this book indicates the Publisher's consent that copies of the chapter may be made for personal or internal use of specific clients. This consent is given on the condition, however, that the copier pay the stated per copy fee through the Copyright Clearance Center, Inc. (222 Rosewood Drive, Danvers, Massachusetts 01923) for copying beyond that permitted by Sections 107 or 108 of the U.S. Copyright Law. This consent does not extend to other kinds of copying, such as copying for general distribution, for advertising or promotional purposes, for creating new collective works, or for resale. Copy fees for pre-2000 chapters are as shown on the title pages. If no fee code appears on the title page, the copy fee is the same as for current chapters. /00 \$35.00

Explicit permission from Academic Press is not required to reproduce a maximum of two figures or tables from an Academic Press chapter in another scientific or research publication provided that the material has not been credited to another source and that full credit to the Academic Press chapter is given.

Academic Press

A Harcourt Science and Technology Company

525 B Street, Suite 1900, San Diego, California 92101-4495, USA

<http://www.academicpress.com>

Academic Press

Harcourt Place, 32 Jamestown Road, London NW1 7BY, UK

<http://www.academicpress.com>

International Standard Book Number: 0-12-182232-X

PRINTED IN THE UNITED STATES OF AMERICA

01 02 03 04 05 06 07 SB 9 8 7 6 5 4 3 2 1

Methods in Enzymology

Volume 331

HYPERTHERMOPHILIC ENZYMES

Part B

METHODS IN ENZYMOLOGY

EDITORS-IN-CHIEF

John N. Abelson Melvin I. Simon

DIVISION OF BIOLOGY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

FOUNDING EDITORS

Sidney P. Colowick and Nathan O. Kaplan

Contributors to Volume 331

Article numbers are in parentheses following the names of contributors.
Affiliations listed are current.

- MICHAEL W. W. ADAMS (11, 12, 13, 16, 18, 19), *Department of Biochemistry and Molecular Biology, The University of Georgia, Athens, Georgia 30602-7229*
- ADOLFO AMICI (24, 25), *Istituto di Biochimica, Università di Ancona, Ancona 60131, Italy*
- HARUYUKI ATOMI (29), *Department of Synthetic Chemistry and Biological Chemistry, Graduate School of Engineering, Kyoto University, Kyoto 606-8501, Japan*
- NILS-KÅRE BIRKELAND (2), *Department of Microbiology, University of Bergen, Bergen N-5020, Norway*
- KIM M. BORGES (3), *Department of Biology, University of Maine, Fort Kent, Maine 04743*
- NINA A. BRUNNER (10), *Universität Essen, Essen 45117, Germany*
- BERNARD CLANTIN (20), *Laboratoire de Microbiologie, Université Libre de Bruxelles, B-1070 Brussels, Belgium*
- GINA CROWHURST (8), *Schools of Chemistry and Biological Sciences, University of Exeter, Exeter EX4 4QD, United Kingdom*
- CHRISTIANE DAHL (31, 32, 33), *Institut für Mikrobiologie und Biotechnologie, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn D-53115, Germany*
- THOMAS DAMS (27), *Abteilung Struktur-forschung, Max Planck Institut für Biochemie, Martinsried D-82151, Germany*
- MICHAEL J. DANSON (1), *Centre for Extremophile Research, Department of Biology and Biochemistry, University of Bath, Bath BA2 7AY, United Kingdom*
- WILLEM M. DE VOS (4), *Laboratory of Microbiology, Wageningen University, 6703 CT Wageningen, The Netherlands*
- REINHARD DIRMEIER (34), *Universität Regensburg, Regensburg D-93053, Germany*
- JOCELYNE DIRUGGIERO (3), *Center of Marine Biotechnology, University of Maryland Biotechnology Institute, Baltimore, Maryland 21202*
- VIRGINIE DURBECQ (21), *Laboratoire de Microbiologie, Université Libre de Bruxelles, B-1070 Brussels, Belgium*
- MONICA EMANUELLI (24, 25), *Istituto di Biochimica, Università di Ancona, Ancona 60131, Italy*
- SATOSHI EZAKI (29), *Department of Synthetic Chemistry and Biological Chemistry, Graduate School of Engineering, Kyoto University, Kyoto 606-8501, Japan*
- ANTONIETTA GIORDANO (15), *Institute of Protein Biochemistry and Enzymology, National Council of Research, 80125 Naples, Italy*
- NICOLAS GLANSDORFF (20, 21), *Microbiology, Free University Brussels (VUB), Research Institute J. M. Wiame and Flanders Interuniversity Institute for Biotechnology, B-1070 Brussels, Belgium*
- REINHARD HENSEL (5, 6, 10), *Universität Essen, Essen 45117, Germany*
- DAVID W. HOUGH (1), *Centre for Extremophile Research, Department of Biology and Biochemistry, University of Bath, Bath BA2 7AY, United Kingdom*
- ANDREA M. HUTCHINS (13), *Department of Biochemistry and Molecular Biology, University of Georgia, Center for Metalloenzyme Studies, Athens, Georgia 30602-7229*
- HILDE HVOSLEF (2), *Department of Microbiology, University of Bergen, Bergen N-5020, Norway*
- TADAYUKI IMANAKA (29), *Department of Synthetic Chemistry and Biological Chemistry, Graduate School of Engineering, Kyoto University, Kyoto 606-8501, Japan*

- MICHAIL ISUPOV (9), *Schools of Chemistry and Biological Sciences, University of Exeter, Exeter EX4 4QD, United Kingdom*
- RAINER JAENICKE (27), *Institut für Biophysik und Physikalische Biochemie, Universität Regensburg, Regensburg D-93040, Germany*
- ULRIKE KAPPLER (32), *Department of Microbiology and Parasitology, The University of Queensland, Brisbane, Queensland 4072, Australia*
- MARTIN KELLER (34), *Diversa Corporation, San Diego, California 92121*
- SERVE W. M. KENGEN (4), *Laboratory of Microbiology, Wageningen University, 6703 CT Wageningen, The Netherlands*
- KASPER KIRSCHNER (23), *Abteilung für Biophysikalische Chemie, Biozentrum der Universität Basel, CH-4056 Basel, Switzerland*
- MICHAEL KOHLHOFF (6), *Universität Essen, Essen 45117, Germany*
- CHRISTIANNE LEGRAIN (20, 21), *Institut de Recherches Microbiologiques Jean-Marie Wiame, B-1070 Brussels, Belgium*
- DONGHUI LI (17), *113 Palmerston Avenue, Toronto, Ontario M6J 2J2, Canada*
- TORLEIV LIEN (2), *Department of Microbiology, University of Bergen, Bergen N-5020, Norway*
- JENNIFER A. LITTLECHILD (8, 9), *Schools of Chemistry and Biological Sciences, University of Exeter, Exeter EX4 4QD, United Kingdom*
- TERESA LORENZI (24, 25), *Istituto di Biochimica, Università di Ancona, Ancona 60131, Italy*
- KESEN MA (16, 18), *Department of Biology, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada*
- DENNIS L. MAEDER (3), *Center of Marine Biotechnology, University of Maryland Biotechnology Institute, Baltimore, Maryland 21202*
- GIULIO MAGNI (24, 25), *Istituto di Biochimica, Università di Ancona, Ancona 60131, Italy*
- XUHONG MAI (13), *Department of Biological Chemistry and Molecular Biology, University of Georgia, Athens, Georgia 30602*
- ALBERTO MARINA (21), *Instituto de Biomedicina de Valencia (CSIC), Valencia-46010, Spain*
- JANE MCHARG (8), *Schools of Chemistry and Biological Sciences, University of Exeter, Exeter EX4 4QD, United Kingdom*
- ANGELI L. MENON (11, 12), *Department of Biochemistry and Molecular Biology, University of Georgia, Center for Metalloenzyme Studies, Athens, Georgia 30602-7229*
- ASTRID MERZ (23), *Abteilung für Biophysikalische Chemie, Biozentrum der Universität Basel, CH-4056 Basel, Switzerland*
- MICHAEL MOLITOR (31), *Merlin Gesellschaft für mikrobiologische Diagnostika, D-53332 Bornheim, Germany*
- RALF MOLL (30), *Institute of Biochemistry, Medical University of Lübeck, Lübeck D-23538, Germany*
- KENNETH M. NOLL (7), *Department of Molecular and Cell Biology, University of Connecticut, Storrs, Connecticut 06269-3125*
- FRANCESCA M. PISANI (25), *Istituto di Biochimica delle Proteine ed Enzimologia, Consiglio Nazionale delle Ricerche, Naples 80125, Italy*
- CRISTINA PURCAREA (22), *Department of Biochemistry and Molecular Biology, Wayne State University School of Medicine, Detroit, Michigan 48201*
- NADIA RAFFAELLI (24, 25), *Istituto di Biochimica, Università di Ancona, Ancona 60131, Italy*
- CARLO A. RAIA (15), *Institute of Protein Biochemistry and Enzymology, National Council of Research, 80125 Naples, Italy*
- SANTIAGO RAMÓN-MAIQUES (21), *Instituto de Biomedicina de Valencia (CSIC), Valencia 46010, Spain*
- FRANK T. ROBB (3), *Center of Marine Biotechnology, University of Maryland Biotechnology Institute, Baltimore, Maryland 21202*

- MARTINE ROOVERS (20), *Flanders Interuniversity Institute for Biotechnology, B-1070, Brussels, Belgium*
- MOSÈ ROSSI (15), *Department of Organic and Biological Chemistry, University of Naples, 80134 Naples, Italy*
- ROOPALI ROY (11), *Department of Biochemistry and Molecular Biology, University of Georgia, Center for Metalloenzyme Studies, Athens, Georgia 30602-7229*
- VICENTE RUBIO (21), *Instituto de Biomedicina de Valencia (CSIC), Valencia 46010, Spain*
- SILVERIO RUGGIERI (24, 25), *Dipartimento di Biotechnologie Agrarie ed Ambientali, Università di Ancona, Ancona 60131, Italy*
- ALEXEI SAVCHENKO (26), *Banting and Best Department of Medical Research, C. H. Best Institute, Toronto, Ontario M5G 1L6, Canada*
- GÜNTER SCHÄFER (30), *Institute of Biochemistry, Medical University of Lübeck, Lübeck D-23538, Germany*
- CHRISTIAN L. SCHMIDT (30), *Institute of Biochemistry, Medical University of Lübeck, Lübeck D-23538, Germany*
- PETER SCHÖNHEIT (14), *Institut für Allgemeine Mikrobiologie, Christian-Albrechts-Universität Kiel, Kiel D-24118, Germany*
- ALEXANDER SCHRAMM (6), *Universität Essen, Essen 45117, Germany*
- GERTI J. SCHUT (12), *Department of Biochemistry and Molecular Biology, University of Georgia, Center for Metalloenzyme Studies, Athens, Georgia 30602-7229*
- SEIGO SHIMA (28), *Max Planck Institut für Terrestrische Mikrobiologie, D-35043 Marburg/Lahn, Germany*
- BETTINA SIEBERS (5), *Universität Essen, Essen 45117, Germany*
- DETLEF SPERLING (32), *Institut für Mikrobiologie und Biotechnologie, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn D-53115, Germany*
- VICTOR STALON (20), *Laboratoire de Microbiologie, Université Libre de Bruxelles and Institut de Recherches, Microbiologiques Jean-Marie Wiame, B-1070 Brussels, Belgium*
- ALFONS J. M. STAMS (4), *Laboratory of Microbiology, Wageningen University, 6703 CT Wageningen, The Netherlands*
- IDA HELENE STEEN (2), *Department of Microbiology, University of Bergen, Bergen N-5020, Norway*
- REINHARD STERNER (23), *Universität zu Köln, Institut für Biochemie, D-50674 Köln, Germany*
- KENNETH J. STEVENSON (17), *Department of Biological Sciences, University of Calgary, Calgary, Alberta T2N 1N4, Canada*
- RUDOLF K. THAUER (28), *Max Planck Institut für Terrestrische Mikrobiologie, D-35043 Marburg/Lahn, Germany*
- RALF THOMA (23), *Abteilung für Biophysikalische Chemie, Biozentrum der Universität Basel, CH-4056 Basel, Switzerland*
- NICCOLA TOLLIDAY (3), *Department of Molecular Biology, Harvard Medical School, Boston, Massachusetts 02114*
- CATHERINE TRICOT (20), *Institut de Recherches, Microbiologiques Jean-Marie Wiame, B-1070 Brussels, Belgium*
- HANS G. TRÜPER (31, 32, 33), *Institut für Mikrobiologie und Biotechnologie, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn D-53115, Germany*
- JUDITH E. TUININGA (4), *Laboratory of Microbiology, Wageningen University, 6703 CT Wageningen, The Netherlands*
- MATXALEN URIARTE (21), *Instituto de Biomedicina de Valencia (CSIC), Valencia 46010, Spain*
- JOZEF VAN BEEUMEN (20), *Laboratorium voor Eiwitbiochemie en Eiwitengineering, Universiteit Gent, B-9000 Gent, Belgium*
- JOHN VAN DER OOST (4), *Laboratory of Microbiology, Wageningen University, 6703 CT Wageningen, The Netherlands*
- MARC F. J. M. VERHAGEN (19), *Allergan, Inc., Athens, Georgia 30602*

CORNÉ H. VERHEES (4), *Laboratory of Microbiology, Wageningen University, 6703 CT Wageningen, The Netherlands*

CLAIRE VIEILLE (26), *Department of Biochemistry and Molecular Biology, Michigan State University, East Lansing, Michigan 48824*

VINCENT VILLERET (20), *Institut de Recherches, Microbiologiques Jean-Marie Wiame, B-1070 Brussels, Belgium*

WEI WANG (26), *Department of Biochemistry and Molecular Biology, Michigan State University, East Lansing, Michigan 48824*

JAE-SUNG YU (7), *Department of Biochemistry, Duke University Medical Center, Durham, North Carolina 27710*

J. GREGORY ZEIKUS (26), *Michigan Biotechnology Institute International, Lansing, Michigan 48909*

Preface

More than thirty years ago, the pioneering work of Thomas Brock of the University of Wisconsin on the microbiology of hot springs in Yellowstone National Park alerted the scientific community to the existence of microorganisms with optimal growth temperatures of 70°C and even higher. In the early 1980s, the known thermal limits of life were expanded by the seminal work of Karl Stetter and colleagues at the University of Regensburg, who isolated from a marine volcanic vent the first microorganisms that could grow at, and even above, the normal boiling point of water. Subsequent work by Stetter and several other groups have led to the discovery in a variety of geothermal biotopes of more than twenty different genera that can grow optimally at or above 80°C. Such organisms are now termed *hyperthermophiles*.

Initial efforts to explore the enzymology of hyperthermophiles were impeded by the difficulty of culturing the organisms on a scale large enough to allow the purification of specific proteins in sufficient quantities for characterization. This often meant processing hundreds of liters of nearly boiling fermentation media under anaerobic conditions. In addition, relatively low biomass yields were typically obtained. Nevertheless, the first “hyperthermophilic enzymes” were purified in the late 1980s. It was demonstrated that they are, indeed, extremely stable at high temperatures, that this is an intrinsic property, and that they exhibit no or very low activity at temperatures below the growth conditions of the organism from which they were obtained. At that time it was difficult to imagine how quickly the tools of molecular biology would make such a dramatic impact on the world of hyperthermophiles. In fact, it was unexpected that the recombinant forms of hyperthermophilic enzymes would, to a large extent, correctly achieve their active conformation in mesophilic hosts grown some 70°C below the enzyme’s source organism’s normal growth temperature. This approach provided a much-needed alternative to large-scale hyperthermophile cultivation. With the ever-expanding list of genomes from hyperthermophiles that have been or are being sequenced, molecular biology provides universal access to a treasure chest of known and putative proteins endowed with unprecedented levels of thermostability.

In Volumes 330, 331, and 334 of *Methods in Enzymology*, a set of protocols has been assembled that for the first time describe the methods involved in studying the biochemistry and biophysics of enzymes and proteins from hyperthermophilic microorganisms. As is evident from the various chapters, hyperthermophilic counterparts to a range of previously stud-

ied but less thermostable enzymes exist. In addition, the volumes include descriptions of many novel enzymes that were first identified and, in most cases, are still limited to, hyperthermophilic organisms. Also included in these volumes are genomic analyses from selected hyperthermophiles that provide some perspective on what remains to be investigated in terms of hyperthermophilic enzymology. Specific chapters address the basis for extreme levels of thermostability and special considerations that must be taken into account in defining experimentally the biochemical and biophysical features of hyperthermophilic enzymes.

There are many individuals whose pioneering efforts laid the basis for the work discussed in these volumes. None was more important than the late Holger Jannasch of Woods Hole Oceanographic Institute. His innovation and inspiration opened a new field of microbiology in deep-sea hydrothermal vents and provided the research world access to a biotope of great scientific and technological promise. Holger will be remembered in many ways, and it is a fitting tribute that the first genome of a hyperthermophile to be sequenced should bear his name: *Methanocaldococcus jannaschii*. We wish to recognize Holger's pioneering efforts by dedicating these volumes to him.

MICHAEL W. W. ADAMS
ROBERT M. KELLY

METHODS IN ENZYMOLOGY

VOLUME I. Preparation and Assay of Enzymes

Edited by SIDNEY P. COLOWICK AND NATHAN O. KAPLAN

VOLUME II. Preparation and Assay of Enzymes

Edited by SIDNEY P. COLOWICK AND NATHAN O. KAPLAN

VOLUME III. Preparation and Assay of Substrates

Edited by SIDNEY P. COLOWICK AND NATHAN O. KAPLAN

VOLUME IV. Special Techniques for the Enzymologist

Edited by SIDNEY P. COLOWICK AND NATHAN O. KAPLAN

VOLUME V. Preparation and Assay of Enzymes

Edited by SIDNEY P. COLOWICK AND NATHAN O. KAPLAN

VOLUME VI. Preparation and Assay of Enzymes (*Continued*)

Preparation and Assay of Substrates

Special Techniques

Edited by SIDNEY P. COLOWICK AND NATHAN O. KAPLAN

VOLUME VII. Cumulative Subject Index

Edited by SIDNEY P. COLOWICK AND NATHAN O. KAPLAN

VOLUME VIII. Complex Carbohydrates

Edited by ELIZABETH F. NEUFELD AND VICTOR GINSBURG

VOLUME IX. Carbohydrate Metabolism

Edited by WILLIS A. WOOD

VOLUME X. Oxidation and Phosphorylation

Edited by RONALD W. ESTABROOK AND MAYNARD E. PULLMAN

VOLUME XI. Enzyme Structure

Edited by C. H. W. HIRS

VOLUME XII. Nucleic Acids (Parts A and B)

Edited by LAWRENCE GROSSMAN AND KIVIE MOLDAVE

VOLUME XIII. Citric Acid Cycle

Edited by J. M. LOWENSTEIN

VOLUME XIV. Lipids

Edited by J. M. LOWENSTEIN

VOLUME XV. Steroids and Terpenoids

Edited by RAYMOND B. CLAYTON

VOLUME XVI. Fast Reactions

Edited by KENNETH KUSTIN

VOLUME XVII. Metabolism of Amino Acids and Amines (Parts A and B)*Edited by* HERBERT TABOR AND CELIA WHITE TABOR**VOLUME XVIII. Vitamins and Coenzymes (Parts A, B, and C)***Edited by* DONALD B. MCCORMICK AND LEMUEL D. WRIGHT**VOLUME XIX. Proteolytic Enzymes***Edited by* GERTRUDE E. PERLMANN AND LASZLO LORAND**VOLUME XX. Nucleic Acids and Protein Synthesis (Part C)***Edited by* KIVIE MOLDAVE AND LAWRENCE GROSSMAN**VOLUME XXI. Nucleic Acids (Part D)***Edited by* LAWRENCE GROSSMAN AND KIVIE MOLDAVE**VOLUME XXII. Enzyme Purification and Related Techniques***Edited by* WILLIAM B. JAKOBY**VOLUME XXIII. Photosynthesis (Part A)***Edited by* ANTHONY SAN PIETRO**VOLUME XXIV. Photosynthesis and Nitrogen Fixation (Part B)***Edited by* ANTHONY SAN PIETRO**VOLUME XXV. Enzyme Structure (Part B)***Edited by* C. H. W. HIRS AND SERGE N. TIMASHEFF**VOLUME XXVI. Enzyme Structure (Part C)***Edited by* C. H. W. HIRS AND SERGE N. TIMASHEFF**VOLUME XXVII. Enzyme Structure (Part D)***Edited by* C. H. W. HIRS AND SERGE N. TIMASHEFF**VOLUME XXVIII. Complex Carbohydrates (Part B)***Edited by* VICTOR GINSBURG**VOLUME XXIX. Nucleic Acids and Protein Synthesis (Part E)***Edited by* LAWRENCE GROSSMAN AND KIVIE MOLDAVE**VOLUME XXX. Nucleic Acids and Protein Synthesis (Part F)***Edited by* KIVIE MOLDAVE AND LAWRENCE GROSSMAN**VOLUME XXXI. Biomembranes (Part A)***Edited by* SIDNEY FLEISCHER AND LESTER PACKER**VOLUME XXXII. Biomembranes (Part B)***Edited by* SIDNEY FLEISCHER AND LESTER PACKER**VOLUME XXXIII. Cumulative Subject Index Volumes I-XXX***Edited by* MARTHA G. DENNIS AND EDWARD A. DENNIS**VOLUME XXXIV. Affinity Techniques (Enzyme Purification: Part B)***Edited by* WILLIAM B. JAKOBY AND MEIR WILCHEK**VOLUME XXXV. Lipids (Part B)***Edited by* JOHN M. LOWENSTEIN

VOLUME XXXVI. Hormone Action (Part A: Steroid Hormones)

Edited by BERT W. O'MALLEY AND JOEL G. HARDMAN

VOLUME XXXVII. Hormone Action (Part B: Peptide Hormones)

Edited by BERT W. O'MALLEY AND JOEL G. HARDMAN

VOLUME XXXVIII. Hormone Action (Part C: Cyclic Nucleotides)

Edited by JOEL G. HARDMAN AND BERT W. O'MALLEY

VOLUME XXXIX. Hormone Action (Part D: Isolated Cells, Tissues, and Organ Systems)

Edited by JOEL G. HARDMAN AND BERT W. O'MALLEY

VOLUME XL. Hormone Action (Part E: Nuclear Structure and Function)

Edited by BERT W. O'MALLEY AND JOEL G. HARDMAN

VOLUME XLI. Carbohydrate Metabolism (Part B)

Edited by W. A. WOOD

VOLUME XLII. Carbohydrate Metabolism (Part C)

Edited by W. A. WOOD

VOLUME XLIII. Antibiotics

Edited by JOHN H. HASH

VOLUME XLIV. Immobilized Enzymes

Edited by KLAUS MOSBACH

VOLUME XLV. Proteolytic Enzymes (Part B)

Edited by LASZLO LORAND

VOLUME XLVI. Affinity Labeling

Edited by WILLIAM B. JAKOBY AND MEIR WILCHEK

VOLUME XLVII. Enzyme Structure (Part E)

Edited by C. H. W. HIRS AND SERGE N. TIMASHEFF

VOLUME XLVIII. Enzyme Structure (Part F)

Edited by C. H. W. HIRS AND SERGE N. TIMASHEFF

VOLUME XLIX. Enzyme Structure (Part G)

Edited by C. H. W. HIRS AND SERGE N. TIMASHEFF

VOLUME L. Complex Carbohydrates (Part C)

Edited by VICTOR GINSBURG

VOLUME LI. Purine and Pyrimidine Nucleotide Metabolism

Edited by PATRICIA A. HOFFEE AND MARY ELLEN JONES

VOLUME LII. Biomembranes (Part C: Biological Oxidations)

Edited by SIDNEY FLEISCHER AND LESTER PACKER

VOLUME LIII. Biomembranes (Part D: Biological Oxidations)

Edited by SIDNEY FLEISCHER AND LESTER PACKER

VOLUME LIV. Biomembranes (Part E: Biological Oxidations)

Edited by SIDNEY FLEISCHER AND LESTER PACKER

VOLUME LV. Biomembranes (Part F: Bioenergetics)*Edited by* SIDNEY FLEISCHER AND LESTER PACKER**VOLUME LVI. Biomembranes (Part G: Bioenergetics)***Edited by* SIDNEY FLEISCHER AND LESTER PACKER**VOLUME LVII. Bioluminescence and Chemiluminescence***Edited by* MARLENE A. DELUCA**VOLUME LVIII. Cell Culture***Edited by* WILLIAM B. JAKOBY AND IRA PASTAN**VOLUME LIX. Nucleic Acids and Protein Synthesis (Part G)***Edited by* KIVIE MOLDAVE AND LAWRENCE GROSSMAN**VOLUME LX. Nucleic Acids and Protein Synthesis (Part H)***Edited by* KIVIE MOLDAVE AND LAWRENCE GROSSMAN**VOLUME 51. Enzyme Structure (Part H)***Edited by* C. H. W. HIRS AND SERGE N. TIMASHEFF**VOLUME 62. Vitamins and Coenzymes (Part D)***Edited by* DONALD B. MCCORMICK AND LEMUEL D. WRIGHT**VOLUME 63. Enzyme Kinetics and Mechanism (Part A: Initial Rate and Inhibitor Methods)***Edited by* DANIEL L. PURICH**VOLUME 64. Enzyme Kinetics and Mechanism (Part B: Isotopic Probes and Complex Enzyme Systems)***Edited by* DANIEL L. PURICH**VOLUME 65. Nucleic Acids (Part I)***Edited by* LAWRENCE GROSSMAN AND KIVIE MOLDAVE**VOLUME 66. Vitamins and Coenzymes (Part E)***Edited by* DONALD B. MCCORMICK AND LEMUEL D. WRIGHT**VOLUME 67. Vitamins and Coenzymes (Part F)***Edited by* DONALD B. MCCORMICK AND LEMUEL D. WRIGHT**VOLUME 68. Recombinant DNA***Edited by* RAY WU**VOLUME 69. Photosynthesis and Nitrogen Fixation (Part C)***Edited by* ANTHONY SAN PIETRO**VOLUME 70. Immunochemical Techniques (Part A)***Edited by* HELEN VAN VUNAKIS AND JOHN J. LANGONE**VOLUME 71. Lipids (Part C)***Edited by* JOHN M. LOWENSTEIN**VOLUME 72. Lipids (Part D)***Edited by* JOHN M. LOWENSTEIN

VOLUME 73. Immunochemical Techniques (Part B)*Edited by JOHN J. LANGONE AND HELEN VAN VUNAKIS***VOLUME 74. Immunochemical Techniques (Part C)***Edited by JOHN J. LANGONE AND HELEN VAN VUNAKIS***VOLUME 75. Cumulative Subject Index Volumes XXXI, XXXII, XXXIV–LX***Edited by EDWARD A. DENNIS AND MARTHA G. DENNIS***VOLUME 76. Hemoglobins***Edited by ERALDO ANTONINI, LUIGI ROSSI-BERNARDI, AND EMILIA CHIANCONE***VOLUME 77. Detoxication and Drug Metabolism***Edited by WILLIAM B. JAKOBY***VOLUME 78. Interferons (Part A)***Edited by SIDNEY PESTKA***VOLUME 79. Interferons (Part B)***Edited by SIDNEY PESTKA***VOLUME 80. Proteolytic Enzymes (Part C)***Edited by LASZLO LORAND***VOLUME 81. Biomembranes (Part H: Visual Pigments and Purple Membranes, I)***Edited by LESTER PACKER***VOLUME 82. Structural and Contractile Proteins (Part A: Extracellular Matrix)***Edited by LEON W. CUNNINGHAM AND DIXIE W. FREDERIKSEN***VOLUME 83. Complex Carbohydrates (Part D)***Edited by VICTOR GINSBURG***VOLUME 84. Immunochemical Techniques (Part D: Selected Immunoassays)***Edited by JOHN J. LANGONE AND HELEN VAN VUNAKIS***VOLUME 85. Structural and Contractile Proteins (Part B: The Contractile Apparatus and the Cytoskeleton)***Edited by DIXIE W. FREDERIKSEN AND LEON W. CUNNINGHAM***VOLUME 86. Prostaglandins and Arachidonate Metabolites***Edited by WILLIAM E. M. LANDS AND WILLIAM L. SMITH***VOLUME 87. Enzyme Kinetics and Mechanism (Part C: Intermediates, Stereochemistry, and Rate Studies)***Edited by DANIEL L. PURICH***VOLUME 88. Biomembranes (Part I: Visual Pigments and Purple Membranes, II)***Edited by LESTER PACKER***VOLUME 89. Carbohydrate Metabolism (Part D)***Edited by WILLIS A. WOOD***VOLUME 90. Carbohydrate Metabolism (Part E)***Edited by WILLIS A. WOOD*

VOLUME 91. Enzyme Structure (Part I)*Edited by C. H. W. HIRS AND SERGE N. TIMASHEFF***VOLUME 92. Immunochemical Techniques (Part E: Monoclonal Antibodies and General Immunoassay Methods)***Edited by JOHN J. LANGONE AND HELEN VAN VUNAKIS***VOLUME 93. Immunochemical Techniques (Part F: Conventional Antibodies, Fc Receptors, and Cytotoxicity)***Edited by JOHN J. LANGONE AND HELEN VAN VUNAKIS***VOLUME 94. Polyamines***Edited by HERBERT TABOR AND CELIA WHITE TABOR***VOLUME 95. Cumulative Subject Index Volumes 61–74, 76–80***Edited by EDWARD A. DENNIS AND MARTHA G. DENNIS***VOLUME 96. Biomembranes [Part J: Membrane Biogenesis: Assembly and Targeting (General Methods; Eukaryotes)]***Edited by SIDNEY FLEISCHER AND BECCA FLEISCHER***VOLUME 97. Biomembranes [Part K: Membrane Biogenesis: Assembly and Targeting (Prokaryotes, Mitochondria, and Chloroplasts)]***Edited by SIDNEY FLEISCHER AND BECCA FLEISCHER***VOLUME 98. Biomembranes (Part L: Membrane Biogenesis: Processing and Recycling)***Edited by SIDNEY FLEISCHER AND BECCA FLEISCHER***VOLUME 99. Hormone Action (Part F: Protein Kinases)***Edited by JACKIE D. CORBIN AND JOEL G. HARDMAN***VOLUME 100. Recombinant DNA (Part B)***Edited by RAY WU, LAWRENCE GROSSMAN, AND KIVIE MOLDAVE***VOLUME 101. Recombinant DNA (Part C)***Edited by RAY WU, LAWRENCE GROSSMAN, AND KIVIE MOLDAVE***VOLUME 102. Hormone Action (Part G: Calmodulin and Calcium-Binding Proteins)***Edited by ANTHONY R. MEANS AND BERT W. O'MALLEY***VOLUME 103. Hormone Action (Part H: Neuroendocrine Peptides)***Edited by P. MICHAEL CONN***VOLUME 104. Enzyme Purification and Related Techniques (Part C)***Edited by WILLIAM B. JAKOBY***VOLUME 105. Oxygen Radicals in Biological Systems***Edited by LESTER PACKER***VOLUME 106. Posttranslational Modifications (Part A)***Edited by FINN WOLD AND KIVIE MOLDAVE***VOLUME 107. Posttranslational Modifications (Part B)***Edited by FINN WOLD AND KIVIE MOLDAVE*