

Methods in Enzymology

Volume 336

Microbial Growth in Biofilms

Part A

Developmental and Molecular Biological Aspects

EDITED BY

Ron J. Doyle

UNIVERSITY OF LOUISVILLE
LOUISVILLE, KENTUCKY



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: 0-12-182237-0

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 336

MICROBIAL GROWTH IN BIOFILMS

Part A

Developmental and Molecular Biological Aspects

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 336

Article numbers are in parentheses following the names of contributors.

Affiliations listed are current.

- WOLF-RAINER ABRAHAM (26), *Division of Microbiology, GBF, German Research Centre for Biotechnology, D-38124 Braunschweig, Germany*
- MOHAMMAD ALAVI (3), *Center of Marine Biotechnology, University of Maryland Biotechnology Institute, Baltimore, Maryland 21202*
- PATRIZIA ALBERTANO (28), *Department of Biology, University of Rome, I-00133 Rome, Italy*
- MORITZ ALTEBAEUMER (8), *Department of Biological Sciences, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
- JENS BO ANDERSEN (12), *Department of Microbiology, Technical University of Denmark, Lyngby DK-2800, Denmark*
- GARY M. ARON (16), *Department of Biology, Southwest Texas State University, San Marcos, Texas 78666*
- RITA R. BACA-DELANCEY (11), *Departments of Medicine and of Molecular Biology and Microbiology, Case Western Reserve University, Cleveland, Ohio 44106*
- GRANT J. BALZER (16), *Department of Civil Engineering, Northwestern University, Evanston, Illinois 60208*
- KATRIN BARTSCHT (20), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- ACE M. BATY, III (24), *W. L. Gore & Associates, Inc., Flagstaff, Arizona 86002*
- ROBERT BELAS (3), *Center of Marine Biotechnology, University of Maryland Biotechnology Institute, Baltimore, Maryland 21202*
- ANTONIO BENNASAR (26), *Division of Microbiology, GBF, German Research Centre for Biotechnology, D-38124 Braunschweig, Germany*
- RODRIGO BIBILONI (33), *Centro de Investigación y Desarrollo en Criotecnología de Alimentos, Facultad de Ciencias Exactas, 1900 La Plata, Argentina*
- J. CLIFF BOUCHER (7), *Department of Microbiology, Harvard Medical School, Boston, Massachusetts 02115*
- JAMES D. BRYERS (9), *The Center for Biomaterials, Department of Biostructure and Function, University of Connecticut Health Center, Farmington, Connecticut 06030*
- JILLIAN CAPSTICK (17), *Department of Biotechnology and Environmental Biology, Royal Melbourne Institute of Technology, Bundoora 3083, Victoria, Australia*
- HOWARD CERI (8), *Department of Biological Sciences, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
- TIMOTHY CHARLTON (12), *School of Microbiology and Immunology and The Centre for Marine Biofouling and Bio-Innovation, University of New South Wales, Sydney 2052, Australia*
- KIMBERLY H. CHONG (1), *Departments of Medicine, and Microbiology and Immunology, Stanford University School of Medicine, Stanford, California 94305*
- PATRICIA L. CONWAY (31), *CRC Food Industry Innovation, School of Microbiology and Immunology, University of New South Wales, NSW 2052, Sydney, Australia*

- BRIAN D. CORBIN (16), *Department of Microbiology and Molecular Genetics, University of Texas–Houston Medical School, Houston, Texas 77030*
- SARAH E. CRAMTON (21), *Mikrobielle Genetik, Universität Tübingen, D-72076 Tübingen, Germany*
- PHILIPPE CRASSOUS (27), *Département d'Environnement Profond, DRO. IFREMER 29280, Plouzané, France*
- PAUL N. DANESE (2), *Department of Microbiology and Molecular Genetics, Harvard Medical School, Boston, Massachusetts 02115*
- GRACIELA L. DE ANTONI (33), *Centro de Investigación y Desarrollo en Criotecología de Alimentos, Facultad de Ciencias Exactas, 1900 La Plata, Argentina*
- CLEMENS DE GRAHL (20), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- MARGARET A. DEIGHTON (17), *Department of Biotechnology and Environmental Biology, Royal Melbourne Institute of Technology, Bundoora 3083, Victoria, Australia*
- ROCKY DENYS (12), *The Centre for Marine Biofouling and Bio-Innovation, University of New South Wales, Sydney 2052, Australia*
- VOJO DERETIC (7), *Department of Microbiology and Immunology, University of Michigan Medical School, Ann Arbor, Michigan 48109*
- XUEDONG DING (11), *Departments of Medicine and of Molecular Biology and Microbiology, Case Western Reserve University, Cleveland, Ohio 44106*
- E. ANIBAL DISALVO (33), *Cátedra de Química General e Inorgánica, Facultad de Farmacia y Bioquímica, Universidad, de Buenos Aires, 1113 Buenos Aires, Argentina*
- ZHENJUN DIWU (24), *Molecular Devices Corp., Sunnyvale, California 94089*
- SABINE DOBINSKY (20, 22), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- NADIA A. DOLGANOV (1), *Departments of Medicine, and Microbiology and Immunology, Stanford University School of Medicine, Stanford, California 94305*
- EWA DOMALEWSKI (17), *Department of Biotechnology and Environmental Biology, Royal Melbourne Institute of Technology, Bundoora 3083, Victoria, Australia*
- CORINNE DOREL (15), *Laboratoire de Microbiologie et Génétique (CNRS ERS 209), Institut National des Sciences Appliquées de Lyon, 69621 Villeurbanne, France*
- GLEN DUNHAM (24), *Interfacial and Processing Sciences, Environmental Molecular Sciences Laboratory, Pacific Northwest National Laboratories, Richland, Washington 99352*
- CALLIE C. EASTBURN (24), *Department of Microbiology and Center for Biofilm Engineering, Montana State University, Bozeman, Montana 59717-3980*
- PAUL D. FEY (19), *Department of Internal Medicine, University of Nebraska Medical Center, Omaha, Nebraska 68198*
- AARON M. FIROVED (7), *Department of Microbiology and Immunology, University of Michigan Medical School, Ann Arbor, Michigan 48109*
- CLAUDIA FISCHER (20), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- HANS-CURT FLEMMING (25), *Department of Aquatic Microbiology, University of Duisburg, 47057 Duisburg, Germany*

- BING S. GAN (32), *Lawson Health Research Institute, St. Joseph's Health Center, and Department of Surgery, University of Western Ontario, London, Ontario N6A 4V2, Canada*
- GILLIAN GARDINER (32), *Lawson Health Research Institute, St. Joseph's Health Center, University of Western Ontario, London, Ontario N6A 4V2, Canada*
- GRACIELA L. GARROTE (33), *Centro de Investigación y Desarrollo en Criotecnología de Alimentos, Facultad de Ciencias Exactas, 1900 La Plata, Argentina*
- GILL G. GEESEY (24), *Department of Microbiology and Center for Biofilm Engineering, Montana State University, Bozeman, Montana 59717*
- CHRISTIANE GERKE (21), *Mikrobielle Genetik, Universität Tübingen, D-72076 Tübingen, Germany*
- MICHAEL GIVSKOV (12), *Department of Microbiology, Technical University of Denmark, Lyngby DK-2800, Denmark*
- AMANDA E. GOODMAN (24), *Flinders University of South Australia, Adelaide 5001, South Australia*
- FRIEDRICH GÖTZ (21), *Mikrobielle Genetik, Universität Tübingen, D-72076 Tübingen, Germany*
- E. P. GREENBERG (4), *Department of Microbiology, College of Medicine, University of Iowa, Iowa City, Iowa 52242*
- JEAN GUEZENNEC (27), *Laboratoire de Biochimie des Molécules Marines, DRV/VP, IFREMER 29280, Plouzané, France*
- CLAUDIA GURTNER (29), *Institute of Microbiology and Genetics, University of Vienna, A-1030 Vienna, Austria*
- JÖRG HACKER (18), *Institut für Molekulare Infektionsbiologie, D-97070 Würzburg, Germany*
- MARTINA HAUSNER (13), *Institute of Water Quality Control and Waste Management, Technical University of Munich, D-85748 Garching, Germany*
- CHRISTINE HEINEMANN (32), *Lawson Health Research Institute, St. Joseph's Health Center, University of Western Ontario, London, Ontario N6A 4V2, Canada*
- LARISSA HENDRICKX (13), *Institute of Water Quality Control and Waste Management, Technical University of Munich, D-85748 Garching, Germany*
- MORTEN HENTZER (12), *Department of Microbiology, Technical University of Denmark, Lyngby DK-2800, Denmark*
- GUILLERMO HERNÁNDEZ-DUQUE (27), *Facultad de Ingeniería, Universidad del Mayab, Cordemex 97310, Mérida, Yucatán, Mexico*
- MATTHIAS A. HORSTKOTTE (20), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- JEFFREY HOWARD (32), *Lawson Health Research Institute, St. Joseph's Health Center, University of Western Ontario, London, Ontario N6A 4V2, Canada*
- JAN JORE (30), *Department of Applied Microbiology and Gene Technology, TNO Voeding Nutrition and Food Research Institute, 3700 AJ Zeist, The Netherlands*
- SIBYLLE KALMBACH (23), *Studienstiftung des Deutschen Volkes, D-53173 Bonn, Germany*
- DANIEL B. KEARNS (10), *Department of Molecular and Cellular Biology, Harvard University, Cambridge, Massachusetts 02138*
- KATHRIN KIEL (20), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- STAFFAN KJELLEBERG (12), *The School of Microbiology and Immunology and The Centre for Marine Biofouling and Bio-Innovation, University of New South Wales, Sydney 2052, Australia*

- JOHANNES K.-M. KNOBLOCH (20), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- ROBERTO KOLTER (2), *Department of Microbiology and Molecular Genetics, Harvard Medical School, Boston, Massachusetts 02115*
- VANESSA KRIMMER (18), *Institut für Molekulare Infektionsbiologie, D-97070 Würzburg, Germany*
- MARTIN KUEHN (13), *Institute of Water Quality Control and Waste Management, Technical University of Munich, D-85748 Garching, Germany*
- RICHARD J. LAMONT (9), *Department of Oral Biology, University of Washington, Seattle, Washington 98195*
- THANH-THUY LE THI (15), *Laboratoire de Microbiologie et Génétique (CNRS ERS 209), Institut National des Sciences Appliquées de Lyon, 69621 Villeurbanne, France*
- ROB J. LEER (30), *Department of Applied Microbiology and Gene Technology, TNO Voeding Nutrition and Food Research Institute, 3700 AJ Zeist, The Netherlands*
- ANDREW LEIS (25), *Department of Aquatic Microbiology, University of Duisburg, 47057 Duisburg, Germany*
- PHILIPPE LEJEUNE (15), *Laboratoire de Microbiologie et Génétique (CNRS ERS 209), Institut National des Sciences Appliquées de Lyon, 69621 Villeurbanne, France*
- ISABEL LOESSNER (18), *Institut für Molekulare Infektionsbiologie, D-97070 Würzburg, Germany*
- ALEJANDRO LÓPEZ-CORTÉS (27), *Laboratorio de Ecología y Biotecnología Microbiana, CIBNOR, Mar Bermejo #195, La Paz, Baja California Sur, Mexico*
- WERNER LUBITZ (29), *Institute of Microbiology and Genetics, University of Vienna, A-1030 Vienna, Austria*
- HEINRICH LÜNSDORF (26), *Division of Microbiology, GBF, German Research Centre for Biotechnology, D-38124 Braunschweig, Germany*
- DIETRICH MACK (20, 22), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- WERNER MANZ (23), *Technical University Berlin, Microbial Ecology, D-10587 Berlin, Germany*
- BEATRIZ MARTINEZ (30), *Instituto de Productos Lacteos de Asturias, CSIC, 33300 Villaviciosa, Spain*
- ROBERT J. C. MCLEAN (16), *Department of Biology, Southwest Texas State University, San Marcos, Texas 78666*
- KARIN MEIBOM (1), *Departments of Medicine, and Microbiology and Immunology, Stanford University School of Medicine, Stanford, California 94305*
- EDWARD R. B. MOORE (26), *Division of Microbiology, GBF, German Research Centre for Biotechnology, D-38124 Braunschweig, Germany*
- PETER MULLANY (6), *Department of Microbiology, Eastman Dental Institute for Oral Health Care Sciences, University College London, London WC1X 8LD, United Kingdom*
- BENJAMÍN OTTO ORTEGA-MORALES (27), *Laboratorio de Microbiología Ambiental y Biotecnología (CIET), Universidad Autonoma de Campeche, Lindavista CP 24030, Campeche, Camp., Mexico*
- A. MARK OSBORN (26), *Division of Microbiology, GBF, German Research Centre for Biotechnology, D-38124 Braunschweig, Germany*

- MICHAEL D. PARKINS (8), *Department of Biological Sciences, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
- MATTHEW R. PARSEK (4), *Department of Civil Engineering, Northwestern University, Evanston, Illinois 60208*
- PABLO F. PÉREZ (33), *Centro de Investigación y Desarrollo en Criotecnología de Alimentos, Facultad de Ciencias Exactas, 1900 La Plata, Argentina*
- GUADALUPE PIÑAR (29), *Institute of Microbiology and Genetics, University of Vienna, A-1030 Vienna, Austria*
- JENS F. POSCHET (7), *Department of Microbiology and Immunology, University of Michigan Medical School, Ann Arbor, Michigan 48109*
- PETER H. POWELS (30), *Department of Applied Microbiology and Gene Technology, TNO Voeding Nutrition and Food Research Institute, 3700 AJ Zeist, The Netherlands, and Special Programme Infectious Diseases, TNO Prevention and Health, 2301 CE Leiden, The Netherlands, and Wageningen Centre for Food Sciences, 6700 AN Wageningen, The Netherlands*
- LESLIE A. PRATT (2), *Department of Microbiology and Molecular Genetics, Harvard Medical School, Boston, Massachusetts 02115*
- CLAIRE PRIGENT-COMBARET (15), *Laboratoire de Microbiologie et Génétique (CNRS ERS 209), Institut National des Sciences Appliquées de Lyon, 69621 Villeurbanne, France*
- PHILIP N. RATHER (11), *Departments of Medicine and of Molecular Biology and Microbiology, Case Western Reserve University, and Research Service, Cleveland Veterans Affairs Medical Center, Cleveland, Ohio 44106*
- GREGOR REID (32), *Lawson Health Research Institute, St. Joseph's Health Centre, and Departments of Microbiology and Immunology, and Surgery, University of Western Ontario, London, Ontario N6A 4V2, Canada*
- SCOTT RICE (12), *The School of Microbiology and Immunology and The Centre for Marine Biofouling and Bio-Innovation, University of New South Wales, Sydney 2052, Australia*
- ADAM P. ROBERTS (6), *Department of Microbiology, Eastman Dental Institute for Oral Health Care Sciences, University College London, London WC1X 8LD, United Kingdom*
- ALEXANDER RODE (25), *Department of Aquatic Microbiology, University of Duisburg, 47057 Duisburg, Germany*
- KARSTEN RODENACKER (13), *GSF National Research Centre for Environment and Health, Institute of Biomathematics and Biometry, D-85764 Neuherberg, Germany*
- HOLGER ROHDE (20), *Institut für Medizinische Mikrobiologie und Immunologie, Universitätsklinikum Hamburg-Eppendorf, 20246 Hamburg, Germany*
- MAURILIA ROJAS (31), *Department of General and Marine Microbiology, University of Göteborg, S-413 90 Göteborg, Sweden and Universidad Autonoma de B.C.S., La Paz, Baja California Sur, Mexico*
- SABINE RÖLLEKE (29), *Institute of Microbiology and Genetics, University of Vienna, A-1030 Vienna, Austria*
- UTE RÖMLING (5), *Research Group "Clonal Variability," Department of Cell Biology and Immunology, Gesellschaft für Biotechnologische Forschung, D-38124 Braunschweig, Germany*
- MARK E. RUPP (19), *Department of Internal Medicine, University of Nebraska Medical Center, Omaha, Nebraska 68198*

- AMY L. SCHAEFER (4), *Department of Microbiology, College of Medicine, University of Iowa, Iowa City, Iowa 52242*
- DIRK SCHNAPPINGER (1), *Departments of Medicine, and Microbiology and Immunology, Stanford University School of Medicine, Stanford, California 94305*
- GARY K. SCHOOLNIK (1), *Departments of Medicine, and Microbiology and Immunology, Stanford University School of Medicine, Stanford, California 94305*
- JOS F. M. L. SEEGER (30), *Special Programme Infectious Diseases, TNO Prevention and Health, 2301 CE Leiden, The Netherlands*
- LAWRENCE J. SHIMKETS (10), *Department of Microbiology, University of Georgia, Athens, Georgia 30602*
- SOOFIA SIDDIQUI (11), *Research Service, Cleveland Veterans Affairs Medical Center, Cleveland, Ohio 44106*
- EGBERT SMIT (30), *Department of Applied Microbiology and Gene Technology, TNO Voeding Nutrition and Food Research Institute, 3700 AJ Zeist, The Netherlands*
- DOUGLAS G. STOREY (8), *Department of Biological Sciences, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
- MARTIN STRATHMANN (25), *Department of Aquatic Microbiology, University of Duisburg, 47057 Duisburg, Germany*
- CARSTEN STRÖMPL (26), *Division of Microbiology, GBF, German Research Centre for Biotechnology, D-38124 Braunschweig, Germany*
- PETER A. SUCI (24), *Department of Microbiology and Center for Biofilm Engineering, Montana State University, Bozeman, Montana 59717*
- SOMKIET TECHKARNJANARUK (24), *Biochemical Engineering and Pilot Plant Research and Development Unit, National Center for Genetic Engineering and Biotechnology, King Mongkut's University of Technology, Thonburi Thakham, Bangkhuntien, Bangkok, Thailand 10150*
- FRANS J. TIELEN (30), *Special Programme Infectious Diseases, TNO Prevention and Health, 2301 CE Leiden, The Netherlands*
- KENNETH N. TIMMIS (26), *Division of Microbiology, German Research Centre for Biotechnology, D-38124 Braunschweig, Germany*
- CLARA URZÌ (28), *Department of Microbiological, Genetic, and Molecular Sciences, University of Messina, I-98166 Messina, Italy*
- TRUNG VAN NGUYEN (17), *Department of Biotechnology and Environmental Biology, Royal Melbourne Institute of Technology, Bundoora 3083, Victoria, Australia*
- MARTIN I. VOSKUIL (1), *Departments of Medicine, and Microbiology and Immunology, Stanford University School of Medicine, Stanford, California 94305*
- ALDWIN VRIESEMA (30), *Department of Applied Microbiology and Gene Technology, TNO Voeding Nutrition and Food Research Institute, 3700 AJ Zeist, The Netherlands*
- MICHAEL WAGNER (23), *Technical University Munich, Department of Microbiology, D-85350 Freising, Germany*
- MICHAEL WILSON (6), *Department of Microbiology, Eastman Dental Institute for Oral Health Care Sciences, University College London, London WC1X 8LD, United Kingdom*
- MICHAEL A. WILSON (1), *National Institute of Allergy and Infectious Diseases, National Institutes of Health, Bethesda, Maryland 20892*
- JOST WINGENDER (25), *Department of Aquatic Microbiology, University of Duisburg, 47057 Duisburg, Germany*

DANIEL J. WOZNIAK (14), *Department of Microbiology and Immunology, Wake Forest University School of Medicine, Winston-Salem, North Carolina 27157*

STEFAN WUERTZ (13), *Institute of Water Quality Control and Waste Management, Technical University of Munich, D-85748 Garching, Germany*

TIMNA J. O. WYCKOFF (14), *Department of Microbiology and Immunology, Wake*

Forest University School of Medicine, Winston-Salem, North Carolina 27157

FITNAT H. YILDIZ (1), *Departments of Medicine, and Microbiology and Immunology, Stanford University School of Medicine, Stanford, California 94305*

WILMA ZIEBUHR (18), *Institut für Molekulare Infektionsbiologie, D-97070 Würzburg, Germany*

Preface

Biofilms are usually characterized as a consortia of microorganisms surrounded by a protecting matrix of secreted polymers that are in most cases acidic polysaccharides, but may possess various functional groups other than carboxylate. In biofilms, the microorganisms possess regulatory molecules distinct from those produced by planktonic microorganisms. It is now possible not only to detect specific species and strains in a biofilm matrix, but also to identify which of their genes are up- or down-regulated in the planktonic cell to biofilm cell transition.

The advances in molecular biology methods have been paralleled by advances in instrumental and chemical probes used to define biofilm properties. Literature has burgeoned on all aspects of biofilms in the past few years. This growing literature, coupled with the recognition that biofilms are important in disease, industry, agriculture, and biotechnology, has prompted the development of a series of *Methods in Enzymology* volumes. The first, Volume 310, was concerned with the general approaches to biofilm molecular biology and the physical methods to probe biofilm structures. Volumes 336 and 337 focus on microbial growth in biofilms. In this volume emphasis is on the genetics and molecular biology of biofilm genesis. Its companion Volume 337 focuses on special environments and specific microorganisms contributing to biofilms. Collectively, the three volumes comprise methods from the leading researchers in the world. The following decades of research on biofilms will borrow heavily from these volumes.

I thank Shirley Light of Academic Press for her competent handling of numerous questions related to the development of the volumes on biofilms.

RON J. DOYLE

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 61. 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