Methods in Enzymology

Volume 206

CYTOCHROME P450

Methods in Enzymology

Volume 206

Cytochrome P450

EDITED BY

Michael R. Waterman

DEPARTMENT OF BIOCHEMISTRY
THE UNIVERSITY OF TEXAS SOUTHWESTERN MEDICAL CENTER AT DALLAS
DALLAS, TEXAS

Eric F. Johnson

DIVISION OF BIOCHEMISTRY
SCRIPPS CLINIC AND RESEARCH FOUNDATION
LA JOLLA, CALIFORNIA

ACADEMIC PRESS, INC.
Harcourt Brace Jovanovich, Publishers
San Diego New York Boston
London Sydney Tokyo Toronto

This book is printed on acid-free paper. ∞

Academic Press, Inc.
San Diego, California 92101

United Kingdom Edition published by
ACADEMIC PRESS LIMITED
24-28 Oval Road, London NW1 7DX

Library of Congress Catalog Card Number: 54-9110

ISBN 0-12-182107-2 (alk. paper)

PRINTED IN THE UNITED STATES OF AMERICA
91 92 93 94 9 8 7 6 5 4 3 2 1

Contributors to Volume 206

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

SANKAR ADDYA (57), *Department of Animal Biology, School of Veterinary Medicine, University of Pennsylvania, Philadelphia, Pennsylvania 19104*

RAGNHILD AHLGREN (62), *Department of Medical Nutrition, Karolinska Institute, Huddinge University Hospital, S-141 86 Huddinge, Sweden*

KAORU AIDA (25), *Pharmacogenetics Section, Laboratory of Reproductive and Developmental Toxicology, National Institute of Environmental Health Sciences, National Institutes of Health, Research Triangle Park, North Carolina 27709*

TOSHIFUMI AOYAMA (8), *Laboratory of Molecular Carcinogenesis, National Cancer Institute, National Institutes of Health, Bethesda, Maryland 20892*

MICHAEL ARAND (19), *Institute of Toxicology, University of Mainz, D-6500 Mainz, Germany*

MICHAEL P. ARLOTTO (43), *Department of Biochemistry, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

NARAYAN G. AVADHANI (57), *Department of Animal Biology, School of Veterinary Medicine, University of Pennsylvania, Philadelphia, Pennsylvania 19104*

CLAUDE BONFILS (33), *Institut National de la Sante et de la Recherche Medicale, CNRS, 34033 Montpellier Cedex, France*

ALAN R. BOOBIS (22), *Department of Clinical Pharmacology, Royal Postgraduate Medical School, London W12 ONN, England*

WILLIAM R. BRIAN (14), *Smith Kline Beecham Pharmaceuticals, King of Prussia, Pennsylvania 19406*

BARBARA BURKHART (25), *Pharmacogenetics Section, Laboratory of Reproductive and Developmental Toxicology, National Institute of Environmental Health Sciences, National Institutes of Health, Research Triangle Park, North Carolina 27709*

JORGE H. CAPDEVILA (42), *Departments of Medicine and Biochemistry, Vanderbilt University Medical School, Nashville, Tennessee 37232*

JOHN Y. L. CHIANG (46), *Department of Biochemistry and Molecular Pathology, Northeastern Ohio Universities College of Medicine, Rootstown, Ohio 44272*

BARBARA J. CLARK (10), *Department of Biochemistry, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

JOAN E. CLARK (41), *Department of Biochemistry, The University of Texas Health Science Center at San Antonio, San Antonio, Texas 78284*

MINOR J. COON (59), *Department of Biological Chemistry, University of Michigan Medical School, Ann Arbor, Michigan 48109*

MARIA ALMIRA CORREIA (30), *Department of Pharmacology, University of California, San Francisco, San Francisco, California 94143*

CHARLES L. CRESPI (13), *GENTEST Corporation, Woburn, Massachusetts 01801*

MARTINE DAUJAT (33), *Institut National de la Sante et de la Recherche Medicale, CNRS, 34033 Montpellier Cedex, France*

XINXIN DING (59), *Department of Biological Chemistry, University of Michigan Medical School, Ann Arbor, Michigan 48109*

ELIZABETH DISHMAN (42), *Department of Medicine, Vanderbilt University Medical School, Nashville, Tennessee 37232*

JOHANNES DOEHMER (12), *Institut für Toxikologie und Umwelthygiene, Technische Universität, D-8000 München 19, Germany*

JANICE G. DOUGLAS (35), *Department of Medicine, Case Western Reserve University, Cleveland, Ohio 44106*

DEBORAH DUNBAR (5), *Wadsworth Center for Laboratories and Research, New York State Department of Health, Albany, New York 12201*

ROBERT J. EDWARDS (22), *Department of Clinical Pharmacology, Royal Postgraduate Medical School, London W12 ONN, England*

CORNELIS J. ELFERINK (38), *Department of Pharmacology, Stanford University School of Medicine, Stanford, California 94305*

RONALD W. ESTABROOK (43), *Department of Biochemistry, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

GÉRARD FABRE (33), *Service Métabolisme et Pharmacocinétique, Sanofi-Recherche, 34082 Montpellier Cedex, France*

ISABELLE FABRE (33), *Institut National de la Sante et de la Recherche Medicale, CNRS, 34033 Montpellier Cedex, France*

J. R. FALCK (42), *Department of Molecular Genetics, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

DJORDJE FILIPOVIC (3), *Department of Biochemistry and Beckman Institute, University of Illinois, Urbana, Illinois 61801*

MICHAEL R. FRANKLIN (55), *Department of Pharmacology and Toxicology, University of Utah, Salt Lake City, Utah 84112*

THOMAS FRIEDBERG (19), *Institute of Toxicology, University of Mainz, D-6500 Mainz, Germany*

YOSHIAKI FUJII-KURIYAMA (16), *Department of Chemistry, Faculty of Science, Tohoku University, Aoba, Sendai 980, Japan*

HARRY V. GELBOIN (8, 9), *Laboratory of Molecular Carcinogenesis, National Cancer Institute, National Institutes of Health, Bethesda, Maryland 20892*

BRIAN GEMZIK (23), *Department of Pharmacology, Toxicology and Therapeutics, Center for Environmental and Occupational Health, University of Kansas Medical Center, Kansas City, Kansas 66103*

LOIS M. GEREN (4), *Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701*

G. GORDON GIBSON (34), *Molecular Toxicology Group, School of Biological Sciences, University of Surrey, Guildford, Surrey GU2 5XH, England*

ARTHUR L. GOLDNER (35), *Department of Medicine, Case Western Reserve University, Cleveland, Ohio 44106*

FRANK J. GONZALEZ (8, 9), *Laboratory of Molecular Carcinogenesis, National Cancer Institute, National Institutes of Health, Bethesda, Maryland 20892*

ALAN C. GOUGH (15), *Human Genetic Resources Laboratory, Imperial Cancer Research Fund, Hertfordshire EN6 3LD, England*

F. PETER GUENGERICH (14), *Department of Biochemistry, Vanderbilt University School of Medicine, Nashville, Tennessee 37232*

JAN-ÅKE GUSTAFSSON (62, 63), *Department of Medical Nutrition, Karolinska Institute, Huddinge University Hospital, S-141 86 Huddinge, Sweden*

PHILIP S. GUZELIAN (32), *Division of Clinical Toxicology and Environmental Medicine, Department of Medicine, Medical College of Virginia, Richmond, Virginia 23113*

JAMES R. HALPERT (53), *Department of Pharmacology and Toxicology, College of Pharmacy, University of Arizona, Tucson, Arizona 85721*

DIANNE K. HAMMOND (64), *Department of Pharmacology and Toxicology, The University of Texas Medical Branch, Galveston, Texas 77550*

OLIVER HANKINSON (37), *Department of Pathology and Laboratory of Biomedical and Environmental Sciences, University of California, Los Angeles, Los Angeles, California 90024*

JAMES P. HARDWICK (26), *Department of Biochemistry and Molecular Pathology, Northeastern Ohio Universities College of Medicine, Rootstown, Ohio 44272*

CHRISTOPHER HASSETT (28), *Department of Environmental Health, University of Washington, Seattle, Washington 98195*

SHIN-ICHI HAYASHI (62), *Department of Biochemistry, Saitama Cancer Center Research Institute, Ina-machi, Saitama-ken 362, Japan*

MARKUS H. HEIM (17), *Department of Pharmacology, Biocenter of the University of Basel, CH-4056 Basel, Switzerland*

YUJIRO HIGASHI (16), *Department of Molecular Biology, Faculty of Science, Nagoya University, Chigusa, Nagoya 464-01, Japan*

PETER J. HORNSBY (36), *Department of Biochemistry and Molecular Biology, Medical College of Georgia, Augusta, Georgia 30912*

RONALD L. HORST (47), *Department of Physiology, National Animal Disease Center, Agricultural Research Service, U.S. Department of Agriculture, Ames, Iowa 50010*

HIROYUKI ISHIZAKI (58), *Laboratory for Cancer Research, Department of Chemical Biology and Pharmacognosy, College of Pharmacy, Rutgers University, Piscataway, New Jersey 08855*

AKIO ITO (7), *Department of Biology, Faculty of Science, Kyushu University, Fukuoka, Fukuoka 812, Japan*

ERIC F. JOHNSON (21), *Division of Biochemistry, Scripps Clinic and Research Foundation, La Jolla, California 92037*

LAURENCE S. KAMINSKY (5), *Wadsworth Center for Laboratories and Research, New York State Department of Health, Albany, New York 12201*

ARMANDO KARARA (42), *Department of Medicine, Vanderbilt University Medical School, Nashville, Tennessee 37232*

RYUICHI KATO (18), *Department of Pharmacology, School of Medicine, Keio University, Tokyo 160, Japan*

BYRON KEMPER (6), *Department of Physiology and Biophysics, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801*

SHIOKO KIMURA (9), *Laboratory of Molecular Carcinogenesis, National Cancer Institute, National Institutes of Health, Bethesda, Maryland 20892*

WOLFGANG KISSEL (19), *Institute of Toxicology, University of Mainz, D-6500 Mainz, Germany*

JOHN A. KOCH (29), *Department of Biological Chemistry and Molecular Pharmacology and Dana-Farber Cancer Institute, Harvard Medical School, Boston, Massachusetts 02115*

DENNIS R. KOOP (35), *Department of Environmental Health Sciences, Case Western Reserve University, Cleveland, Ohio 44106*

THOMAS KRONBACH (49), *Department of Drug Metabolism, Goedecke Research Institute, D-7800 Freiburg, Germany*

RONALD M. LAETHEM (35), *Department of Environmental Health Sciences, Case Western Reserve University, Cleveland, Ohio 44106*

BRIAN G. LAKE (34), *British Industrial Biological Research Association, Carshalton, Surrey SM5 4DS, England*

JANE R. LAPSON (11), *Department of Biological Chemistry, University of Michigan Medical School, Ann Arbor, Michigan 48109*

JEROME M. LASKER (56), *Alcohol Research and Treatment Center, Bronx Veterans Administration Medical Center, and Mt. Sinai School of Medicine, New York, New York 10468*

WILLIAM LAWSON (5), *Wadsworth Center for Laboratories and Research, New York State Department of Health, Albany, New York 12201*

EDWIN D. LEPHART (45), *Departments of Biochemistry and Obstetrics and Gynecology, Cecil H. and Ida Green Center for Reproductive Biology Sciences, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

DONNA LI (32), *Division of Clinical Toxicology and Environmental Medicine, Department of Medicine, Medical College of Virginia, Richmond, Virginia 23113*

J.-Y. LU (60), *Department of Biochemistry, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

MICHAEL P. MANNS (21), *Department of Medicine I, Johannes Gutenberg Universität, D-6500 Mainz, Germany*

CATHLEEN A. MARTIN (47), *Department of Biological Chemistry, The Johns Hopkins University School of Medicine, Baltimore, Maryland 21205*

BETTIE SUE SILER MASTERS (41), *Department of Biochemistry, The University of Texas Health Science Center at San Antonio, San Antonio, Texas 78284*

PATRICK MAUREL (33), *Institut National de la Sante et de la Recherche Medicale, CNRS, 34033 Montpellier Cedex, France*

JAN M. MCALLISTER (36), *Department of Obstetrics and Gynecology, Cecil H. and Ida Green Center for Reproductive Biology Sciences, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

R. A. MCKINNON (48), *Department of Clinical Pharmacology, The Flinders University of South Australia, Bedford Park, South Australia 5042, Australia*

M. E. MCMANUS (48), *Department of Clinical Pharmacology, The Flinders University of South Australia, Bedford Park, South Australia 5042, Australia*

URS A. MEYER (17), *Department of Pharmacology, Biocenter of the University of Basel, CH-4056 Basel, Switzerland*

FRANCIS S. MILLETT (4), *Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701*

BERNARD P. MURRAY (22), *Department of Clinical Pharmacology, Royal Postgraduate Medical School, London W12 ONN, England*

JOSEPH L. NAPOLI (47), *Department of Biochemistry, School of Medicine, State University of New York at Buffalo, Buffalo, New York 14214*

DANIEL W. NEBERT (1), *Department of Environmental Health, University of Cincinnati Medical Center, Cincinnati, Ohio 45267*

MASAHIKO NEGISHI (25), *Pharmacogenetics Section, Laboratory of Reproductive and Developmental Toxicology, National Institute of Environmental Health Sciences, National Institutes of Health, Research Triangle Park, North Carolina 27709*

DAVID R. NELSON (1), *Department of Biochemistry and Biophysics, University of North Carolina, Chapel Hill, North Carolina 27599*

FRANZ OESCH (12, 19), *Institute of Toxicology, University of Mainz, D-6500 Mainz, Germany*

STEVEN T. OKINO (27), *Biomedical Sciences Graduate Program, Cancer Center, University of California, San Diego, La Jolla, California 92093*

JANICE RICE OKITA (41), *School of Pharmacy, Washington State University, Pullman, Washington 99164*

RICHARD T. OKITA (41), *School of Pharmacy, Washington State University, Pullman, Washington 99164*

CURTIS J. OMIECINSKI (28), *Department of Environmental Health, University of Washington, Seattle, Washington 98195*

TSUNEO OMURA (7), *Department of Molecular Biology, Graduate School of Medical Science, Kyushu University, Fukuoka, Fukuoka 812, Japan*

PAUL R. ORTIZ DE MONTELLANO (52), *Department of Pharmaceutical Chemistry, School of Pharmacy, University of California, San Francisco, San Francisco, California 94143*

ANDREW PARKINSON (23), *Department of Pharmacology, Toxicology and Therapeutics, Center for Environmental and Occupational Health, University of Kansas Medical Center, Kansas City, Kansas 66103*

CHRISTOPHER J. PATTEN (58), *Laboratory for Cancer Research, Department of Chemical Biology and Pharmacognosy, College of Pharmacy, Rutgers University, Piscataway, New Jersey 08855*

JULIAN A. PETERSON (60), *Department of Biochemistry, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

RICHARD M. PHILPOT (61), *Laboratory of Cellular and Molecular Pharmacology, National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina 27709*

LYDIANE PICHARD (33), *Institut National de la Sante et de la Recherche Medicale, CNRS, 34033 Montpellier Cedex, France*

CECIL B. PICKETT (39), *Merck Frosst Centre for Therapeutic Research, Kirkland, Quebec H9H 3L1, Canada*

THIERRY PINEAU (33), *Institut National de la Sante et de la Recherche Medicale, CNRS, 34033 Montpellier Cedex, France*

TODD D. PORTER (11), *Division of Pharmacology and Experimental Therapeutics, University of Kentucky College of Pharmacy, Lexington, Kentucky 40536*

THOMAS L. POULOS (2), *Department of Molecular Biology and Biochemistry, University of California, Irvine, Irvine, California 92717*

R. A. PROUGH (40), *Department of Biochemistry, University of Louisville, Louisville, Kentucky 40292*

RIČHARD RAMSDEN (28), *Department of Environmental Health, University of Washington, Seattle, Washington 98195*

JUDY L. RAUCY (56), *Toxicology Program, College of Pharmacy, University of New Mexico, Albuquerque, New Mexico 87131*

A. D. RODRIGUES (40), *Drug Metabolism Department, G. D. Searle, Skokie, Illinois 60077*

JOHN T. ROSS (14), *Fermentation Production Facility, Program Resources, Inc., Frederick Cancer Research Facility, National Cancer Institute, Frederick, Maryland 21701*

THOMAS H. RUSHMORE (39), *Molecular Biology Department, Merck Frosst Centre for Therapeutic Research, Kirkland, Quebec H9H 3L1, Canada*

MARIE-AGNÈS SARI (14), *Laboratoire de Chimie et Biochimie Pharmacologiques et Toxicologiques, Université René Descartes, CNRS, 75720 Paris, France*

JOHN B. SCHENKMAN (31), *Department of Pharmacology, University of Connecticut Health Center, Farmington, Connecticut 06032*

ERIN G. SCHUETZ (32), *Division of Clinical Toxicology and Environmental Medicine, Department of Medicine, Medical College of Virginia, Richmond, Virginia 23113*

RASS M. SHAYIQ (57), *Department of Animal Biology, School of Veterinary Medicine, University of Pennsylvania, Philadelphia, Pennsylvania 19104*

EMILY S. SHEN (38), *Department of Pharmacology, Stanford University School of Medicine, Stanford, California 94305*

EVAN R. SIMPSON (45), *Departments of Biochemistry and Obstetrics and Gynecology, Cecil H. and Ida Green Center for Reproductive Biology Sciences, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

STEPHEN G. SLIGAR (3), *Department of Biochemistry and Beckman Institute, University of Illinois, Urbana, Illinois 61801*

C. A. DALE SMITH (15), *Imperial Cancer Research Fund, Molecular Pharmacology Group, University Department of Biochemistry, Edinburgh EH8 9X8, Scotland*

NIGEL K. SPURR (15), *Human Genetic Resources Laboratory, Imperial Cancer Research Fund, Hertfordshire EN6 3LD, England*

PATRICK S. STAYTON (3), *Department of Biochemistry and Beckman Institute, University of Illinois, Urbana, Illinois 61801*

JEFFREY C. STEVENS (53), *Drug Metabolism and Disposition, Lilly Research Laboratories, Eli Lilly and Company, Indianapolis, Indiana 46285*

HENRY W. STROBEL (64), *Department of Biochemistry and Molecular Biology, The University of Texas Medical School at Houston, Houston, Texas 77225*

MARIA STRÖMSTEDT (63), *Department of Medical Nutrition, Karolinska Institute, Huddinge University Hospital, S-141 86 Huddinge, Sweden*

ELZBIETA SZCZESNA-SKORUPA (6), *Department of Physiology and Biophysics, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801*

SHINJI TAMURA (9), *Laboratory of Molecular Carcinogenesis, National Cancer Institute, National Institutes of Health, Bethesda, Maryland 20892*

JOHN M. TRANT (43), *Department of Zoology and Physiology, Louisiana State University, Baton Rouge, Louisiana 70803*

ROBERT H. TUKEY (27), *Department of Pharmacology and Medicine, Cancer Center, University of California, San Diego, La Jolla, California 92093*

G. VERGERES (51), *Department of Anesthesia and the Liver Center, University of California, San Francisco, and Veterans Administration Medical Center, San Francisco, California 94121*

LARRY E. VICKERY (54), *Department of Physiology and Biophysics, University of California, Irvine, Irvine, California 92717*

J. L. VIGNE (51), *Department of Obstetrics and Gynecology, University of California, San Francisco, San Francisco, California 94143*

MARGARET WARNER (62), *Department of Medical Nutrition, Karolinska Institute, Huddinge University Hospital, S-141 86 Huddinge, Sweden*

LUCY A. WASKELL (51), *Department of Anesthesia and the Liver Center, University of California, San Francisco, and Veterans Administration Medical Center, San Francisco, California 94121*

MICHAEL R. WATERMAN (10), *Department of Biochemistry, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

PAUL B. WATKINS (50), *Clinical Research Center, University of Michigan Medical Center, Ann Arbor, Michigan 48109*

DAVID J. WAXMAN (24, 29, 44), *Department of Biological Chemistry and Molecular Pharmacology and Dana-Farber Cancer Institute, Harvard Medical School, Boston, Massachusetts 02115*

JAMES W. WHITE (64), *Office of Toxic Substances, Washington State Department of Health, Olympia, Washington 98504*

TERRY B. WHITE (64), *Laboratory One, Evergreen State College, Olympia, Washington 98505*

JAMES P. WHITLOCK, JR. (38), *Department of Pharmacology, Stanford University School of Medicine, Stanford, California 94305*

C. ROLAND WOLF (15), *Imperial Cancer Research Fund, Molecular Pharmacology Group, University Department of Biochemistry, Edinburgh EH8 9X8, Scotland*

YASUSHI YAMAZOE (18), *Department of Pharmacology, School of Medicine, Keio University, Tokyo 160, Japan*

CHUNG S. YANG (58), *Laboratory for Cancer Research, Department of Chemical Biology and Pharmacognosy, College of Pharmacy, Rutgers University, Piscataway, New Jersey 08855*

TOSHIO YASUMORI (18), *Department of Pharmacology, School of Medicine, Keio University, Tokyo 160, Japan*

JEONG-SOOK H. YOO (58), *Laboratory for Cancer Research, Department of Chemical Biology and Pharmacognosy, College of Pharmacy, Rutgers University, Piscataway, New Jersey 08855*

ULRICH M. ZANGER (20), *Department of Biochemistry, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas 75235*

PETER G. ZAPHIROPOULOS (62, 63), *Department of Medical Nutrition, Karolinska Institute, Huddinge University Hospital, S-141 86 Huddinge, Sweden*

Preface

The number of P450 enzymes which have been identified has increased tremendously in the thirteen years since publication of Volume 52 of *Methods in Enzymology* which last focused on the cytochrome P450 monooxygenases. This superfamily of more than 160 known members offers almost unlimited opportunities for the investigation of structure–function relationships, of mechanisms of gene and enzyme regulation, as well as of the molecular basis of genetic disorders. The structural diversity of these enzymes precludes universal probes for either P450 mRNA or protein. Nevertheless, in some cases, a close structural similarity is found for these mRNAs and proteins which requires sophisticated and complex approaches to the design of assays for monitoring the expression of individual enzymes. Increasingly investigators have relied on the cloning and expression of individual cDNAs in order to characterize the properties of the many P450 enzymes. As investigators address how a newly discovered P450 is regulated or whether the enzyme functions in a specific metabolic pathway, they are faced with ever-increasing numbers of possibilities in which it may be difficult to resolve one from the other. Consequently the experimental protocols available to address these questions have become wide ranging.

The contributions to this volume provide researchers studying this superfamily of enzymes with procedures and insights representative of this diversity. The contributors have championed the development and application of these technologies and have been more than willing to share not only their protocols, but to provide a discussion of the underlying experimental rationale for their methods and to indicate potential pitfalls and problems. This should greatly reduce the time required by others to adapt these procedures for their needs.

As editors, we are grateful to all the contributors for documenting their working experience for other laboratories studying P450 enzymes. We would also like to acknowledge the pioneering achievements of Drs. R. W. Estabrook, M. J. Coon, R. Sato, I. C. Gunsalus, W. Levin, and A. Y. Lu on which much of the present investigation in this field is based. In addition, we would like to thank the staff of Academic Press for their aid in producing this volume.

MICHAEL R. WATERMAN
ERIC F. JOHNSON

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

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