Methods in Enzymology
Volume 291

Methods in Enzymology

Volume 291

Caged Compounds

EDITED BY

Gerard Marriott

MAX PLANCK INSTITUTE FOR BIOCHEMISTRY
MARTINSRIED, GERMANY

ACADEMIC PRESS
San Diego London Boston New York Sydney Tokyo Toronto

This book is printed on acid-free paper. ♾

Academic Press
15 East 26th Street, 15th Floor, New York, New York 10010, USA
http://www.academicpress.com

Academic Press Limited
24-28 Oval Road, London NW1 7DX, UK
http://www.hbuk.co.uk/ap/

International Standard Book Number: 0-12-182192-7

PRINTED IN THE UNITED STATES OF AMERICA
98 99 00 01 02 MM 9 8 7 6 5 4 3 2 1

Methods in Enzymology

Volume 291

CAGED COMPOUNDS

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 291

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

ANDREW C. ALLAN (26), *Department of Plant Genetics, Weizmann Institute of Science, Rehovot, Israel 76100*

CHRISTOPH ALLIN (12), *Lehrstuhl für Biophysik, Fakultät Biologie, 44780 Bochum, Germany*

E. BAMBERG (17), *Max Planck Institute for Biophysics, D-60596 Frankfurt, Germany, and Johann Wolfgang Goethe-Universität Frankfurt am Main Biozentrum, D-60439 Frankfurt am Main, Germany*

HAGAN BAYLEY (7), *Department of Medical Biochemistry and Genetics, Texas A&M Health Science Center, College Station, Texas 77843*

MICHAEL H. BEALE (26), *IACR-Long Ashton Research Station, Department of Agricultural Sciences, University of Bristol, Bristol BS18 9AF, United Kingdom*

JÜRGEN BENDIG (23), *Institut für Organische und Bioorganische Chemie, Humboldt-Universität Berlin, D-10115 Berlin, Germany*

EDWARD B. BROWN (20), *Department of Physics, Cornell University, Ithaca, New York 14853*

CHRISTOPH BURMESTER (14), *Abteilung Physikalische Biochemie, Max Planck Institute for Molecular Physiology, 44139 Dortmund, Germany*

NICK CALLAMARAS (21), *Laboratory of Cellular and Molecular Neurobiology, Department of Psychobiology, University of California, Irvine, California 92697*

BARRY K. CARPENTER (2), *Department of Chemistry, Section of Biochemistry, Molecular and Cell Biology, Cornell University, Ithaca, New York 14853*

VALENTIN CEPUS (12), *Lehrstuhl für Biophysik, Fakultät Biologie, 44780 Bochum, Germany*

CHUNG-YU CHANG (7), *Worcester Foundation for Biomedical Research, Shrewsbury, Massachusetts 01545*

R. S. CHITTOCK (13, 27), *School of Biochemistry, University of Birmingham, Birmingham B15 2TT, United Kingdom*

JODY A. DANTZIG (18), *Pennsylvania Muscle Institute, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104*

CLAUDIA DZEJA (23), *Institut für Biologische Informationsverarbeitung, Forschungszentrum Jülich, D-52425 Jülich, Germany*

DAVID EPEL (16), *Department of Biological Sciences, Hopkins Marine Station, Stanford University, Pacific Grove, California 93950*

FREDRIC S. FAY* (5), *Department of Physiology, University of Massachusetts, Worcester, Massachusetts 01605*

K. FENDLER (17), *Max Planck Institute for Biophysics, D-60596 Frankfurt, Germany*

STEPHAN FRINGS (23), *Institut für Biologische Informationsverarbeitung, Forschungszentrum Jülich, D-52425 Jülich, Germany*

TAKESHI FUNAKOSHI (19), *Department of Cell Biology and Anatomy, Graduate School of Medicine, University of Tokyo, Hongo, Tokyo 113, Japan*

TOSHIAKI FURUTA (3), *Department of Biomolecular Science, Faculty of Science, Toho University, Chiba 274, Japan*

DANIELA GABRIEL (6), *Max Planck Institute for Biochemistry, 82152 Martinsried, Germany*

KYLE R. GEE (2, 4, 22), *Molecular Probes, Inc., Eugene, Oregon 97402*

* Deceased

KLAUS GERWERT (12), *Lehrstuhl für Biophysik, Fakultät Biologie, 44780 Bochum, Germany*

RICHARD S. GIVENS (1), *Department of Chemistry, University of Kansas, Lawrence, Kansas 66045*

MAURICE GOELDNER (15), *Laboratoire de chimie Bioorganique, Faculté de Pharmacie, Université Louis Pasteur Strasbourg, BP 24-F67401 Illkirch Cedex, France*

YALE E. GOLDMAN (18), *Pennsylvania Muscle Institute, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104*

H. MAURICE GOODMAN, *Department of Physiology, University of Massachusetts Medical School, Worcester, Massachusetts 01605*

ROGER S. GOODY (14), *Abteilung Physikalische Biochemie, Max Planck Institute for Molecular Physiology, 44139 Dortmund, Germany*

CHRISTOF GREWER (25), *Section of Biochemistry, Molecular and Cell Biology, Cornell University, Ithaca, New York 14853*

VOLKER HAGEN (23), *Forschungsinstitut für Molekulare Pharmakologie, D-10315 Berlin, Germany*

K. HARTUNG (17), *Max Planck Institute for Biophysics, D-60596 Frankfurt, Germany*

MANFRED HEIDECKER (6), *Biomolecular and Cellular Dynamics Group, Max Planck Institute for Biochemistry, 82152 Martinsried, Germany*

GEORGE P. HESS (2, 25), *Section of Biochemistry, Molecular and Cell Biology, Cornell University, Ithaca, New York 14853*

HIDEO HIGUCHI (18), *Department of Metallurgy, Faculty of Engineering, Tohoku University, Sendai 980-77, Japan*

NOBUTAKA HIROKAWA (19), *Department of Cell Biology and Anatomy, Graduate School of Medicine, University of Tokyo, Hongo, Tokyo 113, Japan*

ROBERT E. HOESCH (24), *Medical Biotechnology Center, University of Maryland Biotechnology Institute, and University of Maryland School of Medicine, Baltimore, Maryland 21201*

MITSUO IKEBE (5), *Department of Physiology, University of Massachusetts, Worcester, Massachusetts 01605*

MICHIKO IWAMURA (3), *Department of Biomolecular Science, Faculty of Science, Toho University, Chiba 274, Japan*

ANDREAS H. JUNG (1), *Department of Chemistry, University of Kansas, Lawrence, Kansas 66045*

JOSEPH P. Y. KAO (24), *Department of Physiology, University of Maryland School of Medicine, and Medical Biotechnology Center, University of Maryland Biotechnology Institute, Baltimore, Maryland 21201*

U. BENJAMIN KAUPP (23), *Institut für Biologische Informationsverarbeitung, Forschungszentrum Jülich, D-52425 Jülich, Germany*

EDYTA KRZYMAŃSKA-OLEJNIK (8), *AmberGen, Inc., Boston, Massachusetts 02215*

HON CHEUNG LEE (22), *Department of Physiology, University of Minnesota, Minneapolis, Minnesota 55455*

A. MALLAVARAPU (4), *Biochemistry Department, University of California, San Francisco, California 94143*

MICHAEL MARGULIS (24), *Department of Neurology, University of Maryland School of Medicine, Baltimore, Maryland 21201*

GERARD MARRIOTT (6, 9), *Max Planck Institute for Biochemistry, 82152 Martinsried, Germany*

JAMES A. MCCRAY (10), *Department of Physics, Drexel University, Philadelphia, Pennsylvania 19104, and Division of Neurophysiology, National Institute for Medical Research, London NW7 1AA, England*

R. A. MELDRUM (27), *School of Biochemistry, University of Birmingham, Birmingham B15 2TT, United Kingdom*

W. TODD MILLER (7), *Department of Physiology and Biophysics, SUNY Health Sciences Center, Stony Brook, New York 11794*

T. J. MITCHISON (4), *Department of Cell Biology, Harvard Medical School, Boston, Massachusetts 02115*

G. NAGEL (17), *Johann Wolfgang Goethe-Universitat Frankfurt am Main Biozentrum, D-60439 Frankfurt am Main, Germany*

BRETT NIBLACK (7), *Worcester Foundation for Biomedical Research, Shrewsbury, Massachusetts 01545*

JERZY OLEJNIK (8), *Department of Physics and Molecular Biophysics Laboratory, Boston University, Boston, Massachusetts 02215, and AmberGen, Inc., Boston, Massachusetts 02215*

JOHANNES OTTL (6, 9), *Max Planck Institute for Biochemistry, 82152 Martinsried, Germany*

PENG PAN (7), *Boehringer Ingelheim Pharmaceuticals, Inc., Ridgefield, Connecticut 06877*

CHAN-HO PARK (1), *Research and Development Center, Hansol Institute of Science and Technology, Nomyangju-Si, Kyung Ki-Do, Korea*

IAN PARKER (21), *Laboratory of Cellular and Molecular Neurobiology, Department of Psychobiology, University of California, Irvine, California 92697*

LING PENG (15), *Laboratoire de chimie Bioorganique, Faculté de Pharmacie, Université Louis Pasteur Strasbourg, BP 24-F67401 Illkirch Cedex, France*

GERT RAPP (11), *European Molecular Biology Laboratory, Outstation at DESY, D-22603 Hamburg, Germany*

FRANCIS M. ROSSI (24), *Medical Biotechnology Center, University of Maryland Biotechnology Institute, Baltimore, Maryland 21201*

KENNETH J. ROTHSCHILD (8), *Department of Physics, Boston University, Boston, Massachusetts 02215*

K. E. SAWIN (4), *ICRF, Lincolns Inn, London WC2 3PX, England*

AXEL SCHEIDIG (14), *Abteilung Physikalische Biochemie, Max Planck Institute for Molecular Physiology, 44139 Dortmund, Germany*

R. SREEKUMAR (5), *Department of Physiology, University of Wisconsin, Madison, Wisconsin 53706*

ROBERT R. SWEZEY (16), *Department of Pharmacokinetics and Metabolism, Shaman Pharmaceuticals, Inc., South San Francisco, California 94080*

CHA-MIN TANG (24), *Department of Neurology, University of Maryland School of Medicine, Baltimore, Maryland 21201*

J. A. THERIOT (4), *Whitehead Institute, Cambridge, Massachusetts 02142*

ANTHONY J. TREWAVAS (26), *Institute of Cell and Molecular Biology, University of Edinburgh, Edinburgh EH3 9JH, United Kingdom*

AGNES TROULLIER (12), *Lehrstuhl für Biophysik, Fakultät Biologie, 44780 Bochum, Germany*

CAROLA ULBRICH (12), *Lehrstuhl für Biophysik, Fakultät Biologie, 44780 Bochum, Germany*

JEFFERY W. WALKER (5), *Department of Physiology, University of Wisconsin School of Medicine, Madison, Wisconsin 53706*

JANE L. WARD (26), *IACR-Long Ashton Research Station, Department of Agricultural Sciences, University of Bristol, Bristol BS18 9AF, United Kingdom*

DAVID WARSHAW, *Department of Molecular Physiology and Biophysics, University of Vermont Medical School, Burlington, Vermont 05405*

WATT W. WEBB (20), *Department of Applied and Engineering Physics, Cornell University, Ithaca, New York 14853*

JÖRG F. W. WEBER (1), *Department of Chemistry, University of Kansas, Lawrence, Kansas 66045*

C. W. WHARTON (13, 27), *School of Biochemistry, University of Birmingham, Birmingham B15 2TT, United Kingdom*

Preface

Caged compounds are biomolecules whose activity or function is inactivated by chemical modification with a photolabile group. Excitation of a caged compound with (near-ultraviolet) light results in specific cleavage of a bond within the molecule that rapidly liberates the functional biomolecule of interest. One main advantage of this light-directed perturbation technique centers around its ability to overcome the mixing and diffusion time limits of fast-flow methods. This is achieved by precharging the biological sample with a caged substrate, ligand, or protein conjugate, followed by light-directed activation of the caged compound which triggers the specific reaction under investigation within the excitation volume. In addition, concentration jumps mediated by light-directed activation of caged compounds can be conducted without physically disturbing the preparation. Caged groups described in this volume generate active biomolecules within nanoseconds of absorbing light and, furthermore, by using two-photon excitation of the caged compound, the concentration jump can be confined to a volume having a diameter of approximately 250 nm with little or no irradiation-based damage to the preparation. Light-directed activation of caged compounds and rapid monitoring of the ensuing reaction using photomultiplier or imaging-based techniques have been used to understand the molecular mechanism of several biochemical reactions and processes *in vitro* and *in vivo*. This volume also describes the application of caged compounds to studies that aim to understand the molecular basis of neurotransmission, muscle contraction, and ion channel function.

Topics covered in this book include (a) an up-to-date account of the synthetic chemistry and photochemistry of traditional and newer generations of caged groups, (b) a description of new reagents and methods to prepare monofunctional and bifunctional complexes of a diverse array of caged substrates, ligands, and polypeptides, (c) a state-of-the-art practical and theoretical description of lamp- and laser-based excitation sources for light-directed activation of caged compounds in macro- and microscopic samples, (d) the measurement and interpretation of spectroscopic signals derived from light-directed activation of caged compounds to monitor the kinetics of the reaction being studied, and (e) the application of light-directed activation of caged compounds and caged polypeptides to chemical relaxation studies that aim to understand the molecular mechanism of protein-catalyzed reactions in a diverse array of complex molecular environments.

The primary objective of this volume is to provide newcomers to the field with a central source of valuable practical and theoretical information on caged compounds that will allow them to use light-directed activation of caged compounds to address molecular mechanisms of biochemical reactions or processes within biological samples. It provides the investigator with the most up-to-date and comprehensive account of caged compounds that should aid in the design of experiments to compare and interpret data obtained from kinetic measurements of specific reactions triggered by light-directed activation of caged biomolecules.

This volume is dedicated to the memory of Professor Fredric S. Fay.

GERARD MARRIOTT

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

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

VOLUME 108. Immunochemical Techniques (Part G: Separation and Characterization of Lymphoid Cells)
Edited by GIOVANNI DI SABATO, JOHN J. LANGONE, AND HELEN VAN VUNAKIS

VOLUME 109. Hormone Action (Part I: Peptide Hormones)
Edited by LUTZ BIRNBAUMER AND BERT W. O'MALLEY

VOLUME 110. Steroids and Isoprenoids (Part A)
Edited by JOHN H. LAW AND HANS C. RILLING

VOLUME 111. Steroids and Isoprenoids (Part B)
Edited by JOHN H. LAW AND HANS C. RILLING

VOLUME 112. Drug and Enzyme Targeting (Part A)
Edited by KENNETH J. WIDDER AND RALPH GREEN

VOLUME 113. Glutamate, Glutamine, Glutathione, and Related Compounds
Edited by ALTON MEISTER

VOLUME 114. Diffraction Methods for Biological Macromolecules (Part A)
Edited by HAROLD W. WYCKOFF, C. H. W. HIRS, AND SERGE N. TIMASHEFF

VOLUME 115. Diffraction Methods for Biological Macromolecules (Part B)
Edited by HAROLD W. WYCKOFF, C. H. W. HIRS, AND SERGE N. TIMASHEFF

VOLUME 116. Immunochemical Techniques (Part H: Effectors and Mediators of Lymphoid Cell Functions)
Edited by GIOVANNI DI SABATO, JOHN J. LANGONE, AND HELEN VAN VUNAKIS

VOLUME 117. Enzyme Structure (Part J)
Edited by C. H. W. HIRS AND SERGE N. TIMASHEFF

VOLUME 118. Plant Molecular Biology
Edited by ARTHUR WEISSBACH AND HERBERT WEISSBACH

VOLUME 119. Interferons (Part C)
Edited by SIDNEY PESTKA

VOLUME 120. Cumulative Subject Index Volumes 81–94, 96–101

VOLUME 121. Immunochemical Techniques (Part I: Hybridoma Technology and Monoclonal Antibodies)
Edited by JOHN J. LANGONE AND HELEN VAN VUNAKIS

VOLUME 122. Vitamins and Coenzymes (Part G)
Edited by FRANK CHYTIL AND DONALD B. MCCORMICK

VOLUME 123. Vitamins and Coenzymes (Part H)
Edited by FRANK CHYTIL AND DONALD B. MCCORMICK

VOLUME 124. Hormone Action (Part J: Neuroendocrine Peptides)
Edited by P. MICHAEL CONN