Sidney P. Colowick and Nathan O. Kaplan

Methods in ENZYMOLOGY

Volume 81

Biomembranes

Part H

Visual Pigments and Purple Membranes, I

Edited by

Lester Packer

Methods in Enzymology

Volume 81

Biomembranes

Part H

Visual Pigments and Purple Membranes, I

EDITED BY

Lester Packer

MEMBRANE BIOENERGETICS GROUP
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

Editorial Advisory Board

1982

ACADEMIC PRESS

A Subsidiary of Harcourt Brace Jovanovich, Publishers

New York London
Paris San Diego San Francisco São Paulo Sydney Tokyo Toronto

ACADEMIC PRESS, INC.
111 Fifth Avenue, New York, New York 10003

United Kingdom Edition published by
ACADEMIC PRESS, INC. (LONDON) LTD.
24/28 Oval Road, London NW1 7DX

Library of Congress Cataloging in Publication Data
Main entry under title:

Visual pigments and purple membranes.

(Biomembranes ; pt. H) (Methods in enzymology ; v. 81)
Includes bibliographical references and index.
1. Visual pigments. 2. Visual purple. 3. Cell membranes. I. Packer, Lester. II. Series. III. Series: Methods in enzymology ; v. 81. [DNLM: 1. Cell membrane. 2. Membranes--Enzymology. W1 ME9615K v. 31, etc.]
QP601.M49 vol. 81 [QP671.V5] 574.19 82-1736
ISBN 0-12-181981-7 [591.1'823] AACR2

PRINTED IN THE UNITED STATES OF AMERICA

82 83 84 85 9 8 7 6 5 4 3 2 1

Contributors to Volume 81

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

E. W. ABRAHAMSON (67, 94), *Department of Chemistry, University of Guelph, Guelph, Ontario N1G 2WI, Canada*

ALOIS J. ADAMS (11), *Department of Electronics and Instrumentation, Graduate Institute of Technology, University of Arkansas, Little Rock, Arkansas 72203*

L. ADERS (15), *Department of Pathology, Indiana University School of Medicine, Indianapolis, Indiana 46223*

G. AGUIRRE (15), *Section of Ophthalmology, School of Veterinary Medicine, University of Pennsylvania, Philadelphia, Pennsylvania 19174*

TOYOAKI AKINO (47), *Department of Biochemistry, Sapporo Medical College, Sapporo 060, Japan*

RICHARD A. ALVAREZ (63), *Cullen Eye Institute and Program in Neuroscience, Department of Ophthalmology, Baylor College of Medicine, Texas Medical Center, Houston, Texas 77030*

ROBERT E. ANDERSON (44, 105), *Cullen Eye Institute and Program in Neuroscience, Baylor College of Medicine, Texas Medical Center, Houston, Texas 77030*

M. L. APPLEBURY (50), *Department of Biochemical Sciences, Princeton University, Princeton, New Jersey 08544*

BARBARA N. BAKER (52), *Institute of Molecular Biophysics, Florida State University, Tallahassee, Florida 32306*

Y. BARENHOLZ (91), *Department of Biochemistry, University of Virginia School of Medicine, Charlottesville, Virginia 22908, and Department of Biochemistry, Hadassah-Hebrew University Medical School, Jerusalem 91000, Israel*

SCOTT F. BASINGER (101), *Cullen Eye Institute and Program in Neuroscience, Baylor College of Medicine, Texas Medical Center, Houston, Texas 77030*

CHRISTIAN BAUMANN (3), *Physiologisches Institut, Justus Liebig-Universität, D-6300 Giessen, Federal Republic of Germany*

D. A. BAYLOR (56), *Department of Neurobiology, Stanford Medical School, Stanford, California 94305*

HAYDÉE E. PASCUAL DE BAZÁN (103), *Department of Biochemistry, Louisiana State University Medical Center School of Medicine, New Orleans, Louisiana 70112*

NICOLÁS G. BAZÁN (103), *Department of Ophthalmology, Louisiana State University Eye Center, Medical Center School of Medicine, New Orleans, Louisiana 70112*

ELAINE R. BERMAN (13, 16), *Ophthalmic Biochemistry Unit, Hadassah-Hebrew University Medical School, Jerusalem 91000, Israel*

GARY D. BERNARD (99), *Department of Ophthalmology and Visual Science, Yale University School of Medicine, New Haven, Connecticut 06510*

MARK W. BITENSKY (71), *Department of Pathology, Yale University School of Medicine, New Haven, Connecticut 06510*

DEAN BOK (43, 100), *Jules Stein Eye Institute, and Department of Anatomy, UCLA School of Medicine, Los Angeles, California 90024*

TOM BORYS (67), *Department of Chemistry, University of Guelph, Guelph, Ontario N1G 2WI, Canada*

DERIC BOWNDS (31), *Department of Zoology, Laboratory of Molecular Biology, University of Wisconsin, Madison, Wisconsin 53706*

J. BRETON (82), *Service de Biophysique, Département de Biologie, Center d'Études Nucléaires de Saclay, 91190 Gif sur Yvette, France*

C. D. B. BRIDGES (12, 20, 63), *Cullen Eye Institute and Program in Neuroscience, Department of Ophthalmology, Baylor College of Medicine, Texas Medical Center, Houston, Texas 77030*

MICHAEL F. BROWN (96), *Department of Chemistry, University of Virginia, Charlottesville, Virginia 22901*

WILLIAM F. CARLSEN (90), *Department of Structural Biology, Stanford University School of Medicine, Stanford, California 94305*

MARC CHABRE (81, 82, 98), *Laboratoire de Biologie Moléculaire et Cellulaire, Département de Recherche Fondamentale, Centre d'Études Nucléaires de Grenoble, 38041 Grenoble Cedex, France*

ALAN COOPER (41), *Department of Chemistry, Glasgow University, Glasgow G12 8QQ, Scotland*

JOSEPH M. CORLESS (80), *Departments of Anatomy and Ophthalmology, Duke University Medical Center, Durham, North Carolina 27710*

M. JOSEPH COSTELLO (80), *Department of Anatomy, Duke University Medical Center, Durham, North Carolina 27710*

FREDERICK CRESCITELLI (27), *Department of Biology, University of California, Los Angeles, California 90024*

DONNA R. CURTIS (37), *Department of Medical Biochemistry, School of Medicine, and Department of Chemistry and Biochemistry, College of Science, Southern Illinois University at Carbondale, Carbondale, Illinois 62901*

MICHAEL A. CUSANOVICH (59), *Department of Biochemistry, University of Arizona, Tucson, Arizona 85721*

FRANS J. M. DAEMEN (17, 33, 48), *Department of Biochemistry, University of Nijmegen, 6500 HB Nijmegen, The Netherlands*

ALAN J. DEESE (96), *Division of Natural Sciences, University of California, Santa Cruz, California 95064*

WILLEM J. DE GRIP (30, 33, 38), *Department of Biochemistry, University of Nijmegen, 6500 HB Nijmegen, The Netherlands*

PHILIPPE F. DEVAUX (95), *Institut de Biologie Physico-Chimique, 13 rue Pierre et Marie Curie, 75005 Paris, France*

G. W. DE VRIES (14, 69), *Department of Pharmacology, Washington University School of Medicine, St. Louis, Missouri 63110*

EDWARD A. DRATZ (18, 19, 40, 92, 96, 106), *Chemistry Board of Studies, Division of Natural Sciences, University of California, Santa Cruz, California 95064*

ERIK H. S. DRENTHE (48), *Department of Biochemistry, University of Nijmegen, 6500 HB Nijmegen, The Netherlands*

H. DREYFUS (45), *Unité 44 INSERM, Centre de Neurochimie du CNRS, 5 rue Blaise Pascal, 67084 Strasbourg Cedex, France*

ROBERT E. DRZYMALA (89), *Department of Biological Chemistry, University of Maryland School of Medicine, Baltimore, Maryland 21201*

RICHARD M. EAKIN (2), *Department of Zoology, University of California, Berkeley, California 94720*

ROSS B. EDWARDS (6), *Berman-Gund Laboratory for the Study of Retinal Degenerations, Harvard Medical School, Boston, Massachusetts 02114*

ANN TAVORMINA EVANCZUK (72), *The Aerospace Corporation, El Segundo, California 90245*

LEI YEN FAGER (25), *Department of Physiology, University of Virginia Medical School, Charlottesville, Virginia 22908*

ROGER S. FAGER (25, 42, 79), *Department of Physiology, University of Virginia Medical School, Charlottesville, Virginia 22908*

DEBORA B. FARBER (65, 75), *Jules Stein Eye Institute, UCLA School of Medicine, Los*

Angeles, California 90024, and Veterans Administration Medical Center, Sepulveda, California 91343

CHRISTOPHER C. FARNSWORTH (19), *Department of Chemistry, Division of Natural Sciences, University of California, Santa Cruz, California 95064*

LYNETTE FEENEY-BURNS (16), *Department of Ophthalmology, University of Missouri School of Medicine, Columbia, Missouri 65212*

J. A. FERRENDELLI (14, 69), *Departments of Neurology, Pharmacology, and Ophthalmology, Washington University School of Medicine, St. Louis, Missouri 63110*

DARRELL FLEISCHMAN (70), *Charles F. Kettering Research Laboratory, Yellow Springs, Ohio 45387*

SHAO-LING FONG (12, 20, 37), *Cullen Eye Institute, Department of Ophthalmology, Baylor College of Medicine, Texas Medical Center, Houston, Texas 77030*

MICHIKO N. FUKUDA (32), *Division of Biochemical Oncology, Fred Hutchinson Cancer Research Center, University of Washington, Seattle, Washington 98104*

BERNARD KWOK-KEUNG FUNG (39), *Department of Radiation Biology and Biophysics, The University of Rochester Medical Center, Rochester, New York 14642*

WALTER GODCHAUX III (9, 77), *Biological Sciences Group, The University of Connecticut, Storrs, Connecticut 06268*

TIMOTHY H. GOLDSMITH (4), *Department of Biology, Yale University, New Haven, Connecticut 06511*

FRANCES M. HAGINS (7), *Laboratory of Chemical Physics, National Institute of Arthritis, Metabolism and Digestive Diseases, Bethesda, Maryland 20205*

MICHAEL O. HALL (43), *Jules Stein Eye Institute, UCLA School of Medicine, Los Angeles, California 90024*

REIKO HARA (29, 108), *Department of Biology, Faculty of Science, Osaka University, Toyonaka, Osaka 560, Japan*

TOMIYUKI HARA (29, 108), *Department of Biology, Faculty of Science, Osaka University, Toyonaka, Osaka 560, Japan*

PAUL A. HARGRAVE (31, 32, 37), *Department of Medical Biochemistry, School of Medicine, and Department of Chemistry and Biochemistry, College of Science, Southern Illinois University at Carbondale, Carbondale, Illinois 62901*

FERENC I. HÁROSI (86), *Laboratory of Sensory Physiology, Marine Biological Laboratory, Woods Hole, Massachusetts 02543, and Department of Physiology, Boston University School of Medicine, Boston, Massachusetts 02118*

S. HARTH (45), *Unité 44 INSERM, Centre de Neurochimie du CNRS, 5 rue Blaise Pascal, 67084 Strasbourg Cedex, France*

ROSEMARY T. HOFFMAN (101), *Cullen Eye Institute and Program in Neuroscience, Baylor College of Medicine, Texas Medical Center, Houston, Texas 77030*

KEELUNG HONG (22), *Cancer Research Institute, University of California, San Francisco, California 94143*

WAYNE L. HUBBELL (22, 39), *Department of Chemistry, University of California, Berkeley, California 94720*

JAMES B. HURLEY (73), *Department of Structural Biology, Stanford University School of Medicine, Stanford, California 94305*

WOLFGANG JUNGE (78), *Schwerpunkt Biophysik, Fachbereich Biologie/Chemie, Universität Osnabrück, D-4500 Osnabrück, Federal Republic of Germany*

ELIZABETH JUSZCZAK (37), *Department of Medical Biochemistry, School of Medicine, and Department of Chemistry and Biochemistry, College of Science, Southern Illinois University at Carbondale, Carbondale, Illinois 62901*

YOSHIKAZU KANDA (110), *Second Department of Biochemistry, Nippon Medical*

School, 1-1-5 Sengagi, Bunkyo-ku, Tokyo, Japan

MICHAEL W. KAPLAN (88), *Department of Ophthalmology, Neurological Sciences Institute, Good Samaritan Hospital and Medical Center, Portland, Oregon 97210*

U. BENJAMIN KAUPP (78), *Schwerpunkt Biophysik, Fachbereich Biologie/Chemie, Universität Osnabrück, D-4500 Osnabrück, Federal Republic of Germany*

PAUL KILBRIDE (74), *Department of Ophthalmology, Eye and Ear Infirmary of the University of Illinois Hospital, Chicago, Illinois 60612*

YUJI KITO (7, 26), *Department of Biology, Faculty of Science, Osaka University, Toyonaka, Osaka 560, Japan*

PETER J. KNUDSEN (22), *The Biological Laboratories, Harvard University, Boston, Massachusetts 02138*

T. KOBAYASHI (51), *Department of Physics, Faculty of Science, University of Tokyo, 3-Chome Hongo, Bunkyo-ku, Tokyo 113, Japan*

ALLEN KROPF (54), *Department of Chemistry, Amherst College, Amherst, Massachusetts 01002*

HERMANN KÜHN (64, 76), *Institut für Neurobiologie der Kernforschungsanlage Jülich, D-5170 Jülich, Federal Republic of Germany*

HELMUT LANGER (28, 97), *Institute for Zoophysiology, Ruhr-Universität, Bochum, D-4630 Bochum 1, Federal Republic of Germany*

DENIS LARRIVEE (4), *Department of Biology, Benedictine College, Atchison, Kansas 66001*

REHWA H. LEE (65), *Department of Anatomy, UCLA School of Medicine, Los Angeles, California 90024, and Veterans Administration Medical Center, Sepulveda, California 91343*

PAUL A. LIEBMAN (72, 89), *Department of Anatomy, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19111*

GREGORY I. LIOU (20), *Cullen Eye Institute and Program in Neuroscience, Department of Ophthalmology, Baylor College of Medicine, Texas Medical Center, Houston, Texas 77030*

BURTON J. LITMAN (10, 23, 46, 79, 84, 91), *Department of Biochemistry, University of Virginia School of Medicine, Charlottesville, Virginia 22908*

ROBERT S. H. LIU (93), *Department of Chemistry, University of Hawaii, Honolulu, Hawaii 96822*

ELLIS R. LOEW (87), *Department of Physiology, New York State College of Veterinary Medicine, and Division of Biological Sciences, Cornell University, Ithaca, New York 14853*

RICHARD N. LOLLEY (5, 65, 75), *Developmental Neurology Laboratory, Veterans Administration Medical Center, Sepulveda, California 91343, and Department of Anatomy and Jules Stein Eye Institute, UCLA School of Medicine, Los Angeles, California 90024*

O. H. LOWRY (14), *Department of Pharmacology, Washington University School of Medicine, St. Louis, Missouri 63110*

J. HUGH MCDOWELL (31, 37), *Department of Medical Biochemistry, School of Medicine, and Department of Chemistry and Biochemistry, College of Science, Southern Illinois University at Carbondale, Carbondale, Illinois 62901*

P. MANDEL (45), *Unité 44 INSERM, Centre de Neurochimie du CNRS, 5 rue Blaise Pascal, 67084 Strasbourg Cedex, France*

GHEORGHE D. MATEESCU (94), *Department of Chemistry, Case Western Reserve University, Cleveland, Ohio 44106*

HIROYUKI MATSUMOTO (24, 93), *Department of Biological Sciences, Purdue University, West Lafayette, Indiana 47907*

M. MICHEL-VILLAZ (82), *Laboratoire de Biologie Moléculaire et Cellulaire, Département de Recherche Fondamentale, Centre d'Études Nucléaires de Grenoble, 38041 Grenoble Cedex, France*

NAOMASA MIKI (71), *Department of Pharmacology, Cancer Research Institute, Kanazawa University, 13-1 Takaramachi, Kanazawa 920, Japan*

GEORGE P. MILJANICH (40, 106), *Department of Biochemistry and Biophysics, University of California, San Francisco, California 94143*

YASUTOSHI MUTO (110), *First Department of Internal Medicine, Gifu University School of Medicine, 40 Tsukasa-machi, Gifu City, Japan*

S. NAGAKURA, (51), *Institute for Molecular Science, Myodaiji, Okazaki, Aichi 444, Japan*

TAKAYUKI NAITO (26), *Department of Biology, Faculty of Science, Osaka University, Toyonaka, Osaka 560, Japan*

KOZO NARITA (36), *Institute for Protein Research, Osaka University, Toyonaka, Osaka 560, Japan*

KAZUKO NASHIMA (26), *Department of Biology, Faculty of Science, Osaka University, Toyonaka, Osaka 560, Japan*

PETER P. NEMES (18, 40), *Oakes College, University of California, Santa Cruz, California 95064*

G. N. NÖLL (60), *Institute of Physiology, Justus-Liebig University, 6300 Giessen, Federal Republic of Germany*

B. NUNN (56), *Department of Neurobiology, Stanford Medical School, Stanford, California 94305*

DAVID F. O'BRIEN (53), *The Research Laboratories, Eastman Kodak Company, Rochester, New York 14650*

PAUL J. O'BRIEN (21, 102), *Laboratory of Vision Research, National Eye Institute, National Institutes of Health, Bethesda, Maryland 20205*

H. BEVERLEY OSBORNE (98), *Laboratoire de Biologie Moléculaire et Cellulaire, Département de Recherche Fondamentale, Centre d'Études Nucléaires de Grenoble, 38041 Grenoble Cedex, France*

WILLIAM L. PAK (57), *Department of Biological Sciences, Purdue University, West Lafayette, Indiana 47907*

DAVID S. PAPERMASTER (8, 32, 35), *Department of Pathology, Yale University School of Medicine, New Haven, Connecticut 06510*

DAVID R. PEPPERBERG (61), *Department of Biological Sciences, Purdue University, West Lafayette, Indiana 47907*

JORDAN S. POBER (34), *Department of Pathology, Brigham and Women's Hospital, Boston, Massachusetts 02115*

H. WILLIAM READING (104), *MRC Brain Metabolism Unit, University Department of Pharmacology, Edinburgh, EH8 9JZ, Scotland*

P. M. RENTZEPIS (50), *Bell Laboratories, Murray Hill, New Jersey 07974*

JOHN C. SAARI (107), *Department of Ophthalmology, University of Washington School of Medicine, Seattle, Washington 98195*

ROBERT A. SACK (66), *Department of Biological Sciences, State University of New York College of Optometry, New York, New York 10010*

H. SAIBIL (82), *Department of Biophysics, University of London, King's College, London WC 2B 5RL, England*

PETER SCHLECHT (97), *Institute for Zoophysiology, Ruhr-Universität, Bochum, D-4630 Bochum 1, Federal Republic of Germany*

R. J. SCHNELL (15), *Dental Materials Section, School of Dentistry, Indiana University, Indianapolis, Indiana 46223*

PAUL P. M. SCHNETKAMP (17), *Department of Chemistry, University of California, Berkeley, California 94720*

JOACHIM SCHWEMER (28, 97), *Institute for Zoophysiology, Ruhr-Universität, Bochum, D-4630 Bochum 1, Federal Republic of Germany*

TAKAHARU SEKI (7), *Department of Biology, Faculty of Science, Osaka University, Toyonaka, Osaka 560, Japan*

HITOSHI SHICHI (11, 36, 62), *Institute of Biological Sciences, Oakland University, Rochester, Michigan 48063*

YOSHINORI SHICHIDA (49, 85), *Department of Biophysics, Faculty of Science, Kyoto University, Kyoto 606, Japan*

YOSHIHIRO SHIDOJI (110), *Department of Nutrition, School of Health Sciences, Faculty of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113, Japan*

JOHN W. SHRIVER (94), *Department of Biochemistry, University of Alberta, Edmonton, Alberta, Canada T6G 2H7*

A. N. SIAKOTOS (15), *Department of Pathology, Indiana University School of Medicine, Indianapolis, Indiana 46223*

LARRY A. SKLAR (92), *Department of Immunopathology, Scripps Clinic and Research Foundation, La Jolla, California 92037*

H. GILBERT SMITH, JR. (10, 79), *Advanced Techniques Laboratory, GTE, Inc., Waltham, Massachusetts 02154*

ROBERT L. SOMERS (62), *Laboratory of Vision Research, National Eye Institute, National Institutes of Health, Bethesda, Maryland 20205*

LUBERT STRYER (90), *Department of Structural Biology, Stanford University School of Medicine, Stanford, California 94305*

MINORU TANAKA (11), *Department of Ophthalmology, Juntendo Medical College, Hongo, Bunkyo-ku, Tokyo, Japan*

SCOTT M. THACHER (68), *Department of Physiology, Laboratory of Toxicology, Harvard School of Public Health, Boston, Massachusetts 02115*

DAVID D. THOMAS (90), *Department of Biochemistry, University of Minnesota School of Medicine, Minneapolis, Minnesota 55455*

H.-W. TRISSL (58), *Schwerpunkt Biophysik, Fachbereich Biologie/Chemie, Universität Osnabrück, D-4500 Osnabrück, Federal Republic of Germany*

ANDREW T. C. TSIN (20), *Division of Allied Health and Life Sciences, University of Texas, San Antonio, Texas 78285*

MOTOYUKI TSUDA (55), *Department of Physics, Sapporo Medical College, Sapporo 060, Japan*

SUSUMU TSUNASAWA (36), *Institute for Protein Research, Osaka University, Osaka 560, Japan*

RAINER UHL (67), *Max-Planck-Institut für Biophysikalische Chemie, D-3400 Göttingen, Federal Republic of Germany*

N. VIRMAUX-COLIN (45), *Unité 44 INSERM, Centre de Neurochimie du CNRS, 5 rue Blaise Pascal, 67084 Strasbourg Cedex, France*

JANET K. WANG (31), *Department of Medical Biochemistry, School of Medicine, and Department of Chemistry and Biochemistry, College of Science, Southern Illinois University at Carbondale, Carbondale, Illinois 62901*

HENRY L. WEINER (89), *Yale University School of Medicine, New Haven, Connecticut 06510*

REX D. WIEGAND (44), *Cullen Eye Institute and Program in Neuroscience, Baylor College of Medicine, Texas Medical Center, Houston, Texas 77030*

URSULA WILDEN (64), *Institut für Neurobiologie der Kernforschungsanlage Jülich, D-5170 Jülich, Federal Republic of Germany*

THEODORE P. WILLIAMS (52), *Institute of Molecular Biophysics, Florida State University, Tallahassee, Florida 32306*

D. L. WORCESTER (81), *Institut Max von Lauë-Paul Langevin, 38042 Grenoble, France*

EICHI YAMADA (1, 109), *Department of Anatomy, Faculty of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113, Japan*

AKIO YAMAZAKI (71), *Department of Pathology, Yale University School of Medicine, New Haven, Connecticut 06510*

S. YOSHIKAMI (60), *Laboratory of Chemical Physics, National Institute of Arthritis, Metabolism and Digestive Diseases, Bethesda, Maryland 20205*

TÔRU YOSHIZAWA (24, 49, 85), *Department of Biophysics, Faculty of Science, Kyoto University, Kyoto 606, Japan*

HYUK YU (83), *Department of Chemistry, University of Wisconsin, Madison, Wisconsin 53706*

WILLIAM F. ZIMMERMAN (9, 77), *Department of Biology, Amherst College, Amherst, Massachusetts 01002*

Preface

The study of retinoproteins associated with invertebrate and vertebrate visual photoreceptors and bacteria has gathered considerable momentum in recent years. This progress has been made possible by the development of new methods of membrane research and new physical and chemical techniques that have proved particularly useful for the investigation of retinoproteins. Increased interest in retinoproteins has also been greatly enhanced by the discovery of new and interesting pigments associated with visual photoreceptors or energy transformations in bacteria. Until recently, however, no attempt has been made to bring together in one volume the methodologies used for the study of these pigments. In this volume, Part H, we have attempted to meet this need by collecting brief but incisive descriptions of the state-of-the-art methods for the study of visual pigments. The majority of articles, therefore, are brief and to-the-point descriptions of specific methods and techniques. Included are sections on the isolation and characterization of visual pigments, protein chemistry, chemical composition and modification, responses of visual pigments to light, electrical responses in visual photoreceptors, enzymes associated with the visual photoreceptor membranes and their light activation, physical methods specifically useful for retinal photoreceptor studies, and methodologies for studying biogenesis of the photoreceptor cells and their components. In our attempt to be comprehensive, a select number of overview articles have been included to provide background information. Finally, a short section on retinoproteins in invertebrate and vertebrate systems which have not been covered in other volumes in this series has also been included. Our hope is that this collection will prove useful to students and new investigators and will aid progress in this exciting field of research.

We have encountered tremendous enthusiasm in bringing together this volume of "Methods in Enzymology." For this, we would like to acknowledge the Editorial Advisory Board for their wisdom in the selection of the contributors to this volume. In particular, special thanks must be given to Edward A. Dratz and Tom Ebrey for many hours of valuable dialogue and for their help in the conception and development of this project, and to Aaron Lewis and Tôru Yoshizawa for advice and encouragement. I would also like to express my thanks to two talented assistants, Ms. Brenda Soares and Mr. John Hazlett, who helped with the organizational and editorial work involved in assembling this volume.

In Volume 88, methods for the study of halobacteria, bacteriorhodopsin, purple membranes, and halorhodopsin will be covered. There will be sec-

tions on physical and chemical methods common to the study of all retinoproteins, including preparation and use of model chromophores, resonance Raman and other spectroscopic techniques, as well as overviews on molecular structure and theories of color.

LESTER PACKER

METHODS IN ENZYMOLOGY

EDITED BY

Sidney P. Colowick and Nathan O. Kaplan

VANDERBILT UNIVERSITY
SCHOOL OF MEDICINE
NASHVILLE, TENNESSEE

DEPARTMENT OF CHEMISTRY
UNIVERSITY OF CALIFORNIA
AT SAN DIEGO
LA JOLLA, CALIFORNIA

I. Preparation and Assay of Enzymes
II. Preparation and Assay of Enzymes
III. Preparation and Assay of Substrates
IV. Special Techniques for the Enzymologist
V. Preparation and Assay of Enzymes
VI. Preparation and Assay of Enzymes (*Continued*)
Preparation and Assay of Substrates
Special Techniques
VII. Cumulative Subject Index

METHODS IN ENZYMOLOGY

EDITORS-IN-CHIEF

Sidney P. Colowick 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 H. PASTAN