THE PORPHYRINS

Volume I

Structure and Synthesis, Part A

Edited by

DAVID DOLPHIN
Department of Chemistry
University of British Columbia
Vancouver, British Columbia, Canada

ACADEMIC PRESS New York San Francisco London 1978

A Subsidiary of Harcourt Brace Jovanovich, Publishers

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:

The Porphyrins.

Includes bibliographies and indexes.
CONTENTS: v. 1. Structure and synthesis, pt. A. --v. 2. Structure and synthesis, pt. B. --[etc.] --v. 5. pt. c. Physical chemistry.
1. Porphyrin and porphyrin compounds. I. Dolphin, David. [DNLM: 1. Porphyrins. WH190 P837]
QD401.P825 547'.593 77-14197
ISBN 0-12-220101-9 (v. 1)

PRINTED IN THE UNITED STATES OF AMERICA

THE PORPHYRINS

Volume I

Structure and Synthesis, Part A

Contributors

Alan D. Adler

Robert C. Bachmann

Earl W. Baker

R. Bonnett

Johann Walter Buchler

Bruce F. Burnham

C. K. Chang

P. S. Clezy

Robert K. DiNello

David L. Drabkin

A. H. Jackson

A. W. Johnson

Jean B. Kim

Frederick R. Longo

John B. Paine III

Susan E. Palmer

Veronica Varadi

William I. White

List of Contributors

Numbers in parentheses indicate the pages on which the authors' contributions begin.

ALAN D. ADLER (85, 581), Chemistry Department, Western Connecticut State College, Danbury, Connecticut
ROBERT C. BACHMANN (553), Utah State University, Logan, Utah
EARL W. BAKER* (485), Department of Chemistry, Northeast Louisiana University, Monroe, Louisiana
R. BONNETT (1), Department of Chemistry, Queen Mary College, London, England
JOHANN WALTER BUCHLER (389), Institut für Anorganische Chemie, Rheinisch-Westfälische Technische Hochschule Aachen, Aachen, Federal Republic of Germany
BRUCE F. BURNHAM (553), Porphyrin Products, Logan, Utah
C. K. CHANG† (289), Department of Chemistry, University of British Columbia, Vancouver, British Columbia, Canada
P. S. CLEZY (265), Department of Chemistry, University of New South Wales, Kensington, Australia
ROBERT K. DINELLO (289), Department of Chemistry, University of British Columbia, Vancouver, British Columbia, Canada

---

*Present address: Florida Atlantic University, Boca Raton, Florida.

†Present address: Department of Chemistry, Michigan State University, East Lansing, Michigan.

David L. Drabkin (29), Departments of Biochemistry, Schools of Medicine and Dental Medicine, University of Pennsylvania, Philadelphia, Pennsylvania

A. H. Jackson (265, 341, 365), Department of Chemistry, University College, Cardiff, Wales

A. W. Johnson (235), The School of Molecular Sciences, University of Sussex, Falmer, Brighton, England

Jean B. Kim (85), Chemistry Department, Eastern College, St. Davids, Pennsylvania

Frederick R. Longo (85, 581), Chemistry Department, Drexel University, Philadelphia, Pennsylvania

John B. Paine III (101), Department of Chemistry, University of British Columbia, Vancouver, British Columbia, Canada

Susan E. Palmer* (485), Department of Chemistry, Northeast Louisiana University, Monroe, Louisiana

Veronica Varadi† (581), Bell Laboratories, Murray Hill, New Jersey

William I. White‡ (553), Washington State University, Pullman, Washington

---

*Present address: Department of Chemistry, Florida Atlantic University, Boca Raton, Florida.

†Present address: Mrs. Veronica Romer, 23 Waldhausen Strasse, 3 Hanover 81, West Germany.

‡Present address: Physical Sciences Section, Ames Research Laboratories, 1127 Myrtle Street, Elkhart, Indiana.

General Preface

> Man cannot give a true reason for the grass under his feet
> why it should be green rather than red or any other color.
>
> Sir Walter Raleigh
> *History of the World: Preface (1614)*

Just over two centuries after these words of Raleigh, Verdeil in 1844 converted chlorophyll to a red pigment which prompted him to suggest a structural relationship between chlorophyll and heme. Shortly thereafter, Hoppe-Seyler, in 1880, strengthened this hypothesis by showing the spectral resemblances between hematoporphyrin and an acid degradation product of chlorophyll. The final steps in these structural elucidations were initiated by Willstätter and culminated in the heroic work of Hans Fischer who showed that but for two hydrogen atoms grass would indeed be red and that only two more hydrogen atoms would have ensured that Raleigh and his countrymen would indeed have been blue-blooded Englishmen.

The close structural similarity between the porphyrins and chlorins gives little measure of the relationships among and the diversity of their numerous and important biochemical functions. All life on this planet relies directly on the central role of the chlorophylls and cytochromes in photosynthesis by means of which photonic energy is converted and stored as chemical energy. It is likely that long before oxygen was abundant in the Earth's atmosphere the cytochromes were responsible for respiration. With the advent of photosynthesis the oxygen produced is the terminal electron acceptor for all aerobic respiration. For many organisms the means by which oxygen is transported, stored, reduced, and activated are frequently mediated by heme proteins. In mammals, oxygen is transported by the cooperative tetrameric protein hemoglobin and stored by monomeric myoglobin. When oxygen is reduced to water, in the terminal step of respiration, four electrons are transported via a series of cytochromes to cytochrome oxidase. Cytochrome oxidase contains two iron porphyrins and two copper atoms. In addition, nature also brings about one- and two-electron reductions to superoxide and peroxide. Both the decomposition and further activation of hydrogen peroxide are mediated by the heme proteins catalase and peroxidase. Furthermore, heme proteins function as both mono- and dioxygenases, and recently cytochrome *P*-450, which functions as a monooxygenase by combining properties of both oxygen binding and electron transport, has been shown to be important in a wide variety of biological hydroxylations.

This brief insight into a few of the many central roles played by metalloporphyrins in nature plus the challenges that porphyrins present to the inorganic, organic, physical, and biochemist suggest the wealth of knowledge that is documented in these areas. It is the objective of "The Porphyrins" to present a full and critical coverage of all the major fields relating to porphyrins, their precursors, catabolic derivatives, and related systems in a manner that we trust will be useful to those in physics, chemistry, biochemistry, and medicine.

The treatise consists of seven volumes. Volumes I and II (Structure and Synthesis, Parts A and B) cover nomenclature, history, geochemistry, synthesis, purification, and structural determination of porphyrins, metalloporphyrins, and mono- and polypyrrolic compounds and related systems. Volumes III, IV, and V (Physical Chemistry, Parts A, B, and C) cover electronic structure and spectroscopy including uv-vis, ORD, CD, MCD, mass, ir, resonance Raman, Mössbauer, Zeeman, nmr (diamagnetic, paramagnetic), esr, and X-ray crystallography. In addition, redox chemistry, electron transfer, aggregation, oxygenation, and solid state phenomena are included. Volumes VI and VII (Biochemistry, Parts A and B) cover the biosynthesis and enzymatic synthesis of porphyrins, chlorophylls and their precursors, and the chemistry and biochemistry of the bile pigments and the roles of porphyrins and bile pigments in clinical chemistry. The structure and function of the major hemoproteins are also covered.

It remains for me to thank my colleagues and co-workers for their support and assistance. A special debt of gratitude goes to my mentors: Alan Johnson who introduced me to these areas and who taught me why chlorophyll is green, and Bob Woodward who showed the world how to make chlorophyll and taught me why.

DAVID DOLPHIN

Preface

Volume I (Structure and Synthesis, Part A) contains chapters on the history, nomenclature, geochemistry, and purification of porphyrins and related systems. The synthesis of porphyrins from mono-, di-, and tetrapyrrolic intermediates is covered as are the isolation and modification of porphyrins from natural sources. In addition, chapters on the synthesis and properties of metallo-, aza-, and *N*-methylporphyrins are included. The volume complements Volume II (Structure and Synthesis, Part B) which includes chapters on reversible and irreversible reactions at the porphyrin and chlorin peripheries, on linear polypyrroles and their metal complexes, pyrrolic macrocycles related to porphyrins, and on the stereochemistry of these cyclic and acyclic systems.

The final result is an up-to-date and critical review of the areas described above. This treatise provides, for the first time, a complete and comprehensive review of all the major aspects of porphyrin chemistry and biochemistry.

I wish to take this opportunity to thank the contributors to this volume. For those who completed their chapters on time, I give my thanks for their patience during the period between submission of their manuscript and the publication of this book. Of those who were not so prompt I ask that they understand my impatience.

DAVID DOLPHIN

Contents of Other Volumes

VOLUME II STRUCTURE AND SYNTHESIS, PART B

VOLUME III PHYSICAL CHEMISTRY, PART A

VOLUME IV PHYSICAL CHEMISTRY, PART B

VOLUME V PHYSICAL CHEMISTRY, PART C

VOLUME VI BIOCHEMISTRY, PART A

VOLUME VII BIOCHEMISTRY, PART B

Contents

1 Nomenclature

R. Bonnett

2 Selected Landmarks in the History of Porphyrins and Their Biologically Functional Derivatives

David L. Drabkin

6 Synthesis of Porphyrins from Oxobilane Intermediates

P. S. CLEZY AND A. H. JACKSON

7 Isolation and Modification of Natural Porphyrins

ROBERT K. DINELLO AND C. K. CHANG

8 *N*-Substituted Porphyrins and Corroles

A. H. JACKSON

9 Azaporphyrins

A. H. JACKSON