MATERIALS CHEMISTRY

An Emerging Discipline

EDITED BY
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Materials Chemistry

An Emerging Discipline

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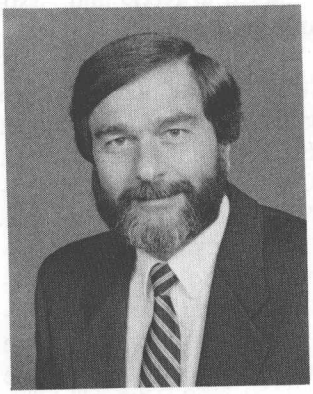
FOREWORD

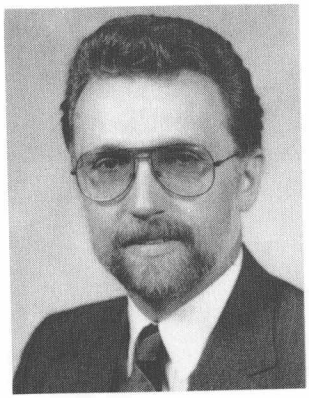
The ADVANCES IN CHEMISTRY SERIES was founded in 1949 by the American Chemical Society as an outlet for symposia and collections of data in special areas of topical interest that could not be accommodated in the Society's journals. It provides a medium for symposia that would otherwise be fragmented because their papers would be distributed among several journals or not published at all.

Papers are reviewed critically according to ACS editorial standards and receive the careful attention and processing characteristic of ACS publications. Volumes in the ADVANCES IN CHEMISTRY SERIES maintain the integrity of the symposia on which they are based; however, verbatim reproductions of previously published papers are not accepted. Papers may include reports of research as well as reviews, because symposia may embrace both types of presentation.

ABOUT THE EDITORS



LEONARD V. INTERRANTE is Professor of Inorganic and Materials Chemistry at Rensselaer Polytechnic Institute. He received his Ph.D. degree in inorganic chemistry with J. C. Bailar, Jr., at the University of Illinois in 1964. He was a National Science Foundation Postdoctoral Fellow at University College, London, and an assistant professor in the Chemistry Department at the University of California at Berkeley from 1964 to 1968. Before coming to Rensselaer Polytechnic Institute in 1985, he spent 17 years as a staff scientist at the General Electric Research and Development Center in Schenectady. He has served as the chair of two Gordon Research Conferences (Inorganic and Chemistry of Electronic Materials) and as Program Chair, Secretary–Treasurer, and Chairman of the Inorganic Division of the ACS. He is currently Editor-in-Chief of the ACS journal, *Chemistry of Materials*. His research areas include molecular precursor routes to ceramic materials, inorganic polymer chemistry, chemical vapor deposition using organometallic precursors, and high-temperature structural composites. He has published more than 140 papers, holds seven patents, and has edited three other books in these various areas of materials-related chemistry.

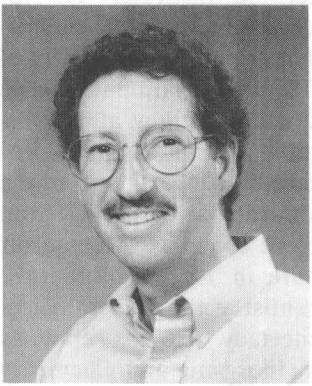


LAWRENCE A. CASPER received his B.S. degree in chemistry from Juniata College and his Ph.D. degree in Chemistry from Lehigh University, both in Pennsylvania. He also earned an M.S. degree in Environmental Science from the University of Alaska. From 1977 until 1982 he conducted research on advanced materials for energy systems at the Idaho National Engineering Laboratory of the U.S. Department of Energy, specializing in surface and thin-film chemistry problems.

From 1982 until 1990, Casper was an Engineering Fellow on the technical staff of the Honeywell Solid State

Electronics Center in Minneapolis, where he developed a materials and device characterization laboratory and worked on development of advanced integrated circuit devices.

In 1990, Casper moved to the University of Wisconsin—Madison, where he is Assistant Dean of Engineering for Industrial R&D and Associate Director of the University–Industry Research program.



ARTHUR B. ELLIS is Meloche–Bascom Professor of Chemistry at the University of Wisconsin—Madison. From 1990 to 1993, he chaired the UW—Madison's interdisciplinary graduate Materials Science Program. Ellis received his Ph.D. degree from Massachusetts Institute of Technology in inorganic chemistry and his B.S. degree in chemistry from Caltech. His research interests are in materials chemistry, specifically in the electro-optical properties of solids, and he has co-authored more than 100 research papers and holds eight patents. Ellis has been the recipient of Exxon, Sloan, and Guggenheim fellowships. He has helped develop a variety of instructional materials for integrating solids into the chemistry curriculum, including a superconductor levitation kit and an optical transform kit. Since 1990, Ellis has chaired an ad hoc committee that has produced a book to help chemistry teachers integrate materials chemistry into introductory chemistry courses. This volume, published by ACS Books, is entitled *Teaching General Chemistry: A Materials Science Companion.*

DEDICATION

THIS VOLUME IS DEDICATED TO THE MEMORY of Kenneth G. Hancock, an author in this volume and the former Director of the Chemistry Division of the National Science Foundation.

As Director of the Division of Chemistry at the National Science Foundation, Hancock pioneered many new initiatives, especially those that encouraged interdisciplinary and international collaborations. He had an expansive view of chemistry as a science and urged chemists to pursue imaginative research on the discipline's traditional boundaries that would expand chemistry's frontiers. In materials chemistry, he saw a vital and growing area to which chemists could make important contributions. Under his leadership, the Division's support for research in materials chemistry grew to over $20 million in 1993.

Hancock died in Budapest, Hungary, in September 1993 while on official travel. He had served as Division Director since 1990, and since 1987 had provided direction either as Acting Division Director or Deputy Division Director. He guided the development of joint programs with the Division of Chemical and Thermal Systems in Electrochemical Synthesis and in Environmentally Benign Synthesis and Processing. Hancock recognized very early the opportunities for U.S. scientists in Eastern Europe

after the demise of the Soviet Union, and the Chemistry Division responded by sponsoring visits by groups of U.S. chemists to Eastern Europe, by granting supplements to promote collaborations, and by bringing an intern from the Soviet Academy of Sciences to the Division. At the time of his death, Hancock was attending a workshop on Environmental Chemistry under joint United States–Hungarian–French sponsorship, a workshop that had been his idea.

Hancock advocated collaboration among government agencies and between government and the private sector. For example, he negotiated pioneering agreements for NSF with the Environmental Protection Agency and the National Institute of Standards and Technology, and helped design a unique pilot program with a private entity, the Electric Power Research Institute. The environmental program he helped fashion included the Council on Chemical Research as a partner.

Hancock received his B.A. from Harvard and his Ph.D. from the University of Wisconsin in 1968. After a National Institutes of Health Postdoctoral Fellowship at Yale, he worked as assistant and associate professor in the chemistry department of the University of California—Davis from 1968 to 1979, where he taught graduate and undergraduate chemistry and did research in organic and organometallic photochemistry. His work opened a new field of study in organoboron photochemistry.

Hancock joined the NSF as a Visiting Scientist in 1977 and held a variety of positions within the Chemistry Division, including Program Director for Chemical Dynamics, for Organic and Macromolecular Chemistry, and for Chemical Instrumentation. He served for two years as Senior Manager of Cooperative Science Programs with Southern Europe in the Division of International Programs, during which time he negotiated, established, and administered a new joint science and technology research agreement with Spain. Several years later, he again worked with International Programs as Interim Office Head, NSF—Europe. To broaden his knowledge of the legislative process Hancock served for one year as a legislative assistant to Senator John C. Danforth, while on leave from NSF as a LEGIS Fellow. He served on numerous NSF-wide committees and task forces, including the Director's Long Range Planning Task Force for Disciplinary Research and Facilities. In 1992, he was awarded the Director's Award for Excellence in Management.

His broad public service included membership on the National Research Council's Committee on Chemical Industry, Chemical and Engineering News' Editorial Advisory Board, the American Chemical Society's Committee on Science, and numerous other posts.

Marge Cavanaugh
National Science Foundation
Washington, DC

PREFACE

MATERIALS CHEMISTRY is receiving increasing recognition worldwide as a key area of chemical research and technology. If we define materials chemistry as chemistry related to the preparation, processing, and analysis of materials[1], it is apparent that "materials chemistry" has always been an integral part of chemistry and that a substantial fraction (approximately one-third by one estimate[2]) of chemists are in fact "materials chemists".

On the other hand, this label is not always applied to the wide range of activities that constitute the component subjects of materials chemistry. Instead, terms such as "polymer chemistry", "solid-state chemistry", and "surface chemistry", are more usually employed by chemists when referring to their background, interest, or research and development (R&D) activity relating to materials. In this context, one might question the need for a relabeling of these various activities under the common heading of materials chemistry. The thesis of this volume, and of a growing number of scientists, engineers, and educators, is that there is indeed a real benefit to be gained by viewing these activities in the broader context of materials chemistry or the "chemistry of materials". In part, this benefit relates to the well-developed concepts of "strength in numbers" and "critical mass". The effectiveness of a group that includes one-third of the entire chemistry profession in promoting changes in policy, the distribution of funding, the education of chemists, etc., can hardly be compared with even that commanded by the largest subgroup of materials chemists.

Beyond this pragmatic line of reasoning, a materials chemistry subdiscipline combines the various components of the subject in a way that makes sense from both operational and educational viewpoints. Many concepts relating to structure, bonding, and properties are common to materials composed of organic molecules, inorganic networks, or polymer chains, and a more integrated perspective could aid both in fundamental understanding and practical applications of new materials.

Although many internal and external obstacles remain to be overcome, considerable evidence supports the idea that the chemistry profession worldwide is gradually accepting the view that there is a distinct chemistry of materials. In the past few years, the American Chemical Society, the Royal Society of Great Britain, and VCH Publishers have

established journals in this area that feature titles such as *Chemistry of Materials, Journal of Materials Chemistry,* and *Advanced Materials*. All of these journals appear to be thriving; the number of papers being published, issues per year, and subscribers are increasing. In general, the number of publications in the materials-related areas of chemistry has grown at a significantly higher rate than the total in all areas of chemistry during the past 20 years or so, and this growth suggests a substantial increase in materials chemistry research over this period.[3]

This revolution in thinking about materials chemistry is beginning to have an impact on the education of chemists. In the United States, several universities have instituted courses at the graduate and undergraduate levels in materials chemistry, and a large number of faculty members in chemistry departments all over the country are engaged in research programs in this area, typically involving interdisciplinary efforts with faculty from other departments. These efforts are in addition to the long-standing programs in many universities in the various component areas of materials chemistry, such as polymer, solid-state, and surface chemistry. In some cases these efforts are being stimulated by funding agencies such as the National Science Foundation, which have established special research initiatives and have funded efforts to evaluate and change the way in which chemists view materials science, and materials scientists view chemistry.

The symposium from which this volume derives was sponsored by the Industrial and Engineering Division of the ACS and was designated, by the ACS Joint Board–Council Committee on Science, as one of the first in a series of pedagogical symposia relating to the 22 National Critical Technologies identified by the White House Office of Science and Technology Policy in 1991, based on previous critical technology studies by the Departments of Defense and Commerce. The symposium was also cosponsored by the Federation of Materials Societies and endorsed by the Materials Research Society. In addition to the ACS Committee on Science, it was supported financially by the Chemistry Division of the National Science Foundation and nine industrial organizations (*see* Acknowledgments). Its five sessions were attended by a large and diverse audience, including scientists, engineers, educators, and members of the press.

The symposium's location in the nation's capital, Washington, DC, was viewed as a unique opportunity to address the role of materials chemistry in national science and technology policy in general; consequently,

the first session of this symposium was devoted to the discussion of broad issues relevant to the needs, opportunities, and problems confronting materials chemistry R&D today. This plenary session featured representatives from the U.S. Government, the National Academy of Sciences, industry, and academia. The second session was directed at educational issues and covered a range of topics relating to education of—and communication between—chemists, materials scientists, and the general public regarding materials chemistry. The last three sessions featured internationally recognized leaders in materials chemistry R&D from universities, government laboratories, and industries throughout the United States. These individuals were asked to highlight a few of the many specific topics that characterize current materials chemistry R&D and to indicate the problems, prospective solutions, and opportunities for new technology in these key areas.

The impetus for this volume came from the symposium, and many of the presentations from that symposium are represented here as chapters or parts of chapters. To broaden the scope of this volume, other individuals were invited to contribute chapters relating to their own topic of interest. Our chief objective is to provide, for chemists, materials scientists/technologists, and the science and engineering community in general, an overview of this emerging "new" subdiscipline of chemistry.

Acknowledgments

It remains only to thank the many individuals and organizations who have made the ACS symposium and volume possible. The ACS Committee on Science and the NSF Chemistry Division in particular provided both financial and moral support, without which we could not have managed a symposium, and a volume, of this type. This support was supplemented by individual grants from nine companies, representing a wide range of products and services in materials chemistry. The companies and the other organizations who provided financial support to the symposium are Allied Signal, Inc.; Air Products and Chemicals; AKZO America, Inc.; AT&T Bell Laboratories; Corning Inc.; General Electric Corporate Research and Development; Hoechst Celanese Corp.; Milliken Research Corp.; and Schumaker.

Next, the authors of the chapters that make up this volume deserve particular thanks for their excellent contributions. We also gratefully ack-

nowledge the help of the individuals who served as reviewers for the papers in this volume. Finally, we thank the ACS Books staff who so ably managed the many details involved in the preparation and publication of a volume of this size.

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[1]Interrante, L. V. "Materials Chemistry—A New Subdiscipline?" *MRS Bull.,* January 1992.

[2]"National Materials Policy", Proceedings of a Joint Meeting of the National Academy of Sciences and National Academy of Engineering; National Academy of Sciences Press: Washington, DC, 1975, p 125.

[3]Based on a comparison of *Chemical Abstracts* by section and publications type for the years 1970 and 1992.

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