Chemistry and the Environment

From the origin of the Earth to climate change, this textbook presents the chemistry of the environment using the full strength of physical, inorganic, and organic chemistry, in addition to the necessary mathematics and physics, using modern notation and terminology. It provides a broad yet thorough description of the environment and the environmental impact of human activity using scientific principles.

Chemistry and the Environment describes the chemistry of Earth's atmosphere, hydrosphere, and lithosphere (including soils) and the biogeochemical cycles. The book presents a variety of industrial processes, from paper and steel to energy and pesticide production, focusing discussion on the environmental impact of these processes and showing how increasing environmental awareness has led to improved methods. The text provides an accessible account of environmental chemistry while paying attention to the fundamental basis of the science, showing derivations of formulas and giving primary references and historical insight. The authors make consistent use of professionally accepted nomenclature (IUPAC and SI), allowing transparent access to the material by students and scientists from other fields.

The authors created this textbook primarily for their own courses, and it has been developed through many years of feedback from students and colleagues. The book will be invaluable for advanced undergraduate and graduate students in environmental chemistry courses, and for professionals in chemistry and allied fields.

Sven E. Harnung is a Senior Lecturer in the Department of Chemistry at the University of Copenhagen and was Head of Department for 12 years. He teaches courses on environmental, inorganic, physical, and analytical chemistry, including pharmaceutical applications. His current research concentrates on magnetic studies of single-molecule magnets. He is the author of three chemistry textbooks in Danish. Dr. Harnung has organized several congresses, including an International Union of Pure and Applied Chemistry (IUPAC) General Assembly. He has been a member of the Danish National Committee for Chemistry for more than 30 years, and he is a Fellow of IUPAC. He has served as a board member of the journals *Acta Chemica Scandinavica* and *Physical Chemistry Chemical Physics*.

Matthew S. Johnson is a Senior Lecturer at the Department of Chemistry at the University of Copenhagen. He teaches courses on environmental chemistry, physical and quantum chemistry, and scientific writing. His main research interest is atmospheric chemistry, including kinetics, spectroscopy, and stable isotopes in atmospheric trace gases. He is a coauthor of more than 70 articles in peer-reviewed journals. He has invented and patented a method for efficient emissions control and improving building energy efficiency. He was awarded a Fulbright Fellowship to study stratospheric chemistry at the Max-lab electron storage ring in Lund, Sweden. He has worked as a researcher for Honeywell and Medtronic and has research collaborations with many groups around the world, including Ford Motor Company and the Tokyo Institute of Technology.

Advance praise for *Chemistry and the Environment*

"This outstanding text brings together fundamental information about the natural chemistry of the Earth and its atmosphere and the environmental impacts of anthropogenic chemicals. It is well suited for upper-level undergraduate and graduate students and researchers in chemistry, Earth sciences, and atmospheric science."

– Mark Jacobson, Department of Civil and Environmental Engineering, Stanford University, author of *Air Pollution and Global Warming*

"Both authors have excellent scientific standing and complementary backgrounds. They have combined well on this excellent textbook, based on their long experience of teaching environmental chemistry to undergraduate students at the University of Copenhagen. There are many textbooks on environmental chemistry aimed at undergraduate and graduate courses, but this is one of the best that I have come across. It will be adopted for courses in every university for the next decade and beyond due to its logical and comprehensive content. I strongly recommend this excellent textbook for environmental chemistry and related courses at the graduate and undergraduate levels."

– Naohiro Yoshida, Department of Environmental Chemistry & Engineering, Tokyo Institute of Technology

"Harnung and Johnson have produced a textbook on environmental chemistry that is firmly rooted in physical and chemical principles and follows a strict quantitative and analytical approach. Nevertheless, the accessible style and informative footnotes make it a joy to read and explore for graduate students and professionals alike. It perfectly fills the gap left by more phenomenological introductions to the field."

– Jan Kaiser, Department of Environmental Sciences, University of East Anglia

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Preface

Chemical species made by humans affect many naturally occurring processes and organisms. The observation of an anthropogenic substance in Nature raises a series of questions: Where did it come from? How and why was it produced and released? How does it move around within the environment? What is its chemistry, including the reaction rate, mechanism, and products, and how does it influence living organisms and the Earth system? More generally, and perhaps not within the focus of scientific chemistry, there are questions such as: Who is entitled to make use of Nature and to what extent? Are there limits to growth? A rational discussion of these questions involves the scientific method and results from the physical sciences, as well as law, economy, and the humanities.

Turning to chemistry: there is no doubt that success in the field of environmental chemistry requires mastering fundamental disciplines such as analytical chemistry, thermodynamics, and modern experimental and theoretical chemistry. The important role of environmental chemistry as a field in its own right is recognized internationally: the International Union of Pure and Applied Chemistry, IUPAC,[a,233] has organized scientific investigations of the environmental impact of chemistry for many years; examples include its series of reports on pesticides,[179] starting long before environmental issues were of political and public interest, and the White Book on chlorine.[191] Recognition of the importance of the subject has driven IUPAC to rename its Applied Chemistry Division the Chemistry and the Environment Division. The significance of this change is underlined by the fact that the word *Applied* is part of the very name of the Union.

Despite the central role of environmental chemistry in sustainable development, we have often wished that there was a textbook that would address the subject using the full strength of physical, inorganic, and organic chemistry, in addition to the necessary mathematics and physics. The target audience for this book is interested professionals and advanced undergraduate and graduate students in chemistry and allied fields.

Scientists with very different backgrounds have contributed to environmental sciences, and various traditions regarding nomenclature are found in the literature. Accordingly, much time and effort are sometimes required in order to interpret scientific papers. For this reason we have emphasized the use of standard ISO-IUPAC nomenclature throughout. The overall objective of a nomenclature is the safe exchange of scientific and technical information among people in different disciplines

[a] The international organizations are discussed in the Introduction.

and between nations.[a] For example, public safety demands that chemists and nonexperts (e.g., customs authorities, emergency and health services) be able to communicate clearly concerning the identities of chemical species involved.

Environmental chemistry is driven by specific examples such as detection of pesticide residues and characterization of the ozone hole. The background knowledge needed to understand these subjects in depth has been put into a separate chapter on environmental dynamics, which includes derivations and formulas related to fluid dynamics, thermodynamics, and reaction kinetics. The intention is that this material not be taught from start to finish, but rather taken up when it is relevant. Similarly, teachers are encouraged to choose the specific sections of the book that are most relevant to their educational programs. The purpose of the forward references in the text is to help the reader during the final reading of the book; they may not be helpful in the first reading. We have included dates of significant events in the history of chemistry and the environment. Dates prior to 1950, mainly of chemical history, may be found in the treatise *A History of Chemistry*,[73a,b] while more recent events are referenced directly. Dates of historical interest for other disciplines are provided without explicit references.

Together we have taught environmental chemistry at the University of Copenhagen for more than 30 years, and this book has grown out of our classes. We are indebted to the many gifted students it has been an honor to teach and who have helped us refine our methods and the material.

[a] The loss of the Mars Climate Orbiter on September 23, 1999, because of confusion of the nonstandard pound force (lbf) with the SI newton (N), illustrates the point.

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- The Department of Chemistry, University of Copenhagen.

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