Edited by Herbert W. Roesky
and Dietmar K. Kennepohl

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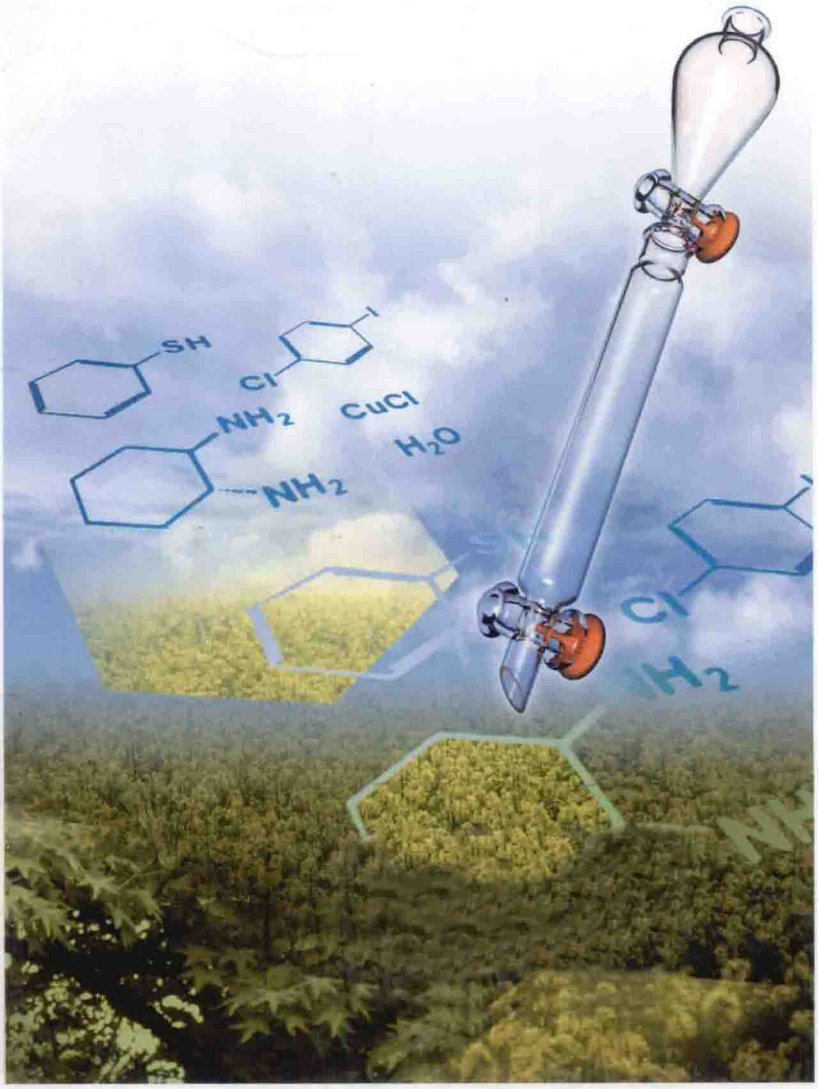
Experiments in Green and Sustainable Chemistry

With a Foreword by Jean-Marie Lehn



GREEN CHEMISTRY

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Herbert W. Roesky and Dietmar K. Kennepohl

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Foreword

Our great appetite for materials and energy is increasing faster than our ability to meet demands. We are seeing limits to the once unlimited resources available to us, and some of the consequences of our current consumption practices are serious. The situation is not trivial, the issues are difficult, and there is no easy way to solve our problems. Yet, sustainable chemistry offers a step in the right direction.

Chemistry has taken on a crucial role in science and society. As the central science, it not only encompasses the simple (such as atomic theory in physics) and the complex (such as life processes in biology), it also is at the heart of many areas that are not necessarily labeled ›chemistry‹. In earth sciences, pharmacy, computing, medicine, materials science, agriculture, nutrition, engineering, and environmental science the practice of chemistry has a profound influence. Because it touches so many of us in everyday life, the science (and art) of transforming matter has become a vital artery both as basic science and in a real tangible sense.

Achieving the transformations of matter with ever-increasing efficiency, selectivity and economy in matter and energy has always occupied the thoughts of chemists, but it is now even more important than ever. Sustainable chemistry builds upon this and covers the whole domain of chemistry. The various experimental examples collected in this book are a wonderful demonstration of a kaleidoscope of chemistry, intertwining the different disciplines.

This contribution by Herbert W. Roesky and Dietmar K. Kennepohl fills a gap. It is particularly welcome for its timeliness. Indeed, it provides a broad coverage of chemistry and highlights the contribution of chemistry to the careful use of the energy and material resources.

The remarkable achievement of this book is its consistent approach to the presentation of green and sustainable chemistry to the younger generation. It can thus be highly recommended to every chemistry teacher.

Strasbourg, July 2008 *Jean-Marie Lehn*

Preface

When we want to reach the goal,
Then we want to have the tools.
Immanuel Kant

Edgar F. Smith, an American student, studied chemistry in Göttingen from 1874 to 1876. He did his PhD with Friedrich Wöhler. Later he was president of the University of Pennsylvania for many years and president of the American Chemical Society. He used to relate how, during his time in Wöhler's laboratory, chemical residues were already being recycled:

I had been working in the laboratory for some weeks when I met Professor Wöhler for the first time. During my practical work I had to produce several pounds of phosphoric chloride. For this purpose I had to generate a considerable quantity of other chlorides, and I deposited these residues in the appropriate container. Once when I was emptying my beaker into the garbage container, somebody tapped me on the shoulder. When I looked up I saw that it was Geheimrat Wöhler. He asked me what I was doing. After I had told him all about the chemical preparation, he asked me about the cost of the chemicals I was using. I was not able to calculate them immediately. He then asked me to find this out and look for a chemical merchant who could use the residues, which contained manganese chloride. Soon I discovered that I could sell them provided that they were chemically pure. Wöhler told me to collect the residues separately and to develop a method for getting a chemically pure product. After thinking for a long time I discovered a method of removing the main impurity, iron, and in this way I could earn enough money to buy additional starting materials for my experiments.

(Göttinger Jahresblätter, 1982)

The future is certainly not what we once thought it to be. We live in a world that is becoming increasingly crowded, complex, and rife with new dilemmas. We are certainly concerned for ourselves, but also possess sufficient sense of responsibility to be concerned about the fate of future generations, who will in their turn share these concerns. Today's students are particularly interested in

matters that affect their health and the well-being of their planet. So, how do we best equip our chemistry students to deal with the challenges they will meet in the twenty-first century? The concept of Green and Sustainable Chemistry not only offers an excellent opportunity to address some of these concerns, but also provides us with a useful vehicle to advance the way we do chemistry. Since a strong laboratory component is at the heart of many foundation science courses, we present experiments that highlight alternatives and bring out the philosophy behind them. Although this book offers a means to develop laboratory skills and reveal useful techniques, it is ultimately more about encouraging an attitude and approach to chemistry by example and through actual practice.

There is no definitive universal nomenclature for the type of chemistry we demonstrate within this book. We describe it simply as Green and Sustainable Chemistry, others have proposed alternative terms such as Chemistry for the Environment and Environmentally Benign Chemistry. However, Green Chemistry and Sustainable Chemistry seem to be the most widely used and accepted terms. The Organization for Economic Cooperation and Development (OECD) defines Sustainable Chemistry as follows:

Sustainable Chemistry is the design, manufacture, and use of environmentally benign chemical products and processes to prevent pollution, produce less hazardous waste, and reduce environmental and human health risks [1].

One should remember that Sustainable Chemistry is primarily designed for pollution prevention as opposed to waste treatment and control or characterization of chemicals in the environment. The precise terminology will no doubt see further discussion and refinement. However, what is more important is that our collective understanding of the concepts and aims of this chemistry are commonly accepted and will continue to mature.

Some have described the rising popularity of Green and Sustainable Chemistry as some sort of revolution. Indeed, historians may look back at this moment in time and label it as a green revolution much like the agricultural and industrial revolutions that characterized periods in previous centuries. In a revolution there is a sense of wholesale throwing out of the old and replacing it with something new. While much has been achieved in Sustainable Chemistry in a few short years (and there have been specific innovations that could indeed be characterized as revolutionary), we see the process as being both complex and more akin to an evolution. We also note that Green and Sustainable Chem-

istry is very much integrated within chemistry itself and cannot be treated as a separate discipline. That mainstream nature of Green and Sustainable Chemistry may mean that in years to come it will simply be absorbed into the normal business of what we call chemistry.

So, why is this change occurring? There are several drivers for change towards Green and Sustainable Chemistry that include important considerations like increasing costs, diminishing resource availability, health/environmental legislation, and public perception. The specific drivers and their relative importance are certainly situational, and often their influence is interconnected. Clarke describes and analyzes several key drivers in detail, showing how they stem from three major sources – economic, environmental and social [2]. Chemists as contributors to the economy, as citizens, and as members of society can certainly appreciate the larger challenges and benefits involved as well as anyone else can. However, there is an additional attraction for the synthetic chemist in moving towards Green and Sustainable Chemistry that is very appealing. Noyori [3] expresses this as a pursuit of 'practical elegance' where the core principles of green chemistry are used in developing a synthetic strategy [4]. To the synthetic chemist whose job is essentially to produce valuable substances from baser elements, it is irresistible. The goal of generating the target compound is no longer enough; the manner in which that target compound can be realized is now of great importance. That challenge has awakened innovation and creativity in many chemists and we think it important to convey this passion to students considering chemistry in their studies.

This book has pulled together a diverse feast of teaching experiments from chemists around the globe. The practical real-world experiments illustrate many of the principles of green and sustainable chemistry. Some contributions are from scholars whose primary research is to develop environmentally friendly chemical processes. Others stem from synthetic chemists who have used principles of Green and Sustainable Chemistry in their own disciplinary research. All are chemical educators who want to share their knowledge and passion for Green and Sustainable Chemistry. We are very thankful for their contributions.

Herbert W. Roesky
Dietmar K. Kennepohl

Caution!

The authors of these experiments have taken great care to describe the nature of the substances and equipment employed. As with all chemistry experiments care should be taken in handling hazardous materials in an appropriate manner. The experiments are intended for students working in a safe laboratory environment under qualified supervision.

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