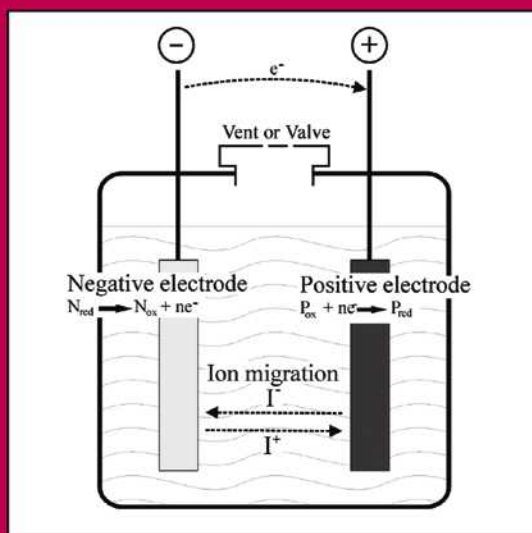




BATTERY TECHNOLOGY HANDBOOK

Second Edition

edited by
H. A. KIEHNE

BATTERY TECHNOLOGY HANDBOOK

Second Edition

edited by
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Technical Consultant
Breckerfeld, Germany



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Additional Volumes in Preparation

Preface to the Second Edition

There have been many changes since the first edition of the *Battery Technology Handbook*, such as technical progress, worldwide changes in the ownership of the battery companies, and the merging of companies into conglomerates. There were also changes in the group of contributors of this book. Some former contributors are no longer with us, while others retired and were replaced by younger experts. All the chapters have been revised, and some chapters are completely new.

[Chapter 1](#), “Electrochemical Energy Storage,” has been revised and expanded by D. Berndt, one of the leading battery experts. Completely revised is [Chapter 5](#), “Battery-Powered Traction: The User’s Point of View,” by a new author, W. König. Also new is [Chapter 8](#), “The Operation of Batteries,” written by U.-C. Stahl. [Chapter 9](#), “Motor Vehicle Starter Batteries,” has been revised by, G. Sassmanhausen and E. Nann, describing the coming 48-volt technology for cars. Chapter 10, “High Energy Batteries,” is now nearly completely new and was revised by C.-H. Dustmann, based on the former chapter by W. Fischer. [Chapter 15](#), “Batteries, an Overview and Outlook” has been revised by H. A. Kiehne, as has [Chapter 16](#), “Feasibility Study for Appliances” based on the former chapter by W. Raudzsus. [Chapter 17](#), “Maintenance-Free Lead Batteries with Immobilized Electrolyte” is completely new and was written by H. Tuphorn, a well-known expert in the field of valve-regulated lead batteries. A new author and an expert on lithium battery technology, W. Jacobi, has entirely rewritten [Chapter 18](#), “Lithium Batteries: The Latest Variant of Portable Electrical Energy.” Following the demand for information on the actual situation in the disposal and recycling of used batteries,

the two authors J. L. Fricke and N. Knudsen give an exciting report in [Chapter 19](#), “The Disposal of Portable Batteries.”

The book is not meant to be a scientific report on brand new developments, which is the task of events such as scientific conferences and their proceedings, but delivers basic information and instructions on how batteries work.

I thank all the authors for their contributions, and the patience of the publishers, Expert Verlag and Marcel Dekker, Inc., in the completion of the manuscripts. I also thank my wife, Renate Kiehne, who assisted me in correcting the translation of the original German manuscripts.

H. A. Kiehne

Preface to the First Edition

Batteries in various applications as rechargeable secondary batteries or as non-rechargeable primary batteries have to be adapted to steadily changing demands. Improvements to the existing and well-established systems, e.g., the lead-acid battery, the nickel-cadmium battery, and the well-known primary battery systems, have been made in recent years. Increased energy density and maintenance-free operation, as well as an extended temperature range, are the main aims of development. At the same time, research and development on new systems, e.g., fuel cells and high-temperature batteries, are needed for coming applications as battery-powered road vehicles with a wider range are already being demonstrated with the existing types of batteries. Furthermore, miniaturized batteries, such as lithium batteries, are needed as power sources for appliances and electronic watches.

The origins of this book go back to two-day seminars on batteries taught at the Technical Academy of Esslingen. In 1980, Expert Verlag published the first edition of *Batteries*. By 1983, a revised second edition was necessary. The chapters dealing with primary batteries and small rechargeable batteries (lead-acid and nickel-cadmium batteries) were published at the same time as a separate book, *Portable Batteries*, which now constitutes the second half of this volume.

Updated editions of *Batteries* and *Portable Batteries* appeared in 1988. It is hoped that this present English edition will be of help to those who want an extensive survey on the technical level of commercial batteries as well as insight into their emerging applications.

I would like to thank all the contributors and the translator for their cooperation and the Technical Academy of Esslingen for lecture materials. My thanks also to Expert Verlag, the original publisher.

H. A. Kiehne

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 - H. A. Kiehne and W. Raudzsus*
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 - J. L. Fricke and N. Knudsen*
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