Lecture Notes in Physics

The Lecture Notes in Physics

The series Lecture Notes in Physics (LNP), founded in 1969, reports new developments in physics research and teaching – quickly and informally, but with a high quality and the explicit aim to summarize and communicate current knowledge in an accessible way. Books published in this series are conceived as bridging material between advanced graduate textbooks and the forefront of research and to serve three purposes:

- to be a compact and modern up-to-date source of reference on a well-defined topic
- to serve as an accessible introduction to the field to postgraduate students and nonspecialist researchers from related areas
- to be a source of advanced teaching material for specialized seminars, courses and schools

Both monographs and multi-author volumes will be considered for publication. Edited volumes should, however, consist of a very limited number of contributions only. Proceedings will not be considered for LNP.

Volumes published in LNP are disseminated both in print and in electronic formats, the electronic archive being available at springerlink.com. The series content is indexed, abstracted and referenced by many abstracting and information services, bibliographic networks, subscription agencies, library networks, and consortia.

Proposals should be sent to a member of the Editorial Board, or directly to the managing editor at Springer:

Christian Caron
Springer Heidelberg
Physics Editorial Department I
Tiergartenstrasse 17
69121 Heidelberg / Germany
christian.caron@springer.com

K. Blaum
F. Herfurth

Trapped Charged Particles and Fundamental Interactions

Springer

Klaus Blaum
Universität Mainz
Inst. Physik
Staudinger Weg 7
55099 Mainz
Germany
blaumk@uni-mainz.de

Frank Herfurth
GSI Darmstadt
Planckstr. 11
64291 Darmstadt
Germany
F.Herfurth@gsi.de

Blaum, K. and Herfurth, F. *Trapped Charged Particles and Fundamental Interactions*, Lect. Notes Phys. 749 (Springer, Berlin Heidelberg 2008), DOI 10.1007/978-3-540-77817-2

ISBN: 978-3-540-77816-5 e-ISBN: 978-3-540-77817-2

DOI 10.1007/978-3-540-77817-2

Lecture Notes in Physics ISSN: 0075-8450

Library of Congress Control Number: 2008923785

Cover design: eStudio Calamar S.L., F. Steinen-Broo, Pau/Girona, Spain

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Preface

Storage and cooling techniques for charged particles gain more and more importance in various areas of modern science. They developed into a universal tool especially when used for precision measurements. For this purpose, there are mainly two types of ion traps in use: radio frequency quadrupole (Paul) traps which use a time-varying quadrupolar electric field applied to the electrodes for confinement and Penning traps where a superposition of a homogeneous magnetic field with a weak electrostatic quadrupolar field is used. Already the very first experiments in ion traps, performed by their inventors Wolfgang Paul and Hans Dehmelt, paved the way for astonishingly precise measurements of fundamental quantities like the electron and positron g-factors and the fine-structure constant α. Their work was honored with the Nobel Prize in physics for "the development of the ion trap technique" in 1989. Since then many experimental physicists worldwide have been using and developing different kinds of ion traps. Today, ion traps are applied widely for instance in mass spectrometry, metrology, plasma physics, molecular and cluster physics, quantum computing, atomic and nuclear physics as well as in chemistry.

Precise investigations are able to link measurable quantities to fundamental aspects of physics. Due to the achievable precision, ion traps have been used for this subject and attracted a conference series "Trapped Charged Particles and Fundamental Interactions." Along the main idea of that conference we organized a Heraeus Winter School that took place in Hirschegg, Austria, in spring 2006. Inspired by the success and the interest from the students we planned a book that should contain the key components of the school: interesting, introductory and up-to-date lectures connected with ion traps.

The volume starts with a theoretical introduction into precision tests of electroweak theory with experiments performed at low energy. The present searches for physics beyond the Standard Model, that are at the same time precision test of the Standard Model itself, are presented and put into their theoretical context. This includes the search for time reversal violation in nuclear beta decay or via permanent electric dipole moments and the experiments about nature and mass of the neutrinos. The second introductory part of the volume deals with the basics of ion trapping and cooling. The principles of operation of the two trap types, Penning traps and Paul

traps, are explained and technical details that are important for using them are given. Since manipulation and cooling are essential for many applications of these devices the most important detection and cooling techniques are presented.

In the second part a practical question that arises sooner or later to all experimentalists dealing with ion traps is discussed: What does the stored particle do in the trap and how can one simulate its motion during storage? The first chapter of this part introduces different methods to model ion dynamics and describes their implementation. In the second chapter the cooling of ions by collisions with buffer gas, one of the most important and most universal tools in ion manipulation in traps is dealt with in detail, the cooling of ions by collisions with buffer gas atoms is discussed. Different numerical approaches and their results for a few existing devices are introduced to the reader.

The third part of the volume is devoted to two applications discussed in depth. The first example is the use of highly charged ions to obtain high-precision mass values. The method is reviewed and examples related to fundamental questions in modern physics are presented. The second application deals with the storage and investigation of charged antiprotons, which not only is one of the prerequisites for the production of antihydrogen, but also allows in several ways to test one of the most fundamental symmetries, the combined charge, parity and time reversal symmetry, CPT. Ongoing and planned experiments are described as well.

We hope that this volume gives the experienced reader an in-depth view of some aspects of trapped charged particles that he/she might only have touched by now. But most importantly, this book shall give a newcomer to the field some feeling, thoughts and maybe also an introduction about the most interesting aspects at the borderline between modern trapping techniques and fundamental physics.

We would like to thank all authors for their effort to create a concise and yet recent picture of what physics is driving us. Special thanks go to H.-J. Kluge for the idea of the school and his help to organize it; to Christian Caron, our contact at Springer for the easy and smooth connection; and to the Heraeus Foundation and GSI Darmstadt for the kind financial support of the winter school on trapped charged particles.

Darmstadt, 2007

Klaus Blaum
Frank Herfurth

Contents