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Mikhail Yavor

Optics of Charged Particle Analyzers

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Preface

It is a pleasure to welcome Mikhail Yavor back to these Advances. In 1993, he contributed a long chapter on parasitic aberrations in electron optics, in 1998 he examined the optics of systems with narrow gaps and now he has written an entire volume on energy and mass analyzers. Although there have been long accounts of some of these instruments, this is the only recent text that covers energy analyzers, mass analyzers, time-of-flight devices and radiofrequency analyzers. This has the additional advantage that the vocabulary and notation are uniform throughout for all these different members of the analyzer family. The choice of topics covered is described in the author's Foreword and hence not repeated here. I will, however, insist that this account is intended to be readable by a wide audience, and in particular by users of these instruments. It is by no means limited to designers of analyzers and those interested in their optics.

I am sure that this long and meticulous account of the optics and behavior of all these different kinds of energy and mass analyzer will be heavily used and am delighted to include it in these Advances. The dedication is a pleasant reminder that they can create family allegiances, for the late Stella Yavor was also a contributor, as long ago as 1989, writing on electrostatic lenses with L.A. Baranova.

When this volume was about to go to press, I learned of the recent death of one of our Honorary Associate Editors, Ben Kazan. A tribute to him will be included in the Preface to the next volume and meanwhile, I extend all sympathy to his family on behalf of the publishers and myself.

Peter W. Hawkes

Foreword

Two main reasons encouraged me to write on optics of charged particle analyzers. The first is the obvious lack of general literature on the subject. Despite ever-growing competition in performance of modern analytical devices using electron and ion spectrometric methods of investigation of the structure of various substances, the principles and specific features of charged particle optical designs of these devices have not been gathered in general-purpose books for decades. The exceptions are quadrupole and ion trap spectrometers, which are well covered by recent publications, also considering among others ion-optical aspects (Ghosh, 1995; Dawson, 1997; March and Todd, 2005). Wollnik's book (1987a) is the only book devoted to the optics of other types of charged particle analyzers, but it is already more than twenty years old and covers only sector field instruments and multipoles. Surveys on charged particle optics of time-of-flight (TOF) mass spectrometers or electrostatic energy analyzers can be found only in relatively short (and older) articles.

Contemporary charged particle spectrometers are, as a rule, complicated devices that often include very different types of optical elements. For example, a TOF spectrometer may consist of a gas-filled quadrupole for cooling ions, a static focusing channel, a pulsed ion converter (sometimes followed by an energy filter), and finally, a mirror- or sector-type TOF mass analyzer itself. Tandem mass spectrometers are even more complex and can combine static and dynamic mass analyzers. Designers of such instruments must have a good knowledge of all these elements. However, no recent literature presents charged particle optical aspects of different types of electron and ion analyzers and their related transporting interfaces. This monograph is intended to fill this gap.

The second reason is a desire to address this monograph to a larger community. It is not a secret that most excellent books written *by* experts in charged particle optics have been intended, with few exceptions, *for* experts in charged particle optics. My experience of communication with people involved in the design of analytical instruments has revealed that many of them, though not designers of particularly charged particle optic schemes, still would like to understand the principles of optical design. They are not particularly interested in complicated expressions for aberration coefficients or other mathematical details, but they want to see how an optical element works, why it is designed in this and not in some other way, and what is essential in the optical design. In talking with such people, as well as with many students, I often experienced problems in recommending suitable reading. Finally, I decided to write this monograph. My intention was to review the current state of charged particle optical knowledge in the field of electron and ion analyzers and, at the same time, to make the material relatively easy to read. Although it was impossible to avoid mathematical formulas, I tried whenever possible to emphasize the physical principles and qualitative descriptions. Readers will judge whether this goal has been achieved.

Because in any discussion of charged particle spectrometers it is difficult to separate functionally pure analyzing optic elements from the elements of particle transporting channels, this monograph presents both. What is left aside is the optics of electron and ion sources, because surveying this subject requires a profound knowledge of solid state physics and other similar topics in which I do not consider myself an adequate expert. The monograph contains two introductory sections. The first contains basic reminders of the properties of quasi-static electric and magnetic fields, as well as the general laws of charged particle motion in such fields. The second section describes the language of aberration expansions used for analysis of charged particle optical properties of all types of analyzers except radiofrequency (RF) analyzers and Penning traps. Sections 3 and 4 are devoted to optics of elements of charged particle transporting channels, both static and RF. Because it is not possible to describe all the numerous types of electron and ion lenses, I attempted to survey those most often used in charged particle spectrometers or those that seem promising but undeservedly forgotten (e.g., crossed lenses). Later sections consider the analyzers themselves: magnetostatic, electrostatic, combined, TOF, and finally, RF ones. The last class of mass analyzers is surveyed more briefly so as to not simply copy similar information available from other recent books. In all cases where details of designs or effects were omitted, I have tried to supply references to the literature in which these details can be found.

Unfortunately, one monograph does not allow the space to accommodate descriptions of all kinds of mass analyzers and all their features. My choice of the mass analyzers presented herein was based on either their popularity or the promises they offer, although my own personal taste also contributed a little. As far as the analyzer properties are concerned, the lack of space has forced the omission in most cases the discussion of space charge effects, manufacturing tolerances, and requirements related to the stability of power supplies.

Writing this monograph was possible because of my many years of interaction with leading experts in the field. First, I would like to thank two persons: Prof. Dr. H. Wollnik and Dr. A. N. Verentchikov. Working with them at different periods allowed me to reach a level at which I could start writing this monograph. My special thanks goes to Dr. A. Berdnikov, whose experience in mathematics in general and in numerical methods of computing charge particle optics systems in particular rendered me a great service. I am very grateful to the scientific leader of the Flerov Laboratory of Nuclear Reactions in JINR (Dubna), academician Yu.Ts. Oganessian, the laboratory and group leaders at GSI (Darmstadt), Prof. Dr. C. Scheidenberger and Prof. Dr. H. Geissel, the group leader at the Second Physical Institute of the Justus-Liebig University in Giessen, Dr. W. R. Plass, and the members of their teams: Dr. A. G. Popeko, Dr. H. Weick, Dr. M. Winkler and others for fruitful collaboration. My sincere thanks to my colleagues in the Institute for Analytical Instrumentation in St. Petersburg: Prof. L. N. Gall, Prof. Yu. K. Golikov, Dr. Yu. I. Hasin, Dr. V. D. Belov, Dr. N. V. Krasnov, Dr. A. P. Shcherbakov, M. Z. Muradymov, and many others for communications affording me invaluable experience. Finally, I am grateful to the experts in charged particle optic design with whom my destiny intersected and from whom I gained a professional experience: Dr. A. J. H. Boerboom, Dr. D. Ioanoviciu, and Dr. E. de Chambost.

Many of the illustrations in the book were created with the aid of the computer programs SIMION 8.0 (Manura and Dahl, 2006) and GICOSY (Wollnik, Hartmann, and Berz, 1988).

Future Contributions

S. Ando

Gradient operators and edge and corner detection

K. Asakura

Energy-filtering x-ray PEEM

W. Bacsa

Optical interference near surfaces, sub-wavelength microscopy and spectroscopic sensors

C. Beeli

Structure and microscopy of quasicrystals

C. Bobisch and R. Möller

Ballistic electron microscopy

G. Borgefors

Distance transforms

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Non-diffracting optical beams

A. Buchau

Boundary element or integral equation methods for static and time-dependent problems

B. Buchberger

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E. Cosgriff, P. D. Nellist, L. J. Allen, A. J. d'Alfonso, S. D. Findlay and A. I. Kirkland

Three-dimensional imaging using aberration-corrected scanning confocal electron microscopy

T. Cremer

Neutron microscopy

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A. Engel (special volume on STEM, 159)
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A. X. Falcão
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R. G. Forbes
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C. Fredembach
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J. Gilles (vol. 158)
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M. Haschke
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