# Preface

Over the last quarter of this century, revolutionary advances have been made both in kind and in precision in the application of particle traps to the study of the *physics* of charged particles, leading to intensified interest in, and wide proliferation of, this topic. This book is intended as a timely addition to the literature, providing a systematic unified treatment of the subject, from the point of view of the application of these devices to fundamental atomic and particle physics.

The technique of using electromagnetic fields to confine and isolate atomic particles in vacuo, rather than by material walls of a container, was initially conceived by W. Paul in the form of a 3D version of the original rf quadrupole mass filter, for which he shared the 1989 Nobel Prize in physics [1], whereas H.G. Dehmelt who also shared the 1989 Nobel Prize [2] saw these devices (including the Penning trap) as a way of isolating electrons and ions, for the purposes of high resolution spectroscopy. These two broad areas of application have developed more or less independently, each attaining a remarkable degree of sophistication and generating widespread interest and experimental activity.

In the case of mass spectrometry, starting in the 1960s there was initially a rapid proliferation of the use of the 3D rf quadrupole in many fields, such as residual gas analysis, upper atmospheric research, environmental studies, gas chromatography. Since then the field has continued to grow and become refined along differentiated specialized directions, for example sequential ion mass spectrometry. The extant literature on the mass spectrometry uses of ion traps is comprehensive, both in the form of monographs and published proceedings of conferences, such as [3, 4].

On the other hand, it was not until tunable laser radiation sources became available that the application of particle traps to the study of atomic and particle physics saw an explosive expansion in interest and laboratory activity. By combining laser techniques with those of particle trapping it became possible to fully exploit the particle isolation property of the latter. Before that, with the notable exception of the exquisitely precise work on the free electron spectrum by Dehmelt's group, the early difficult experiments to exploit the long perturbation-free spectral observation time in ion traps were severely handicapped by small signal-to-noise ratios. These experiments were carried out by students of Dehmelt and Major on the magnetic resonance spectrum of $He^+$, and Jefferts on $H_2^+$. The first successful attempt to detect optical resonance fluorescence from trapped ions using a conventional light source was achieved at NASA Goddard by Major and Werth in measuring the hyperfine interval in $Hg^+$. It was first shown by Werth at Mainz that the scattering of laser light, even from a diffuse distribution of trapped ions, could be readily detected. The ultimate break-through in the laser detection of trapped ions came in the work of Toschek et al., in which single ions were visually observed. This, combined with the demonstration of laser cooling by Wineland et al. led to the incorporation of laser technology into ion trapping, from which evolved a technique in which not only is the signal-to-noise ratio problem eliminated, but also through laser cooling, the Doppler broadening of the particle spectrum is effectively annulled, ultimately leading to the formation of ion crystals as first observed by Walther and coworkers and transforming the technique into one of great power and elegance.

Unlike the application of ion traps to mass spectrometry, the literature on ion trap physics is diffuse, covering many aspects in the form of extensive review articles, including for example [5–8]. Also an overview on different aspects of ion trap physics can be found in the form of conference proceedings, such as [9–11]. A single monograph *Ion Traps* by P. Ghosh (Oxford) appeared in 1995.

Nevertheless in view of the accelerated advances in the technique in recent years, and the fundamental importance of the many applications, it is evident that a serious gap in the literature exists, which this volume is meant to fill. The treatment of the subject matter is designed, on the one hand, to develop an appreciation of the practical evolution of the technique, its current power and limitations, and, on the other hand, to provide the necessary theoretical underpinning, also through appendices and a comprehensive bibliography. It is left for a future volume to deal with the many important applications, such as ultrahigh resolution spectroscopy, atomic frequency/time standards, particle physics, and quantum computation. Having been associated as experimentalists with the development and application of ion trapping from the time of its inception, F.G. Major and G. Werth have a natural desire to attempt an integrated treatment of the subject, which it is hoped will prove authoritative and useful. With the cooperation of V.N. Gheorghe the treatment of the experimental areas is nicely complemented by supporting theory.

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