Preface

This second volume of the *Charged Particle Traps* deals with the rapidly expanding body of research exploiting the electromagnetic confinement of ions, whose principles and techniques were the subject of volume I. These applications include revolutionary advances in diverse fields, ranging from such practical fields as mass spectrometry, to the establishment of an ultra-stable standard of frequency and the emergent field of quantum computing made possible by the observation of the quantum behavior of laser-cooled confined ions. Both experimental and theoretical activity in these applications has proliferated widely, and the number of diverse articles in the literature on its many facets has reached the point where it is useful to distill and organize the published work in a unified volume that defines the current status of the field.

As explained in volume I, the technique of confining charged particles in suitable electromagnetic fields was initially conceived by W. Paul as a three-dimensional version of his rf quadrupole mass filter. Its first application to rf spectroscopy on atomic ions was completed in H.G. Dehmelt's laboratory where notable work was later done on the free electron using the Penning trap. The further exploitation of these devices has followed more or less independently along the two initial broad areas: mass spectrometry and high resolution spectroscopy. In volume I a detailed account is given of the theory of operation and experimental techniques of the various forms of Paul and Penning ion traps. Of crucial significance in the application to spectroscopy is the possibility of using laser fluorescence and manipulation of internal quantum state populations, to cool the confined ions to temperatures approaching absolute zero. The description of the ion behavior under these extreme conditions requires the use of quantum theory; and this is given in volume I for particles confined in harmonic fields subject to laser excitation. At the lowest attainable temperatures, the ion has a high probability of being in the lowest vibrational state, the quantum ground state. When many ions are simultaneously confined in the same trap, sufficient cooling can result in the ions freezing into a crystalline array, a phenomenon also treated at some length in volume I.

In this volume, an attempt is made to present a consolidated view of the present status of representative laboratory activities aimed at advancing applications of ion traps. Among the principal applications are the following: Mass spectrometry in the context of molecular analysis, precise nuclear isotope masses, and precise elementary particle masses; precise magnetic resonance spectroscopy on elementary particles, the g-factors of multiply charged ions, and precise magnetic hyperfine splittings, with application to microwave atomic frequency standards; laser spectroscopy, including long radiative lifetime determination, ultra-high resolution optical spectroscopy and optical frequency standards and measurement; finally, the exciting new field of quantum computing using ion crystals in which internal states and vibrational states are entangled through laser excitations based on the quantum effects in ion traps, including the direct observation of “quantum jumps,” the quantum Zeno effect, entanglement of quantum states between ions, and quantum teleportation.

The literature relating to applications of trapped ions manipulated by laser fields has exploded in recent years and it is hoped that this volume provides a timely and useful addition to the literature.

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