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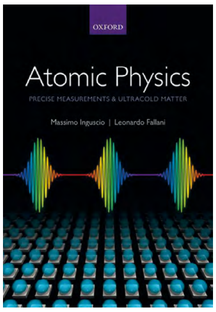

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Atomic Physics
Precise Measurements & Ultracold Matter

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The title of this book is that of few historical books published in the first half of the twentieth century when the study of the energy levels of electrons within atoms, and molecules contributed to the early development of quantum mechanics and later to the establishment as a very powerful theoretical approach to describe precisely atoms and matter. Until around 1980 the topic of atomic physics remained concentrated on the measurements of atomic structures, with an incredible increase in accuracy as soon as tunable lasers became available for the measurements.

Since that time the main target of the atomic physics research has been totally modified, and the present book subtitle is essential to describe the content: "Precise measurements and ultracold matter". These words define the present interest by a community of atomic physicists that is continually expanding worldwide in the number of academic appointments and national laboratories, to a large surprise of the whole physics area.

Within the last twenty years, the previous generic interest for the accurate measurements of atomic and molecular structures was finally concentrated on a few directions, those precise measurements presented in the books. Quantum mechanics is able to explain any small detail of the electronic structure of an arbitrary atom (up to the thirteenth digit presently measurable!). However, let us take uranium with more than ninety electrons and a very highly charged nucleus. The computer effort required to calculate the electronic structures at the level necessary for an efficient comparison with the experiments, is really enormous. Then, is that effort really needed (unless for some probably classified application)? Instead other more accessible issues are explored through precise measurements on simple atomic systems, as hydrogen, antihydrogen, muonium, helium, and so on. In the first instance accurate tests of quantum electrodynamics are performed, because even if the topic is well established, its high-order corrections are difficult to evaluate precisely. That applies also to general relativity investigated by atomic physicists, and to antimatter, whose basic properties, as charge, inertial and gravitational masses, are in the process of being precisely measured in order to test the validity of our present knowledge of the whole universe. Another important issue explored by atomic physicists and well presented in the book, is the real constancy of the fundamental quantities (electron mass, electron charge or, more important, fine-structure constant) that we have assumed so far constant by definition. Is it possible that the evolution of the universe modifies them by a very small amount? Accurate tests performed on atomic clocks, operating on very stable atomic transitions, are progressively lowering the limits on that constancy. A recent surprising result associated to the precise spectroscopic measurements on muonic hydrogen is the determination of the hydrogen nucleus radius, different by five standard deviations from the same determination through collisions of high- energy electrons with hydrogen. The origin of the discrepancy is at present not known, and atomic physics investigations on similar systems are presently planned.

The second part of the subtitle, ultracold matter, defines another research direction that is expanding exponentially and attracting a very large attention, *in primis* by theoretical physics, and also by solid state physics, quantum optics, and so on. This research direction is really on the edge between atomic physics and other areas. In fact the tools required for the preparation of the systems under investigation and for their measurements are exactly those of the precise measurements quoted above. However the scope of the whole research is not the measurement of some important physical quantities. Instead it complies with a very original statement by Richard Feynman: using the uniqueness of the quantum-mechanical Schrödinger equation solution, given two totally different systems that experience the same Hamiltonian, the quantum-mechanical solution of one system provides the solution also of the second system. From that simple statement a new discipline is born: the quantum simulation. The key element is the preparation of ultracold matter, *i.e.*, ultracold atomic or molecular systems prepared in well-defined quantum states. In addition laser optical tools finely manipulated by atomic physicists create an immense variety of Hamiltonians, some of them never imagined by theoreticians. The final target is to simulate Hamiltonians that are of interest to other communities of physicists whose solution by standard classical computers is at least very difficult, or impossible with the present resources. This field has made a very large progress since the first experiment in 2002 in Munich (Germany) on the quantum simulation of a Mott insulator state of solid-state physics. Quantum simulation is not yet quantum computing, where any quantum mechanics problem could be solved given an appropriate number of qubits, but it is a large step toward that quantum device.

It should be clear to a reader that the present book is not organized as a standard textbook where basic quantum mechanics is carefully introduced, and then the secrecies of the laser-atom interactions, the laser manipulation and the production of Bose-Einstein condensates and Fermi degenerate gases slowly revealed to the neophyte in the field. The main authors' target is instead to present very important results achieved by the atomic physics community on the precise measurements and on the ultracold matter. Both authors are high-level atomic physicists operating at LENS (European Laboratory for Nonlinear Spectroscopy) in Florence, and their preferred choice for the atomic physics presentation is based on the excellent results achieved there in the last few years.

Four chapters of the book cover basic systems as hydrogen, helium, alkali and alkali-earth atoms, and finally ions. All these systems are the essential components for the precise measurements quoted above, and for several more described by the authors. Two separate chapters analyze in large detail the laser cooling and the Bose-Einstein condensation, including fermionic systems and cold molecules. Laser cooling, the amazing product of a close collaboration between theoreticians and experimentalists, is the basic tool for the manipulation of atomic systems. In Bose-Einstein condensation atomic physics pushed the atomic control down to the picokelvin range, and demonstrated that no limit really exists for the required optical technologies. The same chapter presents also atom interferometry, mainly for fundamental physics tests. The two final chapters of the book deal with optical lattices, the first one for their impact on precision measurements and the second one on the quantum simulation. In optical lattice ultracold atoms experience a periodic potential produced by the interference of the laser beams. The optical lattice potential allows a precise control of the atomic motion and has originated a new large class of investigations. For instance the precise determination of the *h/m* leading to a more accurate value of the fine-structure constant is stressed within the appropriate chapter. The important role played by quantum simulation with ultracold atoms, discussed within the last chapter, was already pointed out in this review. The book is completed by four appendices where the basic atomic physics instruments, the mathematical description of the Bose-Einstein condensates, and the laser optics are presented. A very extended bibliography provides the reader with a very good overview of the world scenery.

The book is perfect for an advanced readership, as well as for a specialized PhD school. For the atomic physics community it offers a very timely and useful assembly of the present state of knowledge on very hot research topics. In addition it represents a very good reference book for researchers operating not precisely within the covered areas and requiring access to references and results up to now dispersed over several publications.

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