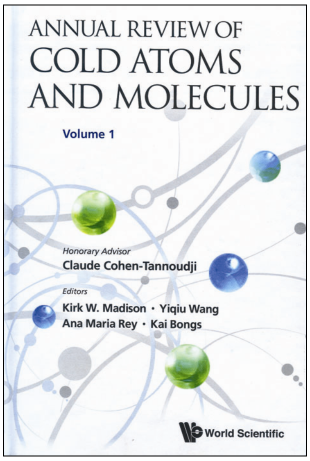

Annual Review of Cold Atoms and Molecules. K. W. Madison *et al.* (eds). World Scientific Publishing Co., 5 Toh Tuck Link, Singapore 596224. 2013. vol. 1, 540 pp. Price: US$ 98.

The field of cold atoms has witnessed explosive growth in recent years and has contributed to many diverse fields, much beyond what one could have imagined. The past three decades have witnessed dramatic developments in quick succession in the field of laser cooling. Cooling and trapping of neutral alkali atoms in the late 1980s was quickly followed by achieving Bose–Einstein condensation in the bosonic species and quantum degeneracy in Fermi gases, the cooling and trapping of two-electron atoms, of radioactive atoms and so on. The field has rapidly expanded in several directions – cooling of Rydberg atoms, cold molecules on the one hand, and studies of specific problems like collective excitations, super-radiance, on the other. In addition, numerous applications have emerged, that have far-reaching consequences – like clocks with unprecedented accuracy. It is therefore apt that a series of *Annual Reviews* is being brought out; in fact, such a series should well have appeared earlier. The book under review is the first of this series, is edited by Madison *et al.* In the foreword, Nobel-prize winner Claude Cohen-Tannoudji points out that the field of cold atoms and molecules has impacted almost every branch of physics. The articles in this volume are testimony to this.

The book is a compilation of 13 chapters, classified into four parts – Atoms and molecules in optical lattices, physics with Bose–Einstein condensates (BECs), Atom–light interactions, and Fundamental physics. Being the first in the series, this book reviews important developments over the last five years. I expect that subsequent volumes will review further developments.

Laser cooling requires the driving of specific electronic transitions in atoms, at the exclusion of others. Therefore, early experiments on laser cooling of neutral atoms were confined to alkali elements, which being one electron systems, have the simplest energy-level structure. Within a few years, scientists had successfully cooled and trapped all the stable alkali elements, and had even Bose-condensed most of them. Attention was then turned to two-electron systems. Of these, Yb was the first to be Bose condensed. The first chapter of the book, devoted to ultracold Yb in optical lattices, is by Sugawa *et al.* They first describe the steps taken in their experimental realization of quantum degeneracy in four of the five Bosonic isotopes of Yb, in both the fermionic isotopes and binary mixtures of these isotopes. This is followed by descriptions of the phase transitions observed with the degenerate gases loaded into an optical lattice – the superfluid to Mott-insulator transition, is the first of these. Moving further, they experimentally realize the dual Mott insulator in a Bose–Fermi degenerate gas mixture. They also load two disparate (in terms of mass) atoms in a lattice – Li and Yb – to mimic lattices with impurities. Next, they introduce the reader to the elementary concepts of photo-association – the light-induced transition of a pair of atoms from the free state to a bound state. The authors then describe their experiments to obtain the scattering length of isotopes. The final section of this chapter deals with optical Feshbach resonance and describes how sub-micron spatial control could be achieved in the inter-atomic interaction in BECs. This chapter gives the reader a flavour of the kind of experiments that are being carried out in this field. By wielding immense control over lattice geometries, over long-range dipolar interactions, and over internal degrees of freedom of the atoms, physics of cold atoms provides a way of creating novel lattice models that cannot be realized in usual condensed matter physics. By tailoring the interactions between ultracold atoms (or molecules) in optical lattices, collective excitations may be induced or suppressed, e.g. rotational excitation in polar molecules. This forms the subject matter of chapter 2, where Litinskaya and Krems present their theoretical calculations of LiCs in an optical lattice. The introductory part, which is well referenced, sets the stage by describing the various phenomena that have been studied by populating optical lattices with ultracold atoms. These range from the fermionic superfluid (BCS)–Molecular condensate (BEC) crossover to the possibility of quantum simulation. The initial emphasis of the authors is on quantum simulation of lattice models, and therefater, they move to other topics – Frenkel excitons, transfer of quantum energy across the lattice, lattices with tunable disorder, resonance scattering and disorder correlation. Chapter 3, by Chen *et al.*, titled ‘Quantum phase transitions of cold atoms in optical lattices’, describes theoretical advances in the field, with emphasis on the lattice symmetry. A well-written introduction initiates the reader to optical lattices – triangular, honeycomb and Kagome lattices are considered. The new techniques employed, namely dynamical cluster approximation and cellular dynamical mean-field theory are explained. Thereafter, quantum phase transitions in optical lattices of various kinds are described. These three chapters form Part I of the book.

Part II, which contains four chapters, deals with the physics with BECs. Chapter 4 by Mashayekhi, Bernier and Zhou, discusses insights obtained on the behaviour of condensates (at 0 K) beyond the dilute limit. The authors briefly review recent experiments and then discuss in detail the theoretical advances. This chapter, written in a lucid and unbiased manner, is well suited for one who is seeking an overview of the field. Chapter 5 by Spielman, is devoted to the intriguing concept of light-induced gauge fields. It describes the technique developed by the author to engineer artificial gauge fields for ultracold neutral atoms using Raman transitions. A particularly nice feature of this article is that the author alternates between a theoretical exposition of the concepts and experimental realization of the aspects discussed. After a well written introduction, the author focuses on the toy model of rotation. Theoretical outcomes are compared with experimental results. Some practical ‘tricks of the trade’ are discussed, like methods to increase the angular momentum per particle, and techniques to obtain 2D gases in laboratory experiments. On the theoretical side, the author considers the application of Raman beams, calculates the resulting dressed states and identifies a mechanical momentum making use of mechanical and canonical variables, leading to the exotic and intriguing concept of the creation of artificial magnetic field. This is supported by experimental results. Chapter 6 by Zhou, Chen and Wang, deals with the manipulation of BECs. It is the longest chapter in the book and perhaps understandably so, as it concerns an area that has witnessed many exciting results in recent years. The use of Majorana transitions to obtain spinor condensates, to issue out atoms in the form of a spinor–atom–laser, super-radiant scattering – the experimental realization of Dicke's cooperative scattering, control of momentum states by standing wave pulses – these are some of the manipulations discussed. They have enabled numerous applications like the atom clock, gravimetry and quantum computing. The authors have done a good job of presenting the important results in a clear fashion. Chapter 7 by Wilson *et al.* deals with an interesting idea – creating 2D turbulence in a BEC. After introducing the concept, they proceed to show the experimental results that they have obtained. Simple intuitive ideas like stirring the BEC with a blue-detuned beam produces interesting results. Emerging concepts like disordered distribution of vortex cores and vortex tangles are discussed.

Part III of the book is devoted to atom–light interactions. The first chapter by Pritchard, Weatherhill and Adams, is devoted to nonlinear optical effects in cold Rydberg atoms. Usually one associates nonlinear optical effects with intense light. However, in recent years, it has been realized that nonlinear effects can be observed even at the level of a few photons. This is made possible by the suppression, by quantum interference of the linear effects that usually overwhelm the nonlinear effects. Electromagnetically induced transparency (EIT) is one such mechanism which has generated a lot of interest because of possible applications, like logic gates, quantum memory and quantum communication. Rydberg atoms, which are essentially neutral atoms, with one of the electrons raised to a highly excited state (principal quantum number ~50), possess large dipole moments. Thus, interaction between neighbouring atoms is quite large, enhancing the strength of dipole–dipole interactions, leading to large nonlinearities. This chapter is well written. Starting from the basics of nonlinear optics, it takes the reader through relevant areas of quantum optics, and then onto technical aspects of recent studies on Rydberg atoms. All through, there is adequate reference to pertinent experiments. After discussing concepts like dipole blockade and super-radiance cascade, the authors discuss several proposed applications of Rydberg atoms like detection of impurities. Two topics of current interest are the deterministic generation of photons (photons on demand) and the generation of correlated pairs of photons. The authors discuss how EIT in Rydberg atoms could provide such sources. Another interesting topic covered in this chapter is photon blockade – prevention of a second photon entering a cavity when there already exists a photon within. These and several other elegant and intriguing concepts are introduced, and their experimental observations highlighted, making this chapter interesting, informative and inspiring. This field is growing at breakneck pace – in fact, the authors point out that during the preparation of the manuscript, several new results have been reported. In Chapter 9, Freegarde *et al.* discuss an emerging topic – mirror-mediated cooling of atoms – one that is gaining considerable attention and progress both in theory and experiment. The chapter provides the theoretical framework. Chapter 10 is devoted to cavity quantum optics with BEC. Zhou *et al*. discuss the theoretical aspects, and demonstrate the simulation of Dicke quantum phase transition – cooperative effects in a collection of two-level atoms interacting with a bosonic field. An interesting effect is the cavity-induced switching between atomic localized and extended states. An avenue of investigation pointed out is the study of the roles of internal atomic spin and opto-mechanical effects.

Part IV of the book deals with reviews, some of the areas of fundamental physics probed by cold atom experiments. Daniel Steck, in the chapter entitled 'Cold atoms and the Maxwell's demon' discusses how the century and a half-year-old gedanken experiment is sought to be physically realized using cold atoms at an asymmetric barrier. The demon, a fictitious entity, by careful opening and shutting of a trap-door between two chambers containing an ideal gas, is able to collect all atoms into one of the chambers. This clearly violates time reversal symmetry and thus, the underlying mechanism should be an irreversible process. As all proposals to date rely on light shifts for providing the asymmetric barrier, the basics are discussed in terms of two- and three-level atoms under the action of a light field. Different proposals and experimental studies are commented upon, providing the reader a good overview of the progress in this field. This chapter, however, presumes the reader has some familiarity with the field of laser cooling and trapping, especially if one were to appreciate the intricacies involved and the clever tricks employed. Chapter 12 by Dunjko and Olshanii is a review of the process of thermalization from the perspective of eigenstate thermalization hypothesis. The authors introduce the concepts and definitions quite well, making the subject matter accessible to the uninitiated non-theorist. Equilibration and thermalization, concepts, which are often taken to mean the same, are differentiated and elaborated upon. The final chapter of the book by Peng *et al.*, reviews some of the precision measurements undertaken in cold atom experiments. On the one hand, technological advances have enabled hitherto unimaginable feats like trapping of a single atom. On the other hand, clever techniques have been devised, like the use of stimulated emission during magneto-optic trap (MOT) loading to enhance atom number. These have resulted in a variety of ultra-high precision measurements, especially in atom interferometry, leading to measurement of the acceleration due to gravity, gravity gradient, cold atom clocks, ultrasensitive gyroscopes, proposals for gravitation wave detection, measurement of the fine structure constant and testing of the equivalence principle.

To sum up, the book gives us a wonderful overview – a description of the current status of the field, the experimental intricacies, theoretical understanding, challenges faced and clever techniques employed. It also shows how this field has addressed a variety of issues over a wide gamut of areas. Practical applications like cold atom clocks, gravity wave detection on the one hand, and testing of fundamental aspects on the other, have emerged from this amazing field.

However, while the preface and foreword emphasize that the term 'cold atoms' refers to neutral atoms as well as ions, there is no article that deals with laser-cooled ions, a field that also has witnessed rapid progress during the recent past. Two other areas, in my opinion, have not received due attention in this book. They are trapping of single atoms, and individual site addressing in optical lattices, both of which have great potential for application, especially in quantum information and quantum computing. Nevertheless, the compilation provides an excellent overview, and amply shows how rich the field of cold atom physics is and how these sub-microscopic, sluggish particles have been able to shed light on unexpected areas in physics. The authors have written the various chapters in a manner that the subject may be understood by a physicist from any field. In fact, most chapters will be easily understood by a person who has completed his Master's in physics. The editors have done a good job of ensuring uniformity in level throughout. Clear figures and explanations enable one to get the gist of the work. Adequate referencing enables interested readers to pursue the field further. The authors have explained the subject matter well, without oversimplification that could lead to dilution of content. I recommend the book to every researcher in this field, as it provides a good compilation of the latest developments in the field. I recommend this book to every student aspiring to make a career in cold atom physics, as it gives a clear overview. I would also recommend this book to every physicist, as it shows how far-reaching the impact of this field has been. I look forward to the next book in this series.

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