UNIVERSAL THEMES OF BOSE-EINSTEIN CONDENSATION

Following an explosion of research on Bose-Einstein condensation (BEC) ignited by demonstration of the effect by 2001 Nobel Prize winners Cornell, Wieman, and Ketterle, this book surveys the field of BEC studies. Written by experts in the field, it focuses on BEC as a universal phenomenon, covering topics such as cold atoms, magnetic and optical condensates in solids, liquid helium, and field theory. Summarising general theoretical concepts and the research to date – including novel experimental realisations in previously inaccessible systems and their theoretical interpretation – it is an excellent resource for researchers and students in theoretical and experimental physics who wish to learn of the general themes of BEC in different subfields.

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Foreword

At the time of the first workshop in this series in 1993, the only experimentally realized Bose condensate (at least in the simple sense conjectured by Einstein) was liquid ^{4}He. In the intervening twenty-plus years, much has happened in the world of Bose-Einstein condensation (BEC). Probably the most exciting development has been the attainment of condensation in ultracold bosonic atomic gases such as ^{87}Rb and ^{23}Na in 1995, followed a few years later by the achievement of degeneracy and eventually Bardeen-Cooper-Schrieffer (BCS) pairing in their fermionic counterparts, and the experimental realization of the theoretically long-anticipated "BEC-BCS crossover" by using the magnetic field degree of freedom to tune the system through a Feshbach resonance. One particularly fascinating aspect of the latter has been the realization of a "unitary gas" at the resonance itself – a system which prima facie has no characteristic length scale other than the interparticle separation, and is therefore a major challenge to theorists. Other systems in which BEC has been realized, sometimes transiently, include exciton-polariton complexes in semiconducting microcavities and, at least in a formal sense, the magnons in a magnetic insulator, as well as ultracold gases with a nontrivial and sometimes large "spin" degree of freedom.

As compared with our "traditional" Bose condensate, liquid ^{4}He, these new systems typically have many more (and more rapidly adjustable) control parameters, and have therefore permitted qualitatively new types of experiment. One particularly fascinating development has been the use of optical techniques to generate "synthetic gauge fields" and thus mimic some of the topologically nontrivial systems which have recently been of such intense interest in a condensed-matter setting. At the same time, there remain long-standing issues from helium physics, such as the nature and consequences of "spontaneously broken U(1) symmetry," the "Kibble-Zurek" mechanism, and more generally the relaxation of strongly non-equilibrium states to equilibrium; in some cases, the new systems have been used to address these more quantitatively than was possible with ^{4}He. The chapters in this volume address all of these questions and more, and should be of intense interest to both the experimental and the theoretical sides of the BEC community.

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Preface

This book marks the twentieth anniversary of the publication of the book *Bose-Einstein Condensation* by Cambridge University Press. The book was the result of the 1993 meeting in Levico-Terme, Italy, organized by Allan Griffin, David Snoke, and Sandro Stringari, with significant help from Andre Mysyrowicz. That meeting grew out of a desire by many theorists and experimentalists to discuss the general themes of Bose-Einstein condensation, to draw connections between different physical systems.

One of the major driving forces for that meeting was the desire to have another example of Bose-Einstein condensation besides liquid helium. There was serious discussion at the time of whether nature abhorred a condensate, and liquid helium was a special, anomalous case. Experiments on spin-polarized hydrogen, excitons in semiconductors, and optically trapped atoms had been going on for more than a decade, without success. To move the field forward, the organizers of the 1993 meeting brought together world experts on the general theory, and experimentalists of all types, to discuss the universal themes of Bose-Einstein condensation generally. There were fascinating and heated debates about such topics as the time scale for condensation (could it be possible that condensation will not occur in a system with finite lifetime?), the concept of spontaneous symmetry breaking (could there ever be a universal "phase standard" for condensates?), and how superfluidity and condensation are related.

The situation is quite changed now. We now have many experimental examples of Bose-Einstein condensation, most notably atoms at very low temperature in optical traps, which led to the Nobel Prize in Physics in 2001. This work of Eric Cornell and Carl Wieman was first announced at the second general meeting on Bose-Einstein condensation in 1995, in Mt. Ste. Odile, France. This led to the successful conference series on atomic Bose-Einstein condensation, which now takes place regularly in San Feliu de Guixols, Spain.

Because of this changed situation, the present book does not have the same form as the 1995 book. At that time, it was possible to survey a good fraction of all the experimental and theoretical efforts in the field. The field is now so large that no book can do that comprehensively, and this book leaves out a good many significant topics. But the meeting[1] which led to this book, held at the Lorentz Center[2] in Leiden, Netherlands, in 2013, had much the same spirit as the original 1993 meeting, namely to bring together many of the world's experts on the general theory and diverse experiments on Bose-Einstein condensation, with the aim of discussing universal questions, some of which are still debated. This book aims to have that spirit of looking at the larger questions, while also surveying many of the particular experimental systems. Several of the people at the 1993 and/or 1995 meetings gave impetus to the 2013 Leiden meeting, such as Gordon Baym, Wolfgang Ketterle, Tony Leggett, David Snoke, Henk Stoof, and Sandro Stringari.

It is with great sadness that we note that the chair of the original 1993 meeting, Allan Griffin, who was a driving force of nonequilibrium and condensate physics and the San Feliu de Guixols conference series for many years, passed away in 2011, before the meeting in Leiden. In fact, the first discussions for organizing a twenty-year anniversary meeting took place between David Snoke and Nick Proukakis during "Griffinfest," a research symposium held in Toronto in May of 2011, attended by colleagues, friends, and family of Allan Griffin, just a few days before he passed away.[3] His energy and zeal would surely have made a significant contribution to this book.

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1 "Universal themes of Bose-Einstein Condensation" workshop, organized by K. Burnett, P. B. Littlewood, N. P. Proukakis, D. W. Snoke, and H. T. C. Stoof, 11–15 March 2013. Details can be found at www.lorentzcenter.nl/lc/web/2013/546/info.php3?wsid=546.

2 We gratefully acknowledge the wonderful support received by all the staff at the Lorentz Center, and in particular Corrie Kuster and Mieke Schutte, whose constant support ensured we could focus on the "science," thus indirectly assisting us in the early stages of planning of this book.

3 Details can be found at ultracold.physics.utoronto.ca/GriffinFest.html.