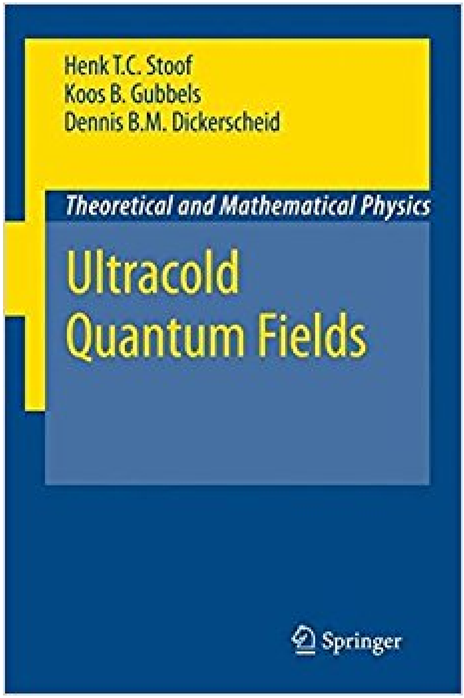
Ultracold Quantum Fields (Theoretical And Mathematical Physics)



Synopsis

On June 19th 1999, the European Ministers of Education signed the Bologna Dec laration, with which they agreed that the European university education should be uniformized throughout Europe and based on the two cycle bachelor masterÃ¢â ¬â„¢s sys tem. The Institute for Theoretical Physics at Utrecht University quickly responded to this new challenge and created an international masterÃ¢â ¬â„¢s programme in Theoret ical Physics which started running in the summer of 2000. At present, the masterÃ¢â ¬â„¢s programme is a so called prestige master at Utrecht University, and it aims at train ing motivated students to become sophisticated researchers in theoretical physics. The programme is built on the philosophy that modern theoretical physics is guided by universal principles that can be applied to any sub?eld of physics. As a result, the basis of the masterÃ¢â ¬â„¢s programme consists of the obligatory courses Statistical Field Theory and Quantum Field Theory. These focus in particular on the general concepts of quantum ?eld theory, rather than on the wide variety of possible applica tions. These applications are left to optional courses that build upon the ?rm concep tual basis given in the obligatory courses. The subjects of these optional courses in clude, for instance, Strongly Correlated Electrons, Spintronics, Bose Einstein Con densation, The Standard Model, Cosmology, and String Theory.

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Customer Reviews

From the reviews:Ã¢â ¬Å“The book offers a substantial and self-consistent introduction into this exciting and challenging subject of present day research. Ã¢â ¬Â¦ Important items in basic quantum theory Ã¢â ¬Â¦ fine and hyperfine spectral structure, are presented in a new way. Ã¢â ¬Â¦ Most appreciable in this essentially theoretical text is the continuous correspondence with events from the laboratories: actually by the extended bibliography laboratories get very close to the reader.Ã¢â ¬Â• (Bassano Vacchini, Zentralblatt MATH, Vol. 1177, 2010)Ã¢â ¬Å"The book has evidently been put together with great care and is very well written. It provides detailed textual explanations to guide the reader through the equations, and includes the intermediate steps in derivations. Ã¢â ¬Â¦ found friendly and understandable by students including, in many cases, senior undergraduates. Ã¢â ¬Â¦ It is pleasure to commend it warmly to those entering, teaching or working in the burgeoning field of ultracold atomic gases as well as in many-particle physics more generally.Ã¢â ¬Â• (Peter V. E. McClintock, Contemporary Physics, Vol. 52 (2), 2011)

Ultracold Quantum Fields provides a self-contained introduction to quantum field theory for many-particle systems, using functional methods throughout. The general focus is on the behaviour of so-called quantum fluids, i.e., quantum gases and liquids, but trapped atomic gases are always used as an example. Both equilibrium and non-equilibrium phenomena are considered. Firstly, in the equilibrium case, the appropriate Hartree-Fock theory for the properties of a quantum fluid in the normal phase is derived. The focus then turns to the properties in the superfluid phase, and the authors present a microscopic derivation of the Bogoliubov theory of Bose-Einstein condensation and the Bardeen-Cooper-Schrieffer theory of superconductivity. The former is applicable to trapped bosonic gases such as rubidium, lithium, sodium and hydrogen, and the latter in particular to the fermionic isotope of atomic lithium. In the non-equilibrium case, a few topics are discussed for which a field-theoretical approach is especially suited. Examples are the macroscopic quantum tunnelling of a Bose-Einstein condensate, the phase dynamics of bosonic and fermionic superfluids, and their collisionless collective modes. The book is based upon the notes for a lecture course in the masters programme in Theoretical Physics at Utrecht.

For those who want updating on the status of low-temperature physics, or for students who are learning the subject for the first time, this book is an excellent choice. It not only has challenging problem sets at the end of every chapter, but it contains insightful commentary and the details of how to approach problems in the physics of ultracold gases. As expected for a book on theoretical physics, there is not much discussion on experimental techniques, but enough however to gain an appreciation for the brilliance behind them. A book like this can be partitioned according to three different areas, namely the strategies discussed for solving problems, the physical insights, and topics that would be of interest to the mathematical community:Strategies for the solution of ultracold many-body problems: 1. The renormalization group, which is a method that allows calculations over and above mean field theory, and which allows higher-order (beyond quadratic) fluctuations to be taken into account. Using the renormalization group one can study critical phenomena by finding the fixed points of the renormalization group transformation. This approach is constructive in that it entails that the fixed points be found explicitly, and not merely a proof of their "existence." The renormalization group can also be used to study quantum phase transitions, and this raises the question as to whether it is always true that near a classical critical point the quantum theory reduces to the classical theory. The renormalization group is applicable at any temperature, and it can be used to determine the homogeneous phase diagram of a strongly-interacting imbalanced Fermi mixture. 2. The Landau approach to phase transitions, which uses an "effective" approach where the microscopic fluctuations have been "integrated out." 3. Hubbard-Stratonovich transformations, which can result in the Hartree-Fock theory of an interacting quantum gas. 4. 'Bogoliubov substitutions 'can be used in the interactive case, and consist of replacing non-commutative operators by complex numbers, which is valid when the occupation number is an appreciable fraction of the total number of atoms. 5. For the case of Bose-Einstein condensation, the true interaction potential is replaced by a 'psuedo-potential', and is valid when the thermal de Broglie wavelength is much larger than the range of interatomic interaction. This strategy can result in ultraviolet divergences. 6. The 'Bogoliubov approximation' which consists of neglecting all terms in the action that are higher than quadratic. 7. The 'Popov theory', which consists of two equations for studying Bose-Einstein condensation in ultracold atomic Bose gases, one being the modified Gross-Pitaevskii equation and the other being the Bogoliubov-de Gennes equation, which takes into account inhomogeneities. 8. The time-dependent Gross-Pitaevskii equation, which assumes the kinetic energy is much less than the interaction energy, and results in the Thomas-Fermi limit. This equation eventually results in the "hydrodynamic" equations for the condensate, which are essentially the collective excitations around the Thomas-Fermi profile). It can also describe the situation of a Bose-Einstein condensate subject to a rotation, where when interactions are present, gives a coherence length for the vortex size, and is essentially a proof of superfluidity. 9. In the study of the BEC-BCS crossover, the 'Nozieres-Schmitt-Rink approximation', which takes into account (up to quadratic) fluctuations around the normal state solution, and detects the effects of non-condensed pairs. 10. The 'decoupling approximation', which describes the Mott-insulating phase.Physical insights: 1. The idea of a quantum phase transition, namely one where phase transitions occur at zero temperature. 2. Phase transitions can be described by an 'order parameter', with the exception of Kosterlitz-Thouless transitions. 3. The 'correlation length', which sets the length scale over which the correlations between atoms, spins, etc decay and is a tool for describing phase transitions. It takes into account spontaneous symmetry breaking, which cannot be described using perturbation theory. For phase transitions that spontaneously break a continuous symmetry, the correlation function of the transverse fluctuations falls off algebraically, not exponentially. This is the origin of the Goldstone theorem. If the correlation function approaches a constant, this is taken to be a sign of long-range order. 4. The Feshbach resonance, which allows atomic interactions to be "tuned", in that a bound state is shifted, which allows the scattering length to be manipulated experimentally. The BEC-BCS crossover can be studied experimentally by use of Feshbach resonances. A magnetic field can be used to tune the scattering length. 5. In an ultracold gas of atoms, the two-body interactions are described by a single parameter, the s-wave scattering length, since at such low temperatures, the scatterings do not involve nonzero angular momentum. 6. At low temperatures, the long wavelength physics is what is relevant, and so ultraviolet divergences are not really an issue as they are in high-energy physics. 7. For an attractive interaction in a homogeneous Bose gas at temperatures close to zero, one obtains a metastable condensate. 8. Superfluidity is viewed as the state wherein an object can move through a gas as if it were absent. For an ideal Bose gas, the superfluid density is the difference between the total density and the normal density. 9. The analog of a BCS transition can be obsrved in a neutral ultracold atomic Fermi gases with attractive s-wave interactions. 10. The 'Thouless criterion', which is a pole in the many-body T-matrix corresponding to long-lived pairs and is induced by the presence of the Fermi sea. 11. The famous (and amazing) Ward identities, which reflect gauge invariance, and are crucial for interpreting measurements in ultracold gases. 12. An analog of X-ray Bragg reflection spectroscopy can occur in ultracold gas experiments, wherein matter waves are diffracted from a periodic light grating. Hubbard models describe the many-body physics of ultracold atoms in an optical lattice. In particular, the Bose gas in an optical lattice gives a new quantum phase of matter, the 'Mott-insulator phase'. 13. Radio-frequency spectroscopy can be used to coherently transfer one atom from one hyperfine state to another by means of a radio-frequency photon field. This technique effectively measures the imaginary part of the photon self-energy. 14. For a trapped Bose gas, phase correlations are indistinguishable for both classical and quantum treatments of the thermal cloud.Of interest from a purely mathematical standpoint:1. The non-analytic behavior of second-order phase transitions. 2. The order parameter, and a discontinuity at the critical temperature, which characterizes a first-order phase transition. 3. The notion of a "universal property" of a gas, which is one that does not depend on the scattering length. For an ultracold quantum gas, the corrections to the universality are "small." 4. The existence of diagonal long-range order, which is periodicity that extends over the entire solid, and is manifested in the diagonal elements of the one-particle density matrix. 5. The definition of Bose-Einstein condensation: one of the eigenvalues of the one-particle density matrix is on the order of the number of particles; with all others being approximately equal to one. 6. The 'Gross-Pitaevski equation', which is a nonlinear differential equation that ensures the expansion in fluctuations has been done correctly. 7. 'Nambu space', which is an additional off-diagonal contribution to the average in the Bogoliubov approximation that is not present in the normal phase of the gas. 8. The 'Lee-Huang-Yang correction', which is a correction to the ground state energy of the Bose-Einstein thermodynamic potential. 9. The 'BEC-BCS crossover', which is analytic as condensed pairs become more tightly bound. 10. The Mermin-Wagner-Hohenberg theorem, which prohibits a condensate in one and two dimensions, and whose proof is based on reductio ad absurdum. One naturally wonders if a constructive proof can be found for this theorem. 11. A system of vortices can be viewed as a two-dimensional Coulomb gas, and this can allow one to study the Kosterlitz-Thouless transition, wherein vortices begin to unbind and superfluidity disappears. 12. There exists a cusp in the ground-state energy of the Mott insulator and van Hove singularities in the density of states.Note: This book was read and studied between May and August 2011.

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