Preface to the Second Edition

The second edition of this book has two additional chapters based on lecture notes of the course "Quantum Field Theory in Condensed Matter Physics" given by the author at the Doctoral School in Physics of the University of Padova. These two chapters are an introduction to the functional integration for bosonic and fermionic fields with applications to superfluids, superconductors, and ultracold atomic gases.

Chapter 8 considers the quantum statistical mechanics of bosons within the formalism of functional integration for the bosonic field, introducing the equation of state of weakly interacting bosons and the dimensional regularization of Gaussian fluctuations. The time-dependent Gross-Pitaevskii equation is analyzed: its connection to the equations of superfluid hydrodynamics and its topological and solitonic solutions (quantized vortices, dark solitons, and bright solitons). Chapter 9 introduces the formalism of functional integration for the fermionic field. The equation of state of weakly interacting repulsive fermions and the paring of attractive fermions within the mean-field Bardeen-Cooper-Schrieffer (BCS) theory of low-temperature superconductivity is derived. A section is devoted to the phenomenological Ginzburg-Landau theory of superconductivity which is quite successful near the critical temperature. Finally, the BCS theory is extended to analyze, in the case of ultracold atomic gases, the BCS-BEC crossover from the weak-coupling BCS regime of Cooper pairs to the strong-coupling regime with Bose-Einstein condensation (BEC) of molecules.

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Padua, Italy
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Preface to the First Edition

This book contains lecture notes prepared for the one-semester course "Structure of Matter" belonging to the Master of Science in Physics at the University of Padova. The course gives an introduction to the field quantization (second quantization) of light and matter with applications to atomic physics.

The first chapter briefly reviews the origins of special relativity and quantum mechanics and the basic notions of quantum information theory and quantum statistical mechanics. The second chapter is devoted to the second quantization of the electromagnetic field, while the third chapter shows the consequences of the light field quantization in the description of electromagnetic transitions. In the fourth chapter, the spin of the electron, and in particular its derivation from the Dirac equation, is analyzed, while the fifth chapter investigates the effects of external electric and magnetic fields on the atomic spectra (Stark and Zeeman effects). The sixth chapter describes the properties of systems composed by many interacting identical particles. The Fermi degeneracy and the Bose-Einstein condensation, introducing the Hartree-Fock variational method, the density functional theory, and the Born-Oppenheimer approximation, are also discussed. Finally, in the seventh chapter the second quantization of the non-relativistic matter field, i.e., the Schrödinger field, which gives a powerful tool for the investigation of finite-temperature many-body problems and also atomic quantum optics is explained. Moreover, in this last chapter fermionic Fock states and coherent states are presented, and the Hamiltonians of Jaynes-Cummings and Bose-Hubbard are introduced and investigated. Three appendices on the Dirac delta function, the Fourier transform, and the Laplace transform complete the book.

It is important to stress that at the end of each chapter, there are solved problems which help the students to put into practice the things they learned.

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