Preface

This book is the fruit of my lectures on "The Theory of Many-Body Systems," which I have been teaching for many years in the degree course on Physics at the University of Trento. As often happens, the outline of the book came from my students' notes; in particular, the notes of the students of the academic year 1999–2000, which were extremely useful to me. Chapter 6, on the Monte Carlo methods, is the work of Francesco Pederiva, a research assistant in our department. During the course Francesco, apart from illustrating the method, teaches the students all the computer programs (continually referred to in this book), by means of practical exercises in our computational laboratory. In particular, he teaches the Hartree–Fock, Brueckner–Hartree–Fock, Kohn–Sham and diffusion Monte Carlo programs for the static properties, the RPA, and time-dependent HF and the LSDA for Boson and Fermion finite systems. These programs are available to anyone who is interested in using them.

The book is directed toward students who have taken a conventional course on quantum mechanics and have some basic understanding of condensed matter phenomena. I have often gone into extensive mathematical details, trying to be as clear as possible, and I hope that the reader will be able to rederive many of the formulas presented without too much difficulty.

In the book, even though a lot of space is devoted to the description of the homogeneous systems, such as electron gas in different dimensions, quantum wells in an intense magnetic field, liquid helium and nuclear matter, the most relevant part is dedicated to the study of finite systems. Particular attention is paid to those systems realized recently in laboratories throughout the world: metal clusters, quantum dots and the condensates of cold and dilute atoms in magnetic traps. However, some space is also allotted to the more traditional finite systems, like the helium drops and the nuclei. I have tried to treat all these systems in the most unifying way possible, hoping to bring all the analogies to light. My intention was to narrow the gap between the usual undergraduate lecture course and the literature on these systems presented in scientific journals.

It is important to note that this book takes a "quantum chemist's" approach to many-body theories. It focuses on methods of getting good numerical approximations to energies and linear response based on approximations to first-principle Hamiltonians. There is another approach to many-body physics that focuses on symmetries and symmetry breaking, quantum field theory and renormalization groups, and aims to extract the emergent features of the many-body systems. This works with "effective" model theories, and does not attempt to do "*ab initio* computations." These two ways of dealing with many-body systems complement each other, and find common ground in the study of atomic gases, metal clusters, quantum dots and quantum Hall effect systems, which are the main application of the book.

I am indebted to many of my colleagues in the Physics Department of Trento for discussions and remarks. Specifically, I'm grateful to G. Bachelet, D.M. Brink, S. Giorgini, F. Iachello, W. Leidemann, R. Leonardi, F. Pederiva, G. Orlandini, S. Stringari, M. Traini, G. Viliani and A. Vitturi. Many aspects of the book were clarified during my stays in Barcelona, Paris and Palma de Mallorca, where I had the occasion to discuss many subjects with M. Barranco, A. Emperador, M. Pi, X. Campi, N. Van Giai, D. Vautherin, Ll. Serra and A. Puente, as well as during the frequent visits to our department by my friends A. Richter and K. Takayanagi.

Thanks are also due to Irene Diamond, for the English translation of the book.

This book has cost me a great investment in time, which recently has kept me from other research projects and, above all, from my family. It is dedicated to my wife, Giovanna, and to my children, Fiorenza, Filippo and Luigi. Filippo has been of enormous help in editing the figures.

Enrico Lipparini
January 2003

Preface to the Second Edition

In this edition the main changes are a new chapter on the spin–orbit coupling in semiconductor heterostructures and a considerable expansion of the chapters dealing with trapped atomic gases, density functional calculations, current response to an electromagnetic field, and the Brueckner–Hartree–Fock and Monte Carlo approaches.

The spin–orbit (SO) interaction in nanostructures has prompted intense activity in recent years since it is an essential mechanism for most spintronic devices. In fact, it links the spin and charge dynamics, opening up the possibility of spin control through an electric field. Indeed, recent experimental and theoretical investigations have shown that the SO coupling affects charge transport, far-infrared absorption, and electronic spin precession in a magnetic field, besides giving rise to the spin-Hall effect. All these topics are analyzed in the new Chapter 6 of this edition.

After the first experimental realization of Bose–Einstein condensation in dilute atomic gases, the field of ultracold gases has become a rapidly growing one. In the last few years a considerable amount of experimental and theoretical work has focused on ultracold Fermi gases. The description of the ground state and excited state properties of these systems has been added in many new sections of the book.

The illustration of density functional calculations in quantum wires and molecules has been subjected to much more detailed examination than before. Particular attention has been given to the description of noncollinear local spin density approximation calculations in nanostructures in the presence of SO interaction.

The sections illustrating current response to an electric field have been expanded to give a detailed description of the conductivity problem, with particular emphasis on Landauer conductance, magnetoconductivity and spin-Hall conductivity. A section on the problem of Hall conductivity in graphene has been added.

The Monte Carlo chapter has been revised and expanded to include numerical applications to trapped Fermi gases and many-nucleon systems. A similar revision and expansion has been carried out for the chapter dealing with the Brueckner–Hartree–Fock theory.

Apart from the above main additions and expansions, the remainder of the book has undergone slight revisions and corrections.

Enrico Lipparini
June 2007