Quantum Theory of Finite Systems

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Preface

This book introduces the quantum theory of finite many-body systems. Finite systems are met with in a variety of fields. Examples are nuclei, atoms, molecules and also solitons in particle physics, vortex lines in quantum liquids, etc. Despite the specialized terminologies many of the methods and approximation schemes used in different fields are strikingly similar. We give a unified presentation of the various methods, hoping that this will contribute to bridging the communication gaps between disciplines.

In contrast to most texts on the many-body problem, this book stresses the finite-system aspects of the theory. Thus special attention is given to the mean field approximations, to the ensuing broken symmetries, and to the associated collective motions such as rotations. The formalism is, of course, quite general and applies to infinite as well as finite systems. However, some specific features of systems with infinite numbers of degrees of freedom are deliberately left out, such as the thermodynamic limit, critical phenomena, and the elimination of ultraviolet divergences.

The book is divided into four parts. Part I introduces the basic mathematical tools: second quantization with special emphasis on coherent states, canonical transformations required to diagonalize quadratic hamiltonians, Wick theorems and the resulting diagram expansions, and oscillator models of finite systems. The basic tools are then applied in parts II–IV, which provide independent but complementary descriptions of the dynamics of many-particle systems. Part II presents mean field approximations, which play an essential role in the description of finite systems. We emphasize the problem of broken symmetries resulting from the mean field approximations, as well as the associated collective motions. Quantization of collective modes is also discussed in terms of recently developed path-integral methods. Part III is a review of perturbation theory in terms of both time-dependent Feynman diagrams and time-independent Goldstone diagrams. Self-consistent schemes are formulated in terms of symmetry-conserving approximations. In part IV we discuss variational methods based on correlated wavefunctions, including spin correlations. The approximations schemes are formulated for fermions and bosons at zero and at nonzero temperature.

The book has been written after several years of lecturing on many-body problems. It has been conceived as a graduate-level course. The material is presented in a self-contained form, and sufficient detail is given to allow a reader with only an elementary knowledge of quantum mechanics to rederive for himself all the results. Each chapter is followed by problems

(190 altogether). These problems have been designed to help the reader practice the theory, as well as to expand on specific points raised in the text.

The book has also been conceived as a research tool and a reference for the working physicist. It provides the background required to understand the more specialized literature, and it includes some of the most recent developments. We have not included physical applications, which would have of necessity been superficially described in a book of this nature. Applications and further developments of the theory can be found in the references given at the end of each chapter. We preferentially cite reviews, where further references can be found. We also cite those papers to which our presentation is most related. Finally, we cite some recent applications. We have made no effort to retrace the historical development of the field, nor have we attempted to make an exhaustive bibliography. We apologize to all those who may justly feel that their work has not been adequately recognized.

The book is admittedly influenced by the prevailing style at the Service de Physique Théorique in Saclay. We express special thanks to Roger Balian and Michel Gaudin for continuous discussions and generous help. We have greatly benefited from the teachings of Bernard Jancovici, Cyrano de Dominicis, Claude Itzykson, and the late Claude Bloch. We owe to numerous physicists more than can be reckoned from the text. Throughout the years we have been deeply influenced by contacts with Manoj Banerjee, Gordon Baym, Georges Bertsch, Aage Bohr, Gerry Brown, Carl Levinson, Ben Mottelson, Phil Siemens, and Igal Talmi. We wish to thank Paul Bonche, Edouard Brezin, David Brink, Stefano Fantoni, Daniel Gogny, Itzhak Kelson, Claude Mahaux, Gene Marshalek, John Negele, Henri Orland, John Owen, Fabre de la Ripelle, Mannque Rho, Hartmut Schulz, Roger Smith, Dominique Vautherin, Felix Villars, and John Zabolitzky for discussions which have led us to a better understanding of specific aspects of the material presented in this book. During the five years needed to complete this work, one of us (J.-P.B.) spent two years at the University of Illinois at Urbana-Champaign. He would like to thank the Physics Department of this university for its stimulating atmosphere and warm hospitality.

We thank the Service de Physique Théorique for the material aid required to complete the manuscript. We are very grateful to Madeleine Porneuf for reading the proofs.

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