Preface

The goal of the present course on “Fundamentals of Theoretical Physics” is to be a direct accompaniment to the lower-division study of physics, and it aims at providing the physical tools in the most straightforward and compact form as needed by the students in order to master theoretically more complex topics and problems in advanced studies and in research. The presentation is thus intentionally designed to be sufficiently detailed and self-contained – sometimes, admittedly, at the cost of a certain elegance – to permit individual study without reference to the secondary literature. This volume deals with the quantum theory of many-body systems. Building upon a basic knowledge of quantum mechanics and of statistical physics, modern techniques for the description of interacting many-particle systems are developed and applied to various real problems, mainly from the area of solid-state physics. A thorough revision should guarantee that the reader can access the relevant research literature without experiencing major problems in terms of the concepts and vocabulary, techniques and deductive methods found there.

The world which surrounds us consists of very many particles interacting with one another, and their description requires in principle the solution of a corresponding number of coupled quantum-mechanical equations of motion (Schrödinger equations), which, however, is possible only in exceptional cases in a mathematically strict sense. The concepts of elementary quantum mechanics and quantum statistics are therefore not directly applicable in the form in which we have thus far encountered them. They require an extension and restructuring, which is termed “many-body theory”.

First of all, we have to look for possibilities for formulating real many-body problems in a mathematically correct but still manageable way. If the systems considered are composed of distinguishable particles, their description can be obtained directly from the general postulates of quantum mechanics. More interesting, however, are systems of identical particles, whose N-particle wavefunctions must fulfil quite special symmetry requirements. Working directly with the required (anti-)symmetrised wavefunctions proves to be extraordinarily tedious. A first perceptible simplification is provided in this connection by the formalism of second quantisation. It allows a quite elegant description, but of course does not provide an actual solution to the problem. The student who has been confronted in lower-division courses with problems which as a rule can be treated with mathematical rigour has to become accustomed to the idea that realistic many-body problems can practically never be treated exactly. In order to nevertheless fulfil the central function of a theoretician, i.e. the description and explanation of experiments, some concessions must be made. This includes, as a first step, the construction of a theoretical model which can be understood as a caricature of the real world, in which nonessential details are suppressed and only the essence of the problem is emphasized. Finding such a theoretical model must be considered to be a nontrivial challenge for theoreticians. Chapter 2 therefore treats the formulation and justification of important standard models of theoretical physics in detail. Their presentation is carried out consistently using the formalism of second quantisation from Chap. 1.

Unfortunately, the real situation can seldom be caricatured in such a way that the resulting model is on the one hand still sufficiently realistic, and on the other can be treated with mathematical rigour. Thus, one usually has to accept additional approximations in order to find solutions. A powerful technique in this connection has proven to be the Green's function method, with its concept of quasi-particles. The abstract theory is discussed in Chap. 3 and then applied to numerous concrete problems in Chap. 4. Diagrammatic methods of solution are worked out in Chaps. 5 and 6. They should be included nowadays within the indispensable repertoire of every theoretician. A number of exercises (together with their explicit solutions) are also included in this volume and are in particular designed to help the student to acquire a facility for working with the formalism and applying it to concrete topics. The solutions given, however, should not tempt the reader to forbear making a serious effort to solve the problems independently. At the end of each major chapter, questions are included, which can be useful to test the knowledge gained by the reader and in preparing for examinations.

This book is the result of diverse special-topics lecture courses on many-body theory which I have given at the universities of Würzburg, Münster, Osnabrück, and Berlin (Germany), Warangal (India), Valladolid (Spain), Irbid (Jordan), and Harbin (China). I am very grateful to the students of those courses for their constructive criticism. It is quite clear to me that the material in this volume with certainty no longer belongs to lower-division physics. However, I also believe that it is indispensable for making the transition to independent research as a theoretician. Since the available textbook literature on the subject of many-body theory as a rule presupposes advanced knowledge and substantial experience on the part of the reader, the present book might – hopefully – be very useful for the "beginner". I am very grateful to the Springer-Verlag for their concurring assessment as well as for their professional cooperation.

Berlin, August 2008 *Wolfgang Nolting*

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Nolting, W.
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