Preface

Intended Audience, Approach and Presentation

This text is intended for a course of about six months for undergraduate students. It arises from the adaptation and the amendments to a text for a full-year course in Structure of Matter, written by one of the authors (A.R.) more than 30 years ago. At that time only a few (if any) textbooks having the suited form for introduction to the basic quantum properties of atoms, molecules, and crystals in a comprehensive and interrelated way, were available. Along the past 20 years many excellent books pursuing the aforementioned aim have been published (some of them are listed at the end of this preface). Still there are reasons, in our opinion, to attempt a further text devoted to the quantum roots of condensed matter properties. A practical aspect in this regard involves the organization of studies in Physics, after the huge scientific outburst of the various topics of fundamental and technological character in recent decades. In most universities there is now a first period of three or four years, common to all students and devoted to elementary aspects, followed by an advanced program in more specialized fields of Physics. The difficult task is to provide a common and formative introduction in the first period suitable as a basis for building up more advanced courses and to bridge the area between elementary physics and topics pertaining to research activities. The present attempt toward a readable book, hopefully presenting those desired characteristics, essentially is based on a mixture of simplified institutional theory with solved problems. The hope, in this way, is to provide physical insights, basic culture, and motivation, without deteriorating the possibility of advanced subsequent learning.

Organization

Structure of Matter is such a wide field involving so many subjects that a first task is to find a way to confine an introductory text. The present status of that discipline represents a key construction of the scientific knowledge, possibly equated only by the unitary description of the electromagnetic phenomena. Even by limiting attention to conventional topics of condensed matter only, namely atoms, molecules, and crystals, we are still left with an ample field. For instance, semiconductors or superconductors, the electric and magnetic properties of matter and its interaction with electromagnetic radiation, the microscopic mechanisms underlying solid-state devices as well as masers and lasers, are to be considered as belonging to the field of structure of matter (without mentioning the "artificial" matter involving systems such as nanostructures, photonic crystals, or special materials obtained by subtle manipulations of atoms by means of special techniques). In this text the choice has been to limit the attention to key concepts and to the typical aspects of atoms (Chaps. 1–5), molecules (Chaps. 7–10) and of crystalline solids (Chaps. 11–14), looking at the basic "structural" subjects without dealing with the properties that originate from them. This choice is exemplified by referring to crystals: electronic states and quantum motions of ions have been described without going into the details regarding the numerous properties related to these aspects. Only in a few illustrative cases favoring better understanding or comprehensive view, derivation of some related properties has been given (examples are some thermodynamical properties due to nuclear motions in molecules and crystals or some of the electric or magnetic properties). Chapter 6 has the particular aim to lead the reader to an illustrative overview of the quantum behaviors of angular momenta and magnetic moments, with an introduction to spin statistics, magnetic resonance, and spin motions and a mention of spin thermodynamics, through the description of adiabatic demagnetization. The four new Chaps. (15–18) introduced in the 3rd Edition deal with relevant phases of solid matter (magnetic, electric, and superconductive) and to the related phase transitions.

All along the text emphasis is given to the role of spectroscopic experiments giving access to the quantum properties by means of electromagnetic radiation. In the spirit to limit the attention to key subjects, frequent referring is given to the electric dipole moment and to selection rules, rather than to other aspects of the many experiments of spectroscopic character used to explore the matter at microscopic level. Other unifying concepts present along the text are the ones embedded in statistical physics and thermal excitations, as it is necessary in view of the many-body character of condensed matter in equilibrium with a thermal reservoir.

Prerequisite, Appendices, and Problems

Along the text the use of quantum mechanics, although continuous, only involves the basic background that the reader should have achieved in undergraduate courses. Knowledge of statistical physics is required based on Boltzmann, Fermi–Dirac and Bose–Einstein statistical distributions, with the relationships of thermodynamical quantities to the partition function (some of the problems work as proper recall, particularly for the physics of paramagnets or for black-body radiation). Finally the reader is assumed to have knowledge of classical electromagnetism and

Hamiltonian mechanics. Appendices are intended to provide *ad hoc* recalls, in some cases applied to appropriate systems or to phenomena useful for illustration. The Gaussian CGS units are used.

The problems should be considered entangled to the formal presentation of the subjects, being designed as an intrinsic part of the pathway the student should move by in order to grasp the key concepts. One of the reasons to entangle problems and institutional theory can be found in what Feynman wrote in the preface to his Lectures: "I think one way we could help the students more would be by putting more hard work into developing a set of problems which would elucidate some of the ideas in the lectures." Some of the problems are simple applications of the equations and in these cases the solutions are only sketched. Other problems are basic building blocks and possibly expansions of the formal description. Then the main steps of the solution are presented in some detail. The aim of the *mélange* intuition-theory-exercises pursued in the text is to favor the acquisition of the basic knowledge in the wide and wonderful field of condensed matter, emphasizing how phenomenological properties originate from the microscopic, quantum features of nature.

It should be obvious that a book of this size can present only a fraction of the present knowledge in the field. If the reader could achieve even an elementary understanding of the atoms, molecules, and crystals, how they react to electric and magnetic fields, how they interact with electromagnetic radiation, and respond to thermal excitation, the book will have fulfilled its purpose.

The fundamental blocks of the physical world are thought to be the subnuclear elementary particles. However, the beauty of the natural world rather originates from the architectural construction of the blocks occurring in the matter. Ortega Y Gasset wrote "If you wish to admire the beauty of a cathedral you have to respect for distance. If you go too close, you just see a brick." Furthermore, one could claim that the world of condensed matter more easily allows one to achieve a private discovery of phenomena. In this respect let us report what Edward Purcell wrote in his Nobel lecture: "To see the world for a moment as something rich and strange is the private reward of many a discovery."

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This book has been written while receiving inspiration from a number of textbooks dealing with particular items or from problems and exercises suggested or solved in them. The texts reported below are not recalled as a real "further-reading list," since it would be too ample and possibly useless. The list is rather the acknowledgment of the suggestions received when seeking inspiration, information, or advices.

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