Preface

Various reasons concurred in my decision of writing this book. Some years ago Freeman Dyson, reasoning on the process of learning and teaching quantum theory, came out with the idea that a physics student, after learning the tricks of the quantum formalism and getting right answers, "begins to worry because he does not understand what he is doing". The student, says Dyson,[1] "has no clear physical picture in his head and tries to arrive at a physical explanation for each of the mathematical tricks". He gets discouraged and after some months of unpleasant and strenuous time, he suddenly says: "I understand now that there isn't anything to be understood". What happens? Dyson suggests that we learn to think in quantum-mechanical language and no longer try to explain in terms of pre-quantum conceptions. As an undergraduate student, facing my first quantum-mechanics textbook, I had similar feelings. I felt lost within a mathematical formalism with abstract objects and concepts. Bras, kets, and operators, came seasoned with counterintuitive statements that shook my own conceptions of nature. Some years later, when I was ready to accept that there was nothing to understand, Thomas A. Brody[2] organized in Mexico a graduate students' seminar on the interpretations of the mathematical formalism of quantum mechanics; a seminar to show that in the quantum theory, besides the facts and excellent agreement with experimental results, one has to recognize the existence of open epistemological problems. After those years, I taught quantum physics repeatedly, and I have tried to present the fundamentals of the theory as a coherent and comprehensive body of phenomena, using, whenever possible, simple mathematical techniques.

The twentieth century was, to some extent, the century of quantum theory. The fundamentals of the present day nanoscience and nanotechnology are closely linked with the electronic and optoelectronic properties of physical systems in the quantum domain. Some systems like the repulsive square barrier and the square-

[1] *Innovation in Physics*, F. J. Dyson, *Scientific American*, **199**, 74 (1958).

[2] *The Philosophy Behind Physics*, T. A. Brody; L. de la Peña and P. E. Hodgson, editors, Springer-Verlag, Berlin-New York, 1993.

well potentials, that were simple academic examples in standard quantum mechanics courses, become systems of current interest in theoretical, experimental, and applied physics. Studying these systems, fruitful approaches, models, and techniques evolved. The scattering approach was one of them, and it has been rather successful for studying transport properties. Since then I have gradually introduced this powerful method in my lectures to discuss some simple problems. Energy–eigenvalue equations and eigenfunctions are straightforwardly derived. The ease with which students learn using this intuitive and algebraic method, enticed me and enabled me to include other systems like the double-barrier potentials, double quantum wells, and superlattices.

The general plan of this book is similar to that of most of the textbooks devoted to a first course of non-relativistic quantum theory. In the first two chapters we will briefly summarize the physical problems that show the limits of the classical theories and the new ideas that explained, permanently or temporarily, those problems. Concepts like energy quantization in the blackbody radiation, wave-particle duality, and the Bohr postulates, are thoroughly discussed. We end up with a simple and intuitive derivation of the Schrödinger equation. On the problem of the interpretation of the wave function, we keep a consistent position, but avoid excessive discussion of some controversial issues, which are studied in other books such as *Introduction to Quantum Mechanics* by L. de la Peña. In the second part of this book (Chaps. 3–5), we study the usual examples: free particle; infinite quantum well; rectangular barrier and the *finite* quantum well. We study also more complex systems like the double barrier, the double quantum well, and the *finite* Kronig-Penney model. Fully solving these examples, we face additional properties like the quantum coherence. We introduce the transfer matrix method and let the students acquaint themselves with systems that are present in industrial opto-electronic devices. Chapter 6 is devoted to the semiclassical method of Wentzel, Kramers, and Brillouin (the WKB approximation). This topic is discussed using also the transfer matrix method. New relations are derived and applied for simple examples. From Chap. 7 onwards, we present most of the standard content in a regular quantum book (operators, expected values, angular momentum and spin, matrix representations, the Pauli equation, etc.), we study the well-known harmonic oscillator, the Hydrogen atom, and the fine structure that spurred the crisis of the old quantum theory, between 1920 and 1925. We end up with a summary of the perturbation theory and a chapter on the distinguishable and indistinguishable identical particles. We analyze the close relation between wave-function symmetries, statistics and spin, and discuss properties like the Bose-Einstein condensation and the Pauli exclusion principle.

Together with the formal presentation of the quantum theory, the main objective of this book is to present a coherent set of concepts and physical phenomena. The most emblematic quantum properties like the tunneling effect through potential barriers and the energy quantization in the confining potentials, appear and reappear in more complex examples, modified or transformed. These phenomena, together with the quantum version of the particle current density, the transmission and reflection coefficients, and the splitting of the energy levels that give rise to the energy bands structure, are some of the physical phenomena studied in this text. One of the aims is to show students that quantum theory, more than a set of axioms and differential equations, is a consistent and intelligible theory that clarifies the quantum behavior present in an uncountable number of realizations of the microscopic and macroscopic systems. We pursue the mathematical rigor and conceptual depth together with simple calculations and enhanced comprehension of the quantum concepts.

The content and depth with which we discuss the fundamental issues of the quantum theory is appropriate for a semester course or a trimester plus a complementary course. In each chapter we have some solved problems, which in certain cases complement the discussion of some topics. The second part of this book can also be used as an introductory course to let electric and electronic engineers get acquainted with semiconductor heterostructures, and the quantum properties of these systems.

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