

Preface to the Second Edition

This textbook on quantum physics is in some aspects different from most books on this topic. While the essential mathematical formalism—in the simplest possible form—both of non-relativistic single particle quantum mechanics and of quantum field theory are presented, selected experiments play an important role in the foundation of the theory and for making contact with modern applications. Hereby a special focus is on nanostructures and nanoelectronics as the subtitle “Schrödinger’s Cat with the Dwarfs (in Greek: nanos)” indicates. The structure of atoms and of the Periodic Table of Elements, for example, is introduced on the basis of the electronic structure of semiconductor quantum dots rather than by considering the hydrogen atom and its extrapolation to multi-electron atoms. “Schrödinger’s Cat” in the subtitle paradigmatically describes the other aim of the book, namely to discuss more in extension than commonly the philosophical background and the counterintuitive aspects of quantum physics.

Why now a second edition of the book after a relatively short time? From discussions with colleagues and students I got the impression that both specific aspects of the book might be deepened somewhat more. For this purpose I have added some more relevant experiments with nanostructures: The quantum point contact in connection with the conductance quantum is introduced and its use as a charge detector in nanoelectronic circuits is explained. As a direct application interference experiments in a nanoscaled Aharonov Bohm ring with an additional probe for “Which Way” information are presented. Furthermore, the realisation and the study of the electronic properties of an artificial quantum dot molecule are presented.

Already in the first edition of the book I had briefly mentioned that non-locality of quantum physics should be better discussed within the frame of quantum field theory. In this new edition I have extended and deepened this idea, that particle-wave duality and non-locality in the Einstein-Podolsky-Rosen (EPR) paradox are much better understood on the basis of quantum field theory than in the frame of single particle Schrödinger quantum mechanics. Correspondingly, an additional new section on the particle picture in quantum field theory and the non-locality of

quantum fields is devoted to this issue. Some counterintuitive aspects of quantum physics, thus, become more acceptable to our understanding.

Apart from these two major additions to the book I have incorporated two interesting new developments having been awarded with the Nobel prize, the realisation of atomic Bose–Einstein condensates and the detection of the Higgs particle. Both topics being relevant to quantum physics are briefly explained in the corresponding context. Also, a quantum interference experiment with giant C_{60} buckyball molecules is reported as an example for present research in the direction of elucidating the border line between classical and quantum behaviour. Some minor errors have been removed in the new edition and some new problems have been added.

I want to thank Gregor Mussler for his help in the preparation of most of the new figures. Stefan Fölsch has supplied nice figures of his work on Indium quantum dot molecules and has critically read the related text; also thanks to him. Thanks are also due to Claus Ascheron of Springer Verlag for his encouragement and his effort in editing this new edition.

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Hans Lüth

Preface to the First Edition

The original German edition of this book was published in 2009. Because of the positive response I have got from students and colleagues I translated the book into English and furthermore added some new problems, the last chapter “synopsis,” and an additional Appendix about the reduced density matrix.

What was the reason to write this book? There are a large number of excellent textbooks on quantum mechanics on the market. Nearly all of these books have in common that quantum mechanics is presented as one of the most important and successful theories to solve physical problems. This is totally in the sense of most physicists, who applied, until the 1970s of the twentieth century, in a first quantum revolution quantum mechanics with overwhelming success not only to atom and particle physics but also to nearly all other science branches as chemistry, solid state physics, biology, or astrophysics. Because of the success in answering essential questions in these fields, fundamental open problems concerning the theory itself were approached only in rare cases. This situation has changed since the last decade of the twentieth century. Since then there are new sophisticated experimental tools in quantum optics, atom and ion physics, and in nanoelectronics, which can touch inherent quantum physical questions and allow interesting tests of the theory itself. Such questions, as for example, origin and consequences of superposition and entanglement, are of predominant importance for fields as quantum teleportation, quantum computing, and quantum information in general.

From this “second quantum revolution” as this continuing further development of quantum physical thinking is called by Alain Aspect, one of the pioneers in this field, one expects a deeper understanding of quantum physics itself but also applications in engineering. There is already the term “quantum engineering” which describes scientific activities to apply particle wave duality or entanglement for practical purposes, for example, nanomachines, quantum computers, etc.

This background in mind I have written the present book. Particular quantum phenomena are more at the center of interest rather than the mathematical formalism. I prefer a more pictorial and sometimes intuitive description of the phenomena, and recent experimental findings from research on nanoelectronic systems are often presented to support the theory. Also, connections to other science

branches such as elementary particle physics, quantum electronics, or nuclear magnetic resonance in biology and medicine are made.

Concerning the formalism, I generally restrict myself to first approximation steps, which are relevant for experimental physicists and engineers in applying the theory or to estimate the order of magnitude of experimental results or data. On the other hand, the Dirac bra-ket notation is introduced in analogy to three-dimensional vectors and it is used for simplicity reasons in many cases. Similarly, commutator algebra is introduced as essentially adding or subtraction of symbols (operators). The mathematical background necessary to read the book is quite simple. Only the knowledge of simple functions, simple differential equations, and basics of matrix algebra is required.

Rather than axiomatically introducing important quantities and equations I have preferred to make the invention of basic equations or the mathematical tools for field quantization plausible by physically reasonable conclusions and extrapolations.

The book was written on the basis of manuscripts of lectures on quantum physics and nanoelectronics, which I have given to physics and electrical engineering students at the Aachen University of Technology (RWTH). Essential extensions are, of course, due to my own research in quantum electronics. In particular, supervising PhD students in this field and the many discussions with them had great influence on the way of presentation. I want to thank all of them for the interesting discussions which also helped me to a deeper insight into the fascinating field of quantum physics.

Furthermore, I want to thank my former coworkers, meanwhile all in academic teaching and research positions, Arno Förster, Michel Marso, Michael Indlekofer, and Thomas Schäpers for many exciting disputes, which contributed to further elucidation of difficult questions.

During the translation of the original German edition into English Margrit Klöcker sometimes improved and corrected my English grammar; also thanks to her.

I owe very special thanks to my late wife Roswitha. She supported me all the time during which I wrote the original German manuscript and she invented the subtitle “Schrödinger’s Cat and the Dwarfs.” This subtitle accurately expresses the main focus of the book, namely a more thorough diving into the physical and philosophical content of quantum mechanics (paradigm: Schrödinger’s cat), and this in the context of the nanoworld (world of the dwarfs). Roswitha found the right words for this aspect of the book that I lacked.

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Schrödinger's Cat and the Dwarfs

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