

Preface

In 1900 there were clouds on the scientific horizon, unexplained phenomena that foretold the coming of the great intellectual revolution that was quantum mechanics. (See Chap. 2.) Today the scientific horizon is not without similar clouds. Quantum field theory, our standard model for understanding the fundamental interactions between particles and fields, tells us that the energy content of the quantum vacuum should be 10^{120} times larger than it actually is. At the interface between general relativity and quantum field theory, information seems to be vanishing at event horizons in a very unphysical way (see Sect. 6.21). Within black holes, singularities are predicted to exist that are completely beyond the reach of contemporary physics. Quantum chromodynamics, our standard model of particles, works very well in agreeing with high-energy physics experiments, but it employs two dozen arbitrary particle masses and interaction strengths. We have no idea where these values came from, how they are related, or how they were set in the early universe.

We can anticipate that our current understanding of Nature at the smallest and largest scales is at best a rickety scaffolding that must inevitably be replaced or improved. It is likely that another scientific revolution is on the way. Quantum mechanics will certainly play a key role in this revolution, but it is currently hampered by our lack of understanding of its inner mechanisms and our inability to visualize the many counter-intuitive aspects of quantum behavior. The Transactional Interpretation of quantum mechanics, presented and illustrated in this book, provides tools for visualization, for understanding quantum processes, and for designing new experiments. It paves the way for future theoretical and technical progress and in our understanding of the way the universe works. These tools should also be useful in the coming computation revolution, based on artificial intelligence, quantum computing, and quantum communication (see Chap. 8) that will, if properly used, lead to improvement of the human condition and benefit all of us.

This book gives an overview of the interpretational problems of quantum mechanics, provides an introduction to the Transactional Interpretation, and then demonstrates the use of it in understanding what is going on “behind the scenes” in

many otherwise strange and mysterious problems of quantum optics. The target audience is the intelligent reader with some grasp of basic mathematics and a curiosity about quantum mechanics, what it is and how it works. We will not shy away from using occasional equations, but we will use them sparingly, and only when they are needed to make an important point.

The style of this book is intended to be wedge-shaped, starting easy and progressing to the somewhat more technical. It begins with a narrative style and introduces new concepts slowly and carefully. It builds up the basic conceptual framework of the Transactional Interpretation slowly, and then swings into action, applying it to a large collection of otherwise mysterious and counter-intuitive experiments that illustrate the curious behavior of quantum phenomena. This requires some mathematics, but the experiments that require the heavy use mathematics for their analysis are placed in Appendix D. The reader can “surf” over the mathematical parts and still gain a deep appreciation of what quantum mechanics is and how it works.

A certain mental flexibility will be asked of the reader in mastering the concept of “advanced” waves that are going backwards in time and carrying negative energy into the past. We are conditioned by the everyday world of experience to expect an “arrow of time” that always points from the past to the future, and we are disturbed by anything that seems to be going in the wrong time direction. However, the fundamental equations of physics have a time symmetry that recognizes no preferred time direction. A movie made of the behavior of fundamental particles looks OK, whether the images are presented in the time-normal or the time-reverse sequence. How this time-symmetric microcosm scales up to become the time-forward-only everyday world is a very deep question that is discussed in some detail in Chap. 9. The Transactional Interpretation, described in this book, uses waves going in both time directions with the two types doing handshakes as one of its basic quantum mechanisms, because that mechanism can be seen in the quantum formalism itself and because it allows us to understand the weirdness of entanglement and nonlocality. However, we note that these advanced time-running-backwards effects are limited to just the formation of time-forward transactions and are never allowed to produce “advanced effects” that would violate cause-and-effect.

The reader is also warned that there are a large and growing number of interpretations of quantum mechanics, of which the Transactional Interpretation is only one. I am reminded of a story that I heard long ago about a young child who was growing up in a house operated by the Berlitz School of Languages as a residence for the language teachers of the School. The child’s mother spoke to him in English, his father in French, and the other occupants of the house each spoke to him in a different language. One day, the child began to speak in gibberish. His parents, after hours of persuasion, finally convinced him to talk to them in a language that they could understand. “Well,” he said, “I’m getting to be a pretty big boy, and I decided that it was time that I had a language of my own.” This is much the way it is with

quantum interpretations: philosophers of science and philosophy-inclined physicists seem to prefer to have an interpretation of their own. Most of the resulting interpretational attempts have the problems that they introduce changes to the standard quantum formalism or they address only a restricted subset of the many interpretational problems and issues of the quantum formalism. In this book we will focus on the Transactional Interpretation and will only compare and contrast it with the orthodox Copenhagen Interpretation. We will discuss alternative interpretations only peripherally. It would require a much larger book (and one that I would not enjoy writing) to comprehensively present and criticize all of the many interpretations of quantum mechanics that are currently out there.

The portraits of physicists used in the opening chapters have been softened and rendered as “oil portraits” by using a conversion procedure on available photographs. The sources of the figures and portraits are specified in the **List of Figures** section on pages *xxiii–xxv*. There, the source notation “JGC” means that the figure was produced by the author.

Readers are encouraged to visit the Q&A section in **Appendix A** of this book whenever they encounter a term or idea that may require further clarification.

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Entanglement, Nonlocality and Transactions

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