

Preface

The early 20th century saw three radical changes that transformed theoretical physics and determined most of the course of physics ever since: the introduction of the theories of relativity, special and general, and of quantum theory. The last of these represented the really revolutionary upheaval. Albert Einstein originated the first two, and he and Niels Bohr initiated the third. However, after the full architecture of quantum theory had been designed by Werner Heisenberg, Erwin Schrödinger, Paul Dirac, and Max Born, the paths of the two revolutionaries who started it all diverged and they became scientific antagonists.

The fundamental point of disagreement between Einstein and Bohr was their clash concerning how quantum mechanics, as the fleshed-out quantum theory was called, dealt with the reality of the physical world. Both agreed that the new theory was based on describing and predicting the probabilities of the outcomes of experiments. Einstein insisted that therefore it did not describe reality. A theory that did not directly deal with reality and concerned itself only with probabilities of observations was unsatisfactory to him and needed completion. For Bohr, the outcomes of experiments were sufficient and, in fact, all that could be said about the sub-microscopic world.

This book recalls, for non-scientific readers, the history of quantum mechanics, the main points of its interpretation, and Einstein's objections to it, together with the responses engendered by his arguments. We point out that most popular discussions of the strange aspects of quantum mechanics ignore the fundamental fact that Einstein was correct in his insistence that the theory does not directly describe reality. While that fact does not remove these counterintuitive features, it casts them into a different light.

In order to set the question of how physics treats reality in its proper perspective, we then follow the history of two central aspects of physics: the elucidation of the basic structure of the world made up of particles, and the explanation, as well as the prediction, of how objects move. This history, prior to quantum mechanics, reveals that whereas theories and discoveries concerning the *structure* of nature became increasingly realistic, the laws of motion, even as they became more powerful also became more and more abstract and remote from intuitive notions of reality. The long history of atomism, beginning in ancient Greece, very slowly evolved from purely philosophical speculation to a theory with some basis in scientific facts. But by the beginning of the 20th century, atoms were firmly recognized as real. When it comes to accounting for the dynamics of moving bodies, the story is quite different. Aristotle's law of motion described intuitively how heavy carts moved against the resistance of the road, but the much more universal and powerful laws established by Newton gained their abstract power by sacrificing direct and intuitive contact with real experience, as every student new to learning physics can attest. The break with a direct description of reality two hundred and fifty years later embodied in quantum mechanics was nevertheless profound.

Another area of theoretical physics in which, in the 19th century, imagination and model building replaced direct description of reality was that of electromagnetism. Faraday's introduction of the seminal concept of a field and Maxwell's mathematical characterization of this field, though based on ideas that were later discarded,

turned out to be of crucial importance in physics throughout the 20th century.

This partial history is followed by a brief account of the enormous achievements of physics based on quantum mechanics and its combination with Faraday's notion of the field, the quantum theory of fields. The accomplishments of physics owed to quantum mechanics all concern details of the fundamental constitutional structure of the world rather than how objects move. The fact that the quantum theory is probabilistic and does not directly touch reality in its basic architecture has not prevented it from being able to account for structural details of nature, intimately tied to reality and experimentally verified to an astounding degree of accuracy, and to bring systematic order to a welter of apparently chaotic experimental discoveries of new particles. As a result, more than half a century after Einstein's death and almost as long after the death of Bohr, there is no doubt among physicists that quantum mechanics, reality-friendly in its basis or not, is here to stay. Physics enters the 21st century with a number of profound open questions, but the validity of quantum mechanics is not one of them.