Quantum Mysteries

The Quantum Theory of Motion. An Account of the de Broglie-Bohm Causal Interpretation of Quantum Mechanics. PETER R. HOLLAND. Cambridge University Press, New York, 1993. xx, 598 pp., illus. $120 or £70.

How can electrons behave sometimes like particles and sometimes like waves? How does an atom know, when it passes through one slit of a double-slit apparatus, that the other slit is also open, so that it should behave so as to contribute to an interference pattern? How does a radioactive atom know when to decay? How can electrons tunnel across classically forbidden regions? How can Schrödinger's cat be simultaneously dead and alive—but only until we look at it and find that it is one or the other?

Quantum mechanics is undoubtedly our most successful scientific theory. At the same time, it is a bizarre theory, so bizarre that, according to Richard Feynman, a master of quantum calculation, "nobody understands quantum mechanics." The features that primarily contribute to its strangeness are its indeterminism and, even more, its apparent subjectivity, its constant appeal to measurement and to the observer, as codified in Bohr's Copenhagen interpretation. One of the clearest statements on this subjectivity is that of Heisenberg: "The idea of an objective real world whose smallest parts exist objectively in the same sense as stones or trees exist, independently of whether or not we observe them ... is impossible." The subjectivity and indeterminism of quantum theory have quite naturally been accompanied by the view that quantum particles don't really have trajectories and that, by Heisenberg's uncertainty principle, any talk of such things is meaningless. In their famous textbook on quantum mechanics Landau and Lifshitz declared flatly that the interference effects in the double-slit experiment "can in no way be reconciled with the idea that electrons move in paths." It is true that strong disapproval of this state of affairs was expressed by some prominent physicists, most notably Einstein, who believed that "the essentially statistical character of contemporary quantum theory is solely to be ascribed to the fact that this [theory] operates with an incomplete description of physical systems." Nonetheless, for several decades it was believed by most physicists that the mathematician John von Neumann had proven, with the utmost mathematical rigor, that a return by physics to any sort of fundamental determinism was impossible. For example, according to Max Born, who formulated the now standard statistical interpretation of the wave function, von Neumann had shown that "no concealed parameters can be introduced with the help of which the indeterministic description could be transformed into a deterministic one."

The "proof" of von Neumann and the claims of Born, Landau and Lifshitz, Heisenberg, and Bohr notwithstanding, in 1952 David Bohm, through a refinement of de Broglie's pilot-wave model, succeeded in providing an objective and completely deterministic account of quantum phenomena. This achievement was greeted by most physicists with indifference, if not outright hostility. John Bell, of Bell's inequality fame, was a refreshing exception. Bell expressed his reaction as follows:

> In 1952 I saw the impossible done. It was in papers by David Bohm. Bohm showed explicitly how parameters could indeed be introduced, into nonrelativistic wave mechanics, with the help of which the indeterministic description could be transformed into a deterministic one. More importantly, in my opinion, the subjectivity of the orthodox version, the necessary reference to the "observer," could be eliminated. ... But why then had Born not told me of this "pilot wave"? If only to point out what was wrong with it? ... Why is the pilot wave picture ignored in text books? Should it not be taught, not as the only way, but as an antidote to the prevailing complacency? To show us that vagueness, subjectivity, and indeterminism, are not forced on us by experimental facts, but by deliberate theoretical choice? [*Speakable and Unspeakable in Quantum Mechanics* (Cambridge Univ. Press, Cambridge, 1987), p. 160]

The Quantum Theory of Motion is the first book to appear that is devoted solely to a systematic presentation of Bohm's pilot-wave formulation of quantum mechanics, a precise, deterministic, microscopic theory describing a motion of particles under an evolution choreographed by the wave function. Here the reader will find detailed answers to the many questions prompted by quantum theory.

Novel resolutions of the quantum mysteries regularly appear. Most cannot withstand careful scrutiny. It is therefore worth emphasizing that the explanations found in Holland's book are genuine. In particular, they are not evasions, in which the real problems are skirted rather than solved. Moreover, as Holland points out, Bohm's theory is "very much a 'physicist's theory' and indeed puts on a consistent footing the way in which many scientists instinctively think about the world anyway."

One very striking and much discussed implication of quantum theory, that of quantum nonlocality, remains in Bohm's account, not as a mystery but as a natural consequence of the mathematical structure of quantum theory itself. In this sense, while the quantum paradoxes are *eliminated* by Bohm's theory, nonlocality is *explained* by this theory. Holland quite appropriately devotes much attention to quantum nonlocality, delineating how it emerges in the quantum theory of motion.

In fact, one has to do astonishingly little to textbook quantum theory in order to transform it into a theory—Bohm's theory—in which the quantum paradoxes are not merely resolved but are eliminated entirely. This simplicity does not shine forth in Holland's presentation, however, but is often obscured by an elaboration of details. Holland provides detailed computations and descriptions of trajectories, quantum forces, and quantum potentials—a description often involving precessing spins and gyrating rotators—for a large variety of situations. Although these details are interesting and are undoubtedly of some value, pedagogical and otherwise, they are often unnecessary and tend to make it difficult to appreciate the essential point of Bohm's account: that the origin of the quantum paradoxes lies neither in quantum phenomena nor in the quantum formalism that governs these phenomena but rather in the quantum philosophy, expressed in the Copenhagen interpretation of quantum theory, with which the quantum formalism has been encumbered. Almost as soon as one dispenses with this philosophy and instead posits that particles have positions regardless of whether or not they are being observed, one arrives at Bohm's theory, which succeeds in completely accounting for all (nonrelativistic) quantum phenomena while avoiding the quantum paradoxes, not so much because of the detailed character of the trajectories that it defines as because of the mere existence of these trajectories.

The level of presentation in this book is not elementary; a solid background in quantum theory would be extremely helpful. On the other hand, the wealth of details and literature citations make this a valuable reference work with which anyone with a serious interest in the foundations of quantum mechanics should become familiar. Despite his strong advocacy of a particular theory, Holland comes across as refreshingly open-minded. He concludes that "we are in a period of transition between two great world views—the universal machine of the classicists and a new holistic universe whose details we are only beginning to glimpse. The end is not in sight for theoretical physics."

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