CHAPTER 1

General Introduction

Everett and His Project

In July 2007, *Nature* celebrated the half-centenary of the "many worlds" interpretation of quantum mechanics with a splashy cover and a series of explanatory articles. That year, there were two international conferences dedicated to dissecting Hugh Everett III's claim that the universe is completely quantum mechanical.[1] Although the theorist had been dead for a quarter century, his controversial theory was alive and kicking.

First published in *Reviews of Modern Physics* in 1957 as "The 'Relative State' Formulation of Quantum Mechanics," the theory was not labeled "many worlds" until 1970, and then, not by Everett, but by his enthusiastic supporter, physicist Bryce S. DeWitt. Today, the Everett interpretation is one of a handful of contenders for explaining the structure of the quantum universe—whether or not its "branching" motion is interpreted as a metaphor for the linear evolution of the universal state or as modeling idealized or ontologically real worlds.

Everett was only 27 years old when he developed his theory, which would become his doctoral dissertation at Princeton. More interested in military game theory than theoretical physics, Everett never published another word on quantum mechanics. And yet his dissertation has stood the test of time and disbelief. Something in Everett's work has continued to resonate with physicists and philosophers alike so that, despite his many critics, three generations of researchers have returned to Everett's strange, counterintuitive theory, trying to find language to capture the quantum universe described mathematically by his pure wave mechanics.

This volume presents the two previously published versions of his theory, Everett's long and short theses, alongside a selected collection of his unpublished works and correspondence, which illuminate how Everett and his contemporaries struggled to answer questions that remain with us today.

Everett developed his interpretation of quantum mechanics, his relative-state formulation of pure wave mechanics, while a graduate student in physics at Princeton University. Matriculating in the fall of 1953, he began writing down his idea a year later. A detailed presentation of the theory,

[1] July 2007 at University of Oxford, Oxford, England, and September 2007 at Perimeter Institute for Theoretical Physics, Waterloo, Canada.

the long thesis, was submitted by Everett to John Archibald Wheeler, his doctoral thesis advisor, in January 1956. It was circulated in April of that year to several prominent physicists, including Niels Bohr.[2]

The long thesis was Everett's earlier, more detailed formulation and discussion of his theory, whereas the short thesis was a highly redacted and refocused version of the long thesis, reworked under the direction of Wheeler to soften the force of Everett's attack on the orthodox Copenhagen interpretation.

The back story is that Wheeler had spent considerable effort in May 1956 trying to convince Niels Bohr and his colleagues at the Institute for Theoretical Physics in Copenhagen, Denmark, that Everett's work should not be taken as a fatal threat to their understanding of quantum mechanics. His efforts were in vain and, with his doctoral degree in limbo due to Wheeler's reluctance to accept his long thesis without a nod of approval from Bohr, Everett left Princeton and took a job outside of academics as a military operations researcher in Washington, D.C., in June 1956.

During the winter of 1957, he and Wheeler rewrote the long thesis, cutting about 75 percent of it, to make it, in Wheeler's phrase, "javelin proof."[3] Subsequently, Everett's doctoral thesis (1957a), the short thesis, was accepted in March 1957, and a nearly identical paper (1957b) was published by *Reviews of Modern Physics* in July of that year. Bryce S. DeWitt and Neill Graham (1973) later published an updated version of Everett's long thesis in their volume entitled *The Many-Worlds Interpretation of Quantum Mechanics*.[4]

Although Everett's notes and correspondence indicate that he continued to be interested in the conceptual problems of quantum mechanics and in the interpretation and reception of his model of pure wave mechanics, he did not play an active role in the public debates surrounding his theory in the 1970s. He died of a heart attack in 1982 without writing any further systematic presentation of it. For many years, his long and short theses remained the primary evidence for how he had intended his formulation of quantum mechanics to work.

[2] See the biographical introduction in this volume for a more detailed account of the circumstances surrounding Everett's development of his relative-state formulation of pure wave mechanics, especially starting on pg. 11.

[3] See pg. 212.

[4] The title of the long thesis submitted by Everett to Wheeler in January 1956 was "Quantum Mechanics by the Method of the Universal Wave Function." In April 1956, it was retitled, "Wave Mechanics Without Probability." After being edited in 1957, the approved dissertation (short thesis) was entitled, "On the Foundations of Quantum Mechanics." The short thesis was again retitled for publication in *Reviews of Modern Physics* in July 1957 as "'Relative State' Formulation of Quantum Mechanics." When the long thesis was published in 1973 in the DeWitt–Graham book, Everett settled on yet another title: "The Theory of the Universal Wave Function." Versions of the long thesis (pg. 72) and short thesis (pg. 173) are included in this volume.

In 2007, the investigative journalist Peter Byrne was invited by Everett's son, Mark Everett, to open a dozen cardboard boxes that had been stored for many years in his basement. The boxes contained numerous items of scientific interest, including correspondence about the theory with Niels Bohr, Norbert Wiener, Wheeler, and other prominent physicists. Hundreds of pages of handwritten and typed and retyped drafts of the long thesis document Everett's thought process as he formulated his theory from the fall of 1954 through the winter of 1956. Importantly, three "minipapers" give an overview of Everett's basic arguments as of September 1955. This newly discovered material helps to illuminate his previously published work, often in striking ways.

Everett's Target: The Measurement Problem

In the long thesis, Everett directly attacked both the von Neumann–Dirac and the Copenhagen formulations of quantum mechanics. He held that neither orthodox formulation could adequately describe what happened to a physical system when it was measured. Everett believed that the standard von Neumann–Dirac collapse formulation of quantum mechanics, the version of the theory found in most textbooks, provided an incomplete and incoherent characterization of measurement and that Bohr's formulation of the theory, called the Copenhagen interpretation, was even worse since it simply stipulated that the process of measurement could not be understood quantum mechanically. Wheeler, as his thesis advisor, wanted Everett to present his controversial theory in a way that he believed would be more easily received by the physics community. This led to the much shorter thesis that Everett defended for his Ph.D. The short thesis still expressed dissatisfaction with the conventional formulations of quantum mechanics, but it now characterized their inadequacies less as fundamental conceptual flaws and more as roadblocks to applying quantum mechanics to field theories and cosmology.

The problem with the standard collapse theory, according to Everett, was that it required observers always to be treated as external to the system described by the theory, one consequence of which was that it could not be used to provide a consistent physical description of the universe as a whole since the universe contains observers. More specifically, the standard collapse theory has two dynamical laws: one says that physical systems evolve in a linear, deterministic way when not measured, and the other says that physical systems evolve in a nonlinear random way when measured. But since the standard theory does not say what constitutes a measurement, it is at best incomplete. And if one takes measuring devices and observers to be described by the deterministic linear law (and why shouldn't they be insofar as they are constructed of simpler systems that each follow the linear deterministic law?), then the collapse theory is logically inconsistent. This is the notorious quantum measurement problem for the standard textbook formulation of quantum mechanics.

Everett was not alone in his dissatisfaction with the prevailing interpretation of quantum mechanics. Other notable discontents included Erwin Schrödinger, Albert Einstein, Boris Podolsky, Nathan Rosen, and David Bohm. Indeed, Bohm, who left Princeton just before Everett arrived,[5] had devised a deterministic "hidden-variable" formulation of quantum mechanics that addressed the quantum measurement problem and made the same empirical predictions as the conventional formulations for those experiments where they made coherent predictions at all. Everett, however, believed that his simpler approach rendered Bohm's hidden variables "superfluous."[6]

Everett tackled the measurement problem by promoting what he called "pure wave mechanics."[7] His formalism characterized the physical state of the universe with a "universal wave function," which describs a superposition of possible classical states that evolves in a perfectly continuous and linear way. This is the simplest possible formulation of quantum mechanics, said Everett, because it entirely avoids the quantum measurement problem, and, unlike most other formulations of quantum mechanics, it can be put in a form that is compatible with the constraints of general relativity. In this sense, it provides an ideal quantum mechanical foundation for modern field theories. Everett's theory is consequently one of the most popular formulations of quantum mechanics among both physicists and philosophers.

Going further than previous critics of the standard collapse postulate, Everett's proposed solution to the measurement problem was to drop the random nonlinear dynamics from the standard collapse theory and take the resulting pure wave mechanics, governed by the time-dependent Schrödinger equation alone, as a complete physical theory. His goal was to deduce the empirical predictions of the standard collapse theory as the subjective experiences of observers who are themselves treated as physical systems described by the theory. He referred to pure wave mechanics with the interpretive apparatus provided by his fundamental principle of the relativity of quantum states as the relative-state formulation of quantum mechanics. It is, however, unclear precisely how Everett intended for the relative-state formulation to be understood. There is agreement among those who study Everett's interpretation of quantum mechanics that his

[5] Bohm's contract was not renewed by Princeton after he took the Fifth Amendment while testifying before Congress to the communist-hunting House Un-American Activities Committee.

[6] See Everett's discussion of Bohmian mechanics in the long thesis (pg. 153).

[7] See pgs. 65, 77, 178–80, and 196, for examples of how Everett characterized pure wave mechanics and his relative-state interpretation of it.

interpretation requires interpretation, and many people have attempted to explain exactly what he had in mind. Indeed, it is fair to say that most no-collapse interpretations of quantum mechanics have at one time or another either been directly attributed to Everett or suggested as charitable reconstructions.[8]

That said, the various many-worlds formulations of quantum mechanics have proven to be the most popular reconstructions of Everett's theory. This way of understanding the relative-state formulation is largely due to Bryce DeWitt's energetic promotion in the early 1970s of what he called the EWG theory, for Everett, Wheeler, and DeWitt's student Neill Graham. Whereas Everett himself never mentioned many worlds or parallel universes in either version of his thesis, DeWitt's interpretation of Everett so captured people's imagination that it remains the most popular understanding of Everett's theory.[9] Nonetheless, a half century after the theory was first published, much work continues to be done to formulate a clear and compelling many-worlds interpretation of pure wave mechanics. The most recent many-worlds interpretations characterize worlds as emergent entities that are roughly individuated by decoherence considerations.[10]

In the end, Everett's remarkable achievement was in providing a compelling case that pure wave mechanics alone constitutes a complete and accurate physical theory and makes the same empirical predictions as the standard collapse theory. According to him, the quantum measurement problem was simply a misunderstanding generated by unnecessarily adding a postulate that measurement is special to a theory that works without that postulate. Although most researchers believe that Everett was not entirely successful in deriving the standard quantum mechanical predictions from the mathematics of pure wave mechanics alone, he got close enough to motivate many others to try filling in the details in his project. Because of the simplicity of the mathematical formalism, its universal scope, and its other theoretical virtues, the stakes are high in understanding Everett's theory and in finding an acceptable interpretation of it.

But in the 1950s at Bohr's Institute for Theoretical Physics in Copenhagen, saying what Everett said was considered "heresy" (Leon Rosenfeld)[11] and "theology" (Alexander Stern).[12] Wheeler (who was researching a theory of quantum gravity) had tried to convince Bohr and his colleagues that the "relative state" model was a theoretical advance, but he ran into a phalanx of closed minds. In 1959 Everett and Bohr met in Copenhagen to discuss the controversial theory, which removed the epistemological barrier that

[8] See, for examples, the interpretations discussed in the conceptual introduction (pg. 37).

[9] See the conceptual introduction (pg. 41) for further discussion of DeWitt's splitting-worlds formulation of Everett's theory.

[10] See the discussion of the emergent-worlds formulation (pg. 45).

[11] Rosenfeld to Bell, 11/30/71, in Byrne (2010, pg. 316).

[12] Stern to Wheeler, 5/20/56; in this volume (pg. 215).

Bohr and his fellow travelers had erected between the overlapping realms of microscopic and macroscopic events. But Bohr dismissed Everett's work, and eventually, so did Wheeler.

History has been more accepting of Everett's theory than his contemporaries were. Shortly after the issue of *Nature* dedicated to the "many worlds" interpretation, the British Broadcasting Corporation and *NOVA* aired an award-winning television program, "Parallel Worlds, Parallel Lives," which is about the theory and, also, Everett's sad relationship with his rock singer son, Mark. But Everett was not around to take pleasure in these events. Of all of the late scientist's immediate family, only his son, the family's sole survivor, witnessed the world paying homage to the strange, brilliant, revolutionary idea widely known as the "many worlds" interpretation of quantum mechanics.

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