Philosophy of Science (2022), **89**, 202–208
doi:10.1017/psa.2021.51

PSA PHILOSOPHY OF SCIENCE ASSOCIATION

PHILOSOPHY OF SCIENCE

BOOK REVIEWS

Review of Jeffrey A. Barrett's *The Conceptual Foundations of Quantum Mechanics*

Jeffrey A. Barrett, *The Conceptual Foundations of Quantum Mechanics*. Oxford: Oxford University Press (2020), 272 pp., $88.00.

In *The Conceptual Foundations of Quantum Mechanics*, Jeffrey A. Barrett provides an excellent introductory-level text for graduate students or advanced undergraduates. Many today teach the philosophy of quantum mechanics through David Albert's classic text *Quantum Mechanics and Experience* (Albert, 1992). Barrett's book fulfills many of the same roles, and more: Barrett reports on cutting edge progress from the intervening decades with historical and contemporary references. Barrett's book can serve either as an entry point for aspiring researchers or as a vehicle to make the foundations of quantum mechanics accessible to philosophers of all stripes.

In the first part of the book (chapters 1–5), Barrett gives a concise presentation of the core of quantum theory, free of unnecessary technical details. Chapter 3 describes the mathematical background of Hilbert space, the primary tool used to describe states of quantum systems. Chapter 4 uses the mathematical tools developed to present the standard formulation of quantum theory. Barrett's central contribution is to distill quantum theory to five digestible postulates. These postulates show how the mathematical tools are used to represent physical systems, that is, how physical states, observables, dynamical evolution, and composition are connected to the apparatus of abstract vectors and operators. In doing so, Barrett introduces a theme of the book: the very formulation of a physical theory should be understood to come with an interpretation that goes beyond mere mathematical laws, and so understood, a theory will both encode and reflect the metaphysical and explanatory commitments of its adherents. Barrett uses this to argue throughout the book that what are sometimes called different "interpretations" of quantum mechanics should be understood as *distinct physical theories*. By the end of chapter 5, Barrett has laid the groundwork for a reader, who started without prior familiarity with quantum physics, to be able to engage with the deep philosophical questions the theory raises.

Chapters 6 and 7 drive to the heart of those questions, framing the *measurement problem* as the central foundational issue. Since the measurement problem challenges the adequacy of the standard formulation of quantum mechanics, Barrett begins chapter 6 with a discussion of early discontents. Barrett reviews the infamous argument of Einstein, Podolsky, and Rosen (EPR) that the standard formulation cannot be a complete representation of physical reality. Barrett follows this line of thinking long enough to present Bell's theorem, which puts constraints on the approach to interpreting quantum theory for which EPR appear to advocate. Barrett's semi-historical discussion of EPR and Bell sets the stage for the way he proceeds to introduce the measurement problem.

In chapter 7, Barrett formulates and clarifies the measurement problem. Barrett begins by affirming EPR's conclusion that the standard formulation of quantum mechanics is incomplete in some sense, while stressing that the notion of incompleteness he has in mind is different from that employed by EPR. The standard formulation of quantum mechanics includes two dynamical laws describing how physical systems evolve over time: one (Barrett's postulate 4.I) describing evolution when a system is *not measured* and another (Barrett's postulate 4.II) describing evolution when a system *is measured*. Postulate 4.I says that when a system is not measured, it evolves continuously and deterministically. But postulate 4.II says that when a system is measured, it instantaneously and probabilistically "collapses" to a state with a definite measurement outcome. Barrett argues that the standard formulation of quantum mechanics is incomplete in the sense that it does not clearly distinguish which physical situations are measurements and which are not. On the other hand, if one tries to rectify the situation by treating measuring devices themselves as physical systems in the purview of quantum theory, then the two dynamical laws come into conflict (in the presence of the other postulates of the standard theory). Postulate 4.I entails that measurements often do not produce determinate results at all, while postulate 4.II entails that they always do. This leads to Barrett's formulation of the measurement problem: *the standard formulation of quantum mechanics is either incomplete* (by virtue of leaving the central theoretical notion of measurement unanalyzed), *or else it is inconsistent* (since the two dynamical laws lead to contradictions). Barrett illustrates the dramatic consequences through an example called "Wigner's friend". Wigner's friend measures a quantum system in his laboratory, while Wigner (outside the laboratory) measures the resulting state of his friend. The different dynamical laws of quantum theory (4.I and 4.II) lead Wigner to different conclusions about macroscopic systems like his friend, and even in principle to different empirical predictions. Indeed, the measurement problem and such illustrations give us serious reason to worry about the foundations of quantum mechanics.

The remainder of the book surveys the landscape of responses to the measurement problem. Chapters 8–12 discuss solutions to the measurement problem while (i) arguing that different interpretations should be thought of as distinct physical theories, and (ii) advocating for the importance of metaphysical and explanatory tradeoffs between interpretations.

Chapter 8 details "collapse interpretations" like the Ghirardi-Rimini-Weber (GRW) theory and its cognates. The GRW theory combines the two dynamical laws of the standard theory (4.I and 4.II) into a single stochastic law governing dynamical evolution. This provides an account of the appearance of determinate outcomes in the process of measurement, but comes with its own host of problems related to relativity, energy conservation, and the existence of "tails" in the distribution after collapse. One contribution of Barrett's book is to provide an up-to-date synopsis of metaphysical views of GRW, including the mass-density ontology (GRWm) and flash ontology (GRWf).

Chapters 9 and 10 deal with "many-worlds" interpretations (broadly construed) in which the quantum state never collapses, and instead always follows the dynamical

https://doi.org/10.1017/psa.2021.51 Published online by Cambridge University Press

law in postulate 4.I. Such interpretations, usually traced back to Everett, require one to give a non-standard interpretation of the quantum state. It follows from postulate 4.I that after ideal measurements, a quantum state can be decomposed into components that each represent a determinate possible outcome of the measurement, but postulate 4.I does not (in general) provide for the evolution of the system into one of those determinate states. Barrett shows, however, that one can interpret the components themselves as corresponding to the determinate measurement outcomes we find in our experience in a number of ways: by treating them as relative states, many-worlds, many-minds, many-threads, and so on. Barrett provides two new contributions here. First, he distinguishes the contemporary many-worlds theories based on decoherence (e.g., advocated by David Wallace) from the original views of Everett himself. Second, Barrett includes his own historical work unpacking Everett's views from his writings and correspondences. Even though the interpretive options multiply in this chapter, a single point remains fixed in Barrett's view. The metaphysical differences between interpretations of quantum mechanics matter for explaining our experience of determinate measurement outcomes, and hence all empirical phenomena.

Chapter 11 deals with hidden variable theories like Bohmian mechanics (de Broglie-Bohm theory), which supplement the quantum state with extra information. In Bohmian mechanics, each physical state is a quantum state supplemented by determinate positions for all particles. The quantum state evolves always according to postulate 4.I, and the Bohmian theory postulates a new dynamical law—"the auxiliary dynamics"—governing how the positions of particles are affected by the quantum state. According to the theory, particles are like marbles floating in a fluid (the quantum state), where the fluid's motion affects the particles according to deterministic dynamical laws. The theory leads to determinate measurement outcomes by asserting that all measurements are ultimately measurements of position, which is always determinate. Procedures that purport to measure other properties are really measurements of the position of a "pointer" on a measuring device after it interacts with the system. Barrett provides a contribution in this chapter by arguing that determinate measurement outcomes in Bohmian mechanics should not be associated with determinate positions because we never actually come to know determinate positions. If we did, we would be able to predict measurement outcomes exactly, which is impossible. Instead, Barrett argues that in Bohmian mechanics we can only come to know the branch of the quantum state that contains the configuration after measurement (the effective wave function).

Barrett's ability to present these problems in the foundations of quantum mechanics so clearly is laudable. Before I close, however, I want to point to a few issues that Barrett only remarks upon cursorily in the book, but which are worth the attention of the book's audience. First, a few times throughout the book (e.g., p. 128) Barrett repeats a dogma that only Hilbert spaces satisfying a technical condition called "separability" are appropriate for characterizing quantum states. This assumption is not so uncontroversial and has been questioned in some recent work (Halvorson, 2004; Earman, 2020). Second, although Barrett treats it only briefly, there is an enormous and burgeoning literature around Bell's theorem and its significance (see references in Myrvold et al., 2019). Parts of this literature can be engaged even independently of the measurement problem and are ripe for future work. Third, Barrett only briefly mentions progress toward understanding quantum probability through the "typicality" approach in Bohmian mechanics (Dürr et al., 1992) or the "decision-theoretic" approach in many-worlds theories (Wallace, 2007). These are deep and open areas where aspiring researchers might find a foothold. I do not mean to suggest problems with Barrett's book; rather, these are topics the same audience may wish to pursue further.

In sum, Barrett's book is a fantastic resource within its scope. It gives a clear summary of the state of the art in the philosophy of quantum mechanics at a level appropriate for readers with no prior background. Barrett draws clear connections to issues in philosophy of science and convincingly argues for the importance of the quantum measurement problem.

Benjamin H. Feintzeig
University of Washington

References

Albert, David Z. 1992. *Quantum Mechanics and Experience*. Cambridge, MA: Harvard University Press.

Dürr, D., S. Goldstein, and N. Zanghi. 1992. "Quantum Equilibrium and the Origin of Absolute Uncertainty." *Journal of Statistical Physics* 67 (5):843–907.

Earman, John S. 2020. "Quantum Physics in Non-Separable Hilbert Spaces." http://philsci-archive.pitt.edu/18363/.

Halvorson, Hans. 2004. "Complementarity of Representations in Quantum Mechanics." *Studies in the History and Philosophy of Modern Physics* 35:45–56.

Myrvold, Wayne, Marco Genovese, and Abner Shimony. 2019. "Bell's Theorem." In *The Stanford Encyclopedia of Philosophy*, edited by E. N Zalta. Metaphysics Research Lab, Stanford University, Fall 2021 edition.

Wallace, D. 2007. "Quantum Probability from Subjective Likelihood: Improving on Deutsch's Proof of the Probability Rule." *Studies in the History and Philosophy of Modern Physics* 38:311–32.

Review of Jean Gayon and Victor Petit's *Knowledge of Life Today*

Jean Gayon, Interviewed by Victor Petit, *Knowledge of Life Today: Conversations on Biology*, London & Hoboken, NJ: ISTE/John Wiley and Sons (2019), xx + 378 pp.

At the time of his untimely death in 2018, Jean Gayon was Professor of Philosophy at Paris 1 Sorbonne and Director of the Institute for the History and Philosophy of Science and Technology (IHPST), whose earlier leaders included Gaston Bachelard and George Canguilhem. The volume makes available in English carefully edited interviews with Gayon that appeared in France not long before he passed away (Gayon &