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REVIEW

DAVID WALLACE
The Emergent Multiverse: Quantum Theory According to the Everett Interpretation
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Lev Vaidman
Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Tel-Aviv, Israel
vaidman@post.tau.ac.il

> We have, then, a theory which is objectively causal and continuous, while at the same time subjectively probabilistic and discontinuous. It can lay claim to a certain completeness, since it applies to all systems, of whatever size, and is still capable of explaining the appearance of the macroscopic world. The price, however, is the abandonment of the concept of the uniqueness of the observer, with its somewhat disconcerting philosophical implications.
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> Everett, 1957

After the recent discovery of the Higgs boson, physics seems to be in better shape than ever to explain all observed phenomena. The basis of physics is quantum theory, which has been confirmed with unprecedented precision. However, there is no consensus among scientists that physics, at large, is finished and that we have reached a basic understanding of nature. One of the main reasons for this is that quantum theory is well confirmed only in terms of descriptions of experimental results; it cannot explain the world we see. It predicts exactly the spectra of lights, but when we analyse an experiment detecting a single photon passing through a beam splitter, we have only a description of a probability of detection. The equations of quantum theory describe waves. In parallel with the wave function corresponding to the detection of the photon, there is also a wave corresponding to a detector that remains silent. We see a detector that clicked or did not, but the theory describes both. Attempts to end up with one picture by collapsing the quantum wave function have not led to attractive theories. In 1957, Everett proposed that it is an illusion that there is just one picture; quantum measurement ends

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up with both. Since quantum measurements happen frequently, there are now numerous pictures. This is the many-worlds (or multiverse) interpretation.

In *The Emergent Multiverse*, David Wallace provides a clear, coherent, and rigorous presentation of the Everett interpretation. In my view, he succeeds in persuading the reader that this interpretation works, though I myself need not to be persuaded. In the introduction, Wallace writes: 'I would be neither surprised nor distressed if David Deutsch, or Max Tegmark, or Lev Vaidman were to regard parts of this book as completely wrong; I would be both surprised and distressed if they merely said that they advocated a different Everett interpretation'. Indeed, there are parts with which I disagree, but Wallace's description of the theory is exactly the many-worlds interpretation (MWI) I believe in. His terminology is different (he avoids the term MWI), but what he describes is the MWI of Everett (who also, though for other reasons, avoided this term). Apart from the philosophical price of accepting multiple realities, the MWI has no unresolved problems for me, though I appreciate the difficulty of writing a persuasive exposition of this theory. I do not think that anyone had succeeded in this before Wallace. Albert ([1992]) and Lockwood ([1989]) provide excellent descriptions of some aspects of the MWI, but do not present a complete picture. Barrett ([1999]) presents a wider exposition, but he is not sympathetic to the MWI; he concentrates on difficulties and does not attempt to present a complete, coherent picture of the MWI. I find there to be interesting insights in (Deutsch [1996]), but this book is suitable for those who already believe in the MWI and does not provide good arguments for non-believers.

A major difficulty in the interpretation of quantum theory is the measurement problem; however, the MWI 'dissolves' it (to use Wallace's term). The book explains the initial problem and how Everett made it disappear. Wallace presents a comprehensive historical review of the various objections and provides very convincing answers to these, showing the superiority of the MWI relative to other alternatives. However, unless the reader has an unusually strong mathematical background, he or she will have to make a serious effort to see this. While Albert ([1992]) was afraid to scare the reader with the concept of spin and complicated his book by simulating it with colours, Wallace uses positive operator valued measures (POVMs), C-star algebras, Borel measure, decoherence functional, decision-theoretic representation theorems, and many other concepts that most physics graduates never encounter. The reader is assumed to have a significant philosophical background too, so that the book is fully accessible only to those few who, like Wallace, have doctorates in both physics and philosophy. This problem is partly solved by Wallace's clear guidance on how to read the book, advising the reader to skip technical sections. But such a reading reduces confidence. I believe that by cutting all these sophisticated parts (reducing the volume by half), Wallace could have made his book a bestseller.

I understand that Wallace has bigger ambitions than just a clear exposition of Everett interpretation and persuading us that it explains perfectly all the paradoxes and mysteries of quantum mechanics. Apart from this book, he has published more papers developing and modifying the Everett interpretation than anyone else in recent years. A lot of this research, included in this book, is not really needed for establishing the basic thesis of the book as Wallace defines it: there is no quantum measurement problem. It is not needed to show that if we take quantum theory seriously, literally, as a description of the world (multiverse), then the MWI is the best way to make a coherent sense of it. Wallace introduces POVMs in his discussion of the decoherent histories approach, which hopefully can be generalized to a field theory. I have to admit that I was sceptical about this programme before reading this book and remain so now. I have never been able to make sense of consistent or decoherent histories approaches. While I certainly view the phenomenon of decoherence as crucial for the emergence of the multiverse, the mechanism is trivial; we do not need decoherence functionals and so on. Wallace's 'spacetime realism' is also orientated for dealing with quantum field theory. In his view, things are simple in algebraic formulations of quantum field theory associating C-star algebra of operators with a particular region of space. I think that the measurement problem is part of quantum mechanics, not of a field theory. A simple model of von Neumann measurements is enough for analysing this problem. In my view, solving the basic conceptual problems in the framework of quantum mechanics will allow analysis in the field theory without encountering these problems again. It is on the level of quantum mechanics that we have paradoxes. We never experience cats in a superposition of being alive and dead, despite the formalism providing a picture of Schrödinger cat's as simultaneously present in two states. The gap between our experience and quantum fields is so large that severe paradoxes are not expected there.

Wallace devotes much attention to the problem of probability in the MWI. He convincingly explains why this framework is not inferior to other interpretations, despite the obvious difficulty in defining the probability of an outcome when all outcomes are realized. He includes in the book the thesis on which he has worked extensively in the last years (following the pioneering work of Deutsch ([1999])): the MWI is superior to other interpretations since the Born rule (postulated in standard quantum mechanics) can be derived using tools of decision theory. In fact, about one-third of the book is devoted to developing this thesis: most of Part 2 and almost all appendices. Like many others, I am sceptical about the success of this programme. But the book probably offers its best account: no space limitations, appropriately presented background, and the full mathematical apparatus. On the other hand, it is in no way accessible to a general reader. The reader who could easily be convinced that the MWI provides a proper answer to the measurement problem will have to work very hard to understand Wallace's derivation of the Born rule.

In Part 3, Wallace returns to accessible language for the most part and he analyses in detail important issues of locality, time symmetry, and several separate topics that are particularly relevant to the MWI. Questions of identity over time, the (ir)relevance of Bell inequality, the possibility that the Universe is in a mixed state, quantum computation, and a curiosity regarding speculation about time travel all received very clear, intelligent treatment. I might not agree with all the conclusions, but Wallace chooses to discuss the right problems presented in the proper context. It is a very extensive and authoritative review.

The Emergent Multiverse seems to be one book imbedded in another: a scientific monograph on the derivation of the Born rule imbedded in a more general philosophy book on the meaning and success of the MWI. Both are good but are directed at different audiences, so that two separate books would be much more effective. Currently, a specialist might be bored reading the introduction to quantum mechanics, while the general audience will surely be scared by the mathematical and decision theory symbols. For a monograph on the Born rule, the presentation is not particularly important; it is the validity of the argument that counts. But for a general book explaining MWI, the presentation is crucial, and here I find it excellent. The dialogic interludes are insightful and entertaining. The quotations at the beginning of each section are incredibly to the point. (I borrowed one for this review.) I recommend to everyone, especially to sceptics of the MWI to read this book: enjoy the brilliant and engaging style; skip freely complicate equations; and believe the author—he understands Everett's theory very well.

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