**Peter J. Lewis, *Quantum Ontology: A Guide to the Metaphysics of Quantum Mechanics*, Oxford University Press, 2016, 207 pp., $35.00 (pbk), ISBN 9780190469818.**

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According to its preface, the aim of "Quantum Ontology" by Peter J. Lewis is "a guide to quantum mechanics for the philosophical consumer" (p. xi). The idea is to use scientific theories to constrain the possible metaphysical views, and this is what this book successfully does in the framework of quantum theories. In fact, the author explains with impressive clarity and comprehensiveness why (in the introduction) and how (in the other chapters) quantum mechanics reshapes the debate over several metaphysical questions. Many things have been claimed about quantum mechanics, but at the same time there is no agreement on what the best formulation of quantum mechanics is, and how we should interpret it. Peter Lewis does a wonderful job in clarifying the different possibilities, including some of the lesser-known alternatives such as the retrocausal hidden variable theories and the transactional interpretation.

In the first chapter, "Phenomena and Theory," Lewis introduces quantum phenomena like interference and entanglement to set the ground for the subsequent discussion. In the second chapter, "Realism", Lewis addresses the question of whether quantum mechanics is incomplete. He introduces the Einstein, Podolsky and Rosen (EPR) argument, identifying non-contextuality (the value of a property of an object does not depend on the experiment performed to measure it) and locality (experiment results cannot influence one another instantly) as the fundamental assumptions. Lewis then explains how Bohr rebutted EPR by endorsing contextuality, motivated by no-go theorems like Bell's theorem and the Kochen-Specker theorem. According to Lewis, these theorems show that pre-existing properties, if they exist, are contextual. Lewis then mentions that another possibility is to reject that operators correspond to physical properties, namely the eigenvalue-eigenstate link. Indeed, this is how Bohm and GRW get around the no-go theorems, while Everett rejects the even more hidden assumption that experiments have unique results. In "Underdetermination," the following chapter, Lewis discusses the measurement problem and its solutions, while in Chapter 4, "Indeterminacy," he considers whether objects have indeterminate properties, as suggested by the eigenstate-eigenvalue link. Lewis dismisses it given that it is based on the measurement postulate, which is untenable. He then criticizes the bare theory, according to which the terms of a superposition state do not represent determinate properties, given that it is (empirically and semantically) incoherent: if true, one would have no evidence for it, and the theory would not mean anything. Lewis analyzes also

the fuzzy link and the vague link, which lead to the so-called counting anomaly, which expresses macroscopic indeterminacy. According to Lewis, massy GRW was introduced to deny the operators-as-properties assumption. Then he discusses retrocausal hidden variable approaches as ways to avoid indeterminacy. Finally he criticizes the strategy of limiting the number of properties (like a Bohmian would do, denying properties other than positions) on the basis that there are reasons (analyzed in chapter 7) to consider the wave function as real, and therefore associate properties to it too. Chapter 5, "Causation," explores whether quantum mechanics reshapes the classical notion of causation. The main worry comes from nonlocality. Bohm and GRW are nonlocal, and strategies to make it compatible with a causal story are suggested. In particular, flashy GRW and the transactional interpretation are introduced and discussed. As for Everett, Lewis argues that even if explanations would be very different from classically causal explanations (in contrast with Bohm), they still would be perfectly acceptable. The next chapter, entitled "Determinism," is mostly devoted to the many-worlds theory, which seems subjectively indeterministic but objectively deterministic. Lewis challenges this view, pointing out that it is unclear where probabilities are coming from. After criticizing the single-mind and the many-minds theories, he presents and defends the view according to which probabilities in Everett are subjective degrees of beliefs of a rational agent. Moreover, the chapter continues addressing questions connected to personal identity, immortality and free will within the quantum domain. Chapter 7 is about the world's spatial dimensions and Chapter 8, "Parts and Wholes," discusses whether entangled states are emergent properties. In addition, Lewis criticizes and rejects priority monism and ontic structural realism as views that there are no individuals. The book then concludes with a chapter that overviews the main alternatives and their implications for the various debates in metaphysics.

I think this is a great contribution to the philosophy of quantum mechanics and to metaphysics in general, and here are some comments. First of all, the exposition of interference in the first chapter is not historical. Lewis in fact believes that phenomena are what they are, regardless of when they have been discovered. However, I am convinced that history played an important role in shaping the quantum orthodoxy and influenced the choice of the perceived viable alternatives. Quantum interference is puzzling not because of the phenomenon in itself: it is perfectly normal for waves to interfere. Rather, it is puzzling because it involves objects we *historically* took with good evidence to be particles. Also in the case of hidden variables, history has played a major role: Bell's theorem and the various no-go theorems have been taken (mistakenly) to

show that hidden variable theories are impossible, and this inevitably (misguidedly) constrained the debate.

Similarly, in chapter 2, while Lewis writes that Bell rejected the conclusion of his own theorem, he does not specify that Bell rejected the locality assumption. I do not think this is just an unimportant historical detail since it was this rejection that prompted Bell to take Bohm's theory seriously. In addition, I was surprised that Lewis does not discuss enough the implausibility of contextuality. If properties depend on the context in which they are measured, in what sense can we think of them as genuine properties? If contextualism is an answer to EPR and 'rescues' properties, doesn't it undermine itself?

In chapter 3, Lewis discusses and evaluates objection against Bohm and GRW that they are many-worlds theories "in a state of chronic denial" (Deutsch, 1996, 225). The idea is that if objects are patterns in the wave function, then Bohm and GRW fail to solve the measurement problem because Bohmian particles and the spontaneous localization of the wave function do not change this fact. Lewis replies proposing that objects could be dynamical patterns. This is a great response, however I think that another (in my eyes more plausible) response is to deny Dennett's criterion of object individuation as patterns in the wave function. If one assumes that objects are not made of the wave function, but of particles in Bohmian mechanics and of mass density in massy GRW or flashes in flashy GRW, then the objection evaporates.

Moreover, in chapter 6 I would have enjoyed an analysis of probabilities along the lines of the typicality approach originally suggested by Everett himself (1957). This view is a distant relative to the frequency interpretation discussed and quickly dismissed by Lewis, and it is developed by myself, Goldstein, Tumulka and Zanghí in our 2011 paper. In the same chapter an omission that may disappoint some (but not me) is the debate over the so-called "free will theorem" of Conway and Kochen (2006).

Chapter 7 is devoted to perhaps the most current debate in philosophy of quantum mechanics and certainly this book is up to date with the literature and correctly points to where the disagreements are. It would be pointless to argue here with Lewis, since this would require a separate journal article, given how rich this chapter is. Indeed, I was very impressed by how the author was careful, accurate and ultimately charitable in presenting the various views. This chapter is the perfect starting point for future debates about the issue of dimensionality and the connected problem about the meaning of the wave function. Consequently, this book will be of incredible value for

the professional philosopher who wishes to start addressing these issues, as well as the one already in the middle of the discussion.

To finish, in chapter 8 Lewis perhaps is being too hasty in dismissing priority monism and ontic structuralism, especially since they have recently received a lot of attention both from metaphysicians and from philosophers of physics. A longer and more complete discussion could have presumably widened the audience of the book.

To summarize and conclude, let me be clear: in addition of being incredibly valuable to the metaphysician for the reasons outlined at the beginning, this book is also a terrific resort for the philosopher of science, given it straightforwardly addresses central questions like scientific realism. Moreover, the philosopher of physics will be able to use this book as the starting point to make progress in many current debates that range from the meaning of quantum nonlocality to the nature of the wave function. Finally, due to his extreme clarity and its impeccably accurate exposition, the book is an excellent resource for teaching courses in metaphysics, philosophy of science and philosophy of physics.

**References:**

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