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Philosophers Look at Quantum Mechanics

Springer

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Editor's Foreword

Philosophers Look at Quantum Mechanics contains 16 essays based on outstanding keynote presentations made at venues of the International Ontology Congress (IOC) up to 2016. The selected essays are preceded by an introduction meant to provide an overview of the topics covered in the volume.

For 20 years now, IOC has held biennial meetings that promote interaction between scientists and philosophers interested in scientific ontology. While each edition has had a different focal point,[1] quantum mechanics has always been present. Operating from the departments of philosophy at Universidad del País Vasco (San Sebastián, UPV-SS) and Universitat Autónoma de Barcelona (UAB), during IOC's 25 years in existence, many of the grandees of contemporary philosophy have participated as principal speakers. One was Hilary Putnam, a dear friend and good supporter of IOC until his death in 2016, whose love of Spain had numerous roots.[2] Although his main presentations at IOC gatherings were about other topics, on several occasions, he offered informal discussions on quantum mechanics that touched on his research interests at the time.

In 1965, Putnam's paper "A Philosopher Looks at Quantum Mechanics" explained to a whole generation why the interpretation of quantum mechanics is a serious philosophical problem. The time was ripe for action. In 1964, John Bell's now-famous theorem had concluded that no physical theory of local hidden variables could reproduce all of the predictions of quantum mechanics. The world, Bell suggested, might be surrealistically different from what it seems to be at first sight. Abner Shimony and other philosophers joined forces with experimental physicists to study the impact of Bell's theorem. The resulting efforts built intellectual bridges between the two disciplines that astonish us to this day, fueling a

[1]These have included the idea of *physis* since antiquity to the present, scientific realism, evolutionary biology, the emergence of mind, the problem of infinity, and social ontology, among other topics.

[2]In particular, his father was Samuel Putnam, a prominent writer who did a very well-received English translation of *Don Quixote* in 1949.

renewed debate about the scope and limits of realism and understanding in scientific discourse.

The title of this volume pays tribute to the memory of Hilary Putnam. Philosophers have kept looking at quantum mechanics ever since, with growing technical skill and fruitfulness, helping the philosophical analysis of quantum physics to develop into one of the most sophisticated and productive areas in contemporary philosophy. As the essays included in this volume show, the foundations of quantum mechanics generate fruitful and exciting debates in contemporary philosophy that, luckily, have a forceful presence at IOC gatherings.

Acknowledgments The 12 editions of the International Ontology Congress reflected in this volume would not have been possible without the unfading support and enthusiasm of Víctor Gómez-Pin, Gotzon Arrizabalaga, and José Ignacio Galparsoro—IOC's miracle workers, efficiently assisted by Juan Ramón Makuso and Ima Obeso. Thanks go also to Bárbara Jiménez for her help with IOC archives and translation of the piece by Alain Aspect and Gómez-Pin included in this collection. At the institutional level, there is a huge debt of gratitude to the two host universities (UPV-SS and UAB) and to Pedro Etxenike Landiríbar (President of the Donostia International Physics Center, San Sebastian) for his help with many of the IOC activities on QM. Special thanks also to Robert Zuneska, M.A. (CUNY), for his generous technical assistance in the preparation of this volume. Finally, I wish to express my personal gratitude to the publisher's anonymous reader for helpful suggestions and to Springer's Project Coordinator Palani Murugesan for his valuable support during the final phase.

Credits All the essays included had presentations in venues of the International Ontology Congress. Three of the contributions have been previously published and appear here with permission of the authors and publisher (Springer); the details are as follows:

Simon Kochen: "A Reconstruction of Quantum Mechanics." *Foundations of Physics* Vol 45 (2015): 557–590.
Tim Maudlin: "The Universal and the Local in Quantum Theory." *Topoi*: Vol 34 (2015): 349–358.
Anton Zeilinger: "A Foundational Principle for Quantum Mechanics." *Foundations of Physics* Vol 29 (1999): 631–643.

New York, USA Alberto Cordero

Contents and Summaries

The contributions in this volume are a selection of outstanding papers presented as keynote addresses at some point between 1994 and 2016 in one of the biennial meetings of the International Ontology Congress (IOC) held in San Sebastian, Spain. The works included are grouped in six parts: Part I contains contributions about Bell's theorem and the debate on realism. Part II has papers on what the physical world is like according to quantum mechanics (QM). Part III concentrates on strategies of local scientific realism in the foundations of QM. Part IV considers arguments on individuals and individuation. Part V presents current proposals to revisit insights from the Copenhagen Interpretation. Part VI comprises proposals in favor of reconceptualizing QM.

Below is a list of the works included, along with their respective authors and summaries. The ordinal after "IOC" indicates congress number, followed by the meeting's year.

Philosophers Look at Quantum Mechanics

Chapter 1 Alberto Cordero: Introductory chapter: "Philosophers Look at Quantum Mechanics." This provides a rough map of the ideas and options discussed in the chapters that follow.

Part I: Bell's Theorem and the Debate on Realism

Chapter 2 Víctor Gómez-Pin: "Inseparable Twins" (IOC-III, 1998). A conversation with Alain Aspect about the philosophical aspects of current experimental work in the foundations of quantum mechanics, especially the experimental tests of John Bell's inequalities Aspect conducted in 1982, the last of which allowed for a choice between the settings on each side during the photons' flight.

Chapter 3 Peter Lewis: "Bell's Theorem, Realism, and Locality" (IOC-XI, 2014). Lewis argues that quantum mechanics is not a unified theory, and what Bell's theorem shows depends on which interpretation turns out to be tenable. He concludes that while the lesson of Bell's theorem could be that quantum mechanics is nonlocal, it could equally be that measurements have multiple outcomes, or that effects can come before their causes, or even, as the anti-realist contends, that no description of the quantum world can be given.

Chapter 4 Tim Maudlin: "The Universal and the Local in Quantum Theory" (IOC-XI, 2014). This contribution proposes that any empirical physical theory must have implications for observable events at the scale of everyday life, even when that scale plays no special role in the basic ontology of the theory itself. The fundamental physical scales are microscopic for the "local beables" of the theory and universal scale for the nonlocal beables (if any). This situation creates strong demands for any precise quantum theory. Maudlin examines those constraints and illustrates some ways in which they can be met.

Part II: Ontological Explorations of QM

Chapter 5 Harvey Brown: "The Reality of the Wavefunction: Old Arguments and New" (IOC-XII, 2016). Brown offers plausibility arguments for the reality of the quantum state and discusses what seem to be weaknesses in QBism as a philosophy of science. (QBism represents an attempt to solve the traditional puzzles in the foundations of quantum theory by denying the objective reality of the quantum state.)

Chapter 6 David Albert: "Preliminary Considerations on the Emergence of Space and Time" (IOC-XII, 2014). This chapter explores the idea that the wave function is the unique fundamental concrete physical stuff of the world *itself*. Albert focuses on two suggestions: (a) First-quantized nonrelativistic quantum mechanics is not a theory of the three-dimensional motions of *particles*, but of the $3\underline{N}$-dimensional *undulations* of a concrete physical *field*—the wave function itself—where N is a very large number that corresponds, on the *old* way of thinking, to the number of elementary particles in the universe. (b) This particularly radical coming-apart of the geometry (on the one hand) and the fundamental arena (on the other) is what's at the bottom of everything that's exceedingly and paradigmatically *strange* about quantum mechanics.

Chapter 7 Roland Omnès: "Decoherence and Ontology" (IOC-IX, 2008). Omnès discusses the consequences of quantum mechanics for our understanding of physical reality, particularly regarding how classical concepts are found to emerge from quantum laws; how commonsense logic stands out as a special case of quantum logic applied to macroscopic objects; how causality and locality are found to be "provincial" consequences of quanta; how tiny probabilities that would seem to turn reality into an appearance are so small that unreality does not matter; how quantum theory agrees with everything observed, except for a uniqueness that (alas) is the very essence of reality.

Chapter 8 James Cushing: "Bohmian Mechanics and Its Ontological Commitments" (IOC-III, 1998). Cushing comments on how the Bohmian option countenances a radically different ontology from the orthodox option that became standard in modem physics. In Bohmian mechanics the measurement process, which is inherently many-body in nature, is basically an act of discovery—there is *no* quantum-mechanical measurement problem. There is a well-defined criterion for a classical limit, so that there is no *conceptual* mismatch between the classical and quantum domains. Finally, insofar as all measurements are *ultimately position* measurements and quantum equilibrium ($P = |\Psi|^2$) obtains, Bohm's theory gives *complete* empirical equivalence with standard quantum mechanics. Ultimately, the choice between determinism and indeterminism in the fundamental laws of quantum mechanics is up to us.

Chapter 9 Albert Solé and Carl Hoefer: "The Nomological Interpretation of the Wave Function" (IOC-XII, 2016). Focusing on Bohm's theory, Solé and Hoefer assess the nomological interpretation, in which the wave function is interpreted as a parameter that defines the law of motion of the Bohmian particles. The authors motivate the nomological interpretation of the wave function on its own and by showing the drawbacks of the field interpretation. They then consider the main problems of the view recently discussed in the literature. Solé and Hoefer conclude with some suggestions regarding the relation of the nomological interpretation and the interpretation of the wave function that takes it to represent dispositional properties of Bohmian particles.

Part III: Local Scientific Realism

Chapter 10 Juha Saatsi: "Scientific Realism Meets the Metaphysics of Quantum Mechanics" (IOC XII, 2016). This chapter examines the epistemological debate on scientific realism in the context of quantum physics, focusing on the empirical underdetermination of different formulations (and interpretations) of quantum mechanics. Saatsi sketches a way of demarcating empirically idle metaphysics of QM from the empirically well-confirmed aspects of the theory in a way that withholds realist commitment to what |Ψ> represents. He argues that such commitment is not required for fulfilling the ultimate realist motivation: accounting for the empirical success of quantum mechanics in a way that is in tune with a broader understanding of how theoretical science progresses and latches onto reality.

Chapter 11 Steven French: "Structural Realism and the Standard Model" (IOC-XI, 2012). This chapter argues for a local approach to scientific realism. According to French, taking the Standard Model seriously means taking the role of symmetries seriously and the way in which kinds and properties "drop out" of that framework. He claims that "ontic" structural realism, which holds that the world *is* structure, does just that. The option the chapter advances proceeds in the spirit of Cassirer and Eddington's efforts, who did not defend their structuralist conceptions on the basis of some commonality with earlier theories; rather they presented them as a way of making philosophical sense of quantum mechanics. French suggests to be a realist about the Standard Model one should be a realist about the symmetries and laws that it embodies and hence one should be a structural realist.

Part IV: Individuals, Individuation, and QM

Chapter 12 Peter Mittlestatedt: "The Problem of Individualism from Greek Thought to Quantum Physics" (IOC-IV, 2000). Individuals in the strict sense do not exist in quantum physics. Mittlestatedt argues, however, that unsharp observables, almost repeatable and weakly disturbing measurements, allow for the definition of unsharp individuals which is sufficient for all practical purposes. Many quantum physical experiments and the obvious existence of individuals in the classical world can be explained in this way. On the other hand, he stresses, if quantum mechanics is considered as universally valid, then there is no classical world in the strict sense. The chapter includes a Divertimento on an analogy between the motion of individual quantum systems and the motion of angels according to the treatment of Thomas Aquinas in his *Summa Theologica.*

Chapter 13 Otavio Bueno: "Weyl, Identity, Indiscernibility, Realism" (IOC-XI, 2012). This chapter reconstructs a technique originally formulated by Hermann Weyl to accommodate, in the foundations of quantum mechanics, aggregates of quantum particles despite these particles' apparent lack of identity. Bueno defends the importance of this technique and provides a variant of Weyl's original formulation by avoiding altogether the use of set theory. He then offers formulations of individuals and nonindividuals, inspired by considerations that Weyl made in the context of his theory of aggregates, and examine the status of nonindividuals with regard to debates about realism.

Part V: Copenhagen Insights Revisited

Chapter 14 Jeffrey Bub: "What Is Really There in the Quantum World?" (IOC-XII, 2016). This chapter argues for an information-theoretic interpretation that harks back to Bohr's original Copenhagen interpretation. The noncommutative theory formalized by Dirac and von Neumann is—Bub stresses—not just a new theory but a new *sort* of theory in which probability arises as a feature of the noncommutative algebraic structure and has a different significance to probability in other statistical theories. On the proposed approach, just as Minkowski geometry encodes generic kinematic constraints on spacetime configurations, the "intertwinement" of commuting and noncommuting observables in Hilbert space encodes generic kinematic constraints on probabilistic correlations between intrinsically random measurement outcomes. According to Bub, these nonclassical probabilistic constraints underlie new information-theoretic applications (e.g., to cryptography, computation, and communication). Quantum probabilities don't represent ignorance, he emphasizes, and they are not introduced because we don't or can't keep track of all the relevant variables. So what is really there in the quantum world? The proposed conception of the quantum world is in terms of probabilities of what you'll find if you measure an observable: (a) when a measurement is made, there is an agent-independent fact of the matter about what the outcome is; (b) the unitary dynamics applies universally, in principle, to systems of any complexity.

Chapter 15 Anton Zeilinger: "A Foundational Principle for Quantum Mechanics" (IOC-X, 2012). In contrast to the theories of relativity, quantum mechanics lacks a firm foundational principle to this day. This chapter proposes that the missing principle may be identified through the observation that all knowledge in physics has to be expressed in propositions and that therefore the most elementary system represents the truth value of one proposition, i.e., it carries just one bit of information. Zeilinger suggests that an elementary system can only give a definite result in one specific measurement, noting that the irreducible randomness in other measurements is then a necessary consequence. For composite systems, entanglement results if all possible information is exhausted in specifying joint properties of the constituents.

Part VI: Calls to Reconceptualize QM

Chapter 16 Simon Kochen: "A Reconstruction of Quantum Mechanics" (IOC-X, 2012). Kochen proposes a reconstruction of the formalism of quantum mechanics mathematically centered on a formulation of relational properties. To mathematically treat the extrinsic properties of quantum mechanics, he replaces the encompassing σ-algebra B(Ω) of properties by a σ-complex Q, consisting of the union of all the σ-algebras of the system elicited by different decoherent interactions, such as measurements. This change allows Kochen to define in a uniform manner the concepts of state, observable, symmetry, and dynamics, which reduce to the classical notions when Q is a Boolean σ-algebra, and to the standard quantum notions when Q is the σ-complex Q(H) of projections of Hilbert space H. Kochen then uses this approach to derive both the Schrödinger equation and the von Neumann-Lüders Projection Postulate. One feature of the reconstruction he offers is that the classical definitions of key physical concepts such as state, observable, symmetry, dynamics, and the combining of systems take on precisely the same form in the quantum case when they are applied to extrinsic properties. Kochen shows [contra Bohr] that once the relational character of properties is accepted, the definitions of the basic concepts of quantum mechanics are as real and intuitive as is the case for classical mechanics. In his view, quantum mechanics describes general interactions in the world, independently of a classical macroscopic apparatus and observer, arguing that the interactions we describe using a macroscopic apparatus could apply equally well to appropriate decoherent interactions between two systems in general. Kochen stresses that the aim of every theory is to predict the probabilities of the outcomes of interactions between systems, experiments being particular instances of such interactions. An experiment gives rise to a Boolean σ-algebra of events which reflects an isomorphic σ-algebra of properties of the system. Kochen derives elementary quantum mechanics by applying the natural classical definitions of the physical concepts to extrinsic properties, and then uses this derivation to resolve the standard paradoxes and problematic questions.

Chapter 17 David Wallace: "What Is Orthodox Quantum Mechanics?" (IOC-XII, 2016). Wallace proposes that the version of QM, as presented in standard foundational discussions (the so-called orthodox theory), relies on two substantive assumptions—the projection postulate and the eigenvalue-eigenvector link—that do not in fact play any part in practical applications of quantum mechanics. He argues for this conclusion on a number of grounds, but primarily on the grounds that the projection postulate fails correctly to account for repeated, continuous and unsharp measurements (all of which are standard in contemporary physics) and that the eigenvalue-eigenvector link implies that virtually all interesting properties are maximally indefinite pretty much always. Wallace presents an alternative way of conceptualizing quantum mechanics that does a better job of representing quantum mechanics as it is actually used, and in particular that eliminates use of either the projection postulate or the eigenvalue-eigenvector link. He reformulates the measurement problem within this new presentation of orthodoxy.

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