Theoria, 2024, 39(2), 137-142
https://doi.org/10.1387/theoria.26755

THEORIA

ISSN 0495-4548 – eISSN 2171-679X

Introduction to "Quantum mechanics and reality"

(Introducción a "Mecánica cuántica y realidad")

Raoni ARROYO*
University of Campinas

Jonas Rafael Becker ARENHART
Federal University of Santa Catarina

Christian DE RONDE
Universidad de Buenos Aires

Raimundo FERNÁNDEZ MOUJÁN
Universidad Diego Portales

ABSTRACT: This paper introduces the Special Issue of *Theoria* entitled "Quantum mechanics and reality". We first comment on its origins related to the *VIII International Workshop on Quantum Mechanics and Quantum Information*, promoted by the International Network on Foundations of Quantum Mechanics and Quantum Information. We then briefly introduce each contribution individually, bringing the papers together under the Special Issue's topic.

KEYWORDS: non-locality, non-reflexive logics, philosophy of quantum mechanics, quantum ontology and metaontology, realism and antirealism.

RESUMEN: *Este artículo introduce el número especial de* Theoria *titulado "Mecánica cuántica y realidad". En primer lugar, se explican sus orígenes en relación con el* VIII Taller Internacional sobre Mecánica Cuántica e Información Cuántica, *promovido por la Red Internacional sobre los Fundamentos de la Mecánica Cuántica e Información Cuántica. A continuación, se presenta brevemente cada contribución de manera individual, agrupándolas en torno al tema del número especial.*

PALABRAS CLAVE: *no localidad, lógicas no reflexivas, filosofía de la mecánica cuántica, ontología cuántica y metaontología, realismo y antirrealismo.*

Correspondence to: Raoni Arroyo. Centre for Logic, Epistemology and the History of Science, University of Campinas, Rua Sérgio Buarque de Holanda, 251, 13083-859, Campinas, Brazil. – raoniarroyo@gmail.com – https://orcid.org/0000-0002-3800-8505

How to cite: Arroyo, Raoni; Arenhart, Jonas Rafael Becker; De Ronde, Christian; Fernández-Mouján, Raimundo (2024). «Introduction to "Quantum mechanics and reality"»; *Theoria. An International Journal for Theory, History and Foundations of Science,* 39(2), 137-142. (https://doi.org/10.1387/theoria.26755).

Received: 1 July, 2024; Final version: 22 July, 2024.
ISSN 0495-4548 - eISSN 2171-679X /

1. *Quantum Mechanics and Reality*

The predictive capacity and the immense instrumental consequences of quantum mechanics seem to tell us with some confidence that this physical theory indeed captures a knowledge of, at least, certain aspects of reality, of a certain necessity within it. Now, what exactly does it tell us about reality? What vision, what representation of reality does it offer? This is where consensus is lacking, things get complicated, and some difficult problems begin. We see in the current debate not only a huge number of disparate interpretations multiplying (with none rising above the others), but even a more general debate reappearing regarding the relationship between physical theories and reality. In this context, positions emerge that even deny —more or less explicitly— that there is such a link with reality, or, at least, its importance.

At this point, the question of metaphysics, and its relationship with physics, enters the debate. Quantum mechanics is the perfect case for discussions about the connection between metaphysics and science: it is extremely well-confirmed, on the one hand, but it is elusive, to say the least, when it comes to telling us what it is about. Is it necessary then to *add* a metaphysics to the formal and empirical content of the theory? Or perhaps a particular metaphysics already appears to be presupposed from the outset in the standard model used by physicists? And, in a broader sense, this specific debate regarding quantum mechanics forces upon us a more general question: what is generally the role of metaphysics within scientific theories?

Concomitant with the question of metaphysics, developments frequently appear that emphasize the need for an *ontology*. If quantum mechanics is going to tell us something about reality, then one should perhaps begin with the subject matter of the theory: is it a theory that deals with waves, particles, or something else entirely different, such as wave functions? And how should we deduce the answer? These are topics that in the current debates are taken to be a question of *ontology*. With the emphasis on ontology, another necessary conceptual question appears: what are the differences and relations between metaphysics and ontology in the context of these debates?

Even when embracing this ontological debate and trying to start by identifying the entities described by the theory, we find some rather strange phenomena that raise another more specific question: are the entities that exist according to quantum mechanics really individuals? If so, what account of individuals would work? Or, perhaps, they are not really individuals? Maybe the very idea of objects, or atoms, is not very fruitful for an understanding of the theory, and radically different categories are required by the theory? Should we create such new categories, or could they perhaps be read-off directly from the theory?

With these important questions in mind, the VIII International Workshop on Quantum Mechanics and Quantum Information was held, promoted by the International Network on Foundations of Quantum Mechanics and Quantum Information and the Research Group of Logic and Foundations of Science (CNPq). It is from the very interesting presentations and debates that took place in that event that this special issue was born.

2. *The contributions*

Contributions to this issue address directly the question concerning the connection between quantum mechanics and reality, in different levels. Here, we briefly present the papers.

— **Allori (2024).** As we mentioned in the previous section, one of the problems with a quantum mechanical view of reality is that it is not easy to see what the theory is telling us. In current literature, options multiply themselves, populating the world with very different posits. The choice of which view to adopt cannot be made on purely empirical grounds. Which features should we privilege? Hidden variables are an option to have more classically related options. Should we go that way? Valia Allori's paper addresses this problem from a specific perspective. After Bell's famous theorem on non-locality, a prominent way to have local hidden variables is in a superdeterministic universe. Superdeterminism is a fancy name for good old fashioned *determinism* in general philosophy, the idea according to which every outcome is already determined by previous causes. So if your theory is superdeterministic, your hidden variables could be local. Allori shows the problems in such a thought, viz. that superdeterministic theories are, in her own words, "uninformative, unfalsifiable, and unconfirmable" (p. 161). In particular, it is argued that contextuality is purely ad hoc in superdeterministic theories, then these aspects must be added to the balance when comparing costs between superdeterminism and non-locality.

— **Aerts and Sassoli de Bianchi (2024).** The paper discusses the construction of spacetime as related to Einstein's relativity revolution which, according to the authors has not been fully accomplished. They argue that "the four-dimensional motion in Minkowski space can be better understood if placed in the broader perspective of quantum mechanics, if non-locality is interpreted as non-spatiality, thus indicating the existence of an underlying non-spatial reality" (p. 165). This discussion is then also related to the conceptuality interpretation of quantum mechanics that has been already developed by Aerts and Sassoli de Bianchi. The paper provides an interesting and original discussion which connects two of the most important theories of the 20th century, namely, relativity and quantum mechanics.

— **Arroyo and Arenhart (2024)[1].** This paper elaborates on the question of what quantum mechanics could teach us about reality, on a more general level. Granting that different versions of quantum theory populate the world with different entities, Arroyo and Arenhart develop upon their previous work on the difference between ontology and metaphysics, this time distinguishing between two senses of 'ontology'. The first part is the catalog one might extract from scientific theories (e.g. whether there are multiverses or not according to the Many Worlds Interpretation of Everettian quantum mechanics). This part is hence 'naturalizable'. The non-naturalizable part of ontology is whether 'worlds' as per in the catalog-aspect of ontology should be categorized as 'objects' or 'structures' in the type-aspect of ontology.

— **da Costa (2024).** Going even deeper on the level of characterization of quantum entities, a venerable tradition dating back to some readings of Schrödinger suggests that quantum entities are not individuals. This claim has received a formal rendering through the development of non-reflexive systems of logic. The pioneer in such developments, Professor Newton da Costa, suggested that this feature could be cap-

[1] This paper went through the peer-reviewing process as usual, and none of the guest editors took part in any stage of the editorial process, so we'd like to thank Javier Gonzalez de Prado Salas for this.

tured by formal languages where the relation of identity is restricted when it comes to writing formulas (these systems were later developed and further explored by Prof. Décio Krause). Now, da Costa honors us with a paper with additional developments on the topic. The new proposal by da Costa consists in restricting identity not at the level of formation of formulas, but of having assertable formulas: we can only assert formulas involving identity provided that the items whose identity are being expressed actually satisfy some very specific conditions. This certainly brings a new perspective on non-reflexive logics. Also, da Costa indicates how to develop a version of quantum mechanics as based on his new system, an account differing from standard non-reflexive accounts (e.g. Krause & Arenhart, 2016). This is the first posthumous publication of Professor Newton da Costa, who passed away shortly after having his paper accepted in this journal.

— **Krause (2024).** Krause's article discusses the methodological aspects of the discussion related to the connection of theory and reality, with special emphasis on the quantum case. In particular, Krause is concerned with the problem of how to connect the empirical world with the highly abstract and mathematised models of our theories. This relation is often taken for granted, but as the paper argues, it is highly problematic. Krause adds a new dimension to the debate bringing to the fore the role of the mathematical theories employed in the constructions of the models; given the plurality of non-classical theories that can do that job, significantly different accounts may result from using different such theories in the metalanguage (which Krause calls the metamathematics). So, in a sense, even the chosen logic matters for the view of reality that one hopes to derive from quantum mechanics. A case study is presented through the theory of quasi-sets and quantum particles lacking individuality.

— **Ruetsche (2024).** Ruetsche's piece is, up to this date, the most thorough presentation and defense of her Locavore stance on the philosophy of science. The locavore position was developed to deal with ontological plurality in science. While previous work in the field dealt with plurality between different domains of science (e.g., non-relativistic quantum mechanics and quantum field theory Ruetsche, 2015), this article tackles how the locavore deals with ontological plurality within the same domain of inquiry. A case in point is the ontological plurality in quantum interpretations, for example, the question of whether or not quantum mechanics implies we're living in a multiverse. If we are (hence the Everettian interpretation is correct), then we should add this entity to the world's ontological catalog. The problem with this catalog is that it is incompatible with another ontological catalog, viz., that quantum mechanics implies that we're living in a single world (hence the Everettian interpretation is incorrect).

Ruetsche's own answer to this is the locavore one, according to which we don't need to choose *and* we don't need to be antirealists as well. The choice for a single picture is, after all, is required only by the locavore's arch-enemy, the Cyclops. The Cyclops' view is the background against which the stalemate between realism and antirealism has been established in quantum foundations, and the locavore's way out of it is to recognize that quantum mechanics is an interesting theory, and to doubt that "interesting theories have winning interpretations" (p. 255). Competing interpretations shouldn't be seen as competing in such a picture, where interpretation diversity is welcomed as a sign of health to the interesting theory. So e.g.

Bohmian mechanics should be used for one end (e.g., to preserve the particle-picture) whereas standard quantum mechanics should be used for other ends (e.g. teaching physics courses). That’s, as the author herself recognizes, a suggestion that is “[...] bold, and liable to be met with resistance” (p. 259).

Acknowledgments

This Special Issue is dedicated to the memory of Professor Newton da Costa (1929-2024).

We would like to thank the Editors of Theoria, especially Javier and Marc, with whom we worked together to find the best referees, and to discuss the best outcome for the papers under peer review, always aiming to provide a sensible and constructive review to the authors (even in the unfortunate rejection cases).

We thank the authors for promptly agreeing to collaborate with the project, and the participants of the VIII International Workshop on Quantum Mechanics and Quantum Information.

REFERENCES

Aerts, D., & Sassoli de Bianchi, M. (2024). The nature of time and motion in relativistic operational reality. *Theoria. An International Journal for Theory, History and Foundations of Science*, 39(2), 165-191. (https://doi.org/10.1387/theoria.24930)

Allori, V. (2024). Hidden variables and Bell’s theorem: Local or not? *Theoria. An International Journal for Theory, History and Foundations of Science*, 39(2), 143-163. (https://doi.org/10.1387/theoria.24617)

Arroyo, R., & Arenhart, J. R. B. (2024). Quantum ontology de-naturalized: What we can’t learn from quantum mechanics. *Theoria. An International Journal for Theory, History and Foundations of Science*, 39(2), 193-218. (https://doi.org/10.1387/theoria.24955)

da Costa, N. C. A. (†) (2024). Remarks on quantum mechanics and non-reflexive logic. *Theoria. An International Journal for Theory, History and Foundations of Science*, 39(2), 219-228. (https://doi.org/10.1387/theoria.24771)

Krause, D. (2024). A way to see the interplay between theory and reality with a look at the quantum case. *Theoria. An International Journal for Theory, History and Foundations of Science*, 39(2), 229-244. (https://doi.org/10.1387/theoria.24759)

Krause, D., & Arenhart, J. R. B. (2016). Presenting nonreflexive quantum mechanics: Formalism and metaphysics. *Cadernos de História e Filosofia da Ciência*, 2(1), 59-91.

Ruetsche, L. (2015). The Shaky Game+ 25, or: On locavoracity. *Synthese*, 192(11), 3425-3442.

Ruetsche, L. (2024). The miracles argument meets quantum mechanics: Toward a locavore philosophy of physics. *Theoria. An International Journal for Theory, History and Foundations of Science*, 39(2), 245-261. (https://doi.org/10.1387/theoria.24976)

Raoni Arroyo is a postdoc researcher at the Centre for Logic, Epistemology and the History of Science, based at the University of Campinas, Brazil, and a research fellow under grant #2021/11381-1, São Paulo Research Foundation (FAPESP); member of Research Group in Logic and Foundations of Science (CNPq). His main philosophical interests are the methodological and epistemological aspects of the metaphysics of science, and its relation with scientific realism.

Address: Centre for Logic, Epistemology and the History of Science, University of Campinas, Rua Sérgio Buarque de Holanda, 251, 13083-859, Campinas, Brazil.
E-mail: raoniarroyo@gmail.com – ORCID: 0000-0002-3800-8505.

JONAS RAFAEL BECKER ARENHART is an associate professor of the Department of Philosophy of the Federal University of Santa Catarina (Florianópolis, Brazil). Member of the editorial board of *Principia —An International Journal of Epistemology*. He is the coordinator of the Research Group in Logic and Foundations of Science (CNPq). His main areas of interest are Logic, philosophy of logic and paraconsistency, and the search for a productive interaction between science and metaphysics, with a focus on quantum mechanics.

ADDRESS: Department of Philosophy, Federal University of Santa Catarina, Campus Universitário Reitor João David Ferreira Lima, s/n Trindade – Florianópolis – SC, CEP: 88035-972. Caixa Postal: 5064, Florianópolis, Brazil. E-mail: jonas.becker2@gmail.com – ORCID: 0000-0001-8570-7336.

CHRISTIAN DE RONDE is an Independent Researcher of the *Consejo Nacional de Investigaciones Científicas y Técnicas* (CONICET) de Argentina. Associate Professor of the National University Arturo Jauretche and coordinator of the group of Philosophy of Physics of the University of Buenos Aires. He is also member of the Center Leo Apostel for Interdisciplinary Studies (Vrije Universiteit Brussel) and of the International Network of Foundations of Quantum Mechanics and Quantum Information. His main areas of interest are the philosophy and foundations of quantum mechanics.

ADDRESS: Instituto de Filosofía Dr. Alejandro Korn, Facultad de Filosofía, Universidad de Buenos Aires, Puán 480, 4to. piso, of. 431, C1406CQJ, Buenos Aires, Argentina. E-mail: cderonde@gmail.com.

RAIMUNDO FERNÁNDEZ MOUJÁN is a postdoctoral researcher at the Philosophy Institute of the Diego Portales University, Santiago de Chile (supported by ANID-FONDECYT, project number: 3240436). He is also a member of the Center Leo Apostel for Interdisciplinary Studies (Vrije Universiteit Brussel) and the International Network on Foundations of Quantum Mechanics and Quantum Information. His main interests are ancient and contemporary theory of knowledge and the philosophy of quantum mechanics.

ADDRESS: Instituto de Filosofía, Universidad Diego Portales, Avenida Ejército Libertador, 260 (8370056 Santiago de Chile-Chile). E-mail: raifer86@gmail.com – ORCID: 0000-0002-7074-8036.