BOOK OF ABSTRACTS

IX INTERNATIONAL WORKSHOP ON QUANTUM MECHANICS AND QUANTUM INFORMATION

QUANTUM MECHANICS AND THE NOTION OF THEORY

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ONLINE
2023

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Online, 2023

IX International Workshop on Quantum Mechanics and Quantum Information

Quantum Mechanics and the Notion of Theory

June 22 and 23, 2023
Online workshop

Promoted by:
Graduate Program in Philosophy, Federal University of Santa Catarina
Graduate Program in Philosophy, Federal University of Maranhão
Centre for Logic, Epistemology and the History of Science, University of Campinas
Roma Tre University,
Research Group of Logic and Foundations of Science (CNPq)
University of Buenos Aires
National University Arturo Jauretche
National Scientific and Technical Research Council (CONICET)
Center Leo Apostel for Interdisciplinary Studies, Free University of Brussels
International Network on Foundations of Quantum Mechanics and Quantum Information

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18:40 End of the workshop.

Abstracts

Six Measurement Problems of Quantum Mechanics[†]

F. A. Muller[*]

The notorious 'measurement problem' has been roving around quantum mechanics for nearly a century since its inception, and has given rise to a variety of 'interpretations' of quantum mechanics, which are meant to evade it. We argue that no less than *six* problems need to be distinguished, and that several of them classify as *different types* of problems. One of them is what traditionally is called 'the measurement problem'. Another of them has nothing to do with measurements but is a profound metaphysical problem. We also analyse critically T. Maudlin's (1995) well-known statement of 'three measurements problems', and the clash of the views of H. Brown (1986) and H. Stein (1997) on one of the six meansurement problems. Finally, we summarise a solution to one measurement problem which has been largely ignored but tatictly if not explicitly acknowledged.

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[†]Forthcoming in in: ARENHART, J. R. B.; ARROYO, R. W. (Eds.). *Non-Reflexive Logics, Non-Individuals, and the Philosophy of Quantum Mechanics: Essays in Honour of the Philosophy of Décio Krause*. Cham: Springer, 2023. (Synthese Library).

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Quantum theories, quantum interpretations, and quantum ontologies

Jonas R. B. Arenhart* Raoni Arroyo†

In this talk, we discuss some perils of ontological extraction.

Quantum interpretations and quantum ontologies walk together: given an interpretation, certain entities are considered real (e.g., minds, worlds, etc.). An ontology is said to be extracted from an interpretation. But what is a quantum interpretation, and how do we extract an ontology from it? There are two methodological responses. A) an interpretation entails an ontology from a particular reading of quantum theory; B) an interpretation is an ontological defining aspect of a quantum theory.

When it comes to epistemological guarantees, method A is the safest in the market. It puts the theory first, and that's why naturalists like it the most. A single quantum theory gives rise to several quantum interpretations; quantum ontologies were supposed to come with each of them for free, but here's a problem with this last claim. Suppose by "quantum theory" we mean a "quantum-mechanical example of a semantic approach to scientific theories in which theories are set-theoretical structures". In that case, there are no ontologies to be found. On the other hand, if a quantum interpretation is something else beyond quantum theory, we need to know how to find its quantum ontology (Carnap and Quine won't help us, as ontological commitment is a commitment of the linguistic formulation of the theory, not of the interpretation). Here's our review: while safest, method A doesn't extract any amount of ontology from the theory. Method A filtrates everything.

Method B is a bit more reckless. It puts ontology first, and naturalists might find it relies on shaky grounds. A quantum theory is only a quantum theory when a quantum ontology is specified, and there is no such thing as two different ontological readings of the same theory. Once the ontology is different, the theory is also different. This ontology-first method, however, extracts too much. It doesn't matter if the (e.g.) many-minds QM and the many-worlds QM have the same Suppes predicates; they would count as two different theories in method B. While reckless, at least method B extracts something (a sales pitch that may be used against its competitor). On the other hand, the amount of ontology extracted is the exact same amount of ontology put in. This puts too much pressure on the epistemic credentials of quantum ontology. Method B filtrates nothing and may pollute quantum ontology with armchair idiosyncrasies.

While methods A and B have problems, we need a minimal quantum ontological aspect. After all, unless one adopts an old-fashioned instrumentalist stance, QM unequivocally talks about several non-mathematical entities such as electrons, protons, energy, and many other non-set-theoretical entities. In order to approach them, we need a better method of ontological extraction.

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The Dual Nature of Quantum Dynamics

Diana Taschetto* Ricardo Correa da Silva†

In the first talk of this Workshop F. A. Muller critically discusses the measurement problem of quantum mechanics from several angles, one of which he poses thus: "The two postulates of standard QM that mutually exclude and jointly exhaust the change of state over time [the Schrödinger equation and the collapse postulate] evoke the question: why two, and why *these* two?" In our talk, we shall give an exact mathematical answer to this question.

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What is it Like to be a Relativistic GRW Theory? Or: Quantum Mechanics and Relativity, Still in Conflict After All These Years

Valia Allori*

The violation of Bell's inequality has shown that quantum theory and relativity are in tension: reality is nonlocal. Nonetheless, many have argued that GRW-type theories are to be preferred to pilot-wave theories as they are more compatible with relativity: while relativistic pilot-wave theories require a preferred slicing of space-time, foliation-free relativistic GRW-type theories have been proposed. In this paper I discuss various meanings of 'relativistic invariance,' and I show how GRW-type theories, while being more relativistic in one sense, are less relativistic in another. If so, the initial claim that GRW-type theories have a greater compatibility with relativity is unwarranted: both type of theories violate relativity, one way or another.

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Scientific Understanding of Defective Theories: Structuralism, Quantum Mechanics and the (Meta)Metaphysics of Individuals[‡]

Moisés Macías-Bustos[*] María del Rosario Martínez-Ordaz[†]

Here, we deal with the role that Quasi-set theory might play *vis-à-vis* rational understanding of the scientific and metaphysical elements of quantum mechanics.

Broadly speaking, *scientific understanding* is considered to be knowledge of relations of dependence. When one understands a theory, one can build a comprehensive picture of that theory as well as of the relations that hold within it. Understanding a theory allows scientists to find new domains of application for it, and understanding an empirical domain makes it possible to build new theoretical approaches to that domain. Science is generally concerned with explanation, prediction, manipulation, and actual knowledge of what the world is like. This last factor is metaphysical in nature, for metaphysics is concerned ultimately with the question of what the world is fundamentally like. Therefore, it is undeniable that scientific understanding is a fundamental component of any successful scientific enterprise.

So far, understanding has been considered to be *factive* and *explanatory*, meaning that its content should only include true propositions and that it should come only after the achievement of explanatory knowledge. Unfortunately, if this were the case, however, we wouldn't be able to legitimately understand any theories, models, or phenomena that are formulated in a defective manner. At least we wouldn't be able to do understand them *qua defective* —yet, if there was no need for understanding defective theories, this wouldn't be a problem.

However, many of our most successful scientific theories, at some point in their development, are or have been *defective*. Some of them, like Bohr's model of the atom, have been, allegedly, inconsistent. Some others have conflicted significantly with observation, like Newtonian dynamics. And some others, like Quantum Mechanics, are conceptually vague and imprecise, as well as (depending on the philosophical reconstruction) inconsistent (Cf. ARENHART; KRAUSE, 2014; DA COSTA; KRAUSE, 2014). This shows that much scientific practice has used and uses defective theories and models. And even more importantly, these theories, even when defective, have grounded and shaped our current science. And yet, while philosophers of science scrutinized the rationality behind using defective theories, they have significantly struggled when explaining how, if possible, to achieve any legitimate understanding of them.

Here, we deal with the question of under which circumstances can scientists achieve a legitimate understanding of defective theories *qua* defective. We claim that scientists understand a theory if they can recognize the theory's underlying inference pattern(s) and if they can reconstruct and explain what is going on in specific cases of defective theories as well as consider what the theory would do if not defective –even before finding ways of fixing it. Moreover, we claim that understanding the inferential structure of the theory involves understanding the structure

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of its domain. Furthermore, this understanding is modal in nature, in that the domain might not actually instantiate that structure, the structure need only be possible. This last point we illustrate with specific reference to quantum mechanics.

In order to do so, we proceed in four steps.

- First, we introduce the generalities of scientific understanding and we discuss the challenges around the legitimate understanding of defective theories; here we also introduce our case study.
- Second, we sketch a structuralist approach to understanding and furthermore elaborate on what sort of presuppositions from metaphysics and meta-metaphysics are required by this type of approach.
- Third, we explain in which way the detection of specific inferential patterns and logical constraints allows for the promotion of scientific understanding in the case of the quantum theory with non-individuality (Cf. KRAUSE; FRENCH, 1995; ARENHART; KRAUSE, 2014).
- Finally, we draw some conclusions.

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Quantum interpretations are quantum theories (and not quantum ontologies)

Lauro de Matos Nunes Filho*

The boundaries between interpretation and theory in quantum physics are unmarked. In this presentation, the so-called *interpretations* are conceived as quantum theories or as conceptual approaches to these *same* theories. Basically, our analysis considers an interpretation not as a medium to understand or explain a theory but as an approach to such a theory by transforming it into a new one. It does not mean that interpretations and theories are the same. After all, interpretations are understood here as extensions or simplifications of quantum theories. For instance, in this analysis, we trace the line that goes from quantum mechanics based on von Neumann's framework for QM to the Heisenberg picture of quantum mechanics. After that, we change our focus to Everett's relative state and again, even further, from Everett's proposal toward Barrett's Many Worlds Interpretation. This exercise will provide us with a complete picture of the dynamic between theory and interpretation as a dynamic between different theories. In sum, we intend to differentiate between interpretations that are theories *per se* and interpretations that are just shallow conceptual approaches to the theories. This proposal tries to shed light on relevant matters for the ontology of physics by denying that interpretations are ontologies for physical theories.

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Invariance, objectivity and operationality as general conditions for physical theories. The case of quantum mechanics.

Christian de Ronde* Raimundo Fernández-Mouján†

Physical theories aim to respond to an old, Greek, question: Is there something that remains the same through change? To answer this question, modern physical theories developed certain general conditions. One of them is formal invariance. Invariance is what allows us to find, in mathematical terms, what is to be considered the same in a physical theory. But equally fundamental has been the development of conceptual representations that allow to connect that formalism to physical reality, and to give meaning to what has been observed. This conceptual representation, in turn, has to be *operational*, that is, it has to contain the conditions under which we can produce and understand observations in accordance with the theory. Taking into consideration these fundamental aspects of physical theories, we approach the case of quantum mechanics. We show how, contrary to what is usually believed, formal invariance was present in the original matrix formalism presented by Heisenberg. This invariance however is the invariance of *intensities*. We show how, historically, instead of developing a conceptual representation in accordance with that aspect of the theory, the invariance of intensities was destroyed due to the projection of classical concepts alien to the quantum theory. After a brief critical analysis of that history, we propose to go back to matrix mechanics, and to develop a conceptual representation grounded on the invariance of intensities. This attempt, as we explain, allows us to escape contextuality and relativism, and to develop an invariant, objective and operational account of quantum mechanics.

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Quantum Interpretations and Metaphysical Additions

Otávio Bueno*

Despite their impressive empirical success, (relativist and non-relativist) quantum theories leave a number of issues open, such as, whether the underlying phenomena are deterministic or not, whether quantum particles are individuals or nonindividuals. Attempts to answer questions of this sort involve the addition of new content to the particular quantum theory, which typically goes beyond what is entailed by the theory but does not generate new empirical predictions. If new predictions were generated, a rival theory to quantum mechanics would be in place rather than a different interpretation (see van Fraassen (1991); see also Ruetsche (2011)). I examine the nature of this content and indicate that it often involves the addition of particular metaphysical assumptions. I then argue how such assumptions may be accommodated within an empiricist setting.

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