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Textbook Quantum Mechanics and the Problem of Ontological Commitment

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How Quantum Mechanics Changed Philosophy
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Outline

How Quantum Mechanics Changed Ontology

For most scientific theories, there is a "standard" way to understand what they are about (their "ontology"). By contrast, standard QM textbooks leave central ontological questions unanswered (e.g. about the referent of $|\psi\rangle$ outside measurement contexts).

A dilemma for quantum ontology

- Relying on non-standard approaches to QM involves speculation, i.e. commitments that are underdetermined by the empirical evidence:
  - mutually conflicting solutions to the measurement problem (Everett, Bohm, GRW),
  - quantum state monism vs. various kinds of primitive ontology.
- Retreating to the standard ("Copenhagen") approach seems ontologically unsatisfactory.

The First Horn: Embracing Speculation

Non-committal version:

- Ontology as spelling out how the world could be, not as issuing claims about how the world is (example: Allori et al. 2014).
- Not interesting if one seeks to avoid (rather than celebrate) ontological speculation.

Ambitious version:

- Commitment to one specific ontology, denying that it is speculative or underdetermined, because its (alleged) alternatives are somehow deficient.
- However, there is no consensus as to which ontology deserves that status (cf. Callender 2020 on the controversy between Wallace and Bricmont).

The Second Horn: Non-Representationalism

Various authors have claimed that we can avoid the speculations of the first horn without embracing the antirealism of the second horn:

- Bub (2016) emphasizes the difference between his information-theoretic approach to QM and an instrumentalist view ot theories.
- Fuchs (2017) insists that his QBism is neither instrumentalism nor any other kind of antirealism, but should instead be viewed as “participatory realism”.
- Healey (2020) advocates a “pragmatist quantum realism”.

However, all these approaches take the quantum formalism to serve some other purpose than to represent elements of reality. Their realism (if it is a realism) does therefore not take QM to be ontologically informative.

Middle Ground? Partial Representationalism

- Ladyman and Ross (2007; 2013) take QM to be ontologically significant, but deny that this commits us to any of the "realistic" solutions of the measurement problem. Instead, they seek to *dissolve* the problem (drawing on ideas from Bohr), which leads to a conflict with even a minimal realism (cf. Egg 2019).
- Saatsi (2019, 2020) takes the quantum formalism to *somehow* represent reality, but refuses to spell out this representing role in ontological terms. His "progress realism" therefore abstains from any ontological commitment (cf. Section 3 below).
- Cordero (2001) gives some concrete examples of what might constitute a non-speculative quantum ontology, but Callender (2020) disputes their pertinence (cf. Section 4 below).

Ontology from QM Textbooks?

The basic idea

- Ontology should be informed by our best scientific theories.
- QM is one of our best (empirically most successful) theories.
- Its success does not depend on any of its (ontologically kosher) non-standard formulations, but on the (rather messy) apparatus of “textbook quantum mechanics” (TQM).
- Hence, TQM should be taken ontologically seriously.

TQM is obviously not a clearly circumscribed theory. Nevertheless, its core is easy to identify, consisting of uncontroversial examples of scientific achievements that any version of QM must be able to reproduce.

Ontology of QM as Non-Fundamental

But how can TQM inform our ontology when it leaves fundamental ontological questions unanswered?

- True, in order to inform fundamental ontology, TQM would have to address the measurement problem (and surrounding ontological issues), which it does not.
- But not all ontology is fundamental ontology. If it were, we should not expect ontological lessons from any version of QM, because QM is inherently non-fundamental. (If QM is sometimes classified as part of “fundamental physics”, this can only mean that QM is fundamental *relative to* other parts of physics.)
- Compare: Even QFT (which is certainly *more fundamental* than QM) is nowadays treated as an effective (i.e. non-fundamental) theory, but this should not stop it from informing our ontology (see Williams 2019).

More on Non-Fundamental Ontology

Essential feature of effective theories: irrelevance of the way in which they emerge from underlying theories.

- In this sense, effective theories do not describe the nature of their posits. How then can they inform ontology?
- Instead of telling us what the posits are (fundamentally), they tell us what they do (effectively). This yields a functional ontology (examples in Sections 3 and 4).

Doesn't this approach yield unwanted ontological commitments, e.g. to phlogiston or gravitational forces?

1. Phlogiston is not a posit of an effective theory, because there is no well-defined energy range successfully described by phlogiston theory.
2. (controversial!) Newtonian gravity arguably is an effective theory, therefore we should accept the reality of gravitational forces just as we accept other non-fundamental entities (cf. Wilson 2007).

The Case of Spin

The quantum notion of spin is a hard case for anyone seeking to find ontological content in TQM:

- On the one hand, spin is crucially involved in the success of QM, hence it should be a core part of quantum ontology:

  In relation to key realist criteria, spin surely ticks all the boxes, by virtue of being deeply explanatory, unifying, and even effectively manipulable. Hence, we should be realists about spin, as much as we are realists about any theoretical notion. (Saatsi 2020, 41)

- On the other hand, the ontological content of theoretical claims about spin seems unavoidably speculative:

  The challenge to truth-content realism is that it seems forced to buy into 'deeply' metaphysical assumptions — assumptions that are epistemologically unwarranted by the realist lights — in trying to spell out what we claim to know about, e.g., silver atoms in a Stern-Gerlach machine. (ibid, 47–48)

Ontology of the Stern-Gerlach Experiment

Reminder: Ontological commitment to spin need not involve any fundamental claim on what spin is, but only functional knowledge of what spin does.

Saatsi challenges even this knowledge (using the simple example of a Stern-Gerlach experiment):

- While TQM views spin as a property of electrons which results in atoms being deflected in a magnetic field, spin is not a property of electrons at all according to other versions of QM.
- Even if spin is acknowledged as a real property, its behaviour (function) differs radically depending on whether it is described by a collapse or a no-collapse version of QM.

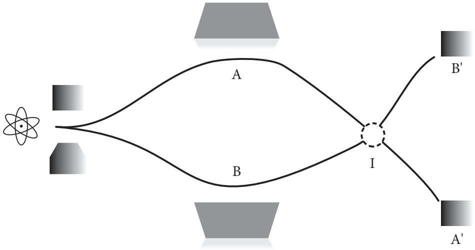
(In the following, I will only respond to the first challenge. See the written version for a response to the second.)

The Universally Acknowledged Reality of Spin

For concreteness, consider the theory that departs most radically from TQM's "spin as a property of quantum particles" picture: According to Super-Humean Bohmian Mechanics (Esfeld and Deckert 2018), particles' only properties are their positions, spin is nothing but a parameter for describing their motion.

- However, the fact that spin is not part of fundamental ontology does not mean that it lacks reality. (Bohmian treatments of spin do not seek to *replace* but to *recover* the TQM account.)
- Indeed, when Wilson (2018) accuses Esfeld and Deckert of instrumentalism, they explicitly acknowledge the reality of spin and other non-fundamental properties.
- Of course, Bohmian Mechanics is compatible with instrumentalism about spin, but the same instrumentalism would then follow for all non-fundamental properties, so there would be nothing special about QM.

Two-Path Interference Experiments



Again, there seems to be a radical discrepancy between TQM and an ontologically serious theory such as Bohmian mechanics: From the viewpoint of TQM, Bohmian trajectories seem "surrealistic", because they bounce at point I (Callender 2020).

- Bohmians respond to the charge of surrealism by pointing out that they do not actually contradict TQM, but only some pretheoretical assumptions about what is measured in a position measurement (Barrett 2000).
- This response turns on TQM's vagueness about trajectories, so it does not yet give us any positive content for a non-speculative ontology.

Do Wave Packets Occupy Space?

Proposal: Our ontological commitment should be to wave packets, because they play an essential role in any account of two-path interference.

Objection: Wave packets are not local beables, so they are not "there" in the same sense as Bohmian particles (and other instances of primitive ontology) are "there".

Reply: "being there" cannot be separated from the dynamics!

> *The most serious danger [of the primitive ontology approach] . . . , is the danger of sliding into thinking that there is a two-step process.* First, *one posits an ontology, with no dynamical assumptions, that is, no assumptions about how it behaves, and* then *one posits a dynamics for it. . . . The problem with this is that, until we have said something about how the purported ontology acts, we haven't yet given sense to the claim that it is there at all. What it is for an object to occupy a region of space, or, indeed, to have any sort of spatial relations to anything, is for it to do something there—exclude other objects, or reflect light, or something of the sort. (Myrvold 2018, 104–105)*

Why Wave Packets Are (Really) "There"

- The inadequacy of separating ontology from dynamics becomes particularly salient in cases where a Bohmian particle triggers a detector located on the path it has *not* taken.
- Granted, the theory has a coherent story to tell about the particle's location and its non-local effect on the detector, but this is a technical sense of "location" and not the ordinary sense of "being there" from which the objection to wave packets derives its force.
- What is "there" in the ordinary sense (of "doing something there") is an empty wave packet, which is just what TQM postulates as well.

Conclusion

- Existing approaches to quantum ontology are either too speculative or they lack an interesting ontological commitment.
- Taking TQM ontologically seriously is a way out of this dilemma. (Of course, its ontological substance needs to be further developed beyond the two examples discussed here.)
- The resulting ontology is inherently non-fundamental, but this is the best we can do anyway (given the present state of physics).
- The insight that an ontology informed by our best current science cannot be fundamental is one of the ways in which QM has changed philosophy.

References

Allori, V., S. Goldstein, R. Tumulka, and N. Zanghì (2014). Predictions and primitive ontology in quantum foundations: A study of examples. *British Journal for the Philosophy of Science* **65**, 323–352.

Barrett, J. A. (2000). The persistence of memory: Surreal trajectories in Bohm?s theory. *Philosophy of Science* **67**, 680–703.

Bub, J. (2016). *Bananaworld: Quantum Mechanics for Primates.* Oxford: Oxford University Press.

Callender, C. (2020). Can we quarantine the quantum blight? See French and Saatsi (2020), pp. 57?77.

Cordero, A. (2001). Realism and underdetermination: Some clues from the practices-up. *Philosophy of Science* **68**, S301–S312.

Egg, M. (2019). Dissolving the measurement problem is not an option for the realist. *Studies in History and Philosophy of Modern Physics* **66**, 62–68.

Esfeld, M. and D.-A. Deckert (2018). *A Minimalist Ontology of the Natural World.* New York: Routledge.

French, S. and J. Saatsi (Eds.) (2020). *Scientific Realism and the Quantum.* Oxford: Oxford University Press.

Fuchs, C. A. (2017). On participatory realism. In I. T. Durham and D. Rickles (Eds.), *Information and Interaction: Eddington, Wheeler, and the Limits of Knowledge*, The Frontiers Collection, pp. 113–134. Cham: Springer.

Healey, R. (2020). Pragmatist quantum realism. See French and Saatsi (2020), pp. 123–146.

Ladyman, J. and Ross, D. (2007): *Every Thing Must Go: Metaphysics Naturalized.* Oxford University Press.

Ladyman, J. and Ross, D. (2013): The world in the data. In: D. Ross, J. Ladyman and H. Kincaid (Eds.), *Scientific Metaphysics*, pp. 108–150. Oxford University Press.

Myrvold, W. (2018). Ontology for collapse theories. In S. Gao (Ed.), *Collapse of the Wave Function,* pp. 97–123. Cambridge University Press.

Saatsi, J. (2019): Scientific realism meets metaphysics of quantum mechanics. In A. Cordero (Ed.), *Philosophers Look at Quantum Mechanics,* pp. 141–162. Cham: Springer.

Saatsi, J. (2020). Truth vs. progress realism about spin. See French and Saatsi (2020), pp. 35–54.

Williams, P. (2019). Scientific realism made effective. *British Journal for the Philosophy of Science* **70**, 209–237.

Wilson, A. (2018). Super-humeanism: insufficiently naturalistic and insufficiently explanatory. *Metascience* **27**, 427–431.

Wilson, J. (2007). Newtonian forces. *British Journal for the Philosophy of Science* **58**, 173–205.