Exploring a Closed Theory Stance Towards Quantum Mechanics

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Idea of the talk

- The background research question is to elaborate on a realist interpretation of QM.
- I explore a novel view to approach QM: the Closed Theories Stance (CTS).
- Work done within this stance will not present a solution to problems from other views; it is an alternative approach.
- The contribution is to provide a novel framework to articulate the problems of QM in a different way.
- There are internal issues with the CTS; as there are with other approaches!
- I will restrict the discussion to physics.
- I don't claim that this is the only/best way forward, but I do want to convince you that this approach deserves to be considered.

Outline

- Closed Theories Stance
- Closed theories stance and QM

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Closed theories

- Heisenberg was one of the most important physicists of the C20th and founding father of QM. But he is a controversial author when it comes to the philosophy of physics, and there is a lot of debate on what kind of position he endorsed (Camilleri, 2009).
- In terms of physical theories, his view has been dubbed "Closed theories" by Bokulich, who clarified and brought up this view back on the debates in the philosophy of physics.

(Bokulich 2004, 2006, and 2008).

Closed theories

Three main claims underlie the closed theories view:

- Domains: A closed theory is related to a limited domain of applicability.
- Accuracy: In its domain, the closed theory is perfectly accurate.
- Finalization: The closed theory provides the ultimate description of the phenomena of its domain, and no further modifications can be made.

  This allows him to conceive 4 theories (in 1958): Newtonian mechanics, thermodynamics, electrodynamics (including special relativity), and QM.

  He doesn't include thermodynamics into Newtonian mechanics.

  What about general relativity?

  Corollary: this shows that there is no a priori restriction to the number of closed theories. More theories could be developed.

(Heisenberg, 1958, Ch. 6). (Bokulich 2006, p. 93).

I want to explore taking this further, as a stance towards the interpretation of QM.

Let's discuss what we mean by this:

Van Fraassen's notion of stance

> A philosophical position can consist in a stance (attitude, commitment, approach, a cluster of such - possibly including some propositional attitudes such as beliefs as well). [...] But it cannot be simply equated with having beliefs or making assertions about what there is. (Van Fraassen, 2002, p. 47-48)

He defends his empirical stance.

His message is: Let's be honest and explicit with our commitments

(Van Fraassen, 2002)

Van Fraassen's notion of stance

instrumentalist	$\longrightarrow$	algoritmic tools & successful empirical predictions
realist	$\longrightarrow$	the world existing out there
structural realist	$\longrightarrow$	structural continuity & structure
constructive empiricist	$\longrightarrow$	agnostic about unobservables

Consequences of expliciting the stance:
- Vulnerability: We are philosophically exposed.

+ Methodological advantage: The relevant problems become easier to articulate. That neither means that the problems are easier, nor that the motivations for the stance are undebatable, nor that the problems in other stances (positions, interpretations, approaches, whatever), are worthless.

not a new idea!

- Bitbol (2010) (quite dismissive towards the analytic philosophy), emphasises the importance for in having a debate over the very formulation of the problems. One can adhere to this strategy without becoming, as he claims, a continental philosopher.
- French and Ladyman's ontic-structural realism was originated in the "need to provide an ontology that can *dissolve* some of the metaphysical conundrums of modern physics" (French & Ladyman, 2003, p. 33, my emphasis).
- Friederich (2014) presents a 'therapeutic approach' claiming that the basic problems encountered in the literature are based on misconceived assumptions which, if changed, dissolve, rather than solve, the problems of the interpretation of QM.

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Closed theories Stance

What I take the Closed theories Stance to involve:

- Realism: A closed theory represents some aspect of the world.
- Domains: A closed theory applies in a limited domain.
- Finalization: It provides the ultimate description of the phenomena of its domain.

Observation 1: There are internal issues with this view.

Observation 2: The focus is Quantum Mechanics.

Observation 3: There is current work in this direction.

Suggest a motivation

- Within realist approaches to QM: There's no agreement on the set of appropriate concepts to interpret QM (particles?, waves?, quantum objects?, do we really need a referent? ...).
- There's a need for "new" concepts to interpret QM.
- But there is no clear strategy on how to...
- Take the current realist alternatives: is there a common methodological guideline? What are the basic assumptions?
- What would happen if we revised that methodology!

Proposal:

one thread that goes throughout the issues around QM is the notion of intertheoretic relationship involved. Closed theories stance proposes a particularly different perspective.

If Closed theories is considered as a stance

- The interpretation of QM is not tied to Classical concepts.
- *Observation 1:* Contra Heisenberg, I do not consider QM is "closed". Precisely that is the challenge: to accomplish the closure.
- *Observation 2:* Previous work in this direction: de Ronde's PhD dissertation at Utrecht, 2011. Contra de Ronde: no progress in clarifying the internal issues with this stance, nor analysis in terms of intertheoretic relationships.
- *Observation 3:* There are a number of challenges.

If Closed theories is considered as a stance

What's new or different? Is it better?

Focus on:

1. Measurement Problem
2. QM-CM limit/relationship

Recall the methodology, quoting Friederich: "The idea is to dissolve (rather than solve) the paradoxes by proposing a perspective [...] according to which at least one of the assumptions necessary to derive the paradoxes is not so much wrong as rather conceptually ill-formed" (2014, p. 50). Or at least contestable assumptions.

Friederich (2014).

1. Measurement problem (MP) within CTS

Overly simplified measurement problem (MP):

1. The final quantum state of the measurement apparatus and the system is a superposition.
2. The empirical result obtained is unique (classical (?)).
3. The eigenvalue-eigenvector link implies a contradiction between 1 and 2.

1. Measurement problem (MP) within CTS

Standard view:

- MP can be seen as a reaction to the need to "justify the appearance of the classical world" (Bacciagaluppi, 2014).
- "the MP consists in the fact that the Schrödinger equation of quantum mechanics generically fails to predict that measurements have outcomes. Instead, it apparently predicts (empirically) unacceptable "superpositions" thereof" (Landsman & Reuvers, 2013).
- "A decent interpretation of quantum mechanics should fullfil at least two criteria. Firstly, it has to elucidate the physical meaning of its mathematical formalism and thereby secure the empirical content of the theory. [...] Secondly (and this is the subject of this paper), it has to explain at least the appearance of the classical world" (Landsman, 2007).
- And many more...

(Bacciagaluppi, 2014). (Landsman & Reuvers, 2013). (Landsman, 2007).

1. Measurement problem (MP) within CTS

In general MP is presented as an internal problem for QM.
In Maudlin's account, the three following statements are mutually inconsistent:

> A. The wave-function of a system is complete, i.e. the wave-function specifies all of the physical properties of a system.
>
> B. The wave-function always evolves in accord with Schrödinger equation.
>
> C. Measurements always have determinate outcomes.

(Maudlin, 1995).

1. Measurement problem (MP) within CTS

What's the situation within CTS?

- To justify the appearance of classical features, is simply not a strong, necessary requirement.
- Classical mechanics is a closed theory. "Everyday experience" does not need justification insofar as it is secured by classical physics (in a sense given within CST).
- An opponent might well say: OK, but it is still the case that the final state of the measurement does not have well defined outcomes (as per superposition state). But we do not see this in the laboratory!
- CTS requires to interpret the formalism of QM, accommodating the experimental results, maintaining coherence. In terms of Maudlin's account: B & C are OK, A is not.

1. Measurement problem within CTS

- Work being done in this direction: (Da Costa and de Ronde, 2013), (de Ronde, 2015). They focus on the superposition.
- There is empirical evidence of the existence of quantum superpositions!
  - Ourjoumtsev, et.al. 2007. "Generation of optical 'Schrödinger cats' from photon number states", *Nature*, 448, 784-786.
  - DiCarlo, L. et.al. 2009. "Demonstration of two-qubit algorithms with a superconducting quantum processor", *Nature*, 460, 240-244.
- Because in this stance you interpret the quantum formalism, the quantum state, quantum probability, etc. without a strong importation/continuation of concepts from other theories.

2. Quantum-classical limit within CTS

2. Quantum-classical limit within CTS

- In the philosophy of science: reductionism vs pluralism.
- In philosophy of physics, Nickles' reductionsim$_2$: a variety of methods: Ehrenfest theorem, mathematical limits, decoherence... all of them are problematic!
- An important response to that is Bokulich (2008, 2012) who puts forward her interstructuralist account.
- Using semiclassical mechanics, hybrid ideas, mixtures between classical and quantum ones, classical ideas in a quantum language and vice versa.
- Fictional mathematical structures, knowingly false and non-referential, she claims, still provide explanatory work, insight into the underlying physics and allows for development.

Potential threat:

Bokulich's interstructuralism provides a novel and fruitfull alternative to traditional reductionisms. The validity of this scheme presents a threat to a pluralist view like CTS, at first sight.

2. Quantum-classical limit within CTS

- In CTS the priority is not to address the QM-CM limit!
- The priority is to finalise QM. In other words: to CLOSE it.
- But Bokulich's interstructuralism is a relevant case that needs to be considered.

Three options: 1. CTS is undermined by Bokulich's intestructuralism. 2. Bokulich's intestructuralism does not undermine CTS. 3. They can collaborate: moderate version of CTS.

1. CTS is undermined by Bokulich's intestructuralism.

Here, say we accept the structural-model-explanation and that there is a trade of features from one domain to the other. Thus, we are not being able to efficiently distinguish different domains of CM and QM. The very notion of closed domain is undermined.

Objections:

1. Internally: (i) Argue against structural-model-explanation. (Belot & Jansson, 2010). (ii) Argue against the semiclassical ideas within QM.

2. Externally: Bokulich's approach is powerful heuristically speaking. However, it does not give a full (realist) response to the problems of QM: what does $|\psi\rangle$ represent? Thus, CTS does not compete with interstructuralism.

2. Bokulich's intestructuralism does not undermine CTS.

Here, say we accept the structural-model-explanation and that there is a trade of features from one domain to the other. Semiclassical approaches provide "physical insight [...] into what is otherwise often opaque quantum dynamics" (Bokulich, 2012, p. 735).

Objections:

1. Internally: Argue that there is an element of inconsistency in Bokulich's, which is imported from the general approach, the semiclassical approach is flawed.

2. Externally: One could argue here that it has been accepted that these fictional-explanations are temporary ones, stopgap explanations... Therefore, if we resolve QM –following CTS– then quantum dynamics will not be opaque any more!

3. They can collaborate: moderate version of CTS.

- Weaken the consequences of CTS.
- Accept a significant continuity between theores, such as interstructuralism suggests!
- BUT maintain autonomy between "weakly" closed theories!
- That is $\longrightarrow$ look at the work in the context of Weak-emergence/Effective theories!
- Work-in-progress...

Conclusions and perspectives

- Closed theories view originally by Heisenberg, taken up as stance towards QM over some modifications.
- There is work already done/inspired by this direction: de Ronde and da Costa.
- Measurement Problem is framed in a novel way: not to justify the classical, but to interpret the quantum formalism considering the experiments.
- QM-CM limit: There are many attempts to *recover* classical from quantum.
- The proposal is to change the way intertheoretic relationships are addressed.
- Bridges/similarities/etc. between the two theories might be found, but first we should close QM and really know what it is all about.
- Interaction between this CTS and intestructuralism. Various options and consequences: promising philosophical work!
- I did't try to convince you that this is the only/best way forward, but I do want to convince you that this approach deserves to be considered.

THANK YOU!

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Superposition

- Say
$$|\psi\rangle = \lambda_1 |\beta_1\rangle + \lambda_2 |\beta_2\rangle$$
$$|\lambda_1|^2 + |\lambda_2|^2 = 1.$$
Where $|\beta_1\rangle$ and $|\beta_2\rangle$ are the eigenstates of observable B associated with eigenvalues b_1 and b_2.
- If you consider a large number N of identical systems in $|\psi\rangle$, it is not equivalent to a case of a proper mixture of $N|\lambda_1|^2$ systems in state $|\beta_1\rangle$ and $N|\lambda_2|^2$ systems in state $|\beta_2\rangle$!
- Say that we want to measure observable A with eigenvalues a_1 and a_2 associated with $|\alpha_1\rangle$ and $|\alpha_2\rangle$.
- If it was a proper mixture, the probabilities would be
$$\mathcal{P}(a_{1,2}) = |\lambda_1|^2 \mathcal{P}(a_{1,2}) + |\lambda_2|^2 \mathcal{P}(a_{1,2})$$

Cohen-Tannudji, Diu, Laloë, 1991, p. 253.

Maudlin 1995, p.9.

But actually, if the state is $|\psi\rangle = \lambda_1 |\beta_1\rangle + \lambda_2 |\beta_2\rangle$, the probability to obtain a_1 is

$$\mathcal{P}(a_1) = |\langle\alpha_1|\psi\rangle|^2 = |\lambda_1|^2 |\langle\alpha_1|\psi\rangle|^2 + |\lambda_2|^2 |\langle\alpha_2|\psi\rangle|^2 + 2\mathrm{Re}\Big(\lambda_1\lambda_2^* \langle\alpha_1|\beta_1\rangle \langle\alpha_1|\beta_2\rangle\Big)$$

interference term!

$$= |\lambda_1|^2\mathcal{P}(a_1) + |\lambda_2|^2\mathcal{P}(a_1) + \boxed{2\mathrm{Re}\Big(\lambda_1\lambda_2^* \langle\alpha_1|\beta_1\rangle \langle\alpha_1|\beta_2\rangle\Big)}$$

Improper mixtures

Start from a composite system in a pure and entangled state:

$$a\,|\alpha_1\rangle\,|\beta_1\rangle + b\,|\alpha_2\rangle\,|\beta_2\rangle$$

$$\rho = |a|^2\,|\alpha_1\rangle\,\langle\alpha_1|\,|\beta_1\rangle\,\langle\beta_1| + |b|^2\,|\alpha_2\rangle\,\langle\alpha_2|\,|\beta_2\rangle\,\langle\beta_2| + \\ ab^*\,|\alpha_1\rangle\,\langle\alpha_2|\,|\beta_1\rangle\,\langle\beta_2| + a^*b\,|\alpha_2\rangle\,\langle\alpha_1|\,|\beta_2\rangle\,\langle\beta_1|\,.$$

Upon measurements on observables $\hat{O}_A \otimes \mathbf{1}_B$ and $\mathbf{1}_A \otimes \hat{O}_B$, you can obtain:

$$\rho_A = Tr^B(|\psi\rangle\,\langle\psi|) = |a|^2\,|\alpha_1\rangle\,\langle\alpha_1| + |b|^2\,|\alpha_2\rangle\,\langle\alpha_2|$$

$$\rho_B = Tr^A(|\psi\rangle\,\langle\psi|) = |a|^2\,|\beta_1\rangle\,\langle\beta_1| + |b|^2\,|\beta_2\rangle\,\langle\beta_2|$$

Thus, the most we can know is

$$\rho' = \rho_A \otimes \rho_B \neq \rho.$$

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