Schematising the Observer in Physics and Metaphysics – The Electron as *Noumenon*

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My main claim:

- It is useful, and illuminating, to view Bohr's approach to the interpretation of quantum mechanics as emerging out of a broadly (neo-)Kantian tradition in the philosophy of science.

My approach:

- Although other authors agree with this general idea, too often the connections between Bohr and Kant are only really gestured at, and are open to the criticism that the similarities are merely superficial.
- My own approach will be to try to provide a more detailed structural analysis of Bohr's and Kant's views that makes the similarities between them more explicit.

Objection: Bohr never called himself a Kantian, and moreover expressed a negative attitude towards "a priorism".

- Bohr, for good reasons, wanted to emphasise that the lessons of quantum mechanics were not, in some sense, deducible from a priori ideas about what nature must be like in advance of experience. Ultimately his philosophy is an empiricist one.
- At the same time, Kant's philosophy (esp. his transcendental idealism, see MEC 2026) is best construed as a kind of metaphilosophy rather than as a substantive metaphysical position regarding what the world must be like in itself, and it contains a strong empiricist component (Hume, he tells us, awoke him from his "dogmatic slumbers").
- While it is too strong to claim that Bohr's view needs to be justified along Kantian lines, I want to claim that viewing them through a Kantian lens is illuminating, especially given that contemporary analytic metaphysics seems to have (a) largely forgotten Kant and (b) largely misunderstood Bohr.

Objection: Bohr never called himself a Kantian (cont'd).

- Bohr was certainly not a Kantian. Bohr was a Bohrian. But Bohrian philosophy emerges against the backdrop of broadly neo-Kantian attitudes that were still very influential at the time.
- Bohr's philosophy is best seen as a response to these ideas and as generally conversant with them, in a way that it is not in relation to contemporary analytic (Quinean) metaphysics, which is for the most part exclusively concerned with questions of ontology.
- This is literally true in so far as there is evidence that many of his ideas were developed in conversation with neo-Kantian thinkers such as Grete Hermann, as well as figures connected to neo-Kantianism such as Harald Høffding, including during the period in which he was working out how to express the wider philosophical significance of his 1928 doctrine of complementarity (Bacciagaluppi, 2024; Faye, 1991).

Objection: But wasn't Bohr a positivist, or a pragmatist?

- Bohr (as recollected by Heisenberg): "... [positivism's] prohibition of any discussion of the wider issues, simply because we lack clear-cut enough concepts in this realm, does not seem very useful to me—this same ban would prevent our understanding of quantum theory." (1971, p. 208).
- At the same time, attempts to identify Bohr's philosophy with positivism or pragmatism often only really have a caricature of these positions in mind. There is more to positivism than verificationism (DiSalle, 2002; Friedman, 1999), and many different versions of pragmatism (Folse, 2017).
- In truth, neo-Kantianism, pragmatism, and positivism are mutually intelligible theses and to some extent continuous with one another. Bohr's view should be seen as falling within this overall intellectual tradition. In fact, all of these can be usefully understood as responses to Kant.
- Therefore, if the aim is to understand Bohr, it is useful (but of course not necessary) to begin with Kant.

Erik Curiel on schematizing the observer (Curiel, 2020, p. 6):

"We need a way to understand the substantive, physically significant contact—the epistemic continuity, as it were—between a precisely characterizable situation in the world of experience and the mathematical structures of what we usually think of as our theories. Such understanding should at a minimum consist of an articulation of the junctions where meaningful connections can be made between the two, and would thus ground the possibility of the epistemic warrant we think we construct for our theories from such contact and connection."

Outline

- The Kantian framework
- Bohr and complementarity
- Complementarity and Kant
- (neo-)Kantian responses

Kant's discursivity thesis:

"Thoughts without content are empty; intuitions without concepts are blind. Hence it is just as necessary that we make our concepts sensible (i.e. that we add the object to them in intuition) as it is necessary that we make our intuitions understandable (i.e., that we bring them under concepts). Moreover, this capacity and this ability cannot exchange their functions. The understanding cannot intuit anything, and the senses cannot think anything. Only from their union can cognition arise." (A51/B75–76).

Kant's framework for theoretical cognition:

I. The pure forms of sensible intuition: space and time

II. The pure forms of thought
    - In relation to possible experience: categories of the understanding
    - When they transcend possible experience: ideas of reason

Intuition:

- The 'this' and 'that' of experience.
- Mediated by our 'faculty of sensibility', i.e., our mind's capacity to be affected by objects (A19/B33).

Appearance:

"The undetermined object of an empirical intuition is called *appearance*" (A20/B34).

- E.g., consider a shape against the wall in a dark room.
  - Before we determine it to be a chair (upon closer scrutiny), we can say merely that it is the appearance of something indeterminate.

Two aspects to every appearance:

- Its matter, i.e., what we sense in it,
- The (pure) forms through which the manifold of the appearance is represented as ordered: space and time.

Concepts of the understanding:

- Rules governing the synthesis of the manifold of intuition
- E.g., "chessboard" (an empirical concept) corresponds to a rule whereby this particular bit of white, that particular bit of black, etc., can be associated together in one representation.
- The Categories: Logical forms of judgements (of *Quantity*, of *Quality*, of *Relation*, or of *Modality*) as they pertain to the objects of possible experience as such (A79/B105).
    - Function as "meta-concepts": Implicit in any empirical concept.

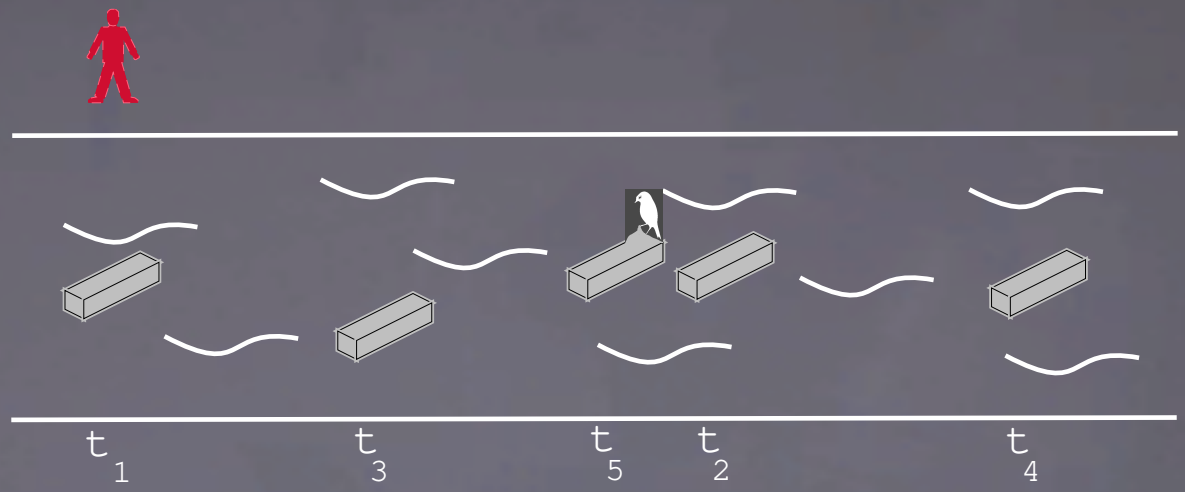
Synthetic a priori principles:

- General principles governing the use of the categories in their application to pure intuition in accordance with their characteristic schema.
- Also (thereby) the general principles for the cognition of objects and their relations in accordance with a possible experience.

Synthetic a priori principles (cont'd)

Constitutive vs. regulative (for appearances):

- Constitutive (mathematical principles): Tell us what an appearance must be like if it is to exist for us at all.
  - I.e., it must have a determinate extent and a particular degree of intensity.
- Regulative (dynamical principles): Govern how given appearances must be connected together in time in order for it to be possible to cognise some object.
  - I.e., as the appearances of possible, actual, or necessary substances that interact with one another and evolve through time in accordance with the principle of cause and effect.



E.g., Kant's Principle of causality tells us that the states of an object are ordered uniquely and objectively (A191/B236),

- as opposed to the series of our subjective perceptions of the object through which we apprehend it.

"we see that appearance, as contrasted with the presentations of apprehension, can be presented as an object distinct from them only if it is subject to a rule that distinguishes it from any other apprehension and that makes necessary one kind of combination of the manifold." (B236).

Kant's principle of causality (cont'd):

- Implies dynamical continuity.
  - For Kant, space and time are continuous, infinitely divisible quantities (B211).
  - But since time, which is the pure form of all sensible intuition (both inner and outer), is infinitely divisible, so is the progression of perceptions (generated thereby) (B255), through which one determines an objective ordering of the states of an object (see MEC 2025).
  - Therefore: All change associated with the possible experience of an object is continuous, and this is presupposed a priori, according to Kant.

Recall:

- Mathematical principles: constitutive for appearances
- Dynamical principles: regulative for appearances

All synthetic a priori principles:

- Constitutive for particular objects,
  - i.e., of what it means to provide an objective description of some thing: If an objective description of any given part of our experience is to be had at all, according to Kant, then the corresponding appearances better be determinable in accordance with the synthetic a priori principles (both mathematical and dynamical).
- Regulative for experience in general.
  - I.e., they don't imply that all of our experience is objectively characterizable.
  - For finite rational cognisers constrained by the forms of sensible experience such as ourselves, that would be impossible to know (A509/B537).

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Heisenberg's uncertainty relations

- Bohr accepted their validity but disagreed with Heisenberg over their significance.
- For Heisenberg (in 1927), they represent a fundamental limitation on what we can know, but the object is conceived of as perfectly determinate in itself.
- For Bohr their significance is deeper. It is conceptual.

"Now the quantum postulate implies that any observation of atomic phenomena will involve an interaction with the agency of observation not to be neglected. Accordingly, an independent reality in the ordinary physical sense can neither be ascribed to the phenomena nor to the agencies of observation. After all, the concept of observation is in so far arbitrary as it depends upon which objects are included in the system to be observed. Ultimately every observation can of course be reduced to our sense perceptions. The circumstance, however, that in interpreting observations use has always to be made of theoretical notions, entails that for every particular case it is a question of convenience at what point the concept of observation involving the quantum postulate with its inherent 'irrationality' is brought in. ..." (1928, p. 580).

"This situation has far-reaching consequences. On one hand, the definition of the state of a physical system, as ordinarily understood, claims the elimination of all external disturbances. But in that case, according to the quantum postulate, any observation will be impossible, and above all, the concepts of space and time lose their immediate sense. On the other hand, if in order to make observation possible we permit certain interactions with suitable agencies of measurement, not belonging to the system, an unambiguous definition of the state of the system is naturally no longer possible, ..." (1928, p. 580).

My gloss (sketch - for further details see MEC 2010):

There are three components involved in the description of an object on the basis of an experiment:

(1) A description of the experimental apparatus through which we come to know, via what is described in (3), an object.

(2) A description of the object itself (what we care about).

(3) A description of the interaction between the apparatus and object, which is then abstracted away from to yield (2).

For Bohr the classical mode of description requires that we disentangle (3) from (2).

What enables this, classically, is the assumption that change is continuous (Passaro, 2026). Compare this also with Kant's argument that causality implies dynamical continuity (see above).

But quantum state transitions are irreducibly discontinuous.

The issue is not one of knowledge but of definition. The limitation is not epistemic but conceptual.

"Indeed, a discontinuous change of energy and momentum during observation could not prevent us from ascribing accurate values to the space-time co-ordinates, as well as to the momentum-energy components before and after the process. The reciprocal uncertainty which always affects the values of these quantities is, as will be clear from the preceding analysis, essentially an outcome of the limited accuracy with which changes in energy and momentum can be defined, when the wave-fields used for the determination of the space-time co-ordinates of the particle are sufficiently small" (Bohr, 1928, p. 583).

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Consider a mark on a photographic plate.

- A classically describable object: definite spatiotemporal coordinates, causally interacts with its environment in a definite way.

But we would like to have more.

- This description includes the photographic plate.
- What we want is an account of how the mark was left by an independently existing object.

From a Kantian perspective, to do this we need to characterise the object in terms of both mathematical and dynamical synthetic a priori principles.

- However in quantum mechanics we are precluded from doing so in general in a determinate fashion because of the uncertainty relations.
- At best, we get an object that is "unsharply defined".
- But that is not an object of possible experience, for Kant. It is merely a *noumenon*, or abstract object.

Noumenon

- For Kant, concepts are analogous to mathematical functions, e.g., $f(x) = 2x + 4$.
- By itself, a function only represents a form for the determination of a variable.
- Getting a determinate answer requires that we fill in something for x.
- Likewise for concepts: concepts yield determinate cognition only when they are applied to determinate content.

"Without [an object] it has no sense, and is entirely empty of content, even though it may still contain the logical function for making a concept out of whatever sort of *data* there are." (Kant, 1998, B298).

Compare Bohr:

'... a sentence like "we cannot know both the momentum and the position of an atomic object" raises at once questions as to the physical reality of two such attributes of the object, which can be answered only by referring to the conditions for the unambiguous use of space-time concepts, on the one hand, and dynamical conservation laws, on the other hand.' (1949, p. 211).

For Bohr and Kant, 'ordinary' concepts, and the dynamical and mathematical principles, respectively, are necessary concepts in the determination of an object as such.

"Here, it must above all be recognized that, however far quantum effects transcend the scope of classical physical analysis, the account of the experimental arrangement and the record of the observations must always be expressed in common language supplemented with the terminology of classical physics."
(Bohr, 1948, p. 313).

However (somewhat ironically), the uncertainty relations themselves guarantee that a causal description of a quantum process can never contradict a spatiotemporal description.

- Any experiment intended to determinately establish the object's spatiotemporal coordinates can tell us nothing about its dynamical parameters, and vice versa.

"the proper rôle of the indeterminacy relations consists in assuring quantitatively the logical compatibility of apparently contradictory laws which appear when we use two different experimental arrangements, of which only one permits an unambiguous use of the concept of position, while only the other permits the application of the concept of momentum ..." (Bohr, 1937, p. 293).

From a Kantian point of view, the key to understanding this (i.e., the sense in which the uncertainty relations save the day) is, again, the noumenon, this time in its positive signification.

- Negative signification: not an object of sensible intuition, therefore not an object of possible experience for us.
  - The concept of the noumenon provides a bound or limit to objective cognition.
- Positive signification: an object of nonsensible intuition (Kant, 1998, B308-309) or idea of reason.

"Concepts of reason serve for **comprehension**, just as concepts of the understanding serve for **understanding** (of perceptions)" (Kant, 1998, A311/B367).

- The regulative ideas of reason guide research and thereby indirectly expand the realm of our cognition.
- They may sometimes conflict. The key to a resolution is to understand that even in their positive signification, regulative ideas do not directly yield cognition.

Critique of judgement (1790):

- Judgement, in general, is the ability to subsume a particular (which can be an empirical regularity) under a universal rule.
- When the rule is not antecedently given, judgement has to reflect on a given empirical regularity in order to find a rule / concept under which to subsume it.
- In some cases, judgement has no choice but to reflect upon the empirical regularities that it finds in nature as if they were part of a purposively designed unified system.

Natural purpose:

- Its various parts and their relations are understood to be based upon the idea of the thing as a whole (analogously to a work of art).
- Unlike a work of art, a natural purpose is a self-organising being, such that its parts reciprocally produce one another

Antinomy of teleological judgement (Kant, 1790):

R1: "Some products of material nature cannot be judged to be possible in terms of merely mechanical laws", but rather must be judged in teleological terms (Kant, 1790, 387).

R2: "All production of material things and their forms must be judged to be possible in terms of merely mechanical laws" (ibid., 387).

Resolution (my gloss):

- It does not follow from the fact that something must be reflected upon in some way X that it is explainable in those terms.
- O must be judged in terms of X is compatible with O must be judged in terms of Y even when X and Y, construed ontologically, disagree in some way Z, as long as Z is not determinable on the basis of a possible experience.
- The merely logical contradiction between the (subjective) principles, R1 and R2, is harmless for the methodological purposes that we actually use them for in science.

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Grete Hermann

"[Quantum mechanics] does away with the notion that these relational networks should be determined at any rate through objective circumstances of things in space and time, and shows them in turn to depend on the manner in which the observer obtains knowledge of the system." (Hermann, 1935 / 2017, p. 275).

"... the splitting of truth goes deeper than philosophy and natural science had previously assumed. It penetrates into the physical knowledge of nature itself; instead of merely delimiting its scope against other possibilities for grasping reality, it separates various equally legitimate representations within the physical description that cannot be unified into a single picture of nature." (Hermann, 1935 / 2017, p. 277).

Ernst Cassirer

'The "crisis of causality" produced by quantum mechanics certainly persists and is quite serious. But it is a crisis not of the pure causal concept but "in the mode of viewing nature" ... it shows us that we can no longer refer this concept, in the customary manner, to the perception of "pure time" or schematize it with the latter. Such schematization has been definitely limited through the advent of quantum theory. We can no longer combine causality with space-time description, let alone amalgamate the two in the manner of classical physics.' (Cassirer, 1956 [1936], p. 164).

"Transcendental logic can thus no longer be connected with or be dependent on transcendental aesthetics, as was the case in Kant's system. The demanded specialization, indispensable for the empirical use of the causal concept, must now be looked for within the domain of concepts itself." (Cassirer, 1956 [1936], p. 164).

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