Bohr’s Complementarity and Kant’s Epistemology

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Roadmap

• **Introduction**: Bohr and Philosophy

1. A forerunner: Bohr’s apparently “conservative” attitude towards classical physics

2. Kant’s theory of knowledge and Bohr’s Kant-like epistemology

3. Bohr’s complementarity as a (wild) stretching of Kant’s requirements for knowledge

4. Naturalized and transcendental readings of the measurement problem of quantum mechanics

• **Conclusion**
Bohr and philosophy

• The so-called “Copenhagen” and “Orthodox” interpretations of quantum mechanics combine elements borrowed from Heisenberg, Dirac, and Von Neumann… with some inspiration from Bohr.

• **Bohr** perceived as “too philosophical” (E. Fermi)

• What is Bohr’s philosophy? Pragmatism, operationalism, positivism, idealism … Or something else?

• **Harald Høffding**: Bohr’s professor of philosophy, and later his friend. Lectures on Kierkegaard and Logic (c. 1905)
Modern Physics: The collapse of Kantianism?

- “Unless one is ready to declare that relativity theory is averse to reason, one cannot stick any longer to Kant’s system of a priori concepts and norms” A. Einstein, 1924
- “Kant’s arguments for the a priori character of the law of causality no longer apply. A similar could be given on the a priori character of space and time as forms of intuition. The a priori concepts which Kant considered as undisputable truth are no longer contained in the scientific system of modern physics” W. Heisenberg, 1958

Space
Time

Substance
Causality
Reciprocity

(General Relativity)
(Quantum Physics)

- BUT Ernst Cassirer (1936), Grete Hermann (1935) etc. advocated a Kantian reading of quantum physics. What’s the problem?
1. A forerunner: Bohr’s apparently “conservative” attitude towards classical physics
The “horrid assumptions” of 1913

<table>
<thead>
<tr>
<th></th>
<th>Classical mechanics</th>
<th>Classical electrodynamics</th>
<th>“Quantum rules”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron on orbit</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Transition between orbits</td>
<td>NO</td>
<td>NO</td>
<td>YES (But Correspondence)</td>
</tr>
</tbody>
</table>

- No inconsistency, but lack of unity. Patchwork-like rules…
- Provisional compromise?
From 1913 to 1925, Bohr varied the articulation of classical physics with quantum postulates, rather than eliminating classical features

**The correspondence principle:** “Although the process of radiation cannot be described on the basis of the ordinary theory of electrodynamics ... there is found, nevertheless, to exist a far-reaching correspondence. ... The present theory of spectra is in a certain sense to be regarded as a rational generalization of the ordinary theory of radiation.” Bohr 1922

**Continuity AND Gap:** “In the limiting region of large quantum numbers, there is ... no gradual diminution of the difference between the quantum theory of radiation and classical electrodynamics, but only an asymptotic agreement of the statistical results” Bohr 1924

**Bad compromise:** Bohr Kramers Slater 1924.

Orbits and virtual radiation fields (semi-classical) + stochastic transition (with no conservation of energy for individual processes, but only statistically)
“Quantenmechanik”!
(1924-1925)

M. Born, “Über Quantenmechanik”, 1924
W. Heisenberg, “Über die Quantentheoretische Umdeutung kinematischer
und mechanischer Beziehungen”, 1925

•Form of Hamilton’s classical equations, but on non-commutative q-
numbers rather than commutative c-numbers

•“A … precise formulation of the tendencies embodied in the
correspondence principle” Bohr 1925

•“a quantitative formulation of the correspondence principle” Heisenberg
1925
WHY this persistence of classical concepts and forms?

- Bohr’s Kantian style: Epistemology rather than Ontology
- Classicity: not in micro-objects; condition of possibility for knowing them
- “No more is it likely that the fundamental concepts of the classical theories will ever become superfluous for the description of physical experience. ... It continues to be the application of these concepts alone that makes it possible to relate the symbolism of the quantum theory to the data of experience”
  Bohr, 1929
• **NO MACRO-REALISM**

• **NO ONTOLOGICAL DIVIDE** between the quantum and the classical domain

• Only an epistemological divide between (a) quantum objects, and (b) the logico-linguistic tools implemented in classical physics.

“Quantum mechanics holds a special position among physical theories. It contains classical mechanics as a *limiting case* and it needs it as a *foundation*”
Landau & Lifschitz, 1967
2. Kant’s theory of knowledge and Bohr’s Kant-like epistemology
Kant’s “Copernican revolution”

- Two meanings of “Copernican”:
  1. Decentration of Human Beings
  2. Relativity of spatio-temporal attributes, such as apparent trajectories on the celestial vault

- Kant retains the second meaning:

  “Thus far it has been assumed that all our cognition must conform to objects ... Let us try to find out by experiment whether we shall not make better progress ... if we assume that objects must conform to our cognition” Kant, 1781

- The form of objects is predetermined by a set of cognitive conditions

- “Object” is the name of experiential invariants, not of something beyond experience

\[ A\text{ priori forms ... again} \]

\begin{align*}
&\text{Sensibility} \quad \{ \text{Space, Time} \} \\
&\text{Understanding} \quad \{ \text{Substance, Causality, Reciprocity} \}
\end{align*}
Bohr’s Copernican revolution

• Remember: **epistemological** rather than ontological status of classical concepts

• In a scientific revolution, old ontologies are questioned and the only firm ground is seen to be *experience*

• “The task of science is both to extend the range of our experience and to reduce it to order” Bohr, 1929

• **Reflective analysis of cognition:**
  
  ✓ “The boundary of our concepts” is “exactly congruent with the boundary to our possibilities of observation” 1927

  ✓ “All knowledge presents itself within a conceptual framework” 1934

  ✓ “… In spite of their limitations, we can by no means dispense with those forms of perception which colour our whole language and in terms of which all experience must ultimately be expressed” 1929
Yet here Concepts no longer apply to spatio-temporal pictures

• **Prediction of phenomena:** not with spatio-temporal representations, but by using “... a purely symbolic scheme permitting only predictions ... as to results obtainable under conditions specified by means of classical concepts” 1936

• “... We must always be prepared ... to expect alterations in the points of views best suited for the ordering of our experiments”. 1929

**Is this a serious divergence?**

• **Modifying *a priori* forms?** Sounds like a contradiction…

• **No!**
  
  – Kant’s epistemology = a research program (Cassirer and “symbolic forms”, Reichenbach and “relative *a priori*”)
  
  – Bohr’s anthropological condition of possibility of microphysical knowledge

  – “What Kant had not foreseen was that these *a priori* concepts can be the conditions for science and at the same time have a limited range of applicability”. Heisenberg, 1958
The relational status of attributes

• “Whatever [characteristics] we are acquainted with in matter are nothing but relations (what we call its intrinsic determinations is intrinsic only comparatively); among these relations there are independent and permanent ones, through which a determinate object is given to us” Kant, 1781

• “Thing-in-itself” is a word for the impossibility to subtract the contribution of the knower from what is known.

⇒ “The properties of atoms are always obtained by observing their reactions under collisions or under the influence of radiation”. Bohr 1929

⇒ No “Disturbance”

⇒ “Impossibility of a strict separation of phenomena and means of observation” Bohr 1929

⇒ “... Interaction forms an inseparable part of the phenomena” Bohr 1958
3. Bohr’s complementarity as a (wild) stretching of Kant’s requirements for knowledge
Relational attributes and complementarity

- In **classical physics**, where the influence of the measurement can be substracted, data “supplement each other and can be combined into a consistent picture of the behaviour of the object under consideration”. Bohr 1958

- In **quantum physics**, “… evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects”. Bohr, 1935

○ Afshar’s 2004 claim and disclaim
○ Quantitative which-way experiments etc.
Three complementarities

1. Between incompatible / conjugate variables. “In quantum physics ... evidence about atomic objects obtained by different experimental arrangements exhibits a novel kind of complementary relationship”

2. Between causation and spatiotemporal location of phenomena. “The very nature of quantum theory (...) forces us to regard the space-time coordination and the claim of causality, the union of which characterizes the classical theories, as complementary features of the description, symbolizing the idealization of observation and definition respectively”.

3. Between wave and particle pictures. “The individuality of the elementary electrical corpuscles is forced upon us by general evidence. Nevertheless, recent experience, above all the discovery of the selective reflection of electrons from metal crystals, requires the use of the wave theory”
Two problems of complementarities (1)

- Why should conjugate variables be *jointly indispensible*?
- “(...) evidence obtained under different experimental conditions (...) must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects” Bohr 1935
- ABOUTNESS…
- Is it still possible to refer to some “micro-object in itself” characterized by mutually incompatible probings?
- … Or should we look for a new mode of objectification that retains nothing of the classical corpuscularian concept?

**Bohr vs. Schrödinger**

*Old visualizable concepts vs. “New concepts”*
Two problems of complementarities (2)

- "The very nature of the quantum theory forces us to regard the space-time co-ordination and the claim of causality as complementary features of the description". Bohr, 1929

How can we compensate for the dismantling of Kant’s connection between the category of causality and spatiotemporally-shaped sensory experience?

- Quantum physics “forces us to replace the ideal of causality by a more general viewpoint called ‘complementarity’”. Bohr, 1937

- “Complementarity is called for to provide a frame wide enough to embrace the account of fundamental regularities of nature which cannot be comprehended within a single picture”. Bohr, 1958
4. Naturalized and transcendental readings of the measurement problem of quantum mechanics
On the transcendental status of measuring instruments

Transcendental ≠ Transcendent

• Nucleus of meaning: “Exceeds experience”

Precondition of experience ≠ Existing beyond experience

• A precondition of experience shapes up experience without being part of experience.
  ✓ The knower is not known in the act of knowing (Kant)
  ✓ The instrumental preconditions of a quantum description cannot be described quantum-mechanically (Bohr)

• Extra-Territoriality of measuring device in Bohr’s thought:
  ✓ No special nature of measuring instruments
  ✓ Just special function: condition of possibility of intersubjective agreement about experimental results

• We have “free choice” of the location of the object/precondition transition. Bohr 1935
Advantage of transcendental status of measurement devices

It dissolves the measurement problem from the outset

✓ Since a classic-like actualistic description of measuring instruments is taken as a presupposition of quantum account of phenomena, there is no need for a mechanism of transition between potentialities and actuality

✓ Since the quantum description is prevented from extending to the totality of the measurement chain, there is no such thing as a superposition of pointer macrostates
Should we criticize this bohrian strategy?

- John Bell (1990): “Against measurement”
  ✓ Do not stick to propositions that are valid only “for all practical purposes (FAPP)”
  ✓ Do not accept Bohr’s “shifty split”

- Project of a naturalized theory of knowledge: cognitive apparatus part of described nature, not precondition for describing.
  ✓ “The measurement process should be understood as a special case of the general laws applying to the entire universe” Bohm 1993

- Counter-objection: “Quantum theory can describe anything, but not everything” Peres & Zurek 1982, Fuchs & Peres 2000

- The metatheory (or the pre-theory) can be restricted, expelled outside the domain of description of a theory, but not eliminated ...
Conclusion

• Bohr’s Kant-like interpretation of quantum theory is not outmoded

• Instead, it might well represent a general Framework for Any future Philosophy of Physics (FAfPP) ...