Copenhagen and complementarity

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More Bohriana

Jan Faye, “Copenhagen interpretation of quantum mechanics”, *Stanford Encyclopedia of Philosophy*
Niels Bohr, “On the notions of causality and complementarity”, *dialectica* **2** (1948): 312-319.

- Let us revisit and reconsider some of the things we said about Bohr, correspondence, complementarity, and collapse.
- This will help set the stage for the measurement problem.
- Copenhagen interpretation $\neq$ Bohr “complementarity view” (although the two are closely related)
- Copenhagen interpretation: standard interpretation, forged by Bohr, Heisenberg, Born, Pauli, Dirac, von Neumann, termed coined by Heisenberg in 1955
- for very long time uncontested received view, but now no longer majority view among people in foundations of QM (although probably still first among physicists)

The correspondence principle again

- Originally: a rule that stated that the transition bw stationary states of electrons in an atom is allowed *iff* there is a corresponding harmonic component in the classical motion
- Then: recognition that frequencies of radiation due to electron transitions bw stationary states with high quantum numbers coincide approximately with classical electrodynamics
- Also: methodological requirement that QM/thy of atom should give predictions for high quantum numbers that closely match those of classical physics
- electron spin $\Rightarrow$ no classical analogue $\Rightarrow$ limitation of correspondence principle

Complementarity again

- two kinds of complementary sets of descriptions: wave-particle and position-momentum (or any non-commuting pair of observables)
- key point: two descriptions that bring out two distinct and classically inconsistent (sets of) properties of the system at stake, depending on the experimental set-up

$\Rightarrow$ tacit abandonment of wave-particle complementarity since e.g. in double-slit experiment where interference pattern (wave) consists of single dots (particle), i.e. no different set-ups are required to bring out duality

- After, Bohr only talks of non-commuting observables such as position and momentum as complementary (cf. also the *dialectica* article)

Thesis (Bohr's indefinability thesis)

The "truth conditions of sentences ascribing a certain kinematic or dynamic value to an atomic object are dependent on the apparatus involved, in such a way that these truth conditions have to include reference to the experimental setup as well as the actual outcome of the experiment." (Faye, Sec. 4)

$\Rightarrow$ Faye: no collapse of the wave function for Bohr (bc a necessary condition for collapse of ψ-function would be that it be given a "pictorial representation",something Bohr vigorously denied)

- But: perhaps no literal collapse, but surely a collapse in "representation" is required (and perhaps more), in order to not fall prey to charge that QM-descriptions are incomplete!
- Also, today, Bohr is often viewed as an entity realist who opposed theory realism (rather than just a straightforward positivist).

$\Rightarrow$ realism about $\psi \Rightarrow$ need collapse

Bohr's mature view

- experimental practice presupposes pre-scientific, commonly categorized, ordinary-language practice of description
- concepts of classical physics are merely exact specifications of these common categories

$\Rightarrow$ classical concepts necessary in any description of physical experience or observation report

- QM requires a radical revision of these concepts
- in QM experiments, the application of classical concepts don't refer to independent properties of the object, independently of experimental setup
- There is an uncontrollable interaction bw object and apparatus.

- "The quantum mechanical description of the object differs from the classical description of the measuring apparatus, and this requires that the object and the measuring device should be separated in the description." (Faye, Sec. 4) (although this line of separation does not have to be bw object and apparatus)
- ψ ought to be interpreted "pictorially", but as expressing the probability amplitude for the measurement outcomes (as Born suggested)
- Complementarity: manifestations of phenomena may depend on mutually exclusive measurements
- information gained through complementary experiments exhausts possible objective knowledge one can have about object

Copenhagen today

1. indeterminism
2. reduction of the wave fct, dynamical collapse
3. Bohr's correspondence principle
4. Born's statistical interpretation of the wave fct
5. Bohr's complementarity

Bohr's *dialectica* article

Niels Bohr, "On the notions of causality and complementarity", *dialectica* **2** (1948): 312-319.

Let's look at some quotes from the *dialectica* article to expose a tension in the Copenhagen way of thinking. He starts out by explaining how the wave-aprticle duality shows how the classical way of thinking breaks down in atomic physics. Then he proceeds:

> *"... 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. This is a simple logical demand, since the word 'experiment' can in essence only be used in referring to a situation where we can tell others what we have done and what we have learned.*

> *"The very fact that quantum phenomena cannot be analysed on classical lines thus implies the impossibility of separating a behaviour of atomic objects from the interaction of these objects with the measuring instruments which serve to specify the conditions under which the phenomena appear." (313)*

He then goes on to explicate the complementarity of non-commuting observables along the lines we discussed. A little later, he writes:

"[I]t is, of course, to a certain degree a matter of convenience to what extent the classical aspects of the phenomena are included in the proper quantum-mechanical treatment where a distinction in principle is made between measuring instruments, the description of which must always be based on space-time pictures, and objects under investigation, about which observable predictions can in general only be derived by the non-visualizable formalism." (315)

He finally declares:

> *"[T]he observational problem in atomic physics is free of any special intricacy, since in actual experiments all evidence pertains to observations obtained under reproducible conditions and is expressed by unambiguous statements referring to the registration of the point at which an atomic particle arrives on a photographic plate or to a corresponding record of some other amplification device." (317)*

$\Rightarrow$ so Bohr obviously didn't think that there was a measurement problem...

Fuchs and Peres: no “interpretation” needed

C. Fuchs and A. Peres, “Quantum theory needs no ‘interpretation’ ”, *Physics Today*, March 2000, 70-1.

- claim “internal consistency of an ‘interpretation without interpretation’ for quantum mechanics” (70)
- It is contingent whether from a compact description of experimental results a deeper, independent reality can be inferred.
- Common feature of all interpretations: desire to identity such a deeper, independent reality (be it by means of hidden vars, multiple worlds, spontaneous collapse etc)
- All these interpretations do not improve on the thy’s predictive power and are to be rejected as unnecessary.
- Only interpretation ever needed: QM only provides “algorithm for computing probabilities for the macroscopic events (“detector clicks”) that are consequences of our experimental interventions.” (70)

"What do you mean, 'a quantum fluctuation?' Didn't we discuss cause and effect?"

- Fuchs & Peres affirm Born's rule, eigenstate-eigenvalue link, completeness of wave fct
- interpretation of probabilities: "quantitative formulation of how to make rational decisions in the face of uncertainty" (70)
- They don't deny the possibility of an independent reality, at least at macroscopic level.
- But no "microscopic reality" can be described by QM or "by any other reasonable theory." (70)

- In support of this conclusion: Bell's thm
- But (as they acknowledge), this only rules out local HV thys, not HV thys tout court.
- They seem to believe that a nonlocal HV thy, such as Bohm's, would lead to "bizarre self-referential logical paradoxes" (70).
- If QM applies to the entire universe, and the " 'wavefunction of the universe' has to give a complete description of everything, including ourselves, we again get the same meaningless paradoxes" (70).
- But the world is quantum mechanical, they insist ("Nothing in principle prevents us from quantizing a colleague, say." (71))
- Does this mean that they think that QM is ultimately incomplete?

Incompleteness?

- Story of Cathy (the experimentalist) and Erwin (the theoretician) reinforces this suspicion (or a suspicion of extreme relativistic positivism): wavefct is just “mathematical expression for evaluating probabilities and depends on the knowledge of whoever is doing the computing” (71)

⇒ no objective fact of the matter as to which wavefct correctly describes a system

- Question: are there facts e.g. about Cathy’s state when according to Erwin she is in a 50/50 superpositionof states with some cake and some fruit in her stomach?
- If so: QM is incomplete bc it doesn’t tell us anything about these facts
- If not: how can one ever have definite measurement results?
- Fuchs & Peres seem to think yes: “She knows better [than Erwin].” (71)

- Furthermore, they claim that "[a]ttributing reality to quantum states leads to a host of 'quantum paradoxes' "and should thus be avoided, and that the "[c]ollapse is something that happens in our description of the system, not to the system itself." (71)
- All these statements EITHER mean that they believe QM is incomplete (although they negate that), in which case we need some HV thy, OR that there simply is no reality beyond the QM-description, in which case Cathy is indeed in a superposition state, OR that reality is fragmented, in which there are things which in principle are no facts for Erwin, but facts for Cathy...
- Whichever horn they grab, they offer what is called an interpretation of QM, against their explicit denial.
- This is not surprising, since the measurement problem forces us to pick an interpretation...