History of interpretations of quantum mechanics: 1950s through to 1970s

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Seven Pines Symposium XVII
The conceptual development of quantum physics
May 15–19, 2013

Outline:

- The 1950s - Bohm & Everett
- The 1960s - Measurement & Bell theorem
- The 1970s – Experimental blossoming & interpretations
- Nowadays – The inconvenient truth

The 1950s ...

- The intellectual landscape concerning interpretations of quantum theory has dramatically changed
- Complementarity no longer reigns alone and alternative interpretations have begun to appear.
- Two American physicists, David Bohm and Hugh Everett, were the main protagonists challenging the received views on the interpretation of Quantum Theory (QT).

David Bohm (1917-1992)

- Criticized the abandonment of determinism and the well defined properties in the quantum domain.
- Built a model for electrons taking them as bodies with a position and momentum simultaneously well defined. He was able to reproduce results obtained by QT in the non-relativistic domain.
- His interpretation received both the technical name of "hidden variables" and the more philosophically inclined "causal interpretation".
- Poorly received, then abandoned by himself, and later taken up by others, it was revived in different strands.

Hugh Everett (1930-1982)

- Everett built his interpretation dispensing with the second kind of evolution of quantum states that von Neumann had taught would govern measurements.
- Measurement ruled by the Schrödinger equation through relative states
- Disliked the complementarity assumption that quantum physics requires the use of classical concepts while limiting their use in the quantum domain.
- Work badly received in Copenhagen, he pursued neither it nor physics as a whole.
- Revived from the late 1960s on in different strands and research programs

The 1960s …

- The mid 1960s was not a time for new interpretations
- Instead, it was the time for research and quarrels around the quantum measurement problem: Wigner versus Rosenfeld & Italians (DLP), Shimony, d'Espagnat, Ludwig …
- Bohm's interpretation produced offspring: Bell's theorem and the beginning of 'experimental metaphysics'
- Cultural and political unrest of the late 60s led to the blossoming of its 'hundred flowers': the Varenna school, the revival of Everett's interpretation, debates in Physics Today, …

The 1970s …

- The puzzle of the first experiments with Bell's theorem
- The solution of the puzzle and corroboration of quantum entanglement
- The number of alternative interpretations of QT continues to grow … and nowadays there is a plethora of different interpretations
- Almost all of them are empirically equivalent, at least in the non relativistic domain
- Experimental tests have discarded a few categories of interpretations (hidden variables implying local realism, non contextual, …)
- However, the most interesting interpretations have survived these tests

Since then ...

- Increasing technical capabilities continue to confirm quantum predictions in the most extreme experimental situations:

  - Entanglement and its diverse variants (GHZ, quantum teleportation, etc.)
  - Manipulation of single systems, such as electrons, photons, neutrons, and atoms
  - Measurement of decoherence times
  - Bose-Einstein condensates
  - Aharonov-Bohm effect
  - First quantum computers

Nowadays: An inconvenient truth

- Never were there so many equivalent interpretations, never was quantum theory so confirmed
- Interpretations have become an industry for physicists and philosophers, populating many technical journals and books
- However, they are notably absent from physics teaching and from most of the research on physics teaching
- How to deal with such a situation, particularly in the presentation of quantum theory for wider audiences and in the introductory quantum physics teaching?

Two choices to face this truth:

1) To present it as a temporary result and say that future experiments will settle the controversy

- To foster new experiments is part of physics business
- But it seems naïve to hope for such a settling, it has yet to occur

Or,

2) to present the inconvenient truth – the existence of rival but equivalent interpretations – as a real part of physics

- Philosophers, logicians, and historians may help us as they are familiar with this kind of issue. Indeed, the plethora of quantum interpretations is one of the most telling examples of the so-called Duhem-Quine thesis: the underdetermination of theories by the empirical data.

Duhem-Quine Thesis

Pierre Duhem (1861-1916): *The aim and Structure of Physical Theory* (French edition, 1906)

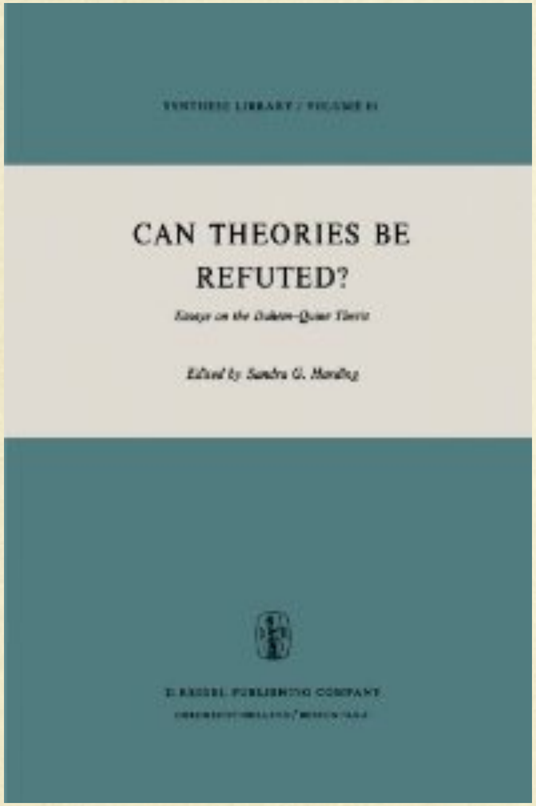
If a theory is contradicted … it is a conjunction of hypothesis that is refuted

Willard Van Orman Quine (1908-2000)

Two Dogmas of Empiricism (1951)

There is much latitude of choice as to what statements to reevaluate in the light of any single contrary experience

Duhem-Quine Thesis Afterthoughts



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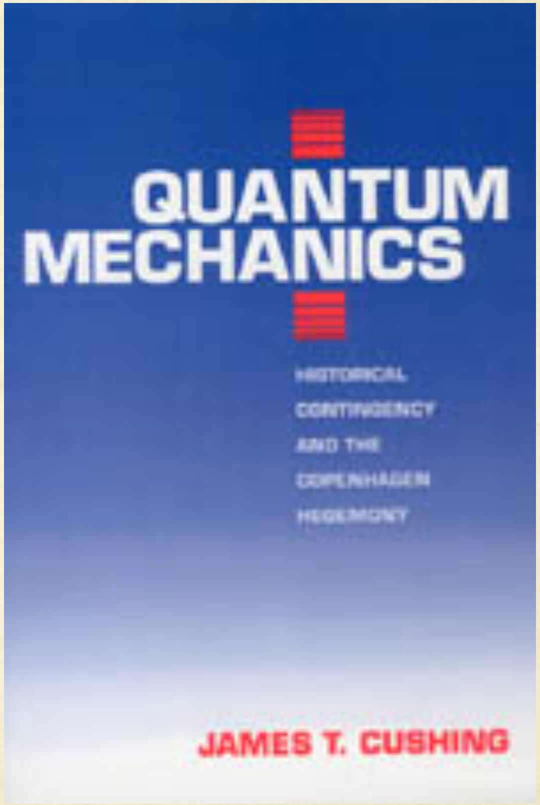

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- The challenge lies in sophisticating the way we present quantum physics:
  - Make explicit the diversity of equivalent interpretations
  - Emphasize the level of empirical corroboration of quantum theory mainly through current experiments
  - However, experimental advances may not settle the controversy: Duhem- Quine thesis is a good portrait of real science
  - Choice of quantum interpretations has been a practical matter. It is a good example of how physicists select theories: not only empirical corroboration and internal consistency. Cognitive reasons such as empirical evidence; generalization; mathematical consistency; physics consistency; beauty; simplicity; rich source to approach different problems; but also cultural contingencies such as philosophical presumptions; cultural and professional trends.