Alternative interpretations of quantum mechanics since the 1970s

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The Proliferation of Interpretations

The most impressive feature when interpretations of quantum mechanics are considered is the proliferation of interpretations of the same mathematical formalism.

The Compendium of Quantum Physics (Greenberger, Hentschel et al. 2009) provides short introductions to these interpretations: Bohm interpretation, Bohmian mechanics, Complementarity principle, Consistent histories, Copenhagen interpretation, GRW theory, Hidden-variables models of quantum mechanics, Ithaca interpretation, Many worlds interpretation, Modal interpretations, Orthodox interpretation, Probabilistic interpretation, and Transactional interpretation.

While there is some redundancy in this list, it is not comprehensive. It does not include, for instance, the stochastic, ensemble, and information-theoretic interpretations. Indeed, this list has been growing in recent decades.

Proliferation of quantum interpretations:

Are they talking of the same object?

The Proliferation of Interpretations

The proliferation begs a question, often asked by the non experts in foundations of quantum physics.

Why this ongoing proliferation if predictions coming from standard quantum theory have been so widely confirmed in the last decades?

Distinction between formalism and interpretation

Since the 1950, it has arisen the awareness of the existence of conceptual problems in the foundations of quantum mechanics.

- Quantum measurement problem, and its related problem of the transition from quantum description to classical descriptions
- Compatibility between quantum theory and the prospects of a unified theory of quantum gravity
- In addition, traditional interpretations have an unequivocal instrumentalist flavor. The problem comes from the conflict between such a flavor and the increasing realist trend among physicists and philosophers.

This was the fuel both for the birth of new interpretations

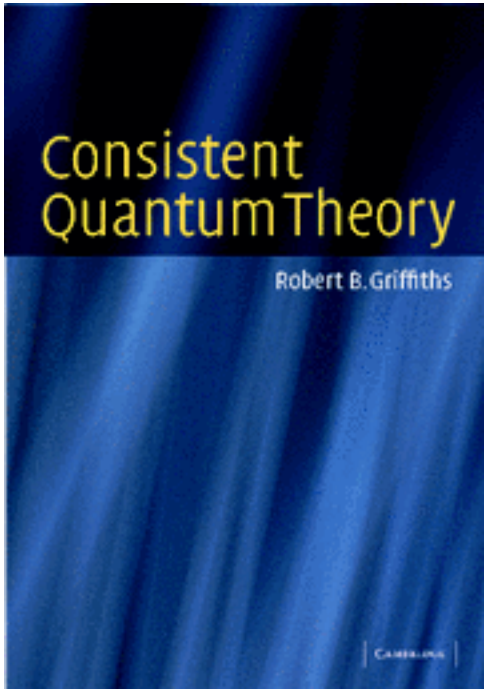
- consistent histories
- spontaneous collapse

And the revival of old ones

- Bohm - de Broglie’s models
- Everettian approaches
- ensemble
- stochastic

Consistent histories

Griffiths



Gell-Mann

Omnès

Hartle

Consistent histories:

The consistent history interpretation was born between 1984 and 1990, and its founding fathers were Robert Griffiths, Roland Omnès, and Murray Gell-Mann and James Hartle

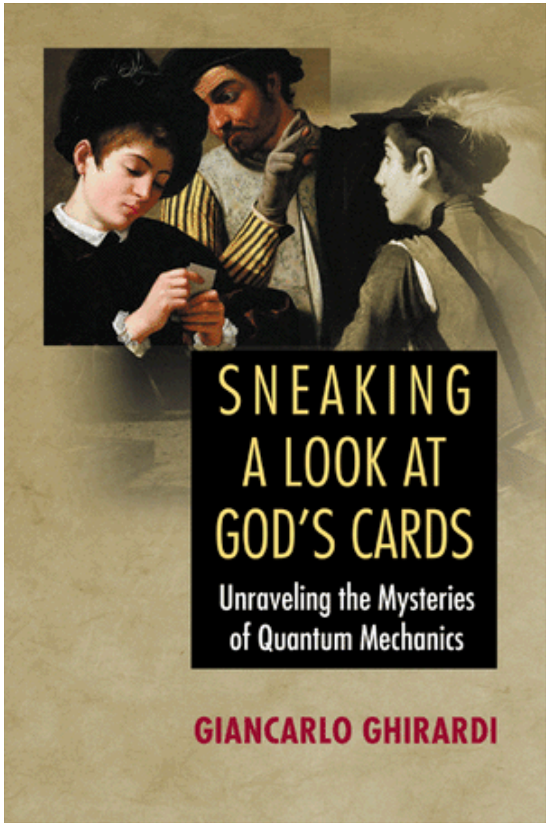
They suggested mathematical criteria for using classical rules of probability to produce conditional probabilities for sequences of events at different times and showed that such criteria could be applied to systems described by the usual quantum mechanical formalism.

Griffith called these criteria a “consistent history approach” because they were able to identify sequences of events, now called consistent histories, which were meaningful in a quantum mechanical treatment.

These criteria constitute, for him, a regulatory principle to adopt in quantum theory. The main advantage of his approach was that it could be applied to closed (isolated) quantum systems between successive measurements thus without taking measurement as a central process for quantum theory.

Collapse theories

Ghirardi



Pearle

The Collapse Theories:

The collapse theory was introduced in 1986 by GianCarlo Ghirardi, Alberto Rimini, and Tullio Weber, which explains why such a theory is dubbed a GRW theory and jointly developed with Philip Pearle

They faced the measurement problem suggesting to change the Schrödinger equation adding a stochastic term to it, thus changing it into a nonlinear one.

Thus this proposal should not be considered in strict terms an interpretation of quantum mechanics. Indeed it is a modified theory.

This term is responsible for the collapse of the quantum states during measurements. The rate of collapse increases with the number of systems or degrees of freedom

This stochastic term should not lead to different predictions from standard quantum theory for microsystems with few degrees of freedom and at the same time should explain the absence of superposition of eigenstates in the description of macroscopic systems. Thus the theory introduces new constants of nature.

The contrived mathematical apparatus thus constructed implies in the existence of domains in which the two theories do not yield the same predictions.

Changing Schrödinger equation into a nonlinear equation had been envisioned by many - including Louis de Broglie and Eugene Wigner – unsuccessfully.

The theory was notoriously supported by John Bell and it is seen with affection by many for the possibility of an experimental contrast with standard quantum mechanics.

The collapse theories fulfill a lacuna in the broad spectrum of possible solutions for the concerns many physicists have with the standard quantum theory.

Adrian Kent, who is a supporter of the collapse theories, acknowledges their shortcomings (“the mathematics of collapse seems a little ad hoc and utilitarian”; “at best only a step in roughly the right direction”). His interest in these theories derive from the possibility of revealing limits of the validity of quantum theory, which he, maybe optimistically, expects to happen in the next two decades (Kent 2014)

The revival of Bohm's ideas

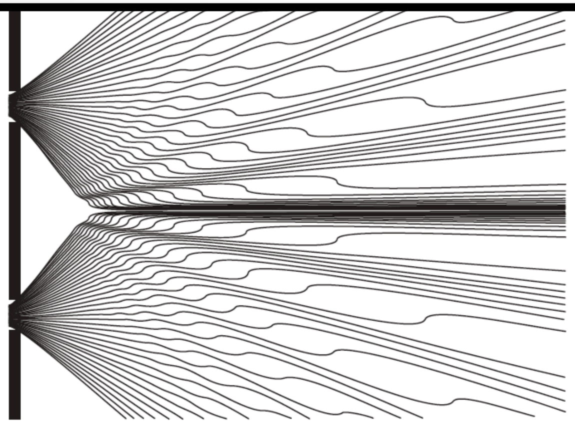


Fig. 1 Possible Bohmian trajectories in the double-slit experiment (from C. Philippidis, C. Dewdney and B.J. Hiley, Il Nuovo Cimento **52**, 15 (1979))

Goldstein

Valentini

- **The revival of Bohm's ideas:**
- In 1979 Philippidis and Dewdney, jointly with Basil Hiley used computers to obtain graphs of trajectories from Bohm's model and this called the attention of many researchers.
- Dürr, Goldstein, and Zanghi construed a new approach adopting just two premises: the state which describes quantum systems evolves according to Schrödinger's equation and particles move, that is, they have a speed in the configuration space. With this approach, without referring to quantum potential and the difficult problem of its physical interpretation, they derived the same results one gets both with standard quantum mechanics and with Bohm's original approach for nonrelativistic phenomena – Bohman mechanics
- This approach has been useful for discussing quantum chaos, and for this reason it has received acceptance well beyond physicists just interested in the foundations of quantum mechanics.

- In other direction, and more recently, one of the supporters of Bohm-de Broglie’s causal interpretation, Valentini, has extended it in order to lead it to empirically distinct predictions, at least in the cosmological domain.

- Valentini achieved such a result making a different derivation for the quantum equilibrium hypothesis, which Bohm had assumed in the 1950s.

- This derivation has been challenged by the supporters of Bohmian mechanics, thus setting controversial issues among Bohm’s intellectual heirs.

Everett's intellectual heirs

Deutsch

Wallace

- **Everett's intellectual heirs:**

- Everett's many-worlds also split into many variations.

- It was influential on the early work of Zurek, on Gell-Mann and Hartle's work on consistent histories, and on Deustch's work on quantum computation, as we will see.

- In the turning of the 20th century it has gained a stronghold among physicists and philosophers, which reflected in the commemoration of the 50th birthday of Everett's thesis through colloquia and cover page of the prestige journal *Nature* on 5 July 2007.

- Everett's supporters however continue to deal with an intractable problem:
- How to obtain statistical laws from the Everettian framework where there is no ingredient of randomness?
- According to the critics, such as Kent (2014), "the key scientific question is why the experimental evidence for quantum theory justifies a belief in many worlds in the first place." Kent acknowledges the work Everettians have done, "but think they have all failed."

Conclusions:

A few lessons from the proliferation of alternative interpretations of quantum mechanics.

- All of them present unsatisfactory features, which explain why none of them obtained an expressive support among physicists and philosophers.

- Possibilities of different predictions continue to keep expectations in high, as testified by Valentini's and Ghirardi's proposals and by Kent's comments. Meanwhile, with the currently available evidence, they are empirically equivalent.

- This illustrates the philosophical thesis of the underdetermination of scientific theories by empirical data, at least in some of its versions, a thesis due to Pierrer Duhem and Willard Van Orman Quine.

- **Diversity and tolerance**

- Finally, the diversity of proliferation has been useful for the development of physics. Bell's theorem appeared as an inspiration from Bohm's interpretation, and Everett's interpretation has been influential in works at the birth of decoherence and quantum computation. We may extend further this final conclusion saying that tolerance towards diversity may be more helpful to science than strict adhesion to the dominant views.

- Thus, at least in science, a Hundred Flowers policy may fare better than a Nonproliferation treaty