The Rashomon Effect:
when interpretations of quantum theory disagree

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The most widely accepted interpretation:

99%

Shut up and calculate

This is a talk about the rest 1%
The Rashomon Effect: the same event is given contradictory interpretations
“… quantum theory is the most useful and powerful theory physicists have ever devised. Yet today, nearly 90 years after its formulation, disagreement about the meaning of the theory is stronger than ever. New interpretations appear every day. None ever disappear.”


Wikipedia: 17 + “Other interpretations”
What is the meaning of the Psi-function?
Randomness & Probabilities

Half-silvered mirror

The Psi-function predicts only probabilities for individual outcomes.
Interpretations of quantum theory

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About „Reality“: The probabilities of measurement outcomes are determined by intrinsic properties of the observed system. (Einstein, Bohm, Bell, Spekkens, …)

About „Knowledge“: Quantum state as an observer’s knowledge or belief about the results of future experiments. (Wheeler, Rovelli, Fuchs, Zeilinger, …)
Randomness & Probabilities

Is there a cause, even a "hidden" one, that determines which outcome will be observed in an individual quantum measurement?

Quantum theory predicts only probabilities for individual outcomes observed in an individual quantum measurement?
Randomness & Probabilities

Half-silvered mirror

Are there „hidden variables“? \( \lambda_+ \)

detector +

detector -
Randomness & Probabilities

Half-silvered mirror

Are there „hidden variables“? λ

detector +
detector -
Randomness & Probabilities

About “Reality”:  \[ p(+) = p(\lambda_+)p(+) | \lambda_+ \) + \[ p(\lambda_-)p(- | \lambda_-) \]

Probabilities reducible to determinism
\[ = \frac{1}{2} \quad = 1 \quad = \frac{1}{2} \quad = 1 \]

About “Knowledge”:  \( p(+) = \frac{1}{2}, \quad p(-) = \frac{1}{2} \)

“Irreducible” probabilities

These are the directly observable probabilities
W. Pauli to M. Born:

“… one should no more rack one’s brain about the problem of whether something one cannot know anything about exists …, than about the ancient question of how many angels are able to sit on the point of a needle.”
Bell’s theorem

Local „hidden variable“ theories are in contradiction with quantum theory and nature.

Every “hidden variable” theory is necessarily non-local. (e.g. Bohmian mechanics)

J. S. Bell (1964)
Bell‘s experiment

**Non-locality**: Bob‘s choice of measurement influences instantaneously „hidden“ probabilities for Alice‘s outcome

\[ p(a|x_1, y_1, \lambda) \neq p(a|x_1, y_2, \lambda) \]

This „influence“, however, cannot be used to signal. This „influence“, however, cannot be used to signal.
Thought experiment: Schrödinger’s cat

Schrödinger (1935):
“One can even set up quite ridiculous cases …”

A cat, a flask of poison, and a radioactive source are placed in a sealed box ... After the half-life time the box is opened ...

\[
|\Psi\rangle = \frac{1}{\sqrt{2}} (|\text{atom decayed}\rangle |\text{cat dead}\rangle + i |\text{atom undecayed}\rangle |\text{cat alive}\rangle)
\]
Einstein in a letter to Schrödinger, dated 1950:

“You are the only contemporary physicist, besides Laue, who sees that one cannot get around the assumption of reality, if only one is honest. Most of them simply do not see what sort of risky game they are playing with reality – reality as something independent of what is experimentally established. Their interpretation is, however, refuted most elegantly by your system of radioactive atom + amplifier + charge of gunpowder + cat in a box, in which the psi-function of the system contains both the cat alive and blown to bits. Nobody really doubts that the presence or absence of the cat is something independent of the act of observation.”
Copenhagen interpretation

While the box is closed, the system exists in a superposition of the states “decayed atom/dead cat” and “undecayed atom/living cat”, and only when the box is opened and an observation performed does the wave function “collapse” into one of the two states.

The cat is neither in „dead“ nor in „living“ state before the box is opened; the superposition represents a new feature of the cat.

*On the basis of Wikipedia entry*
Objective collapse models

According to objective collapse theories, superpositions are destroyed spontaneously (irrespective of external observation) when some objective physical threshold (of time, mass, complexity, irreversibility, etc.) is reached.

Objective collapse theories require a modification of standard quantum mechanics.

*On the basis of Wikipedia entry*
Many-worlds interpretation

Both alive and dead states of the cat persist after the box is opened, but in different worlds, i.e. are “decoherent” from each other.

When the box is opened, the observer and the cat split into an observer looking at a box with a dead cat, and an observer looking at a box with a live cat.

*On the basis of Wikipedia entry*
Hugh Everett (right) challenged Niels Bohr's interpretation of quantum physics in his 1957 paper.
Relational interpretation

allows that different observers can give different accounts on the physical situation depending on the information they have about the system.

Before the box is opened, the cat has information about the state of the apparatus (the atom has either decayed or not decayed); but the experimenter describes the box content (the cat plus the apparatus) in the superposition.

*On the basis of Wikipedia entry*
There might be something intrinsically deficient in the idea of looking for the meaning of a physical theory exclusively on the basis of its formalism ("from the inside").

Instead, one can attempt to extract meaning along with extracting the formalism, in the reconstruction of the theory from some deeper physical principles ("from the outside").

Reconstruction of Quantum Theory

A plethora of reconstructions: ...
Fivel (1994),
Hardy (2001),
Dakic & Brukner (2009),
Massanes & Müller (2011),
Chiribella, D’Ariano, Perinotti (2011), ...

The level of plausability of axioms is far below of the one of the theory of relativity.
Instead of Conclusions:

Many-worlds:
There exists a world in which you were convinced by this talk (and the one in which you were not).

Relational:
Truth is in the eye of the beholder.

Thank you!