Quantum “measurement” A closer look at various resolutions

How to go from a deterministic theory with superimposed possibilities to a random single experience is known as the ‘measurement problem’.

There are a variety of ideas about how to deal with it- all lousy.

Saturday Physics talk 10:15 AM on Sausages and Science

Remember last week
I said the loopholes were
about to be closed.

Loopholes?

1. The initial passage of the particles through the angular momentum selectors are space-like separated. In the first generation of experiments, the conversion of those micro-events to some large-scale device setting was slow enough for it to be conceivable that a time-like signal could propagate between the detectors before "measurement" is complete. This loophole is now closed in some experiments, e.g. with satellites many km apart.

2. Detection efficiency. There's a complication in that many particles are missed, requiring some extrapolation. This is now closed in some experiments using atoms rather than photons and now in photon experiments here!

- No experiment yet reported quite closes all the loopholes simultaneously. Still, it's a long-shot to think that these loopholes offer any escape.

SCIENCE

Sorry, Einstein. Quantum Study Suggests 'Spooky Action' Is Real.

By JOHN MARKOFF OCT. 21, 2015

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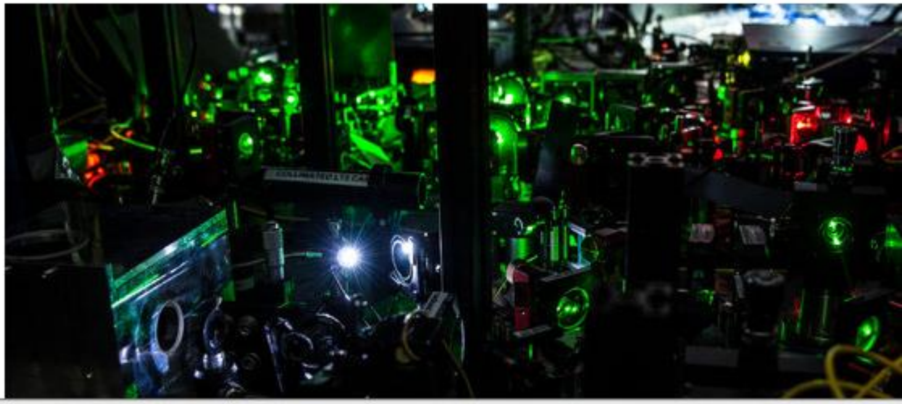
In a landmark study, scientists at Delft University of Technology in the Netherlands reported that they had conducted an experiment that they say proved one of the most fundamental claims of quantum theory — that objects separated by great distance can instantaneously affect each other's behavior.



The new experiment, conducted by a group led by Ronald Hanson, a physicist at the Dutch university's Kavli Institute of Nanoscience, and joined by scientists from Spain and England, is the strongest evidence yet to support the most fundamental claims of the theory of quantum mechanics about the existence of an odd world formed by a fabric of subatomic particles, where matter does not take form until it is observed and time runs backward as well as forward.

The researchers describe their experiment as a "loophole-free Bell test" in a reference to an experiment proposed in 1964 by the physicist John Stewart

Discussion Question

- Did Heisenberg prove that everything is uncertain?

Ideas to deal with the measurement problem

- (folk version of Copenhagen) ψ collapses, don't ask how
- (formal Copenhagen) ψ wasn't ever real, so don't worry about how it collapses. It was just a calculating tool
- "macro-realism": ψ does too collapse, but that involves deviations from the linear wave equation. (Pearle, …)
- mentalism: ψ does too collapse, due to "consciousness", which lies outside the realm of physics. (Wigner, …)
- "hidden variables" were always around to determine the outcome of the experiments, so ψ doesn't have to collapse. (Einstein, DeBroglie, Bohm …)
- (Many Worlds). There's nothing but the linear wave equation, you just have to understand what it implies. ψ doesn't collapse, all those different branches occur but have no reason (until you understand the wave equation) to be aware of each others existence. (Everitt, …)
  – (Many Thoughts) There are non-linear criteria for what constitutes a thought. Under special circumstances that may lead to $|\psi|^2$ probabilities. (Hanson, Mallah)
- (Many Many Worlds). As above, but the linear equation predicts incorrect probabilities, so you need non-linear terms to give the right probabilities. (only mbw*)
- Many Interacting Worlds. Cloud of worlds exerting forces on each other (Wiseman,…)
- (quantum logic). Classical Boolean logic is empirically disproved (as a description of our world) by QM, just as Euclidean geometry was shown by G.R. not to describe our world. (Putnam*, …) *(no longer holds that view)

Non-local hidden variables?

- Rather than reproduce the twists and turns in this development (it's very hard, and we hope you've learned about scientific twists and turns in the easier context of Copernicus/Newton/Einstein) we turn to the current question:
- Is there any NON-LOCAL HV theory that reproduces the results of QM?
- The answer is apparently yes, thanks again to Bohm.
- Bohm's *local* theory works approximately as follows:
  - There is some <u>actual value to the position</u> of any particle. There is also an <u>actual wave</u>, guiding those particles. (shades of DeBroglie returned.)
  - The <u>wave obeys the usual linear equation of QM</u>.
  - There is <u>an equation describing how the actual set of positions changes in time, under the influence of the wave</u>.
  - For some reason, not entirely clear, it is not given to us to know the actual positions of everything, but rather we only know some probabilities, with the probability of some set of coordinates proportional to $|\psi^2|$ for those values.
- It follows directly from Bohm's equation describing the motion of the coordinates that the probability density remains proportional to $|\psi^2|$ forever, if it starts that way. A swarm of dots distributed in coordinate space according to the probability rule would follow streamlines in the probability flow.
  - Crude observation allows us to measure macro-variables, so that we can always eliminate the possibility that the actual coordinates are in one of the remote branches of the solution of the wave equation.

Bohm's limits

Bohm's interpretation seems to reproduce all the measured properties of QM. Any objections?

- You can't have separate coordinate dots for each particle (local). You need a single multi-dimensional coordinate to stand for every single particle!
- Does saying that a true set of coordinates exists make a testable claim? Is it like saying "there is a special reference frame in which the ether is at rest, but we can never find it"? If the assertion that one set of coordinates is "real" does have some meaning, what are the experimental implications?
- The underlying theory requires a unique reference frame. Only the statistical averages for large-scale variables (on the assumption that the "equilibrium" distribution has been reached) show Lorentz invariance.
- It restores dualism: the wave function and the real particle coordinates are very different entities. The particles don't even have any influence on the wave-function. Why do ordinary position coordinates play a special role for the particles, but not for the wave?
- The probability densities are fixed by the actually occurring "branches" of the wave function, the other branches are irrelevant. Why can we observe well enough to say which distinct macroscopic branch of the wave function contains the actual particle coordinates, but not well enough to have *any* effect on the probabilities *within* a branch? In other words, how does Bohm maintain the sharp distinction between the measured and unmeasured properties, i.e. between the parts of the wave function within which the coordinate probabilities precisely obey the "equilibrium" $|\psi^2|$ law, and those for which no probabilities are needed at all?

Mentalism

Proposed by von Neumann and advocated by Wigner, among others, especially pop-journalists. There is something special about consciousness. It lies beyond the laws of physics as usually understood. E.g. Mermin: "Physical reality is narrower than what is real to the conscious mind."

- Human observation collapses the wave function, so a superposition is never observed.
- This is a bit hard to argue with since (shades of Berkeley) we don't have much access to a world devoid of consciousness.
- However, there are some serious difficulties:
- The whole proposal requires putting people at the center of the existence of the universe. How does that square with everything else we know, e.g. evolution? The world we see shows overwhelming evidence of having once been free of consciousness. Were the laws of physics entirely different then? Who (bacterium, amoeba, monkey, Wigner,…) was finally conscious enough to collapse the wave function and make positions, etc. of particles exist? Just how did Wigner get there before anything had positions?
- There is NO evidence that consciousness plays some role distinct from any other phenomena involving macroscopic masses and times.

<u>Mentalism</u> (cont.)

- Mermin's form (not exactly collapse):
  - "The problem of consciousness is an even harder problem than the problem of interpreting quantum mechanics,,, consciousness is beyond the scope of physical science, at least as we understand it today… Physical reality is narrower than what is real to the conscious mind. Quantum mechanics offers an insufficient basis for a theory of everything if everything is to include consciousness… The notion of *now*- the present moment- is immediately evident for consciousness… Physics has nothing to do with such notions. … This *particularity* of consciousness- its ability to go beyond time differences….has a similar flavor to its ability to go beyond its own correlations with a subsystem, … to an awareness of a particular subsystem property."
- The question is not whether we understand consciousness but rather whether consciousness violates general physical laws. I.e. does weak reductionism hold?
- Is being aware exclusively of one part of the whole state going "beyond" physical reality? Or is it consciousness that is "narrower" than reality?
- I won't follow up mentalism further, because I can't pretend to take it seriously. However, that does NOT mean that we can't later seriously consider how, if the wave function represents many qualitatively distinct outcomes, the nature of the outcome we see is determined by the pre-selection for its consistency with consciousness.

Many Interacting Worlds

- Bohm gives a *dualistic* account:
  - Coordinate dot guided around by pilot wave via explicit equation
  - Why one dot? Wouldn't multiple dots give more natural probability?
- Wiseman et al. propose (PHYSICAL REVIEW X 4, 041013 (2014))
  - Replace the wave with the mutual influence of the other classical dots
  - Swarm of "worlds" each influencing other worlds for which *all* particles are in almost the same locations (very non-local!)
  - Toy models reproduce standard QM behavior
  - Bell violations promised in next paper
  - Requires dense enough swarm to behave like continuous wave
    - Probably given for free by anthropic post-selection
  - Not yet complete, not yet relativistic,

Bohm and MIW
2-slit trajectories

For Bohm, need starting probability distribution following $|\Psi|^2$.

For MIW, probability is obtained from a simple count of worlds.

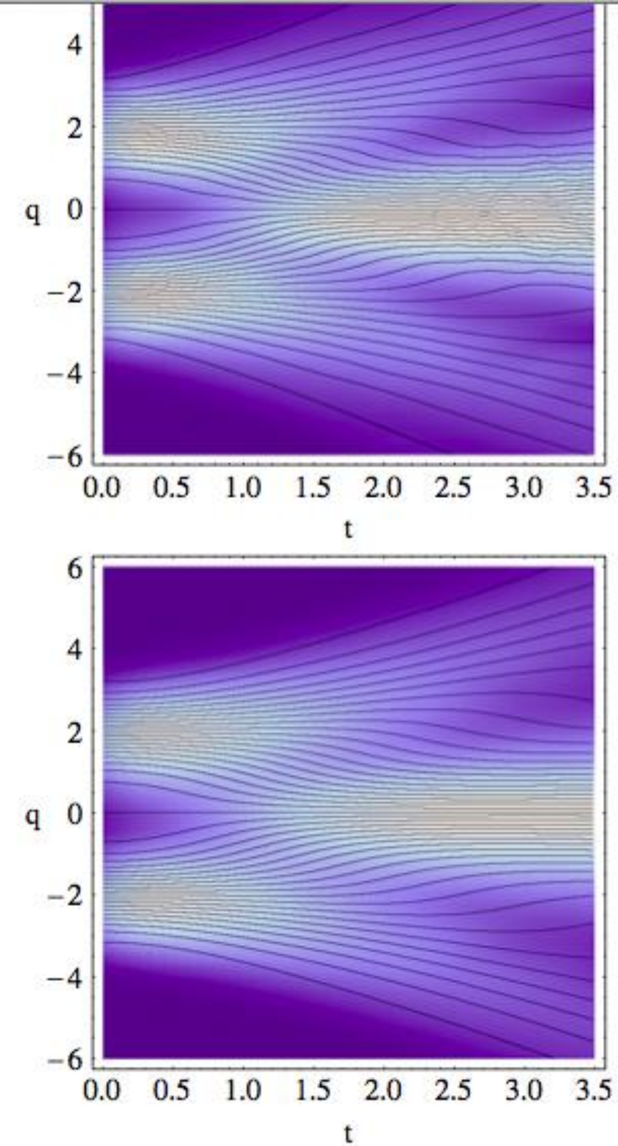


FIG. 6. Trajectory and (smoothed) density plots of the co puted MIW (top) and dBB (bottom) world trajectories for t identical initial Gaussian wave packets in units of the ini spread (i.e., $\sigma = 1$) and $N = 41$ worlds; time is given in un of $\hbar/(2m)$.