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The Conscious Observer in the Quantum Experiment[1]

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Abstract

A quantum-theory-neutral version of the two-slit experiment displays the intrusion of the conscious observer into physics. In addition to the undisputed experimental results, only the inescapable assumption of the free choice of the experimenter is required. In discussing the experiment in terms of the quantum theory, other aspects of the quantum measurement problem also appear.

KEY WORDS: Consciousness, quantum, experiment, free-will, John Bell

1. INTRODUCTION

The intrusion of the observer into physics appeared at the inception of quantum theory eight decades ago. With this "quantum measurement problem," the physics discipline encountered something apparently beyond "physics" (Greenstein & Zajonc 1997).

Photons and electrons manifested "wave-particle duality": They exhibited wave properties or particle properties depending on the experimental technique used to observe them. Wave properties imply a spread-out entity, while particle properties imply a *not* spread-out entity. The contradiction was perhaps acceptable for these “not-quite-real” photons and electrons seen only as effects on macroscopic measuring apparatus.

Today, quantum weirdness is demonstrated in increasingly large systems, and interpretations of "what it all means" proliferate. Essentially every interpretation ultimately requires the intrusion of the conscious observer to account for the classical-like world of our experience (Penrose, R. 2005).

The quantum measurement problem is often considered a problem arising in the quantum *theory*: How to explain the collapse of the multiple possibilities of the wavefunction to a single observed actuality. This is indeed unresolved. However, the measurement problem also arises in the quantum-*theory-neutral* experiment, and depends crucially on the assumption of the free will of the experimenter. We present a version of the archetypal quantum experiment illustrating this intrusion of the conscious observer into the experiment.

[1] Very slightly edited to improve clarity. Unedited version is in Journal of Cosmology.

2. THE ARCHETYPAL QUANTUM EXPERIMENT

"[The two-slit experiment] contains the only mystery. We cannot make the mystery go away by "explaining" how it works. . . In telling you how it works we will have told you about the basic peculiarities of all quantum mechanics" (Feynman, et. al. 2006).

With the two-slit experiment, one can choose to demonstrate *either* of two contradictory things: that each object was a compact entity coming through a single slit or that each was a spread out entity coming through both. Similar experiments have been done with photons, electrons, atoms, large molecules, and are being attempted with yet larger objects such as live viruses (Clauser 2010). We will just refer to "objects."

We present an equivalent version of the two-slit experiment in which one can choose to show that an object was *wholly* in a single box. However, one *could have* chosen to show that that same object was *not* wholly in a single box. By telling the story with objects captured in boxes, one can decide *at leisure* which of these two contradictory situations to demonstrate for each isolated object (Rosenblum & Kuttner 2002). We thus display the quantum challenge to our intuition that an observer-independent physical reality exists "out there." We describe *quantum-theory-neutral* experiments, telling only what could be directly observed.

An experimenter is presented with a set of box pairs, say twenty pairs of boxes. Each *pair* of boxes contains a single object. How the box pairs were prepared is irrelevant for our quantum-theory-neutral experiments. It's easier to describe the preparation in quantum language, so we do that in the next section.

The "Which Box" Experiment

The experimenter is instructed to determine, for *this* set of box pairs, which box of each pair contains the object. He does this by placing each box pair in turn in the same position in front of a screen that an object would mark on impact. He then cuts a narrow slit *first* in one box of the pair, and *then* the other. For some box pairs, an impact occurs *only* on opening the first box, and then not on opening the second box. For others, the impact occurs only on the second opening. In this "which box" experiment, the experimenter thus determines which box of each pair contained the object, and which box was empty. The experimenter establishes that for *this* set of box pairs, each object had been *wholly* in a single box of its pair.

Repeating this with box pairs placed in the same position in front of the screen, the experimenter notes a more or less random spread of marks on the screen.

The "Interference" Experiment

The experimenter is presented with second set of box pairs. This time he is instructed to cut slits in both boxes of each pair at about the *same time*. He does so, positioning each box pair in the same position in front of the screen. (It's an interference experiment, and we so name it. But we make no reference to waves.)

This time the objects do not impact randomly. There are regions where many objects land, and regions where none land. Each object followed a *rule* specifying the regions in which it was allowed to land.

To investigate the nature of this rule, the experimenter repeats the experiment with different spacings of the boxes of a pair from each other. He finds that the rule each object follows *depends on the spacing* of its box pair. Each object "knows" the spacing of its box pair. Therefore *something* of each object had to have been in *each* box of its pair. The experimenter establishes that–unlike the previous set, in which each object was wholly in a single box–for *this* set of box pairs, objects were *not* wholly in a single box.

The Free Choice Of Experiment

The experimenter is reminded that he established that the objects in the first set of box pairs were *wholly* in a single box, while the objects in the second set of box pairs were *not* wholly in a single box. Now presented with a third set of box pairs, he is asked to establish whether the objects in *this* set of box pairs are, or are not, wholly in a single box.

The experimenter arbitrarily chooses to do the "which box" experiment, and thus establishes that *this* box-pair set had contained objects wholly in a single box. Given another set of box pairs and similar instructions, he chooses the "interference" experiment, and establishes that the objects in *this* set were *not* wholly in a single box. Offered further sets of box pairs, the experimenter finds that each time he chooses to do a "which box" experiment, objects were wholly in a single box. Each time he chooses an "interference" experiment, he establishes a contradictory physical situation, that objects were *not* wholly in a single box. His free choice of experiment seemed to *create* the prior history of what had been in the boxes. He's baffled.

If the experimenter's choice of experiment were somehow predetermined to match what was actually in each box pair set, he would see no *logical* problem. He recognizes this, but he is *certain* his choices were freely made. It is his conscious certainty of his own free will that causes him to experience a measurement problem with the archetypal quantum experiment. (The free choice of observation set is, in fact, *assumed* in any inductive science.)

We emphasize that the theory-neutral quantum *experiment* raises the issue of free will. No *experiment* in classical physics raised the issue of free will. In classical physics, questions of free will arose only out of an ignorable aspect of the deterministic *theory*.

In describing the intrusion of the observer into the archetypal quantum experiment we never referred to quantum theory, wavefunctions, or waves of any kind. Even were quantum theory never invented, one could do these experiments, and the results would present an inexplicable enigma (Greenstein & Zajonc 1997).

3. THE BOX-PAIR EXPERIMENT IN QUANTUM THEORY

The Preparation Of The Box Pairs:

Objects are sent one at a time, at a known speed, toward a "mirror" that equally transmits and reflects their wavefunction. In Figure 1, a wavefunction is shown at three successive times. The reflected part is subsequently reflected so that each part is directed into one of a pair of boxes. The doors of the boxes are closed at a time when the wavefunction is within the boxes.

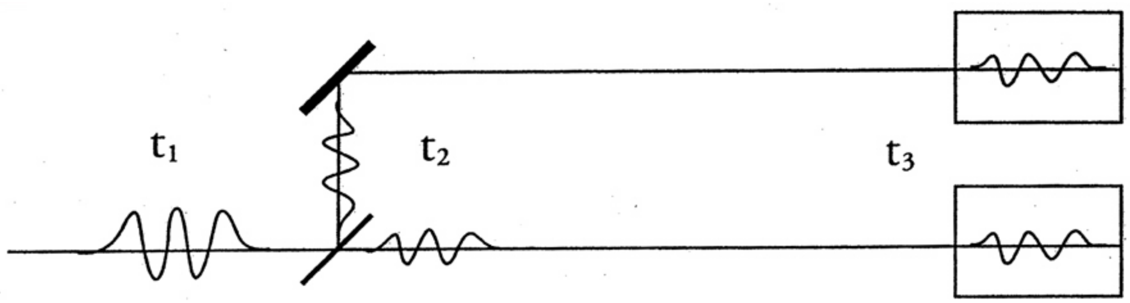

Figure 1. Schematic diagram of the preparation of the box pairs. The object's wavefunction is shown at three successive times.

Dividing a wavefunction into well-separated regions is part of every interference experiment. Holding an object in a box pair without disturbing its wavefunction would be tricky, but doable in principle. Capturing an object in physical boxes is not actually required for our demonstration. A sufficiently extended path length would be enough. The box pair is a conceptual device to emphasize that a conscious choice can be made during the time an object exists as an isolated entity.

Observation

In the box-pairs version of the two-slit experiment, the wavefunction spreads widely from the small slit in a box. In the "which box" experiment, it emerges from each single box and impinges rather uniformly on the detection screen. In the "interference" experiment, parts of the wavefunction emerge simultaneously from *both* boxes and combine to form regions of maxima and minima on the detection screen.

The Born postulate has the absolute square of the wavefunction in a region giving the probability of an object being "observed" there. In the Copenhagen interpretation of quantum mechanics, observation takes place, for all practical purposes, as soon as the microscopic quantum object encounters the macroscopic screen. Other interpretations of quantum mechanics, attempting to go *beyond* practical purposes, consider observation to be more involved with the actual conscious experience of the experimental result.

History Creation

Finding an object in a single box presumably implies that the whole object came to that box on a particular single path after its earlier encounter with the semi-transparent mirror. Choosing an interference experiment implies a different history: that aspects of the object came on two paths to both boxes after its earlier encounter with the semi-transparent mirror. (As noted above, the question of history creation also arose in the quantum-theory-neutral experiment.) Quantum cosmologist John Wheeler suggested that quantum theory's history creation be tested. He would have the choice of which experiment to do delayed until *after* the object made its "decision" at the semi-transparent mirror of whether to come on a single path or whether to come on both paths.

The experiment was done with photons and a mirror arrangement essentially like our Figure 1. Getting the same results as in the usual quantum experiment would imply that the relevant history was indeed created by the later choice of experiment. For a human to make a conscious choice of which experiment to do takes perhaps a second, in which a photon travels 186,000 miles. Therefore the actual "choice" of experiment was made by a fast electronic switch making random choices. The most rigorous version of the experiment was done in 2007 (Jacques et al., 2007), when reliable single-photon pulses could be generated, and fast enough electronics were available. The result (of course?) confirmed quantum theory's predictions. Observation created the relevant history.

Non-locality and Connectedness

When an object is observed to be in a particular location, its probability of being elsewhere becomes zero. Its wavefunction elsewhere "collapses" to zero, and to unity (a certainty) in the location in which the object was found. If an object is found to be in one box of its pair, its wavefunction in the other box *instantaneously* becomes zero–no matter how far apart the boxes are.

In its usual interpretation, quantum theory does not include an object in *addition* to the wavefunction of the object. The wavefunction is, in this sense, the physical entity itself. Thus the wavefunction being affected by observation everyplace at once is problematic in the light of special relativity, which prohibits any matter, or any message, to travel faster than the speed of light. The non-local, instantaneous collapse of the wavefunction on observation poses a quantum measurement problem as viewed from quantum theory.

The instantaneous, non-local collapse of the wavefunction provoked Einstein to challenge the completeness of quantum theory with the famous EPR paper (Einstein, et al. 1935). To avoid what Einstein later derided as "spooky action at a distance," EPR held that there must be properties at the microscopic level that quantum theory did not include. However, since EPR provided no *experimental* challenge to quantum theory, it was largely ignored by physicists for three decades as merely arguing a philosophical issue.

John Bell (1964) proved a theorem allowing experimental tests of whether objects could have properties beyond quantum theory ("hidden variables") that could explain the experimental results without the existence of an instantaneous connectedness. The experiments (Freedman & Clauser, 1972; Aspect et al. 1984) showed that if objects had interacted, what an observer *chose* to observe about one of them would *instantaneously* influence the outcome of what an arbitrarily remote observer chose to observe for the other object. Einstein's "spooky actions," which Bohr called "influences," do exist.

The Bell result included the assumption of the free will of the experimenters, that their choices of what to observe were independent of each other and independent of all prior physical events. Denying that assumption would be "more mind boggling" than the connectedness the denial attempts to avoid. Such denial would imply, Bell wrote: "Apparently separate parts of the world would be conspiratorially entangled, and our apparent free will would be entangled with them" (Bell 1981).

4. THE ROBOT FALLACY

The most common argument that consciousness is *not* involved in the quantum experiment is that a *not*-conscious robot could do the experiment. However, for any experiment to be meaningful to us, a human must eventually evaluate it. A programmed robot sees no enigma. Consider the human evaluation of the robot's experiment:

The robot presents a printout to the human experimenter. It shows that with some sets of box pairs the robot chose a which-box experiment, and established that those objects were wholly in a single box. With other sets of box pairs, it chose the interference experiment, and established that those objects were *not* wholly in a single box.

On the basis of this data, the human experimenter could conclude that certain box-pair sets actually contained objects wholly in a single box, while others contained objects *not* wholly in a single box. However, a question arises in the mind of the experimenter: How did the robot choose the *appropriate* experiment with each box-pair set? What if, for example, the robot chose a which-box experiment with objects *not* wholly in a single box? A partial object was never reported.

Without free will, the not-conscious, programmed robot must use some "mechanical" choice procedure. Investigating the robot's procedure, the experimenter finds, for example, that the robot flips a coin. Heads, it does a which-box experiment; tails interference. The experimenter is troubled by the mysterious correlation between the landing of the coin and what presumably actually existed in a particular box-pair set.

To avoid that inexplicable correlation, the experimenter replaces the robot's coin flipping with the choice method she is most sure is *not* correlated with the prior contents of a box-pair set: her own free choice. Pushing a button telling the robot which experiment to do, she establishes precisely what she would establish by doing the experiment directly, that by her conscious free choice she can establish either of two contradictory physical situations. Ultimately, the robot argument to deny the encounter with consciousness establishes nothing.

5. CONCLUSION

Extending the implications of quantum mechanics beyond the microscopic realm admittedly leads to ridiculous-seeming conclusions. Nevertheless, the experimental results are undisputed, and quantum theory is the most basic and most battle-tested theory in all of science.

The embarrassing intrusion of the conscious observer into physics can be mitigated by focusing on observation in quantum *theory*, the collapse (or decoherence) of the wavefunction. However, this cannot evade the enigma. The inescapable assumption of free choice by the experimenter displays the intrusion of the observer in the quantum-theory-neutral quantum *experiment*, logically prior to the quantum theory.

The intrusion was less disturbing when confined to never-directly-observed microscopic objects. However, the vast no-man's-land that once separated the microscopic and the macroscopic realms, allowing a tacit acceptance of this view, has been invaded by technology. The separation seems to disappear.

Bell's theorem, and the experiments it stimulated, seems to rule out a resolution of the quantum measurement problem by the existence of an *underlying* structure, somehow involving only properties localized in quantum objects. An *overarching* structure, somehow involving conscious free will, seems required.

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