

The death of Schrödinger's cat and of consciousness-based quantum wave-function collapse

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ABSTRACT. The implications arising from the “Schrödinger's cat” thought experiment have led some authors to argue that observation of a measurement by a conscious observer is required to collapse quantum wave-functions. Here we combine Schrödinger's experimental paradigm with a system for splitting the information about the quantum state between two observers, thereby allowing distinct outcomes to be recorded without either observer knowing the state of the measured quantum event. Our results imply that to collapse a quantum wave-function, measurement alone, rather than conscious observation of a measurement, is sufficient.

RÉSUMÉ. Les implications provenant de l'expérience imaginaire du "chat de Schrödinger" ont amené certains auteurs à prétendre que la réduction du paquet d'ondes quantique nécessite l'observation du résultat d'une mesure par un être conscient. Ici, nous combinons le paradigme expérimental de Schrödinger avec un système qui partage entre deux observateurs l'information relative à l'état quantique, de sorte qu'on peut enregistrer les résultats séparément sans qu'aucun observateur n'ait connaissance de l'état de l'événement quantique. Nos résultats impliquent que pour réduire la fonction d'onde quantique, l'opération de mesure seule suffit, sans observation consciente..

1 Introduction

When a measurement is made at a quantum level, the superposition of possible outcomes described by the quantum wave-function collapses into a definite, single state. The question of exactly what constitutes a measurement is unresolved, however, and represents the so-called “measurement

problem” of quantum physics [1,2]. In particular, if the measuring apparatus also is considered to be a quantum object, then its state is not fixed until a measurement is, in turn, made upon it; such an argument may continue *ad infinitum*. One solution, originally proposed by von Neumann [3] is that for wave-function collapse to occur, information from the measuring device must be observed by a conscious being: in J. A. Wheeler’s memorable phrase “No elementary phenomenon is a real phenomenon until it is an observed phenomenon” [4]. The argument has been developed particularly fully by Wigner [5,6], and continues to enjoy support from some authors [7-10].

The measurement problem is highlighted in Erwin Schrödinger’s hypothetical experiment in which a radioactive sample, if undergoing decay within a given period, triggers the release of a hammer that breaks a vial of hydrocyanic acid and so kills a cat [11]. The sample, the triggered device and the cat are in a sealed box. Taken as a complete system, the wave-function for the sample-device-cat contains a superposition in which the cat is both dead and alive. If conscious observation is required to collapse this wave-function, then the fate of the cat is not fixed until an observer opens the box. Alternatively, if conscious observation is not required, then the cat is either dead or alive before the box is opened. Most modern physicists probably would favour the latter alternative, invoking a non-linear, stochastic equation for the evolution of the wavefunction to explain why measurements can be made in the absence of a conscious observer [2]. It is not enough, however, for there to be a general change of consensus away from a theory of consciousness-based wave-function collapse; what is needed is an argument, or experiment, that makes it impossible rationally to believe it. Unfortunately, in the case of Schrödinger’s cat experiment, both the consciousness-based and consciousness-free interpretations of quantum measurement are indistinguishable to the observer outside the box. What is needed is a way of getting information out of the box, but without an observer being conscious of the quantum state that produced this information.

Here we describe an experiment, using a variant of Schrödinger’s paradigm, that does precisely this. The quantum detecting outcome is coded by two pieces of partial information that are supplied separately to two observers (Fig. 1). Neither piece alone enables the outcome to be known without opening the box, but taken together they do. This arrangement allows, therefore, an observer to observe a macroscopic state that is dependant upon a quantum state, as in Schrödinger’s paradigm, but *before* the quantum state is itself consciously appreciated. We can achieve this in one of two ways:

(i) *Autonomously*. The outcome is coded redundantly; observer A receives a message *purporting* to describe the outcome (e.g. “sample decayed” or “sample not decayed”) whereas observer B receives a message stating whether the message received by observer A is true or false.

(ii) *By intervention*. Observer A sets up the apparatus to give either a true or a false message about the decay event to observer B. Therefore, Observer A knows in advance whether the information given to observer B is true or false, but neither observer alone is conscious of the state of the quantum event. This method is easier to implement than the autonomous version, and was the one we chose for the investigation described in this paper.

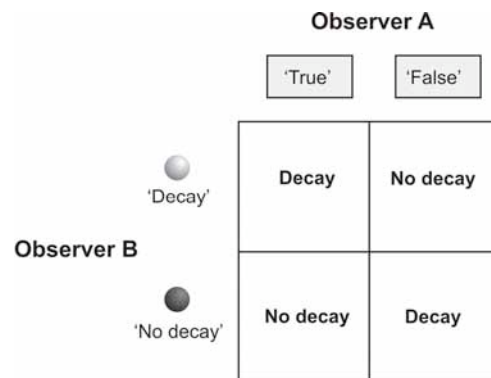


Figure 1. The principle behind the experiment. Information about the outcome of the quantum event is split between two observers. Observer B receives from the apparatus a ball whose colour purports to represent the outcome (red = ‘decay’ / black = ‘no decay’). But Observer A has previously set the apparatus up so that – with equal probability – the ball in fact provides either true or false information. Neither observer alone has enough information to know the actual outcome; together, they have complete knowledge of it.

2 Materials and Methods

A schematic representation of our apparatus is shown in Fig. 2. We used an electronic timer and Geiger counter to detect alpha particle released from a small sample of radium over a 0.19 second window. A decay event within the measuring window released the hammer in the chamber labelled “de-

cay”, whereas the absence of a decay event released the hammer in the “no-decay” chamber. A separate reset circuit released the unfallen hammer, if desired, thereby destroying the information about the decay event encoded by the hammers. The release of a hammer caused a ball to drop into an output box: if a decay event occurred, this was the ball loaded into the hole labelled “true”, otherwise the ball loaded into the hole labelled “false”.

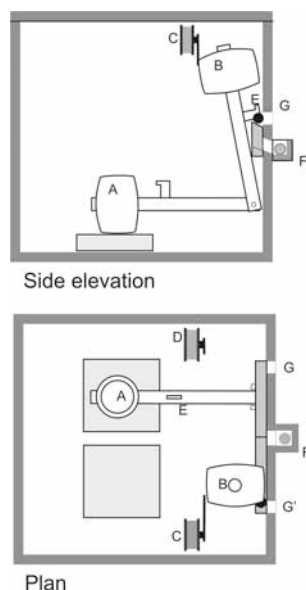


Figure 2. A schematic representation of the experimental box, as viewed from the side (upper panel) and from above (lower panel). A decay-event within the timed window triggered the solenoid D, releasing hammer A. In turn, this removed a baffle (E) and allowed a ball, previously loaded through hole G, to roll into the output box (F). Conversely, if no decay-event occurred within the timed window, solenoid C was triggered, releasing hammer B and allowing a ball, previously loaded through hole G', to roll into the output box. Hole G was labelled “True”, indicating that if a ball labelled “decay” was loaded in this hole, it would appear in the output box if a decay event occurred. Conversely, hole G' was labelled “False”. The box was opaque, but had a hinged lid to allow observation of the state of the hammers.

We shielded the Geiger counter and radium sample with lead to ensure that an average of 84% of decay events resulted from the radium sample,

rather than from background radiation, and that the probability of a decay event occurring in the 0.19 second recording window was 0.5 (Fig. 3). The Geiger counter was a Brown 150 (Mini-instruments, London), and the radium sample was the luminous face of a small clock. The electronic timer was a custom-built circuit, which was remotely triggered by a switch mounted in a different room. A reset switch, which released both hammers, was similarly remotely mounted.

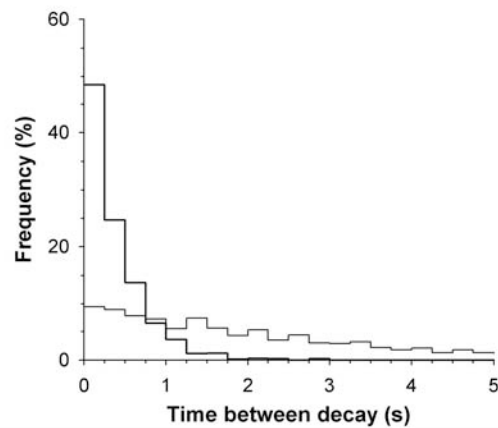


Figure 3. Decay histograms for the background (thin line) and for the sample-plus-background (thick line) conditions, based on 1000 measurements each. The output of the Geiger counter was sampled at 500Hz, and decay events separated by at least two samples detected automatically by a computer. The average number of events per second was 0.43 for the background and 2.64 for the sample-plus-background conditions.

To determine how to load balls into the box, we used “truth-cards” that were printed by a computer using a random number generator [12] seeded from the computer’s clock. In the main experiment, Observer B remained in an isolated waiting room (waiting room B) whilst Observer A loaded a ball labelled “decay” into either the “true” or “false” hole, depending upon a printed truth-card withdrawn from a sealed envelope, and loaded an unlabelled ball into the remaining hole. Observer A then exited the laboratory to a separate isolated waiting room (waiting room A), and remotely triggered the timed recording by the Geiger counter. After the recording, Observer B entered the laboratory and retrieved the ball from the output box. At this point in the experiment, the true nature of the quantum event is not known

by either observer, and can only be determined by a combination of the information known to Observer A and Observer B, as outlined in the truth-table in Fig. 1. Observer A then returned to the laboratory and, whilst observing his truth-card, asked Observer B to report which ball he was holding and looking at. It was only at this point that the information from Observer A and Observer B was combined, and that Observer A became conscious of the quantum state. Any change in the state of the truth-card (from “true” to “false”, or vice versa) or the ball (from labelled “decay” to unlabelled, or vice versa) was recorded. Observer B then opened the box, and compared the state of the hammers with the state predicted from the truth-card/ ball combination. We performed the experiment nine times, giving a probability of >0.99 that at least one repetition contained a decay event resulting from the radium source, rather than background radiation. We then repeated the experiment with the roles of Observer A and Observer B reversed. For all experiments, we used a continuous background of auditory noise that masked any sounds emanating from the box. We checked for any procedural errors (e.g. mis-loading of the box) by reviewing a videotape-recording of events at the conclusion of the experiment.

3 Results and Discussion

In all repetitions, we found that neither the state of the ball nor the state of the truth-card changed upon Observer A becoming conscious of the true output of the Geiger counter. In addition, the state indicated by the ball/truth-card combination always agreed with the state of the hammers within the box. Our results imply that an observer does not need to be conscious of the outcome of a quantum detection event in order for a quantum wavefunction to collapse.

A potential objection to the above experiment is that the state of the ball, and hence Observer B’s perception of the state of the ball, may exist as a superposition until such time as Observer A becomes conscious of the measurement result. Therefore, we designed an extra experiment to investigate this possibility. The experiment proceeded as described previously, save for the following changes. Observer A loaded only the ball labelled “decay” into the box, using either the “true” or “false” hole as determined by a coin toss (“true” = heads). Meanwhile, in waiting room B, Observer B performed a coin-toss to decide which state (heads or tails) would be used to represent whether a ball was present in the output box. It should be noted that such coin-tosses, although chaotic, are not quantum events and so have outcomes that are fixed. Observer B, after noting the presence or absence of a ball in the output box but not removing the ball, then remotely triggered the reset

circuit. This circuit destroyed the information encoded by the hammers in the box, thereby leaving the combined information possessed by the two observers as the only way of determining the quantum state. No videotape recording was made of the experiment. Observer B never revealed the outcome of his coin-toss to Observer A, however, thus if a superposition existed regarding the potential state of the ball it remained permanently uncollapsed. Such a superposition can be allowed to escape the confines of our laboratory by telling the reader that the state of the output box in the experiment was “heads”. Therefore, all readers of this article are now part of any superposition lingering in the experiment.

The fact that we can state a definite outcome, albeit coded, from the experiment is inconsistent with the presence of an uncollapsed superposition, however. Therefore, any explanation of our main experiment that requires a superposition involving both the boxed-system and one or more of the observers can be discounted. Our results are consistent with the idea that a measurement from the Geiger counter is sufficient to collapse the quantum state, most likely because the counter involves amplification processes that are irreversible [13]. Conscious perception of the outcome of a quantum measurement is not a prerequisite for the collapse of a quantum wave-function.

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