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The Dead-Alive Physicist Gedankenexperiment Debunked

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Abstract: We refute a recently proposed thought experiment namely the Dead-Alive Physicist (DAP) whose authors claim it to be the falsification of the von Neumann interpretation in Quantum Mechanics. We discover major misunderstandings and flaws in their model and our justification serves the purpose of disregarding further claims and assertions made in the paper at various stages. Thus, in yet another situation, it is proven that the formalism advanced by von Neumann is non-trivial and non-falsifiable.

Keywords: Quantum Superposition; Interpretations of Quantum Mechanics; State Vector Reduction; Measurement Problem; von Neumann Interpretation

1 Introduction

There has been various attempts to provide an explanation for the transition from a state of potentialities to a state of actuality in a quantum measurement. Each attempt, known as an interpretation, tries to address the problem from its own guiding principles [1-25]. Several interpretations exist in the literature ranging from the Copenhagen interpretation to QBism and several are being proposed as we speak, for instance a recent one by Nobel laureate Gerard 't Hooft which focusses on using conservation laws [26] [1]. Among these interpretations, two schools of thought exists between physicists and philosophers of physics regarding the existence of a quantum state, one is ontic (state of reality) and the other is epistemic (state of knowledge). An epistemic interpretation such as QBism (stands for quantum Bayesianism) can avoid the measurement problem totally, however, the Pusey-Barrett-Rudolph theorem, which is a no-go theorem, rules out the possibility of such an interpretation [29, 30]. Nevertheless, out of the so many quantum mechanical interpretations, one of the least supported and the one regarding which there are so many misconceptions is von Neumann's idea that the observer's consciousness is responsible for the collapse of the quantum wave function [31]. The Nobelist Eugene Wigner also supported this interpretation for a period of time [32]. Famous physicists in recent times who support this idea are Henry Stapp and Adrian Kent [33-36]. In [37] , the authors claimed to have empirically falsified the Consciousness Causes Collapse Hypothesis (CCCH) using delayed choice quantum eraser experiment [38]. However recently, researchers have strongly refuted their claims [39, 40, 41]. In [42], the basic ideas of CCCH has been employed to understand quantum paradoxes such as the measurement problem and the contrasting and conflicting behaviour of classical and quantum particles in a double-slit.

In this paper we focus our attention on another recent proposed thought experiment aimed at putting to rest the CCCH [43]. We show that the method employed by them contains several conceptual flaws and paradoxes which we believe, invalidates their proposal.

The paper is organised in the following manner. In section 2 we provide a brief mathematical treatment of the process of state vector reduction and also see what von Neumann's idea has to say about it. Then in section 3 we introduce the DAP thought experiment and provide a logical refutation of some of the key points propounded in the same. Finally, the paper is closed with some important conclusions.

[1] See also [27, 28]

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2 Collapse of The Quantum State Vector

Consider a quantum superposition state of the form,

$$|\Psi\rangle = \sum_{\zeta} |\zeta\rangle \langle\zeta|\Psi\rangle \tag{1}$$

It should be noted that the above state exists before any measurement has been made on the system. The above equation uses the identity operator $\hat{I} = \sum_{\zeta} |\zeta\rangle \langle\zeta|$ in some fixed orthonormal basis $\{ |1\rangle , |2\rangle , ..., |\zeta\rangle \}$ as follows:

$$|\Psi\rangle = \hat{I}\,|\Psi\rangle = \sum_{\zeta} |\zeta\rangle \langle\zeta|\Psi\rangle = \sum_{\zeta} (\langle\zeta|\Psi\rangle)\,|\zeta\rangle = \sum_{\zeta} a_{\zeta}\,|\zeta\rangle \tag{2}$$

where the quantum probability amplitudes have been set as, $a_{\zeta} = \langle\zeta|\Psi\rangle$. If we express the quantum state $|\Psi\rangle$ explicitly in the basis $\{ |1\rangle , |2\rangle , ..., |\zeta\rangle \}$, it is obtained as,

$$|\Psi\rangle = \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_{\zeta} \end{pmatrix} \tag{3}$$

Now the probability of each possible value of the variable ζ being measured is given by the Born rule as,

$$P(\zeta) = \langle\Psi|\,\hat{\mathbb{P}}\,|\Psi\rangle = \langle\Psi|\zeta\rangle \langle\zeta|\Psi\rangle = a_{\zeta}^{*} a_{\zeta} = |a_{\zeta}|^2 \tag{4}$$

An explicit computation of the same can be done using matrix multiplication,

$$\begin{pmatrix} a_1^{*} \; a_2^{*} \; \dots \; a_{\zeta}^{*} \end{pmatrix} \begin{pmatrix} 0 \; 0 \; \dots \; 0 \\ 0 \; 0 \; \dots \; 0 \\ 0 \; 0 \; \ddots \; \vdots \\ 0 \; 0 \; \dots \; 1 \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_{\zeta} \end{pmatrix} = |a_{\zeta}|^2 \tag{5}$$

As soon as the measurement yields the outcome ζ, the state vector reduces to a new state given by,

$$|\Psi\rangle \rightarrow \frac{\hat{\mathbb{P}_{\zeta}}\,|\Psi\rangle}{\sqrt{\langle\Psi|\,\hat{\mathbb{P}_{\zeta}}\,|\Psi\rangle}} \tag{6}$$

where the state has been normalized. In simple terms it means that after the collapse the state is with absolute probability (equal to 1) in the eigenstate $|\zeta\rangle$ of the projection operator $\hat{\mathbb{P}_{\zeta}} = |\zeta\rangle \langle\zeta|$ and belonging to the eigenspace $\mathbb{V}_{\zeta}$. Note that although the state in eq. (6) is normalized, it has an extra pure phase factor,

$$|\Psi\rangle \rightarrow \frac{\hat{\mathbb{P}_{\zeta}}\,|\Psi\rangle}{\sqrt{\langle\Psi|\,\hat{\mathbb{P}_{\zeta}}\,|\Psi\rangle}} = \frac{1}{|a_{\zeta}|}\hat{\mathbb{P}_{\zeta}}\,|\Psi\rangle = \frac{1}{|a_{\zeta}|}\begin{pmatrix} 0 \\ 0 \\ \vdots \\ a_{\zeta} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ e^{i\theta} \end{pmatrix} \tag{7}$$

with the phase factor being computed using the knowledge of polar form of complex numbers viz. $a_{\zeta} = re^{i\theta}$ where $r = |a_{\zeta}|$ and θ is the counter-clockwise angle from the real axis, in the following manner,

$$\frac{a_{\zeta}}{|a_{\zeta}|} = \frac{re^{i\theta}}{r} = e^{i\theta} \tag{8}$$

Thus we have a well defined state vector before the measurement, $|\Psi\rangle$, and a well defined state vector after the measurement, $|\zeta\rangle$. Unambiguously, the quantum reduction of the state vector can be represented by $|\Psi\rangle \rightarrow |\zeta\rangle$ or $\sum_{\zeta} a_{\zeta}\,|\zeta\rangle \rightarrow |\zeta\rangle$. This is the essence of what happens when a quantum mechanical state vector collapses to a new state. Now from the perspective of the CCCH, the collapse shouldn't take place unless a conscious observation is made. The above point is something which should be quite obvious. Each possible element of a superposition state is known as soon as the parameters are known and one can write down the mathematical form of the state which is nothing but the linear combination of the known elements in a particular basis. However, one never observes a superposition of any kind. Physically, the observer would find the system in a single definite eigenstate. The boundary that separates an un-observable superposition state and the observed eigenstate is a measurement which can be made either by a measuring device or a conscious observer or even by both in succession. The superposition would never actually get destroyed for an observer unless it is registered in his consciousness. This is also the solution to the measurement problem specified by this interpretation.

3 The DAP Experiment

We first discuss briefly the main points of the proposed experiment and then provide our response to the claims made in the paper. The setup involves a physicist inside a sealed room. On the ceiling a photon source L has been attached and scheduled to emit a single photon at a certain time and is followed by a beam splitter BS, vertically in line with the photon source. Two photo-detectors D and D' are fixed beyond the beam splitter and the efficiency of both of them is supposed to be 100%. D is located along the path of the photon and is fixed on the top of a box. D and D' have an angular separation of 90 °. Inside the box there is a hammer and a glass flask containing a fatal gas called LGD. The emitted photon from L would be in a state of superposition after reaching the beam splitter BS, given by the following equation

$$|\Psi\rangle_{Photon} = \left(\frac{|T\rangle + |R\rangle}{\sqrt{2}} \right) \tag{9}$$

where the kets $|T\rangle$ and $|R\rangle$ represent the transmitted and the reflected parts of the photon wave function respectively. The experiment is supposed to be working in the following manner: Photon reaches detector D$\rightarrow$ Hammer gets activated$\rightarrow$ Flask breaks down and gas is released$\rightarrow$ the physicist dies. If D gets activated, the physicist results into the state $|Dead\rangle$ and if D' gets activated the end result is the state $|Alive\rangle$. The experiment has been formulated along the similar lines as that of the Schrodinger's cat scenario. Where the latter relies upon the radioactive decay of atom, the former depends on the probabilistic behavior of the photon. The crux of the matter in [43] is however the introduction of CPB strategy which distinguishes it from the Schrodinger's cat (and all concomitant experiments) and its interpretation by the authors is also the prime reason which leads the authors to the faulty claim that their *gedanken* experiment falsifies the von Neumann postulation. This would be justified in a while from now.

The strategy requires that the physicist drugs himself with a Conscious Perceptions Breaker (CPB) so that he is not able to watch the experiment directly and is unconscious throughout the course of the experiment. The physicist comes back to his normal experience only at 1:00 PM. The state during the course of the experiment, i.e. between 12:00 - 1:00 PM is formulated in [43] as the following,

$$|\Psi\rangle_{System} = \left(\frac{|T \rightarrow D \rightarrow Dead\rangle + |R \rightarrow D' \rightarrow Alive\rangle}{\sqrt{2}}\right) \tag{10}$$

Note that we have modified the mathematical presentation of equations (9) and (10) from the original for clarity.[2] The state $|Alive\rangle$ is actually an unconscious state [44]. At this moment there is entry of another person called W (supposedly playing the role of Wigner from the Wigner's Friend). It has been stated in [43] that W is a supporter of the CCCH and her intention is to open the room at 1:30 PM inorder to check whether P is dead or alive, while taking the necessary precautions by wearing a gas mask. Two possible outcomes have been listed by the authors as a result of this action which would be elaborated later on. In the subsection following this, we re-examine the claims of [43] and classify them as consistent and inconsistent. Moreover, we justify why they are inconsistent.

3.1 Accurate and Erroneous Conclusions of The DAP Analysis

While reading the paper on the DAP experiment we discovered that some of the statements made by the authors are infact correct and surprisingly, in support of the CCCH and on the other hand there were claims which were found to be quite inconsistent.

*The authors rightly point out that on the occasion that the CPB were not used, P's consciousness would cause the collapse of the wave function as soon as P has become aware of whether he was bound to die or to survive.

*The authors do accept the fact that in a quantum physics experiment the observer has to perform a necessary measurement/observation inorder to gain knowledge about the state of the system and that in this case consciousness is transitive and plays an active role on the surrounding physical environment.

The above points seem to be accurate enough and coherent with the principles of the CCCH. However, the authors write that since they have introduced the concept of CPB in their formulation, the observer plays a passive role and the above facts do not fit the logic of the DAP experiment and hence it falsifies CCCH.

Considering that the CPB strategy is legitimate, according to us one is mistaken if he/she considers that the strategy falsifies the CCCH. This is so because there is an interpretational flaw with this reasoning. Let us consider what the CPB is actually doing to the physicist. For that we need to understand briefly, the two differentiable states of consciousness. One is the basal state which corresponds to pure awareness and the next one is cognitive awareness which is basically a derivative of the basal state and it also involves memory, differentiation, conceptualisation etc whereas the former is free of all these properties [45, 46].

So when the physicist is exposed to the CPB, it actually affects the latter state which is the cognitive awareness whereas the fundamental state is untouched which means consciousness is not really lost, only some of its derived properties are. What CPB really does is that it results in the loss of the memory and conceptualisation ability of the physicist.[3] This is a strong point which we believe can invalidate their entire hypothesis since it is primarily based on concepts which are not well understood in the first place and are debatable.

Moving ahead, they state (which we are quoting exactly as in the paper),

> "In fact P, as soon as conscious at 1:00 PM, is neither in the same situation of the observer who deliberates to open the Schrödinger's box for verifying the state of the cat nor in the same status of attentiveness of Wigner's friend when checking whether he did perceive a flash or did not."

The above is another point which is agreeable with the authors of [43] and is quite apparent considering our

[2] Equation 2 of [43] (which is eq. 10 in this paper) is mathematically erroneous. So the equation I wrote in a previous draft also had an error. I thank the anonymous referee for pointing this out and suggesting the correction.

[3] Perhaps this also instigates us to rethink some of the terminologies that we have labelled to concepts such as "consciousness", "unconscious" , "memory" etc (Look at [47] for a good deal on consciousness and memory and at [48] for a novel unified approach to understanding space, memory, consciousness etc and its interrelationships). Obviously our description and justification needs to be elaborated but it is not possible for us to provide a detailed description of the difference between consciousness and memory in this article and it should be a matter for a future article focusing on this issue.

justification of the previous point. One cannot expect the physicist to be in the state as quoted above since he was under the effect of CPB during the course of the empirical test.

Earlier we noted that two possible outcomes were listed in [43] as a result of W entering the framework. According to the first outcome W would find P in the state $|Dead\rangle$ and would conjecture that it was her own act which caused the collapse of the wave function from the superposition state $|\Psi\rangle_{Physicist} = \frac{\alpha|Dead\rangle+\beta|Alive\rangle}{\sqrt{2}}$ to the definite eigenstate $|Dead\rangle$. On the other hand, the second outcome expresses that W would find P in the state $|Alive\rangle$ and would enquire him about the experiment, to which P's response is that he is conscious from the past half hour. W then concludes that the wave function collapse occurred at sharp 1:00 PM, thus removing the dead state from the superposition but the authors write that W's conjecture is wrong because W mistakenly believes that the emergence of P's consciousness and the collapse of the wave function are distinct processes whereas according to the authors Roselli and Stella, only one event is taking place at 1:00 PM and that is, P realizing that he is alive.

We would like to throw some light on this point and flesh out the ideas in a more explicit way than Roselli and Stella. First of all we need to accept the fact that when two or more observers are involved in the same experiment entailing a superposition state, the collapse of the wave function would happen at different instances for different observers due to their independence from each other, unless there is some sort of instantaneous communication between them. In this case, W and P lack any communication channel prior to their interaction at 1:30 PM. Taking these points into consideration, W is right when she states in the first outcome that it was her own act of conscious observation which collapsed the wave function but exclusively only for herself (W would know later than P whether the photon hit detector D or D' and hence the wavefunction would collapse for W after P regains his original state). That is, the wavefunction collapses at different moments in different observers' reference frames. Roselli and Stella also seem to indicate that it would be "solipsistic" for W to believe that her consciousness caused the wavefunction collapse. It is perhaps explicit that our explanation solves the problem of solipsism hence their implication is ill founded over here.

Luckily, the above discussion is essentially based on known features of quantum mechanics. For instance, consider Alice and Bob, take measurements of non-commuting observables A and B on the same system, but Alice measures A then B, while Bob measures B then A. Then at the end of this, the system is an eigenfunction of B for Alice, but an eigenfunction of A for Bob. Thus the same wavefunction collapse can't be compatible for both and therefore measurement outcomes significantly depend on each individual observer's reference frame. Similarly in the second outcome, the physicist didn't know whether the photon hit detector D or D' (because of the CPB effect) and hence for him there would be a superposition of the macroscopically distinct states in some corner of his mind (P would have the superposition state in his mind even before drugging himself with CPB since there are only two possibilities, $|Dead\rangle$ or $|Alive\rangle$). As soon as P regains his original state slightly later than 1:00 PM, the quantum superposition now reduces to the state $|Alive\rangle$ for him.

The authors of [43] write at the end of section 4 that the physcist is now certain that the emergence of his consciousness can't be responsible for the collapse of the waveform and the emergence must have been the effect resulting from the collapse occurred reasonably when D' received the photon. It is perhaps understandable that they have written so because P ultimately ends up being alive. The only other possibility is that P would have been dead and this could only happen if D would have registered the photon. However it is important to clarify here that the wavefunction doesn't "collapse" until an observer is involved so it couldn't have collapsed at the time either D or D' receives the photon since there is no one present in the room between 12:00-1:30 PM other than P who unfortunately is also under the effect of CPB.

At this point it is important to highlight that Roselli and Stella have also made a paradoxical conclusion at the end of section 4 of their paper according to which P's consciousness emerges as an effect of the wave function collapse as well as the CPB reaction fading away.[4] It is difficult to see how they could both be consistently true as the logic suggests that the CPB reaction fades away which results in P becoming conscious and which ultimately collapses the wavefunction for P. So P's consciousness emerges essentially because the reaction has gone and the collapse only occurs a few moments after this (specifically for P).

However, it is also difficult for us to ignore the fact that cause and effect are intimately related in this case. The wavefunction reduction cannot happen without P returning to consciousness and equally, until the wavefunction reduces, P is in a superposition state so he cannot identify himself as truly conscious until this occurs. Thus it is another paradox which brings about the inherent inconsistency. The anonymous referee helps demonstrate this quite elegantly in the review report, which I reproduce here in my own language. Consider two outcomes – 1) measurement by P at 1:00 PM (of his state), 2) No measurement at 1:00 PM. According to the first possibility, P returns to consciousness at 1:00 PM and confirms that he is alive. Now considering the second possibility, no measurement takes place at 1:00 PM, hence the waveform does not collapse, so P remains in a quantum superposition at 1:00 PM, and obviously continues to be in the same thereafter. However, one of

[4] Thanks to the anonymous referee for bringing this into my notice.

the possibilities in the superposition is that the photon hits D' at 12:00 PM. This means P returned to consciousness at 1:00 PM (after the CPB effect is terminated), thereby performing the measurement. This is in contradiction with the supposition that no measurement takes place at 1:00 PM, so the state cannot be in superposition after 1:00 PM. We clearly have a major inconsistency coming up here.

Finally, we have addressed more or less all the necessary claims and have expressed the inconsistencies in the proposal by Roselli and Stella. We discovered some major errors made in the formulation of the DAP thought experiment and provided the justification for the same. This directs us to the only cessation that the model propounded in [43] fails to falsify the von Neumann premise.

3.2 Evidences in favour of CCCH

In this section we will touch briefly upon the existing evidences in the scientific literature that suggest or atleast support, in some way or the other, the active role played by consciousness in the quantum mechanical measurement and collapse process. For keeping this section short, we will only cite some instances from one particular reference which seems to be significant enough and accurately contains what we require to justify here. A more comprehensive account is beyond the scope of this article and would be presented elsewhere.

In [49], Chalmers and McQueen present an idea that coherently integrates a mathematical theory of consciousness called integrated information theory with a form of quantum collapse dynamics called Continuous Spontaneous Localization (CSL). The authors have argued that CCCH is empirically testable and have presented the idea in a way that it signifies the non-triviality of the same. Quoting them [49],

> "Crucially, when different precise theories of consciousness are combined with the consciousness-collapse view, these yield subtly different experimental predictions. As a result, we have a further motivation for taking consciousness-collapse interpretations seriously: they can be tested experimentally. As we discuss in section 7, there is a long-term research program of experimentally testing consciousness-collapse interpretations and eventually supporting a precise consciousness-collapse interpretation. The required experiments are difficult, but advances in quantum computing may already exclude certain simple consciousness-collapse interpretations. Because of these considerations, the under-determination of conditions for consciousness does not reflect any fundamental imprecision in consciousness-collapse views. It simply reflects an experimentally testable degree of freedom".

Section 7 of [49] particularly emphasizes on the existing and potential experimental tests on the consciousness-collapse hypothesis. The authors have described proposals based on two categories, fast-collapse models and slow collapse models. To put it simply, fast-collapse models are those on which large superpositions of an observable are rare and in slow-collapse models, large superpositions are common. The authors have also expressed the suitability of fast-collapse models over slow-collapse models for the consciousness-collapse hypothesis. Quoting them on this [49],

> "Still, where consciousness-collapse models are concerned, fast-collapse models are arguably preferable to slow-collapse models, as the latter allow that large superpositions of conscious states are common."

> "The consciousness-collapse thesis (in fast-collapse versions) tends to fit more comfortably with non-panpsychist views on which consciousness arises only in relatively complex systems. These views are consistent with existing and likely near-term-future observations, while still being subject to experimental test eventually."

The section 7 of their paper goes on to describe some more empirical tests for the consciousness causes collapse hypothesis including those requiring quantum computation.

4 Conclusions & Discussion

von Neumann's interpretation, just like any other formulation of quantum mechanics provides solution to the issues encircling the foundations of quantum theory. Although there have been instances where proposals were made claiming its falsification but to the contrary it has hopefully passed them. There are two categories of physicists who criticize this interpretation, the first category are those who do not provide the basis on which they make the judgement and the second category consists of those who actually come up with empirically testable models. For the former, we can attribute Stapp's thought on this on why the critics do so [33]. According to him, physicists are generally quite hostile towards ideas which have metaphysical variables associated with them. However, many other interpretations of quantum mechanics such as Everett's interpretation and de Broglie-Bohm theory involve such variables which are currently beyond the scope of testable mainstream physics (in particular the former requires the concept of parallel universes and the latter requires an infinite dimensional universe without a clear mechanism of how it leads to a three dimensional universe in our perception). Consequently, it would perhaps be not wise for one to reject ideas simply because they are not yet testable or not yet in everybody's knowledge. Coming to the second class, the testable models they offer have suffered severe refutation on grounds that they contain several misconceptions and flaws, such as [37].

In physics, we can't prove any theory. We can only verify it to a more accurate precision but we can nonetheless disprove a theory through repeated experimental tests. A proposed model can also be refuted by finding logical and conceptual incompatibility in its fundamentals and we believe that [43] belongs to similar category. However, the authors should be commended for coming up with this thought experiment (which is interestingly a new version of such type of existing *gedanken* experiments in the literature) as it bestows a yet another testing ground for the theory and would only strengthen the von Neumann interpretation.

Finally it should be noted that every theory in physics has its proponents and critics and similar is the case with CCCH. We are definitely not saying that CCCH is the best theory out there but certainly it is a non-trivial interpretation which does reveal many important aspects of the interactions of a quantum system and as argued in [49], consciousness-collapse interpretations are a research program that are certainly worth pursuing which can help improve them to a higher level of precision. It is also important that the interpretation is considered in the same category as other interpretations of quantum mechanics without being biased and which is also the main motive we have conveyed through this paper by debunking the DAP proposal.

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