Can an Experiment with Delayed-Choice Quantum Erasers and Time Crystals show evidence of a Multiverse?

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Abstract

A short and informal essay proposing a modification to the delayed-choice quantum eraser experiment by including time crystals as an additional feature. The possible results or outcomes are considered including speculations on possible applications and philosophical interpretations. A proposed experiment using two observers at three points in time and a bank of delayed-choice quantum erasers each linked to a time crystal might either show we live in a multiverse, possibly send messages back in time, or redefine or even refute the current understanding of the nature of time crystals. The hope is that this proposal can help the debate over the nature of the delayed-choice quantum eraser experiment and help further clarify the nature of time crystals and even the role of conscious observers in quantum eraser experiments.

Keywords: delayed-choice quantum eraser, time crystals, multiverse, experiment.

"Time is the cruelest force of all."
-- Cixin Liu, Death's End

"Time, time, time
See what's become of me
While I looked around for my possibilities…
Seasons change with the scenery
Weavin' time in a tapestry
Won't you stop and remember me?"
-- Paul Simon lyrics, Hazy Shade of Winter

"Time is but memory in the making"
-- Vladimir Nabokov

The experimental demonstration of time crystals at various major laboratories has recently been achieved in a remarkable technological leap from theory to reality.[1] This has led to speculations about their application in the booming and competitive Quantum Computing space. However, perhaps, another application or experiment is not only easier to achieve, but potentially more essential to the future of mankind.

Time crystals are “a novel phase of matter that physicists have strived to realize for many years, a time crystal is an object whose parts move in a regular, repeating cycle, sustaining this constant change without burning any energy.”[2] “Time crystals are also the first objects to spontaneously break time-translation symmetry, the usual rule that a stable object will remain the same throughout time. A time crystal is both stable and ever-changing, with special moments that come at periodic intervals in time.”[2] In addition, a research group in 2021 claimed to have created a time crystal in a diamond.[3]

Another remarkable experiment and theoretical achievement related to Quantum Mechanics is the delayed-choice quantum eraser (DCQE) experiment that evolved from the original quantum eraser proposal from John Wheeler.[4] The online encyclopedia Wikipedia has a useful high-level summary:

> The delayed-choice quantum eraser experiment investigates a paradox. If a photon manifests itself as though it had come by a single path to the detector, then "common sense" (which John Wheeler and others challenge) says that it must have entered the double-slit device as a particle. If a photon manifests itself as though it had come by two indistinguishable paths, then it must have entered the double-slit device as a wave. Accordingly, if the experimental apparatus is changed while the photon is in mid-flight, the photon may have to revise its prior "commitment" as to whether to be a wave or a particle. Wheeler pointed out that when these assumptions are applied to a device of interstellar dimensions, a last-minute decision made on Earth on how to observe a photon could alter a situation established millions or even billions of years earlier. While delayed-choice experiments have confirmed the seeming ability of measurements made on photons in the present to alter events occurring in the past, this requires a non-standard view of quantum mechanics. If a photon in flight is interpreted as being in a so-called "superposition of states", i.e., if it is interpreted as something that has the potentiality to manifest as a particle or wave, but during its time in flight is neither, then there is no time paradox.[5]

There exists a large philosophical debate over the interpretation of the results of the delayed-choice quantum eraser. Many scientists believe that the Hugh Everett “Many Worlds” or multiverse theory easily explains the experiment’s apparent paradox while others believe that the consistency of the “rules” of Quantum Mechanics supersedes human concepts like locality or even time (e.g., time asymmetric interpretations[6]) and that Quantum Mechanics thus can use retrocausal (backwards in time) actions or messages if needed to ensure consistent histories and to avoid any causal or logical paradoxes. These proponents believe that the DCQE experiment literally demonstrates retrocausal behavior. Retrocausality, or backwards causation, is defined as “a concept of cause and effect in which an effect precedes its cause in time and so a later event affects an earlier one - in quantum physics, the distinction between cause and effect is not made at the most fundamental level and so time-symmetric systems can be viewed as causal or retrocausal[7].” Physicist and author Sean Carroll describes in detail this debate in the September 21, 2019, entry of his online blog Preposterous Universe called *The Notorious Delayed-Choice Quantum Eraser*:

> The electron is simply part of the wave function of the universe. It doesn't make choices about whether to be wave-like or particle-like. But a number of serious researchers in quantum foundations really do take the delayed-choice quantum eraser and analogous experiments (which have been successfully performed, by the way) as evidence of retrocausality in nature - signals traveling backwards in time to influence the past. … To an Everettian, the result makes perfect sense without anything traveling backwards in time. The trickiness relies on the fact that by becoming entangled with a single recording spin rather than with the environment and its zillions of particles, the traveling electrons only became kind-of decohered. With just a single particle to worry about observing, we are allowed to contemplate measuring it in different ways. If, as in the conventional double-slit setup, we measured the slit through which the traveling electron went via a macroscopic pointing device, we would have had no choice about what was being observed. True decoherence takes a tiny quantum entanglement and amplifies it, effectively irreversibly, into the environment. In that sense the delayed-choice quantum eraser is a useful thought experiment to contemplate the role of decoherence and the environment in measurement. But alas, not everyone is an Everettian. In some other versions of quantum mechanics, wave functions really do collapse, not just the apparent collapse that decoherence provides us with in Many-Worlds. In a true collapse theory like GRW (Ghirardi–Rimini–Weber theory)[8] the process of wave-function collapse is asymmetric in time; wave functions collapse, but they don't un-collapse. If you have collapsing wave functions, but for some reason also want to maintain an overall time-symmetry to the fundamental laws of physics, you can convince yourself that retrocausality needs to be part of the story. Or you can accept the smooth evolution of the wave function, with branching rather than collapses, and maintain time-symmetry of the underlying equations without requiring backwards-propagating signals or electrons that can't make up their mind. [9]

So, in our modern world with experimental apparatus as described that are sensitive enough to create time crystals and to perform delayed-choice quantum eraser experiments, could an experiment be conducted to show that we live in a multiverse or not? Otherwise, could an experiment actually send messages back in time or redefine, or even refute, the very definition of a time crystal? Consider this variation to the delayed-choice quantum eraser experiment.

We start with a bank of DCQEs – in our simple example there are four separate DCQEs where each is linked to its own time crystal via a sensor. The sensor, upon identifying a wave interference pattern output (where the "which path" information for photons are not known or have been erased), activates the time crystal in a supercomputer. Note we also could setup the experiment where, once "which path" information is known (causing the superposition to collapse in the DCQE), the sensor or trigger, via the final screen pattern where no interference patten is observed, then activates or creates the time crystal. Each time crystal, when activated, lights up an LED of a letter, like the letters of the name "BOB," otherwise they are simply "XXXX." For our discussion, in the future our observer Alice, who setups up the experiment, will never observe the LED letters and our observer Bob will only observe the LED letters but never the actual quantum eraser output.

At some point in the future, say on DAY 3, after the experiment has been created on DAY 1, our observer Alice will make the choice to "open the box" of the experiment and, in our experiment, erase "which path" information by inserting a beam-splitter into each of the four DCQE experiments, thus creating an interference pattern in her present and, in theory, also in the past for each DCQE experiment. One can consider this experiment with our DCQEs in a concealed box similar to the classic Schrodinger's Cat scenario where the lack of a decision or observation to "look in the box" keeps the experiment in a theoretical quantum mechanical *superposition* state until our later time in the future when Alice acts to "look in the box" and chooses to create the interference pattern.

However, in our experiment, the quantum eraser is not the direct trigger of the LED letters but, rather, the time crystals are. The time crystal, upon activation is a structure that is symmetric in time and thus exists, in theory, in the present and in the future – symmetry in time – theoretically immediately upon its creation. Thus, when a future act on a quantum eraser (the "delayed choice" act) collapses the experiment and thus causes the interference pattern on the screen to be observed, there is no longer any superposition of the screen however the activation of the time crystal "should" be set for that present moment and the future - immediately! In essence, it would be a goal of the experiment to confirm this occurs. If the time crystal's effect is actually instantaneous into the future, then there could be paradoxical situations that could help us prove which possible theory of a quantum reality we exist in.

The experiment can be explained better by separating the event timelines (T0, T1, T2) into a day 1, day 2, and day 3 diagram.

On DAY 1, Alice builds the experiment with four banks of DCQE each linked to its own time crystal. Only Alice knows which DCQE connects to which of the time crystals to further "hide" any possible "which path" information that Bob might be able to deduce by seeing the output of the LED letters as we want Bob to only observe the LED letters and never the actual DCQE output directly. The four LED letters are XXXX upon the experiment's initial T0 creation (Figure 1).

On DAY 2, Bob does not look into the box of the experiment, he only looks at the screen of four LED letters. In theory Bob will see the letters "BOBX." In this initial T1 timeline Bob does not talk to Alice yet (Figure 2).

On DAY 3, Alice decides to collapse the experiment superposition that, in theory, should still exist (at least for her) and thus her *delayed choice* on DAY 3 collapses the experiment into screen output of an interference pattern in the present for Alice and, in theory, in the past - although that can never be known by only the DCQE output alone. That activates the sensor and the LED letters "BOBX" can be seen on DAY 3 - but let's assume Alice does not even look at the LED letter output - although it should still be XXXX until she makes the delayed choice. Alice is not aware of anything Bob has done in the past on DAY 2 (Figure 3).

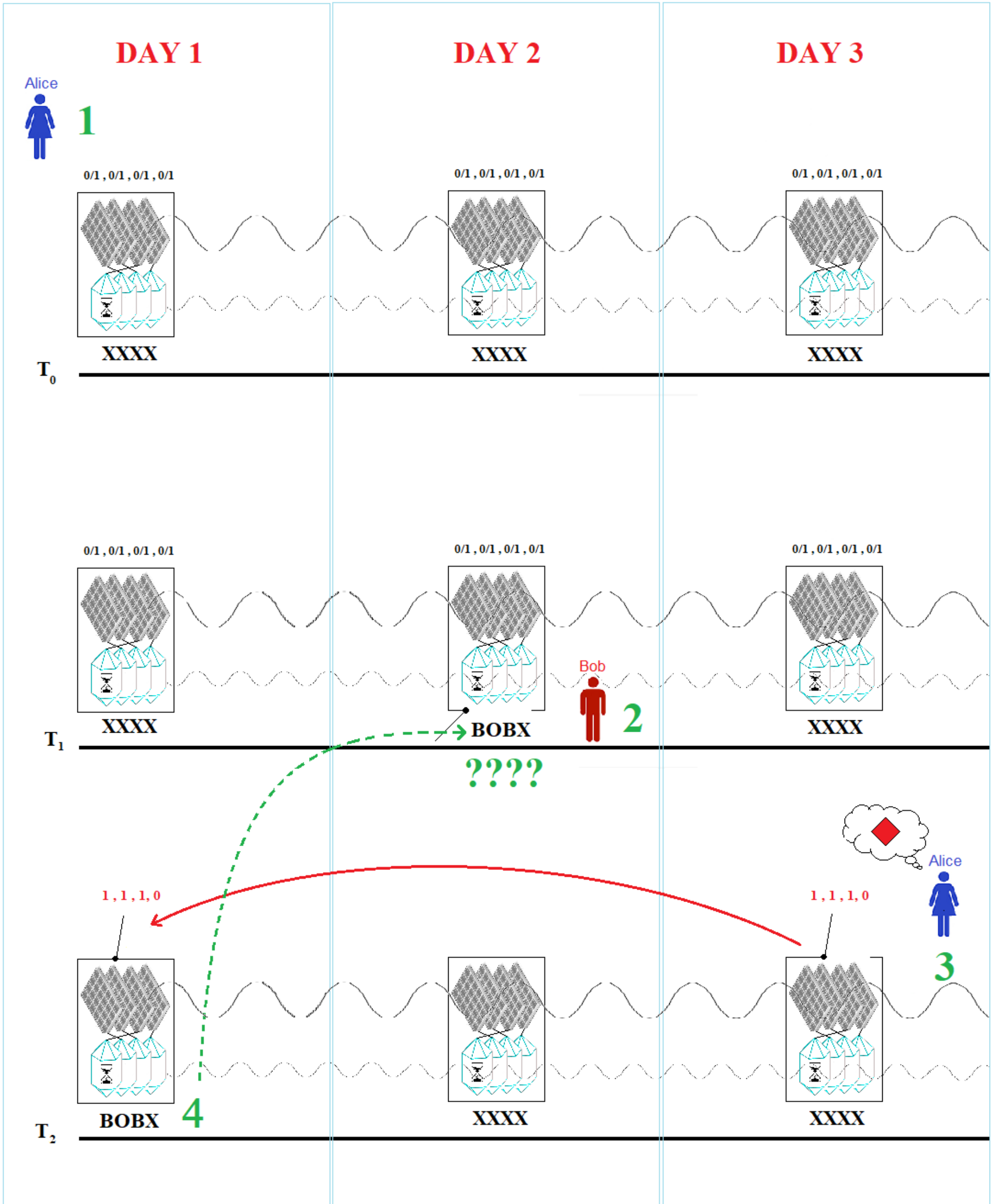


Figure 1. The proposed experiment could possibly send messages back into time i.e., a retrocausal solution.

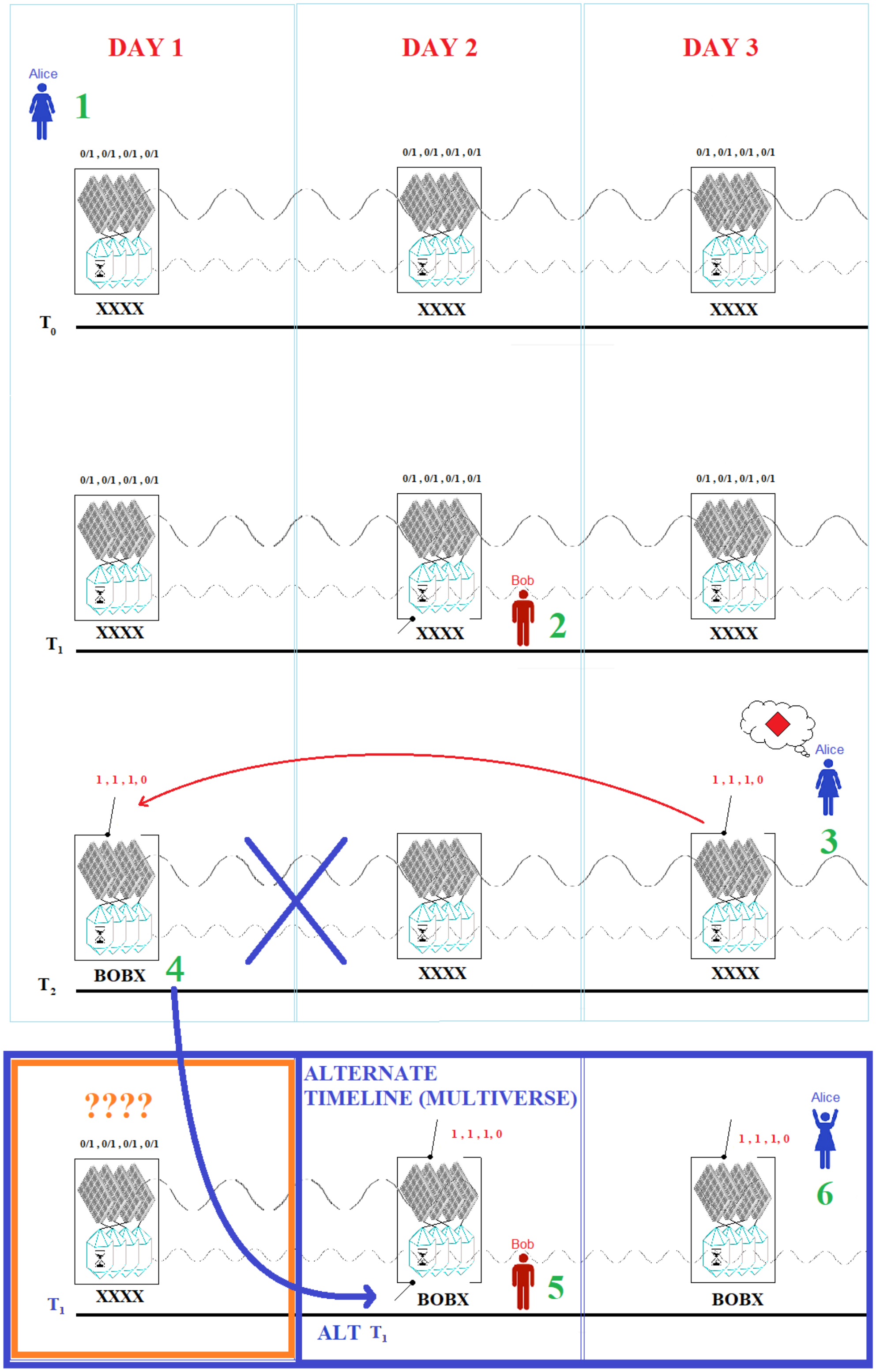


Figure 2. The experiment could prove the existence of an Everettian or Deutsch Multiverse.

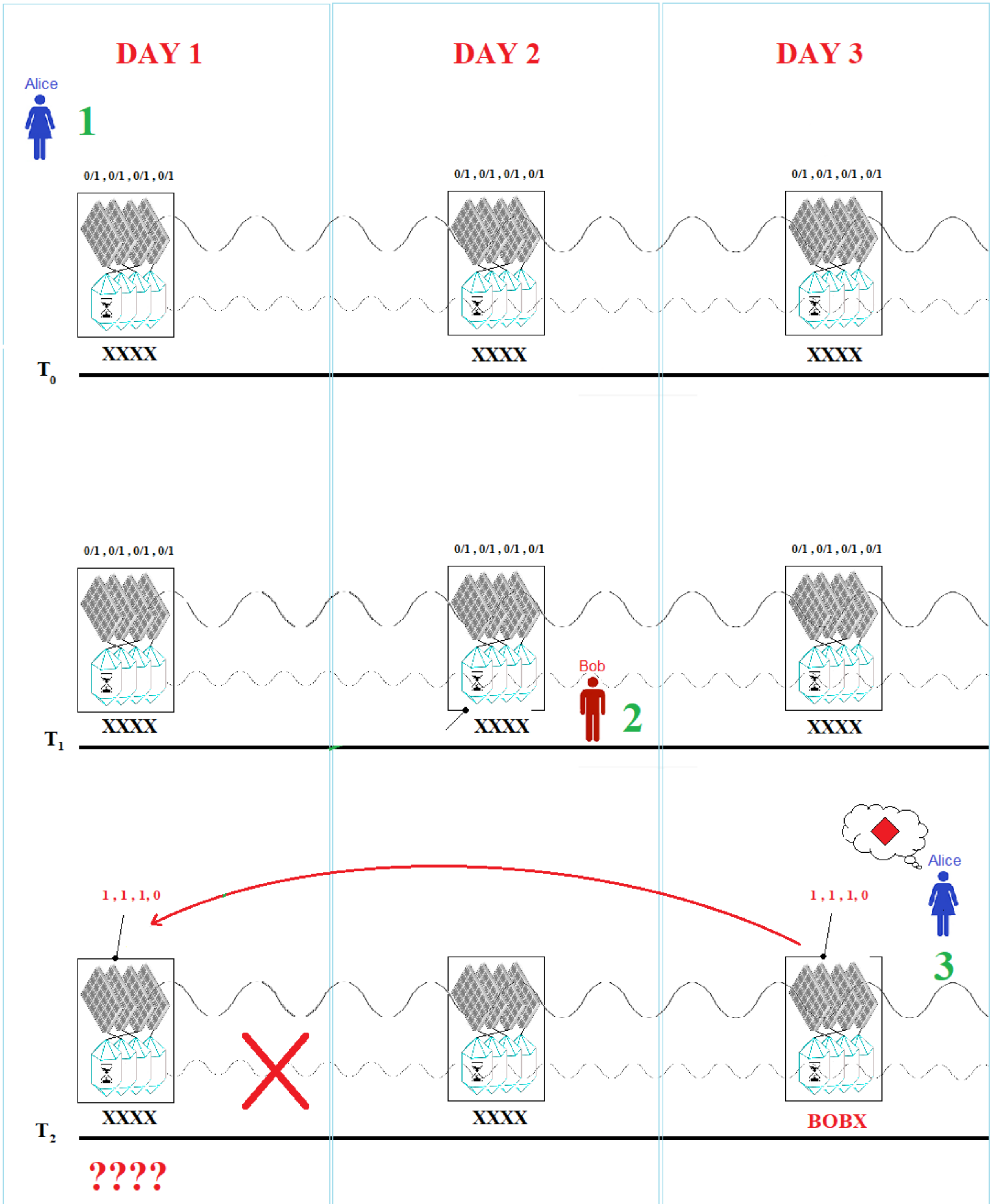


Figure 3. The experiment may show that the role of time crystals requires clarification or limitations.

Bob on DAY 4 will then inform Alice that he saw the letters “BOBX” on the LED screen on DAY 2. In this scenario, Alice has sent a message back in time to Bob, thus creating a paradox. The key assumption on the experiment is that the reality or choice of Alice on DAY 3 effects the entire history of the experiment thus changing the DCQE screen output even back to DAY 1, that Alice can never go back into time and confirm, and the DCQE has no way to leave a record of its change in the past relative to Alice on DAY 3. Here is the major assumption of the experiment where the time crystal, however, can leave a record in the past of this change by its assumed immediate ability to create a symmetry or “long-range interaction” relationship with the future via its future self being immediately in existence.[10] The other assumption is that Bob will see “BOBX” and not “XXXX” and that this does not automatically separate Bob from Alice into his own separate “branch” or universe in a multiverse.

If we logically assume that this creates a causal paradox, then how can we explain this if this turns out to be an actual physical result or outcome of actually running this experiment? Here we are drawn to the Hugh Everett multiverse or “alternate timeline” solution.[11] Here, in essence, a larger “reality space” of multiple universes exists where Bob either branches off upon his observation (the universe splits) or he enters a new universe or timeline that already exists - a la David Deutsch’s multiverse where there is also already a parallel DAY 1 that exists in a different parallel Universe (Figure 4) and, thus, to avoid the casual paradox, the only way Bob can see “BOBX” is if he exists in a new reality that cannot change or prevent the action of Alice on DAY 3 or prevents Alice from sending information back in time in her universe as seen in Figure 2.

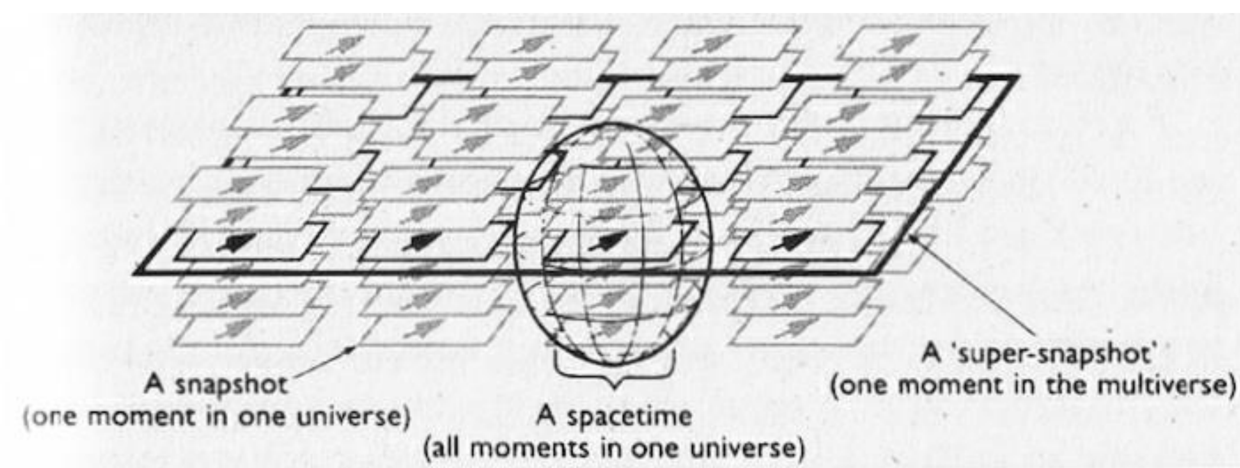


Figure 4. Time is represented as a sequence of moments in a David Deutsch multiverse with the multiverse being a collection of interacting spacetimes[12]. Source: *The Fabric of Reality* by David Deutsch.

Note that if Bob is able to receive messages from Alice from DAY 3, then here we also have a potential test to see if Bob is possibly in a multiverse or "alternate timeline." Alice can message Bob that on the morning of DAY 3 the three winning horses in a race were H, J, and K. If Bob then, once he bets on the same race on the morning of DAY 3 does not see the same outcome, then Bob's receiving of information from Alice has apparently changed his timeline and thus he has likely branched into an alternate future versus theoretically changing a "the future" as where did Alice ever see the H, J, and K results.

One can also speculate, akin to “Wigner’s friend”[13] and Schrodinger’s Cat[14] proposals, that because the experiment has not yet collapsed when Bob observers the LED letters that Bob is still part of a large aggregate experiment superposition and that on DAY 2 Bob will still see XXXX. But the key difference with the design of this experiment is that it is intentionally designed to not be a “Wigner’s friend” scenario. One can argue that any linkage at all between any possible system and observer will always makes it such however, if so, then that may break the symmetry of the time crystal as described by the very definition of a time crystal. Otherwise, we are left with a scenario where time crystals that are defined to be symmetric in the present and future upon creation, actually may not be and they also could merely “flow” through time like all other matter slower than light and are also thus subject to the same constraints of Wigner’s friend and Schrodinger’s Cat quantum superposition challenges as seen in Figure 3.

Again, to summarize the proposed experiment, on DAY 2 Bob sees either XXXX or BOBX. Then on DAY 4, three scenarios could occur when Bob goes to talk to Alice: 1) Bob saw XXXX so Bob, even without having any “which path” information, is still part of the large experiment akin to Schrodinger’s Cat at a larger scale (this is similar to the Wigner’s Friend scenario if Bob sees XXXX but Alice observes Bob still in the box as seeing BOBX), or 2) Bob has received on DAY 2 the message that Alice sent on DAY 3 - to the shock of Alice, or 3) Bob mentions to Cassandra in another universe that is part of a multiverse that he saw a message BOBX that Cassandra never sent (Figures 5-6).

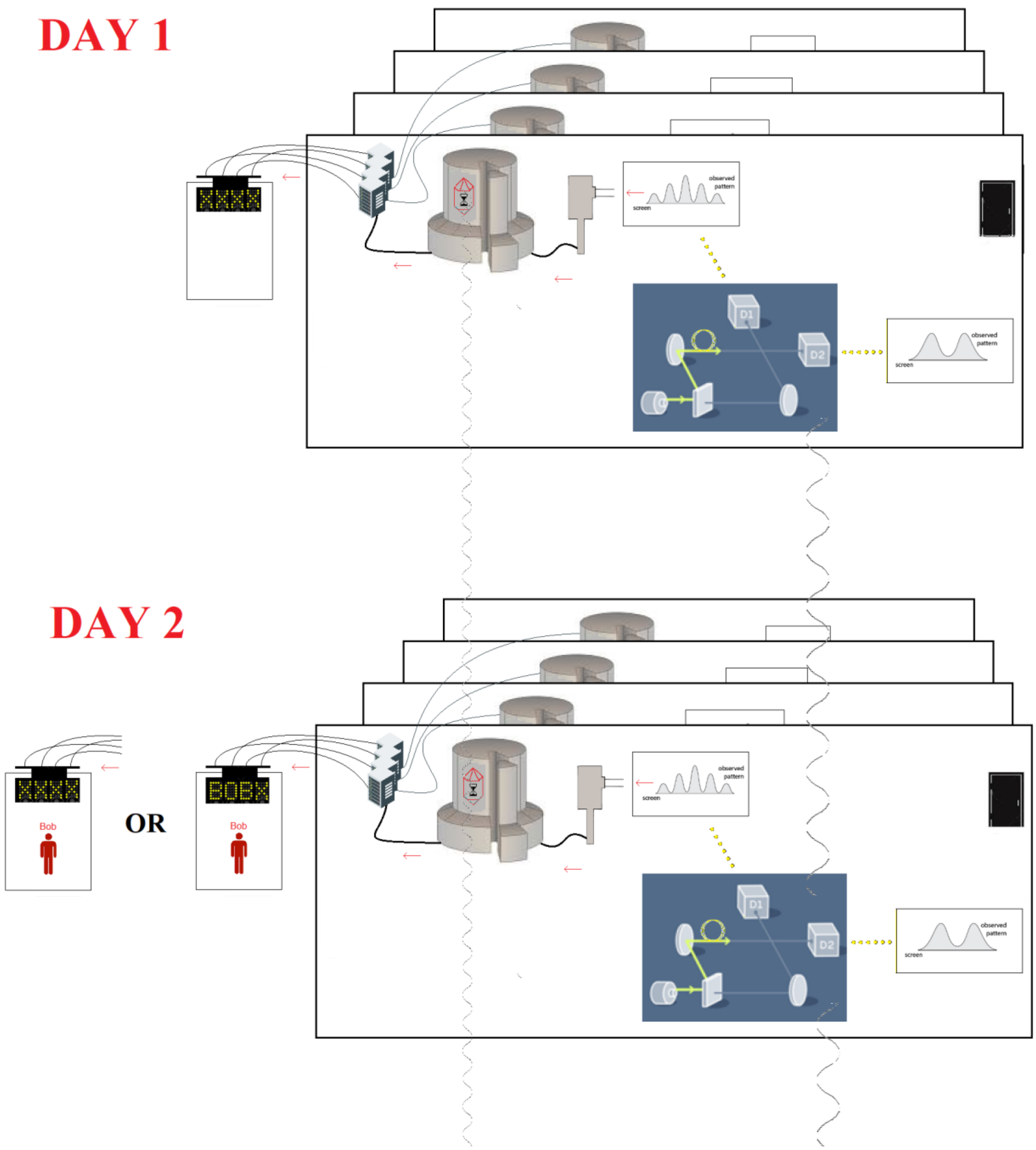
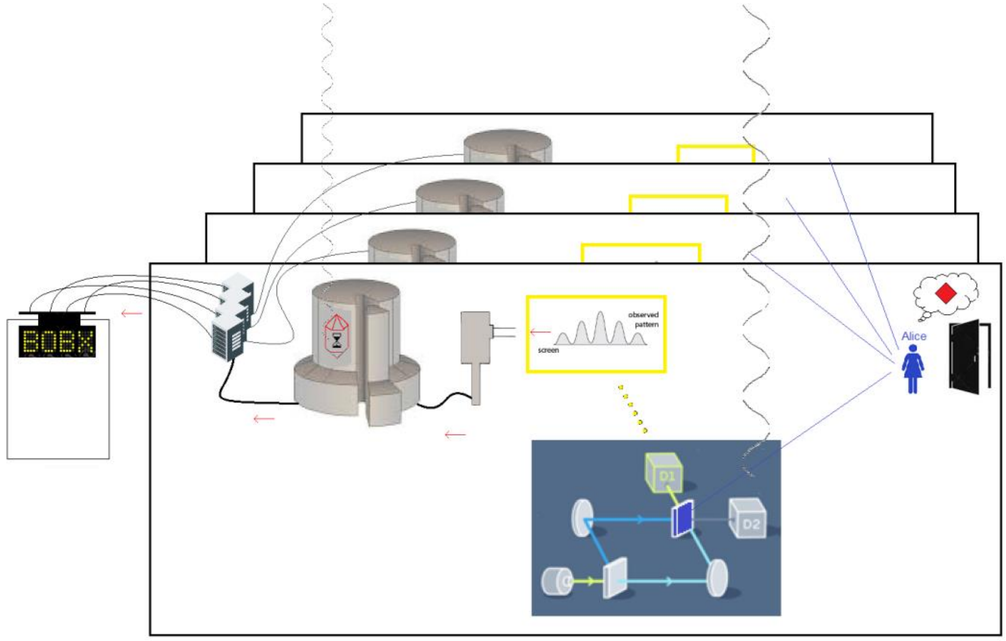


Figure 5. on DAY 2 Bob sees either XXXX or BOBX.

DAY 3



DAY 4

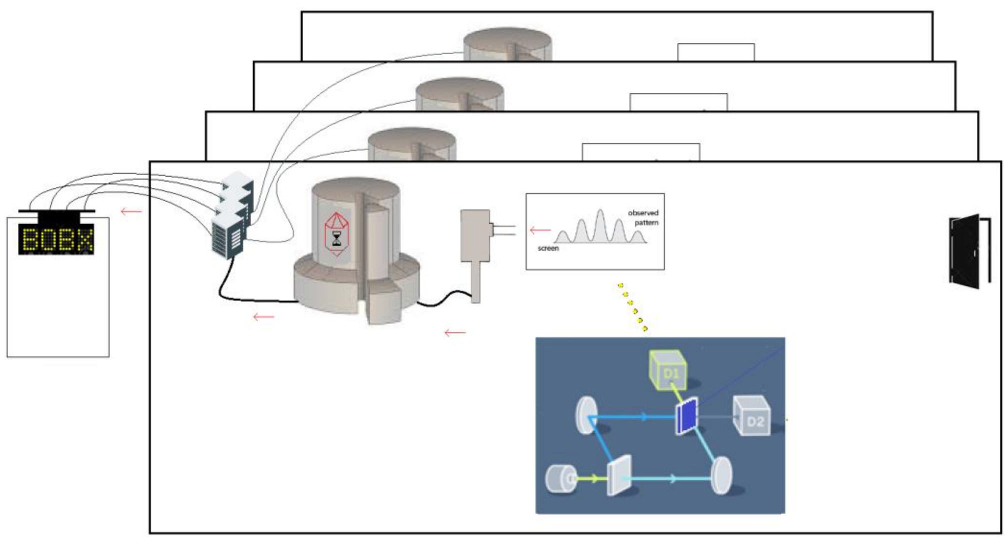


Figure 6. On DAY 4 when Bob goes to talk to Alice either: 1) Bob saw XXXX so he is still part of the experiment, or 2) Bob has received on DAY 2 the message that Alice sent on DAY 3, or 3) Bob mentions to Cassandra in another universe that they are part of a multiverse as he saw a message BOBX that Cassandra never sent.

The concepts of the delayed-choice quantum eraser experiment and time crystals are modern technical achievements and complex concepts and best explained in simple diagrams (Figures 7-10).

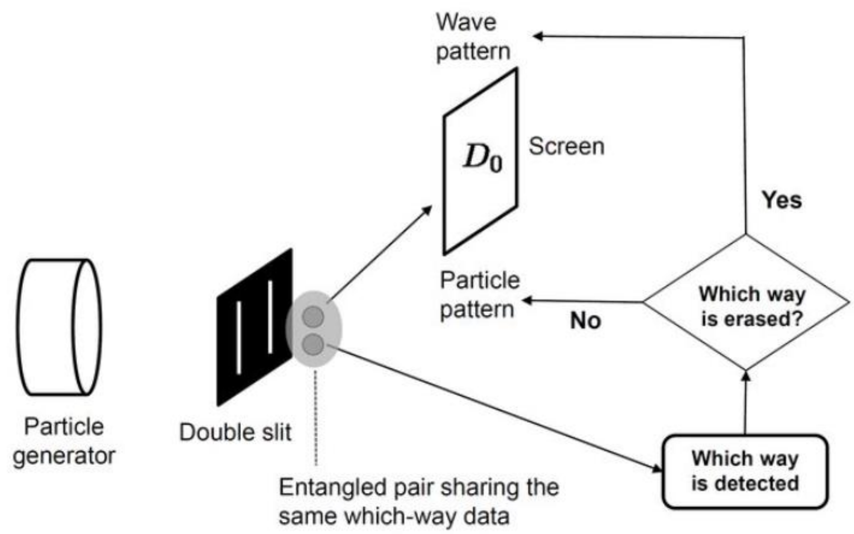


Figure 7. High level diagram of the Delayed Choice Quantum Eraser experiment.[15]

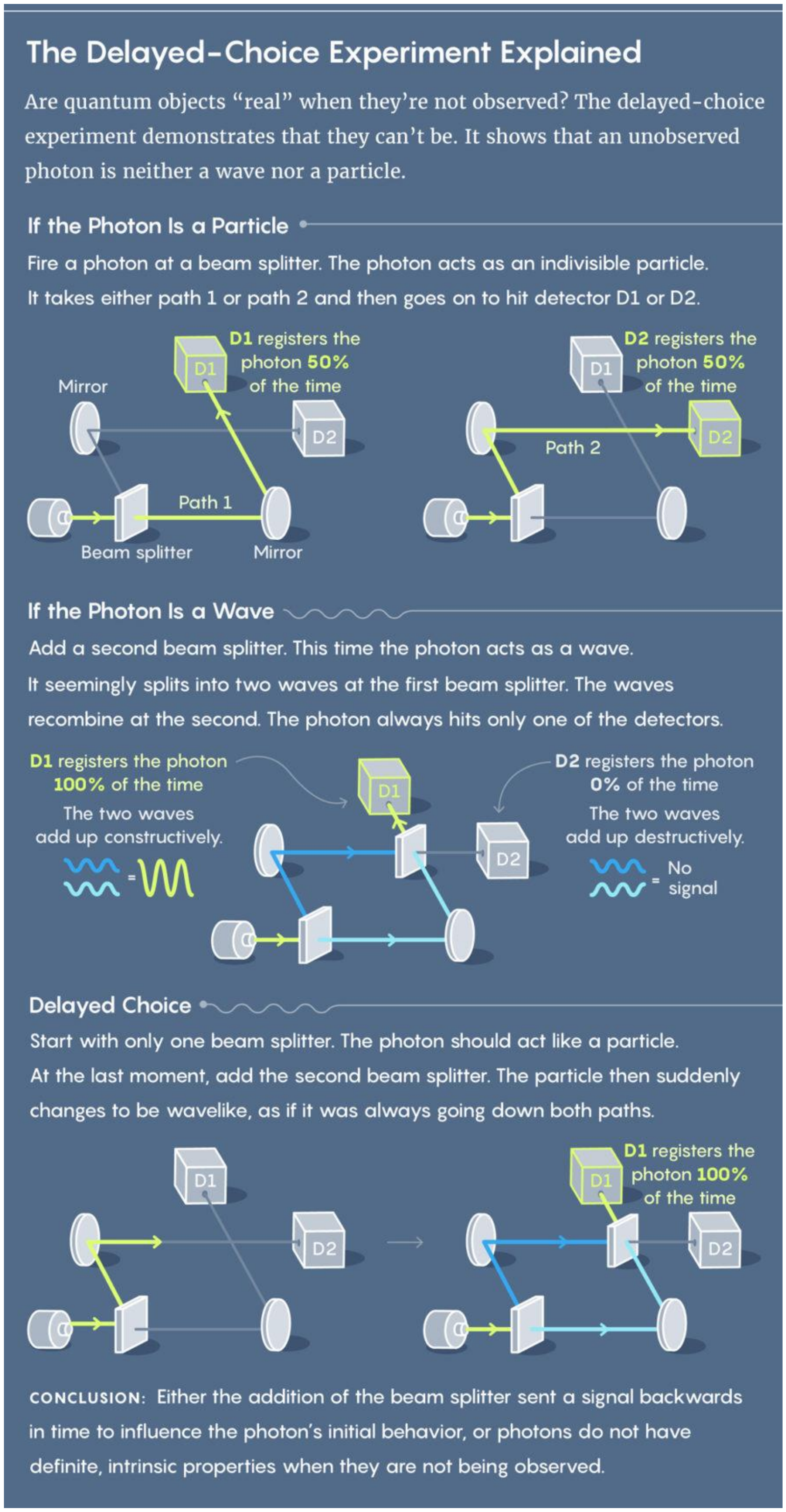
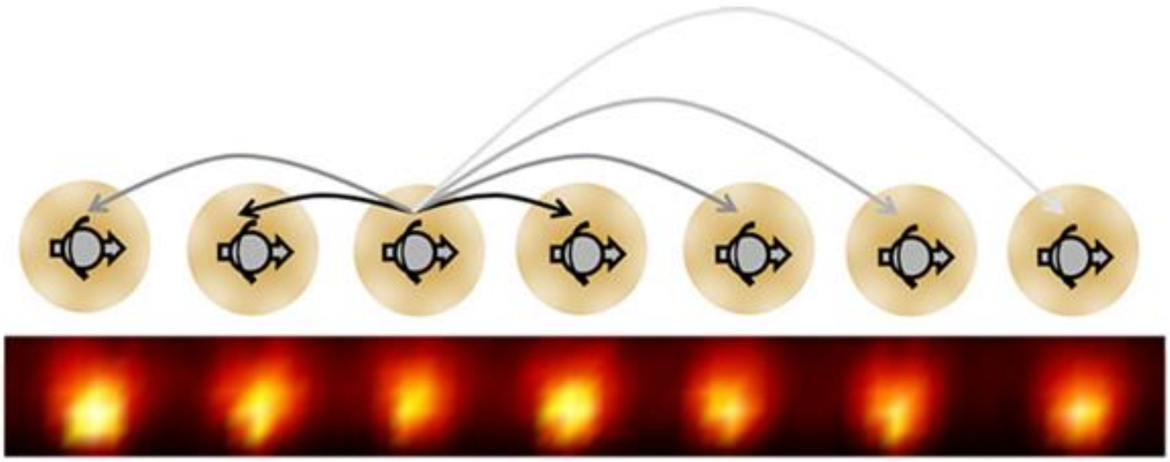


Figure 8. Step by step explanation of the Delayed-Choice experiment explained.[16]
Source: Lucy Reading-Ikkanda/Quanta Magazine



A one-dimensional chain of ytterbium ions was turned into a time crystal by physicists at the University of Maryland, based on a blueprint provided by UC Berkeley's Norman Yao. Each ion behaves like an electron spin and exhibits long-range interactions indicated as arrows. (Image courtesy of Chris Monroe)

Figure 9. This experiment can show if long-range interactions associated with Time Crystals is instantaneous or not or not at all. [10]

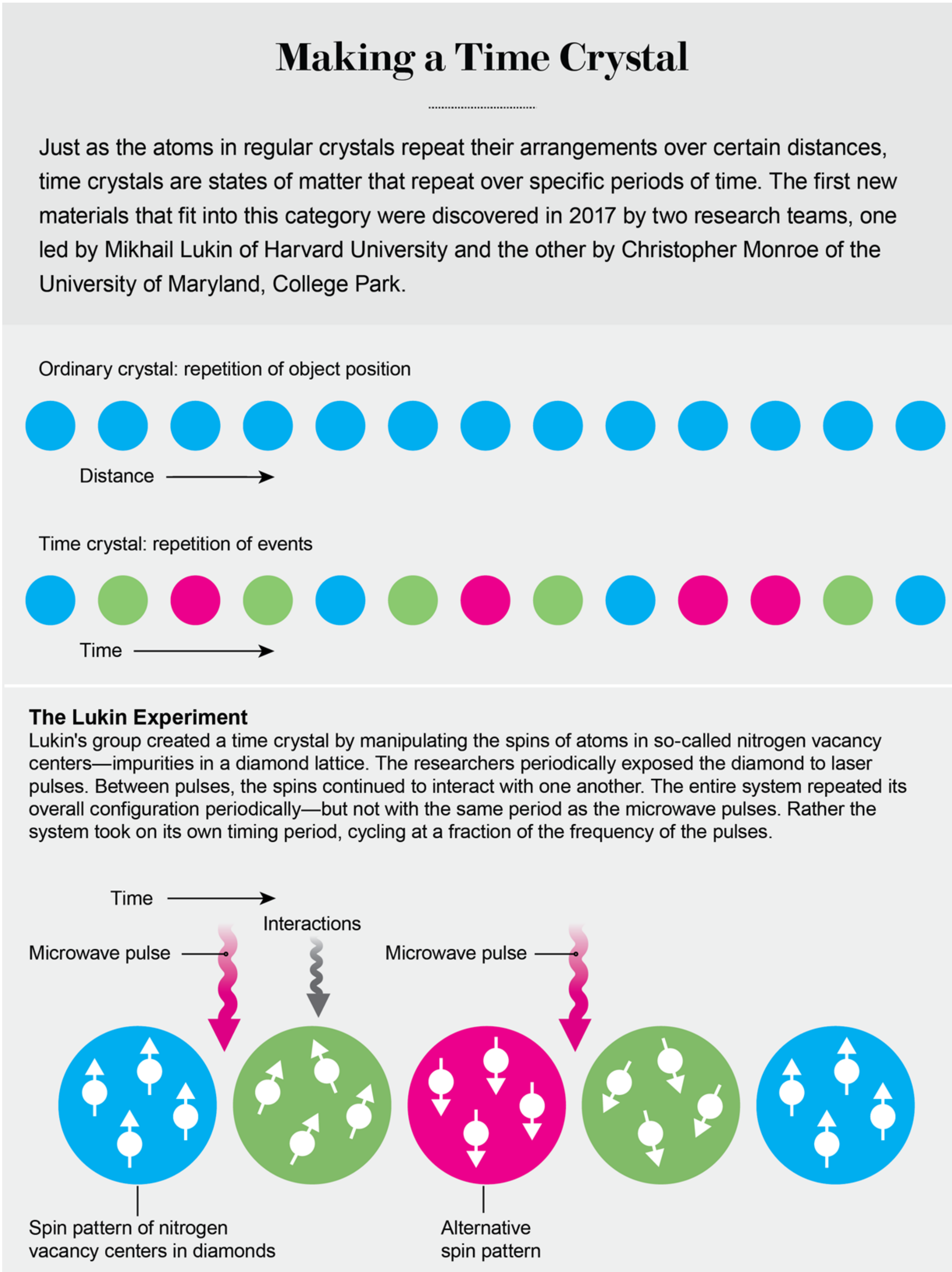


Figure 10. Background on the creation of Time Crystals.[1]

It is thus the desire of the author to challenge technical universities and institutions to perform the experiment, which can be done with present technology, to confirm which scenario actually is observed and to help further define the behavior of time crystal's behavior relative to past, present, and future symmetries.

References

[1] Wilczek, Frank. (2019, November 1). "Crystals in Time" in Scientific American 321, 5, 28-36 (November 2019). doi:10.1038/scientificamerican1119-28. Retrieved December 2, 2021, from https://www.scientificamerican.com/article/the-exquisite-precision-of-time-crystals .

[2] Quanta Magazine. (2021, July 30). Retrieved December 2, 2021, from https://www.quantamagazine.org/1st-time-crystal-built-using-gs-quantum-computer-20210730 .

[3] Randall, J., Bradley, C., van der Gronden, F., Galicia, A., Abobeih, M., Markham, M., Twitchen, D., Machado, F., Yao, N. and Taminiau, T., 2021. Many-body-localized discrete time crystal with a programmable spin-based quantum simulator. Retrieved December 2, 2021, from https://arxiv.org/abs/2107.00736v1 .

[4] Wikipedia contributors. (2022, December 11). Wheeler's delayed-choice experiment. In *Wikipedia, The Free Encyclopedia*. Retrieved 17:22, January 5, 2023, from https://en.wikipedia.org/w/index.php?title=Wheeler%27s_delayed-choice_experiment&oldid=1126757094

[5] Wikipedia contributors. (2022, November 10). Delayed-choice quantum eraser. In *Wikipedia, The Free Encyclopedia*. Retrieved 13:46, January 3, 2023, from https://en.wikipedia.org/w/index.php?title=Delayed-choice_quantum_eraser&oldid=1121085907

[6] Wikipedia contributors. (2022, December 22). Interpretations of quantum mechanics. In *Wikipedia, The Free Encyclopedia*. Retrieved 16:00, January 18, 2023, from https://en.wikipedia.org/w/index.php?title=Interpretations_of_quantum_mechanics&oldid=1128905646

[7] Wikipedia contributors. (2022, October 22). Retrocausality. In Wikipedia, *The Free Encyclopedia*. Retrieved 18:15, January 5, 2023, from https://en.wikipedia.org/w/index.php?title=Retrocausality&oldid=1117587021

[8] Wikipedia contributors. (2022, October 21). Ghirardi–Rimini–Weber theory. In *Wikipedia, The Free Encyclopedia.* Retrieved 17:43, January 5, 2023, from https://en.wikipedia.org/w/index.php?title=Ghirardi%E2%80%93Rimini%E2%80%93Weber_theory&oldid=1117473674

[9] Carroll, S. (2019, September 21). The Notorious Delayed-Choice Quantum Eraser. *Preposterous Universe blog*. Retrieved January 5, 2023, from https://www.preposterousuniverse.com/blog/2019/09/21/the-notorious-delayed-choice-quantum-eraser/

[10] Sanders, R. (2017, January 26). Scientists unveil new form of matter: time crystals. Berkely News. Retrieved January 3, 2023, https://news.berkeley.edu/2017/01/26/scientists-unveil-new-form-of-matter-time-crystals/

[11] Wikipedia contributors. (2022, December 9). Many-worlds interpretation. In *Wikipedia, The Free Encyclopedia.* Retrieved 17:38, January 5, 2023, from https://en.wikipedia.org/w/index.php?title=Many-worlds_interpretation&oldid=1126448217

[12] Deutsch, D. (1998). The Fabric of Reality. Penguin. pg. 276.

[13] Wikipedia contributors. (2022, December 5). Wigner's friend. In *Wikipedia, The Free Encyclopedia*. Retrieved 20:25, January 5, 2023, from https://en.wikipedia.org/w/index.php?title=Wigner%27s_friend&oldid=1125753857

[14] Wikipedia contributors. (2022, December 27). Schrödinger's cat. In Wikipedia, The Free Encyclopedia. Retrieved 20:27, January 5, 2023, from https://en.wikipedia.org/w/index.php?title=Schr%C3%B6dinger%27s_cat&oldid=1129893156

[15] Campbell, Tom & Owhadi, Houman & Sauvageau, Joe & Watkinson, David. (2017). On testing the simulation hypothesis. Retrieved January 3, 2023, from https://www.researchgate.net/publication/314153135_On_testing_the_simulation_hypothesis

[16] Ananthaswamy, A. (2018, July 25). Closed Loophole Confirms the Unreality of the Quantum World. *Quanta Magazine*. Retrieved January 3, 2023, from https://www.quantamagazine.org/closed-loophole-confirms-the-unreality-of-the-quantum-world-20180725/