File of Investigation

Time is Dead:

A Eulogy to the Timeless Quantum Universe

[DECEASED]

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Figure 1[1]. Time as a line with three components: past, present, and future. The past and future are always divided by the present.

0 Prologue

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INVESTIGATION OPENED:
  Time is DEAD.
  §Location found: Quantum universe
  §Objectives: To investigate the
  death, and to write the following
  in your report:
    1. Who the victim was
    2. What brought about the tragic
       death
    3. The impact of its death
I await eagerly your report.
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1 What Time are we talking about?

The detective came, flipped open her rumpled notepad and turned to the forensic team on site. "So who is this unlucky victim?"

1.1 Classical Time: Doing Physics in a Box

When we did Newtonian physics in secondary school, one of the most common experiments would be measuring the speed of objects travelling (Fig.2). In such experiments, there is usually an isolation: We as the observers are outside of the system, holding a stopwatch to check the time elapsed against any motion that occurs within the system. This separation of the system and the observer is coined as "doing physics in a box" by physicist Lee Smolin[2] (p.37). The direct consequence of this separation is that Time[*] becomes an ***external*** entity to the system being studied.

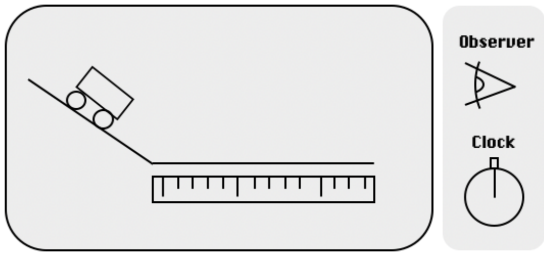

Figure 2. Illustration of a typical Newtonian experiment to determine the speed of a toy cart. The system being studied is isolated.

This was exactly how Classical Time was perceived: an ***external*** passage marking a succession of events. Aristotle, the Greek philosopher, thought of Time as *the number of motion in respect of 'before' and 'after'*[3]. Similarly, Newton[4] visualised an Absolute Time which passes uniformly, indifferent to the motion of the world, just like the clock would continue running even if nothing happens inside the box, and would continue running in exactly the same manner anywhere else in the universe.

1.2 A Classical Clock in Quantum Realm

In conventional quantum mechanics, the methodology of "doing physics in a box" has been inherited from Newtonian physics. This means that the notion of Time sits in the quantum realm in a largely classical sense. But to understand what impact a Classical Time has to the quantum universe, we must first lay down some basic quantum knowledge:

Imagine if we have some particles in a box. Theoretically, with Newtonian physics, we can work out the configurations of particles (eg. their speed and position) at any given time if we are given the initial state of the box. Newtonian mechanics is deterministic i.e. we can predict

[*] Note the distinction between "Time" and "time". The capitalised "Time" is used when it stands for a separate entity, a self-contained object.

what exact configuration will occur. Quantum mechanics is not like this. It tells us instead the possibility of finding the box in a certain configuration at some time after the initial state, and we can only determine the precise value of any observables i.e. physical quantities of the system after a measurement is taken[2] (p.78).

In classical mechanics, we have Newton's Second Law to help us predict the configuration of the evolving system. Similarly, in conventional quantum mechanics, for every dynamical system there is a wavefunction $|\psi\rangle$ that contains all the information of how probable each measurement outcome is, and we have the Schrödinger equation that dictates the time evolution of the wavefunction[5]:

$$i\hbar\frac{\partial}{\partial t}|\psi\rangle = \hat{H}|\psi\rangle, \qquad (1)$$

where $\hat{H}$ is the Hamiltonian operator associated with the system's total energy. An operator operating on a wavefunction enables us to measure the observable it corresponds to.

We can thus see from the Schrödinger equation that the impact of Time appearing as a classical parameter in quantum mechanics is such that the quantum Time is not subject to any operators, nor is it treated on equal footing[6] as an observable in the system like momentum or position[6] (p.2).

So this is the "victim" of our case, the central figure that would soon suffer a thousand deaths in the quantum universe – just as Fig.1 illustrates – an ***external*** Time that behaves like a ***universal*** line against which any system should evolve. This is the Time that is most likened to what we experience: Inert, transcendent, ever-flowing. The tide washes up and down the beach; the Sun rises and sets in the sky; the man begets, ages and dies on this Earth.

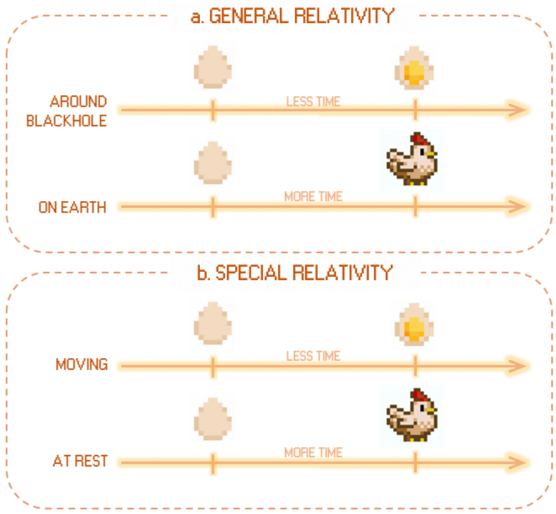

Figure 3[7]. Diagram showing object experiencing different passage of time (a) when subject to different gravitational field strength; (b) when moving at different relative velocity.

2 The Inevitable Death

"I've started without you," said the medical examiner to our fellow detective who just arrived at the autopsy room, "it wasn't an instant death. Your victim had its life slowly drained out of its body… but the mortal blow was delivered by –"

2.1 Primary Injury – Loss of Universality

Having done Year 1 Special Relativity course, you might find it quite unsettling in seeing a classical description of Time in quantum mechanics: A universal line which flows uniformly everywhere in the universe. Indeed, one of the most important results (Fig.3b) we learnt in Special Relativity is that the rate at which time passes is dependent on the velocity of the object's frame relative to its observer's frame[8]:

$$t' = \gamma t, \qquad (2)$$

where γ is the Lorentz factor dependent on the relative velocity between the two frames. Eq.2 forcefully states that speed slows down time. It is also known as the *Time Dilation Equation*.

In like manner, General Relativity establishes from the interaction of matter and the curvature of spacetime that the flow of time can also be hindered by mass (Fig.3a): an object resting in a gravitational field appears to experience slower time when viewed by an observer external to the field[9].

The staggering consequences of Relativity Theory go thus: the Time it conjures up is unresolvably *incompatible* with the Classical Time in quantum physics. It also kills off the ***universality*** aspect of our Time. There can be thousands of different clocks across the sky and your Time is no truer than my Time.

2.2 Murder Weapon: Wheeler-DeWitt Equation

"– the mortal blow was delivered hand in hand by quantum physics and general relativity." She finished the medical examiner's sentence.

Ever since the birth of Relativity and quantum physics, scientists such as Bryce DeWitt and John Wheeler[2] have been looking to unite the two pillars in the study of quantum cosmology in hope of bringing a *grand unified theory of everything* (p.70). DeWitt approached the unification by quantising General Relativity, and the equation he subsequently obtained is the *Wheeler-DeWitt Equation*:

$$\widehat{H}|\psi\rangle = 0 \qquad (3)$$

Note that both $\widehat{H}$ and $|\psi\rangle$ in Eq.3 are substantially different from the Schrödinger Equation pf Eq.1. $|\psi\rangle$ becomes *a functional of field configuration on all of spacetime*[10], and $\widehat{H}$ is no longer an operator that determines the time-evolution of the system, but is instead the total Hamiltonian constraint[11] that treats Time dynamically on equal footing with the system (p.3).

Simply speaking, *Wheeler-DeWitt Equation* is an equation that attempts to incorporate the quantum state of the entire universe by treating space and Time as equally fundamental, and it is abruptly clear with Eq.3 that the quantum state of the universe remains static. Our quantum universe is a *TIMELESS* universe.

It is done. In a Nietzschean manner, the murder is confirmed and Time is dead. It comes as a shock to most, but for some, the death was not so unexpected. Sean Carroll[12] believed the result of a frozen quantum universe was already foreshadowed in the innate *contradiction* (§2.1) of the notion of Time in the two theories. In a more radical view, Smolin[2] argued that the death is only logical since the clock in quantum mechanics is always outside of the system it is tracking (Fig.2). But since nothing can exist outside the universe by definition, there cannot be an ***external***, absolute Time that permits a changing universe(p.80).

2.3 Futile Remedy – Boltzmann's Entropy

Boltzmann: I think I come bearing good news … Never mind!

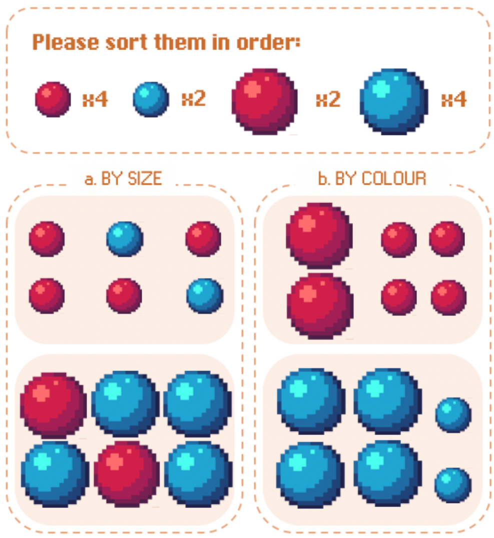

Figure 4[13]: A collection of balls can be put in order either by their size or colour. Each configuration is as valid as the other. Likewise, in a complex system, objects can be arranged in many configurations equally.

"Is that it?" You may ask, "if Time for the universe must disappear once it is on equal footing with space, then why unlike in space are we so bounded in Time, unable to reach the forbidden realms of past and future? Maybe Time can make its way back to the quantum universe from some fundamental distinction of the past and future?"

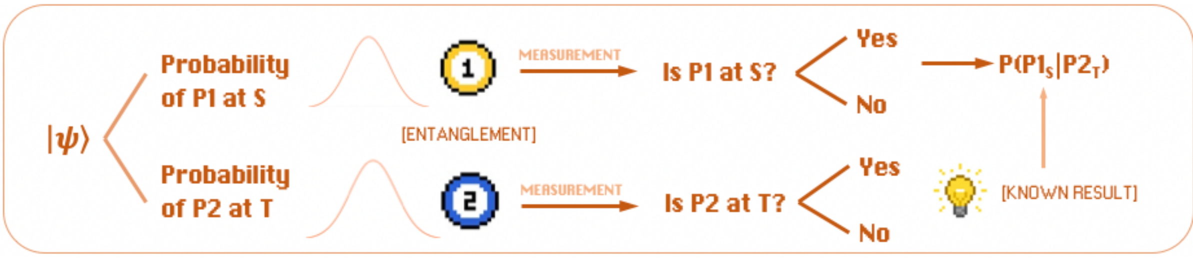

Figure 5[14]. Illustration of how conditional probability arises from two entangled particles P1 and P2 in a closed quantum system. The measurement outcome of P1 is entangled with the known result of P2. P2 can act as a clock which tracks the evolution of P1.

Ludwig Boltzmann, the 19th century Austrian physicist, posited that the distinction of past and future hinges on the concept of entropy[15] – the measurement of how disordered a system is, or equivalently, how much useful work can be extracted from a system. For instance, if I mix two stacks of balls that were initially sorted according to their sizes (Fig.4a), I will be increasing the entropy of the system of balls. Even if I rearrange the balls back to their original organisation, the amount of work I put into the system would still mean that total entropy of the overall system has increased.

This is the *Second Law of Thermodynamics*: the change in entropy of any closed system cannot be negative. In other words, Time would always start from a place of low entropy, the past, and flow in the direction of increasing entropy.

Given the quantum universe does not disobey the *Second Law of Thermodynamics,* would it therefore suffice to say that some form of fundamental Time is resurrected? According to Carlo Rovelli[16], the Italian physicist who specialises in the *Problem of Time*, the blunt answer is *no*. He argued that this is because the *Second Law of Thermodynamics* is rooted in a blurred and inaccurate vision of the world. It is a law of nature as the result of choosing one particular configuration over another. An example of this particularity would be arranging a box of marbles according to either size or colour (Fig.4): it is impossible to which configuration is more orderly unless one configuration is favoured over the other.

But reality plays no favourites. It is only to the extent the *Second Law of Thermodynamics* obscures particular configurations that the illusion of Time appears. As soon as we sharpen our focus, Newtonian physics creeps up microscopically and the arrow of Time disappears[16,17]. As much as Boltzmann has hoped, he was only able to provide a remedy of an illusional cure; the tumor is removed but cancer remains. With much frustration towards what DeWitt called "[the] damned equation"[17], the death of Time is unsaviourable (p.39).

3 Page and Wootters: Let's set sail from the tombstone of Time!

"So how are you going to break this *upbeat* news to the world?" The detective asked sarcastically to the journalist while accepting the roll of cash into her pocket.

"We must pretend, fake its existence in all places, so that our life has a chance to be normal again."

3.1 The Conditional Probability Interpretation

To deal with the brute fact of a timeless quantum universe, theorists have come up with numerous interpretations. Some remain in deep denial of the fact and restlessly search for ways to revive a fundamental Time, whilst others like Don Page and William Wootters[18] decide to seek harmony between the *Wheeler-DeWitt Equation* and a time-dependent quantum theory. They posited that the conventional time-dependent quantum theory would still work because a dynamical system can evolve for an internal observer with a "clock" that is entangled within the system (Fig.5).

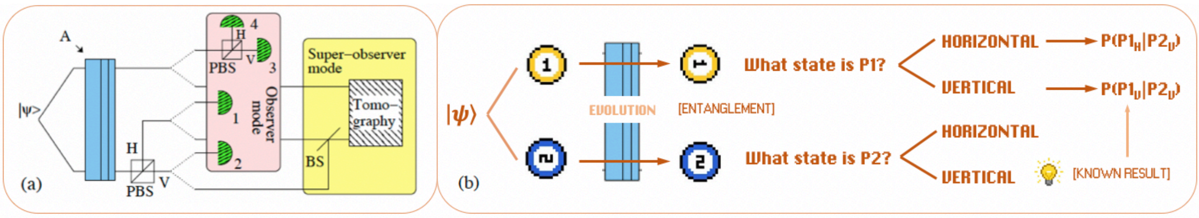

Figure 6. (a)[19] The setting of the photon clock experiment. The blue block A represents quartz plates of different thickness through which the photons change their polarisation. PBS stands for the polarising beam splitter and it prepares the photons to be in either horizontal or vertical state. The shaded green components are the photodetectors which fire according to the polarised state of the photons.
(b)[14] Illustration of how the conditional probability of the state of P1 is connected to the photon clock P2.

The same system would appear static for an external observer who has access to an *abstract coordinate time*[19†] (p.1).

As illustrated in Fig.5, the central idea in the Page-Wootters mechanism[20] (PaW) is the postulate that $P(P1_S|P2_T)$ denotes the conditional probability of finding P1 at S given the known state of P2. In this sense, even without any reference to an external Time, we can still formulate a wavefunction of P1 with the conditional probability function that evolves with respect to P2, which we choose to be the internal "clock" of the system (p.70).

3.2 The Photon Clock ticks!

So far, the PaW mechanism seems to work well ***on paper*** in rendering a localised Time to a quantum system that should be static by nature as a result of treating Time and space on equal footing under the Wheeler-DeWitt framework.

To Page's delight[21], in 2013, a group of scientists[19] confirmed that PaW works in practice by creating a "toy universe" that contains two polarised photons that exist in a superposition of horizontal and vertical states until observed (Fig.6).

In the observer mode (Fig.6a), there is entanglement between the polarisation of the clock photon P2 and P1. The conditional probability of P2 becomes time-dependent since reading the "clock" P2 would in term affect the outcome of P1 (Fig.6b).

In the super-observer mode, the information of the lower photon is erased through a beam splitter (Fig.6a) to ensure the external observer is completely unentangled with the "clock". The extent to which each photon rotates is varied by alternating the thickness of the plate – an information that is only accessible to the super-observer but not to the internal[6,21]. Within anticipation, the system stays static to the super-observer regardless of the thickness of plates used[19] (p.3). *There is no Time present for a holistic view of the system*.

Nevertheless, insofar as a correlated observer perceives, Time arises from the system internally: Although the internal observers have no knowledge of the thickness of the plate, they can still observe the evolution of the upper photon P1 against the internal "clock" of the lower photon P2 whose polarisation differs with each thickness.

Seemingly, there is a beautiful correspondence between the photon clock experiment and the model of "doing physics in a box". The results of an experiment (outcome of P1) is measured against the lab's clock (P2), except the clock in this case is entangled within the system. This is significant because it affirms that, to the extent the experimenter is entangled in the system (which is always the case when

† As discussed in §2.2, no such abstract coordinate time can exist when the system is the entire universe.

the system remains a subsystem of the universe), all the existing theories in physics that are subject to the Newtonian paradigm[2] of "doing physics in a box" still work, even after the death of Time (p.42).

4 One Branch in a Gigantic Tree

'Quid est ergo tempus? Si nemo ex me quaerat, scio; si quaerenti explicare velim, nescio'‡.

------St.Augustine of Hippo

In §1, we introduced our "victim" – the classical notion of Time in conventional quantum mechanics. In §2, we walked through the execution of such a classical Time delivered by a combination of Relativity Theory and quantum mechanics using the *Wheeler-DeWitt Equation*, and showed the timelessness of the universe cannot be restored even by the powerful *Second Law of Thermodynamics*. In §3, we explored the conditional probability interpretation of the conclusion of a static quantum universe, and the photon clock experiment that provides an experimental verification for the interpretation. Eventually, we seem to arrive at a position that the laws of physics are unimpaired under the death of Time, sheltered by the PaW approach. All problems solve. Order restored.

Is that so?

The truth is, the article has only focused on the sole approach of conditional probability within a single Wheeler-Dewitt framework of quantum cosmology when there is much more to it. The Problem of Time is a vastly complex problem that extends way beyond the realm of quantum cosmology, consists of a much more extensive number of interpretation theories corresponding to not just one, but several quantum cosmological frameworks.

This is how I want to leave you – in awe with a problem that is much bigger than what has been revealed.

Exclaimed by St. Augustine a little more than 1500 years ago, the epigraph written in Latin translates thus[22]: *What then is Time? If no one asks me, I know, if I wish to explain it to one that asketh, I know not.*

Reference

[1] Image modified by the author with the Nyan Cat part contributed by: Khelif . Rainbow Cat - Nyan Cat YouTube Desktop Wallpaper PNG [Internet]. 2018 [cited 2022]. Available from: https://favpng.com/png_view/rainbow-cat-nyan-cat-youtube-desktop-wallpaper-png/RbFE29E2#_=_

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‡ On which Ludwig Wittgenstein remarked thus: *Something that we know when no one asks us, but no longer know when we are supposed to give an account of it, is something that we need to remind ourselves of*[23].

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