Technical note

Journal of High School Science

An argument against the compatibility of the Many Worlds Interpretation with backward time travel using the Superposition principle

Bozkurt K.B[1]

Submitted: January 30, 2023, Revised: version 1, February 15, 2023, version 2, March 29, 2023
Accepted: April 1, 2023

Abstract
Although forward time travel can theoretically be achieved with Special Relativity, backward time travel is believed to be impossible by many physicists since it requires faster than light speeds, imaginary mass, exotic mass, and/or an infinitely long Tipler Cylinder, which are concepts that are either impossible to achieve or highly speculative. Despite the lack of a fundamental law that prohibits backward time travel, this type of time travel would break causality and lead to paradoxes. This can be demonstrated with the simple Grandfather paradox. The Grandfather paradox can be solved with the Many Worlds Interpretation of quantum mechanics by isolating the worlds that the events take place in, without breaking causality. However, this solution overlooks the superposition principle and allows interactions between wave functions. For backward time travel to be compatible with the Many Worlds Interpretation, the Schrödinger Equation must be non-linear which contradicts the assumption made by the interpretation itself.

Keywords
Quantum mechanics, Backwards time travel, The Grandfather paradox, Schrödinger equation, Many Worlds Interpretation, Superposition principle

[1]Kerem Berk Bozkurt, Ankara Science High School, Alacaatlı Mahallesi 3278 Sokak 2/17 Park Sera Çankaya, Ankara, Turkey, kberkboz@gmail.com

Introduction

This paper is on time travel and its compatibility with the Many Worlds Interpretation of quantum mechanics. Forward time travel is possible due to the relative nature of time (1). On the other hand, backward time travel is generally regarded impossible as it breaks causality. This can be demonstrated in simple paradoxes like the Grandfather paradox and the Bootstrap paradox. It is suggested that the Many Worlds Interpretation can provide a solution to these paradoxes by postulating separate worlds for the actors of events and thus preserving causality (2). Yet, this argument overlooks the superposition principle which states that waves can overlap but not interact with each other after decoherence for the non-linear Schrödinger Equation (3). For backward time travel to be compatible with the Many Worlds Interpretation, the Schrödinger Equation must be non-linear or incomplete. This detail is pointed out as an argument against this compatibility in this paper.

The Wave Function

A wave function is a mathematical description of a quantum state and is derived by solving the Schrödinger equation for a given system (4). The Schrödinger equation, developed by Erwin Schrödinger, is the fundamental proposition of quantum mechanics (5).

$$i\hbar \frac{\partial \Psi(x,t)}{\partial t} = \left[\frac{-\hbar^2}{2m} \frac{\partial^2}{\partial x^2} + V(x,t) \right] \Psi(x,t)$$

Equation 1 states the Schrödinger equation for a single particle in one dimension where: $\Psi(x,t)$ is a wave function, m is the mass of the particle, $V(x,t)$ is the scalar potential representing the environment, $\hbar$ is the Planck constant. The square of the wave function is the probability density of finding the particle in a certain state when measured. All quantum systems can be represented using these wave functions.

The Many Worlds Interpretation of Quantum Mechanics

The Copenhagen interpretation, the most popular interpretation of quantum mechanics, states that the wave function representing multiple states randomly collapses into a single state when measurement is made (6). This randomness is suggested to be truly random and not deterministic.

On the other hand, the Many Worlds Interpretation proposed by Hugh Everett in 1957 states that a universal wave function representing the entirety of existence exists and this universal wave function evolves with quantum measurements (7). This wave function does not collapse and is divided into isolated parts or “worlds” with each quantum measurement.

All possible outcomes of a quantum measurements are played out in different worlds. In other words, each measurement creates new parallel worlds (8).

Time Travel

To begin with, it should be noted that when time travel is discussed, usually the time travel of information is implied. Although time traveling objects are possible, information traveling through time is much more likely.

Since intervals of time can be stretched with high speeds according to the theory of Special Relativity, forward time travel can be simply achieved by moving at high speeds. Time ticks slower while this high speed movement occurs, and time travel is achieved upon deceleration to normal speeds (9).

On the other end of the spectrum, backward time travel presents non-trivial challenges. As movement gets faster, the time ticks slower and at the speed of light it stops ticking. If an object was able to travel faster than the speed of light, time would tick backwards. However, the laws of physics do not allow faster than light travel for objects with normal mass. Tachyons, objects that have imaginary mass, are theorized to travel faster than light, but it is not clear if they exist (10).

General Relativity allows time travel through wormholes. Wormholes can warp space-time and can be used to travel between different points in space and time. For this to be possible, there must be a wormhole large enough to travel that is stable. However, large wormholes are not stable and cannot be used to travel through time. Exotic matter can be used to keep the wormholes from collapsing; however, their existence is also highly speculative (11).

A recent breakthrough regarding wormholes is also worth noting. Juan Maldacena and Leonard Susskind proposed the ER=EPR Conjecture in 2013 (ER is the eponymous paper by Einstein and Rosen describing wormholes, EPR refers to the paper by Einstein, Podolsky and Rosen describing quantum entanglement). This proposal suggests that the physics of quantum entanglement and the physics of two black holes linked with a wormhole are mathematically equivalent. Thus, creating a pair of entangled particles is equivalent to creating a wormhole (12).

A team of physicists lead by Maria Spiropulu based their study on this conjecture. They managed to create and traverse a holographic wormhole in Google's Sycamore quantum computer. This wormhole consisted of 7 pairs of entangled quantum particles. They also utilized a magnetic field to keep this holographic wormhole from collapsing. On the other hand, there are physicists that argue that the conjecture which is the basis of the experiment is unreasonable (13).

Another solution for time travel is the Tipler Cylinder proposed by Frank Tipler. An infinitely long and highly dense cylinder rotating would create a vortex of space-time. This vortex would create closed time-like curves. An object traveling along these curves would end up in its own past (14).

These potential methods for backward time travel are presented to lay a foundation for the rest of the paper. If time travel was strictly impossible, it would not be reasonable to discuss the compatibility of the Many Worlds Interpretation in the first place. On the other hand, solutions for backward time travel seem highly unlikely. Still, there does not seem to be a fundamental law that prohibits it.

Results and Discussion

Backwards time travel is theoretically possible as discussed in the previous sections. However, many physicists believe there must be some fundamental law that prohibits backward time travel. This is because backward time travel breaks causality and results in paradoxes.

One of these paradoxes is the Grandfather paradox that is described as follows: 'Imagine you had a time machine. You travel back in time to kill your grandfather. Since your grandfather is dead, he never marries your grandmother, one of your parents never get born thus, you never get born. If you were never born, who killed your grandfather (15) ?'

Another popular time travel paradox is the Bootstrap paradox, which is described as follows: 'Imagine that a physicist is conducting an experiment. After completing the experiment, the physicist sends the information of the results back in time to before the experiment was conducted. After receiving the results of the experiment, the physicist skips the experiment and publishes the acquired results. Where does the information of the experimental results originate (16)?' The paradox thus implies that everything is predetermined since the past is dependent on the future.

The Grandfather paradox and the Bootstrap paradox are simple paradoxes that demonstrate the effects of breaking causality. Both of these paradoxes are avoided with the Many Worlds Interpretation of quantum mechanics and the interpretation is generally regarded to be compatible with time travel (2). This argument is explained below using the Grandfather paradox.

When the time traveller travels back in time and kills the grandfather, a new world is created in which the grandfather is killed. In this world, there is no time traveller, however the causality does not break since the time traveller still exists in the world where the grandfather is still alive. This is demonstrated in Figure 1.

It could be argued that pushing classical paradoxes to a quantum interpretation is an unscientific approach. However, the implications of these paradoxes would also apply to the quantum world. In the Bootstrap paradox, if the classical experiment was substituted with a quantum experiment, thus making the information of the results quantum and not classical, no change would occur in the series of events that follow. The quantum information would lead to classical events after traveling through time. Even if the information vanished after traveling, this would not be an argument against the incompatibility of the Many Worlds Interpretation. Thus, the argument that these classical paradoxes cannot be linked to the quantum Many Worlds Interpretation needs further examination.

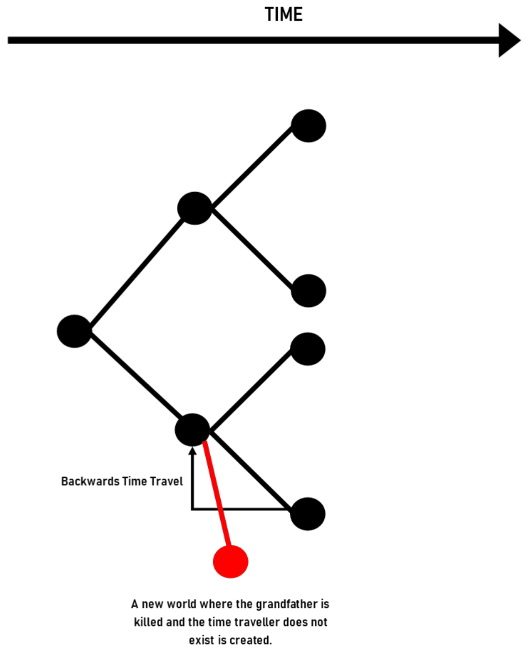

Figure 1: The grandfather paradox

This solution to the paradox poses a major flaw. Traveling backward in time, requires interacting with other worlds, thus conducting measurement(s), and creating the new branch suggested in the solution.

In linear systems, waves act according to the superposition principle which states that waves can overlap and not be affected by the other wave. This principle is what the Many Worlds Interpretation is built upon, and the linearity of the Schrödinger Equation is assumed for the interpretation to be viable (7).

Worlds are represented as wave functions, and once decoherence occurs, these are separated forever. After the decoherence these wavefunctions (worlds) can overlap but cannot interact, once again obeying the superposition principle (3). For there to be interaction between these worlds (thus, time travel), the Schrödinger Equation must be non-linear which contradicts the assumption that allowed the interpretation itself.

Non-linear Schrödinger Equations have been suggested before (17). However, as stated previously, the Many Worlds Interpretation assumes that these Schrödinger Equations are not viable options, and the equation must be linear.

Conclusion

Contrary to general consensus, backward time travel is incompatible with the Many Worlds Interpretation as it requires interaction between two worlds and contradicts the linearity of the Schrödinger Equation, which the interpretation itself assumes.

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