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One-Way Speed of Light Experiment (Quantum Entanglement Approach)

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ABSTRACT

Since Einstein stated the constancy of the speed of light to be a mere "stipulation … to arrive at a definition of simultaneity", theorists argued that it could be possible for the speed of light to differ in different directions since there are many anisotropies like the amount of matter vs antimatter. However, this assumption has not been confirmed yet. No experiment has been proposed that measures the one-way speed of light; all experiments to date measure the round-trip speed of light. The experiment proposed in this paper seeks to measure the one-way speed of light by using an entanglement-controlled stopwatch while remaining blind (during the experiment) on whether the speed of light is isotropic or anisotropic, thereby answering the century-long question.

Introduction

1.1 History

In Albert Einstein's 1905 paper "On the Electrodynamics of Moving Bodies", Einstein introduced the principle of light constancy stating that light must travel at a speed c relative to all observers[1]. He later stated that the assumption that the speed of light is constant in all directions, "is neither a supposition, nor a hypothesis about the physical nature of light, but a *stipulation*, that I can make of my own free will to arrive at a definition of Simultaneity". Since this statement, some theorists introduced the concept of an anisotropic model of the speed of light, stating that the speed of light could vary in different directions. Since there was no conclusive proof as to whether the speed of light is isotropic or anisotropic, physicists have attempted to measure the one-way speed of light to determine whether or not the speed of light is isotropic or anisotropic. To date, the scientific community assumes the speed of light to be a universal constant because astronomical observations make it seem so.

1.2 The Problem

The reason why a simple linear two-clock measurement to measure the speed of light will not work is due to the effects of special and general relativity on clock synchronization.

The general theory of relativity states that objects in different gravitational potentials experience different time flow relative to one another. This effect, albeit minuscule, is observed over distances as small as a meter. Therefore, even if two clocks used in an experiment begin synchronized, the rate of passage of time may differ between the clocks[2]. The flaw in the idea where a synchronizer is placed in the middle of two clocks - synchronizing them by sending light pulses on both sides at the same time - is that the experimenter has to assume that the speed of light is isotropic - violating the very aim of the experiment. One could potentially argue that the clocks could start together, synchronized, and then spread apart. In the case of two clocks moving apart from the same starting point, they will be unsynchronized in accordance with Einstein's theory of special relativity where a moving object experiences a slower time flow in the reference frame of a stationary observer[3].

Therefore, a two-clock model will not work to calculate the speed of light as the clocks may not remain synchronized.

1.3 Research Gap

The research and experiments in the past have yielded unsatisfactory results as they failed to either factor in special relativity, general relativity, or failed to remain blind as to whether the speed of light is anisotropic or isotropic. Usually, the apparatus that causes these problems are mirrors, optical cables, the inclusion of a second clock, or any such apparatus that requires light to take a round trip.

The experiment proposed in this paper seeks to measure the one-way speed of light by using an entanglement-controlled stopwatch.

1.4 Review of Past Research

Over the years, researchers have published papers analyzing the plausibility of measuring the one-way speed of light and there have been papers that have attempted or proposed experiments to find the same.

In the 2009 paper by E. D. Greaves, An Michel Rodríguez, and J. Ruiz-Camacho, "A one-way speed of light experiment", an experiment was conducted that consisted simply of a laser, a sensor, a coaxial cable, and graphing equipment to show the waves of light sent out and recorded[4,5]. The process they describe is, in essence, a laser emitting light to a sensor which then, through a coaxial cable, sends a signal back to the vicinity of the laser where it is electronically graphed. The reason they perceived this to be a viable measurement of the one-way speed of light is that the coaxial cable was said to have a fixed time delay of 79ns and stated that this would account for the phase shift that would occur, allowing them to then gauge the speed of light.

In 2010, Dr. J Finkelstein rebutted this paper, stating that it was again a round-trip speed of light measurement[6]. The cause for this assertion was that the 'fixed time delay' that they took to be a constant was in fact variable, since to measure the induced time delay, one would have to have two synchronized clocks at the ends of the cable. However, since the paper made no mention of synchronization, and in accordance with Reichenbach's principle that the accurate speed of light will depend on a system that achieves synchronization of clocks[7], the experiment did not measure the one way speed of light.

Experiment

2.1 Description

Incorporating the concept of quantum entanglement to control a clock in a continuous system with the quantum states of the atoms as variables, a stopwatch is made.

The experiment commences with the activation of the system to entangle the atoms. Refer to figure 1.

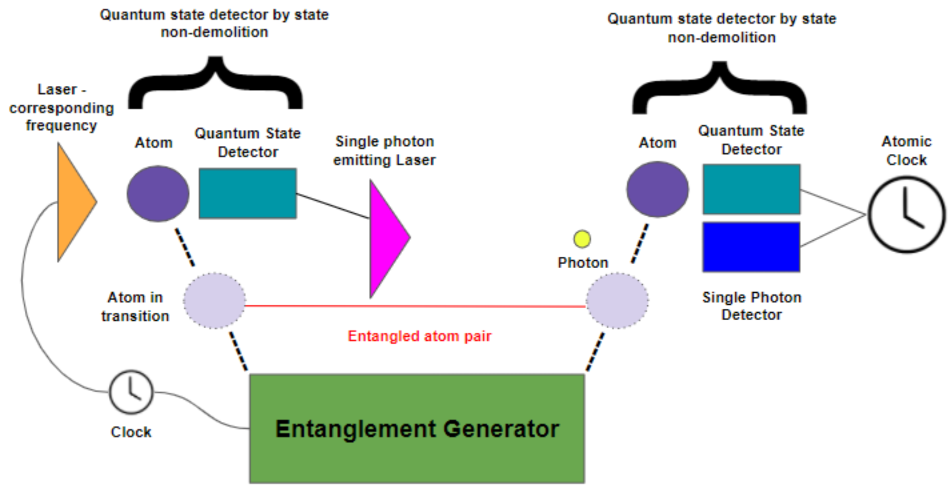

Figure 1. The setup is mounted on a three-dimensional rotating stand not illustrated here. The entanglement generator routes the atoms in a trajectory to the state readout system. After the pre-determined time gap, a quantum state change of the atom is induced, resulting in the laser and clock starting at the same time (if lack of perfect synchronization and general relativity are ignored). After the photon interacts with the single-photon detector, the clock stops and speed is measured.

2.2 Procedure

The procedure is chronologically delineated in a four-part structure as the functioning of the experiment moves from left to right.

2.2.1 Initiation

The experiment commences with the activation of the atomic entanglement generator[8,9,10] which routes the produced atoms in a trajectory[11] that guides it to the quantum state readout setup. When the entanglement is produced, the clock connected to the 'atomic entanglement generator begins a countdown (time to be set based on the experimenter's discretion). This ensures a fully automatic experiment. Giving the experiment some time also ensures that both sides have the initial quantum state readout stored to minimize error due to synchronization.

2.2.2 Left Side

All measurements pertaining to the entangled atoms are carried out in a quantum state non-demolition readout setup[12,13]. This method ensures that the state of the atom does not get destroyed (the wave function does not collapse) and the experiment can proceed. The detector detects the quantum state of the atom and stores the value as a set parameter to compare any new values against. After the countdown concludes, the laser (yellow) changes the state of the atom. Upon interrogation, the state change is detected by the detector (green) and compared to the set parameter. Since the value is different, it sends a signal via the wire to the laser resulting in the emission of a photon.

2.2.3 Right side

At the same time as the quantum state of the first atom changed, the state of the atom on the right changed too. The new state is detected, compared, labeled an anomaly, and a signal is sent to start the clock. It is at this time – simultaneous with the process on the left with minor synchronization uncertainty depending on the gravitational force – the photon from the single-photon emitting laser is emitted. This photon then interacts with the single-photon detector. This then signals the clock to stop. The time displayed after the stop of the clock is recorded.

2.2.4 Completion

The experiment ends and the display is read to find the time taken for the photon from the left to reach the detector on the right. We can calculate the speed of light knowing the distance between the photon source and detector and the total elapsed time. The experiment can be conducted multiple times in the same direction to measure a precise value of the speed of light in that direction and this is crucial since this experiment does not ensure synchronization of the time of detection in detectors and the emission of the photon and clock start/stop. Multiple repetitions are also useful to figure out a precise calibration of results by factoring in detector dead time and the switching on and off of equipment (laser and clock).

The same setup can be mounted on a 3D rotating device that allows it to measure the speed of light in multiple possible directions, and therefore determines whether the speed of light is isotropic or anisotropic.

The Physical Reality of a Universe with an Anisotropic Speed of Light

Currently, the speed of light is accepted as the constant c at 299792458 m/s. Upon this are based numerous astrophysical calculations, the distances, and positions of celestial objects, the size of the observable universe, and more. If the speed of light was to differ in different directions, it could open all these to scrutiny.

As for astronomy, the distance of stars would be incorrect and so would the Doppler shift since it would be variable across directions[14,15,16]. The existence and predicted amounts of dark energy and dark matter are predicated on doppler shift, the speed, and intensity of the rotating galaxies, and these are all calculated by using c as a constant. This also could affect our predictions as to the age of the universe and impact several research fields.

As a basic law, matter cannot travel faster than light. However, if the speed of light could vary by direction, then technically numerous bodies in space have been accelerated by black holes to enormous speeds that could surpass the speed of light in some directions.

The Lorentz transformations and therefore, by extension, Einstein's theories of relativity may need revision[17,18,19,20].

Discussion

There are significant sources of time delay in the experiment. The quantum state readout of the atoms takes – for an accurate readout by repetition – around the ballpark of 1.2 milliseconds[21], but, since it is before the emission of the photon, it does not factor in (except for the lack of synchronization that cannot be measured precisely but can be minimized by repetition). However, the single-photon detector, the laser, and the clock all take time to read results or switch on. The dead time of the photon detector borders on the magnitude of 30 nanoseconds or such and the laser and clock can take around 20 nanoseconds to turn on. This can be accounted for in the final results but it is best to keep these fixed time delays to a minimum and use clocks and lasers that have closely related turn off and turn on times.

The other case of uncertainty that might prove to be detrimental, is the fluctuation rate of the quantum states of the entangled atoms. However, since the periods for these fluctuations are known, the experiment can be calibrated corresponding to the time for these fluctuations, thus, circumventing the issue.

The vital point when designing the experiment is that the wires and signals are set in one direction so the measurement results will not rely on an isotropic speed of light.

The setup must be held in a near-perfect vacuum system with low gravitational fluctuation across distance. The time must be measurable on the scale of milliseconds as the synchronization error will be close to one millisecond. To attain a 25% accuracy, using the currently accepted speed of light constant, the experiment should be conducted over a distance of $\frac{299.792458}{0.25} \approx 1200$ km.

Since this experiment does not include the synchronization of the two sides while performing the quantum state readout of the qubits, in compliance with Reichenbach's assertion that the speed of light cannot be determined without assuring synchronization, this experiment does not provide an exact reading for the one-way speed of light[7]. The readout of the quantum state of the atoms on both sides will not necessarily happen together and there is no way to ascertain the time delay. This has to then be resolved by repetition of the experiment. However, this experiment can be quite reliable to find whether or not the speed of light is anisotropic, and based on that a more precise experiment can be conducted to find the one-way speed of light if it does prove to be anisotropic; if it does prove to be isotropic then the current paradigm stands.

Although it seems impossible to eliminate a source of indeterminable reading errors (general relativity and synchronization), repetition and calibration of the experiment will negate their effects.

Conclusion

Incorporating quantum entanglement to start and stop the setup provides a reasonably accurate measurement for the one-way speed of light. The use of quantum entanglement does introduce uncertainties and complexities into the experiment; however, considering the predicament of the unreliability of wires and other media of signal transmission, it proves to be the best solution.

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