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Research Article

Theoretical Foundations of Isotropic One-Way Light Speed in Vacuum Experimental Setup for Measuring One Way Light Speed

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Abstract

In the current paper we set the theoretical foundations for justifying the fact that one-way light speed in vacuum has to be isotropic. Once we establish the theoretical foundations for one-way light speed isotropy, we proceed with describing the experimental setup for measuring one-way light speed. The specialty literature is full of reasons why measuring one-way light speed is not possible, in the second half of this paper we show why this is not true. We also describe two different approaches, one based on Einstein clock synchronization, and one based on clock transport for measuring one-way light speed.

Keywords: one-way light speed anisotropy constraints; experiments that can be done with one-way light speed; clock synchronization; setup for measuring one-way light speed

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Introduction

A considerable amount of literature has been dedicated to proving that one-way light speed is not measurable [1,2]. The proofs revolve around the circular dependency between the fact that the act of measuring one-way light speed depends on clock synchronization while clock synchronization depends on knowing the values of one-way light speed. We start our paper laying the foundations that one-way light speed has to be isotropic (a fact confirmed by a multitude of experiments that constrain one-way light speed anisotropy to a very high degree [3-17]). Once the foundations are laid out, we proceed with describing the experimental setup used for measuring one-way light speed. The argument against the measurability of the oneway speed of light hinges on the existence of an infinity of possible synchronization schemes for the setting of the clocks to be used in the measurement. One cannot single out from these some particular choice without assuming something, a priori, about the speed of light. This circularity is most obvious in the use of light signals to synchronize distant clocks with a master clock. This method, where a light signal is sent from a master clock at a time, t, to a distant clock which, on reception of the signal, is set to time t +T (where T is the travel time of the signal), is referred to as "light synchronization". To know the travel time of the signal, one must make an assumption about the one-way speed of light between the different clocks, thus defeating attempts to measure the one-way speed of light. This situation exists for light travelling along, not only a constant direction, but also any open path. There is no such objection to measuring the return trip (closed path) speed of light since only one clock is used for this case, avoiding synchrony considerations altogether.

Theoretical Foundations of One-Way Light Speed Isotropy

Let's assume that one-way light speed depends on the orientation of a light beam with respect to the x-axis according to the rule $c(\theta)$ where $\theta \in [0,\pi]$ is the angle made by the light beam with the x axis. The light beam going in the opposite direction will have the speed $c(\theta+\pi)$. Over an arbitrary distance L the two-way light speed, c is the two=way distance divided by the average transition times of the respective one-way light speeds:

$$c = \frac{2L}{\frac{L}{c(\theta)} + \frac{L}{c(\theta+\pi)}} \quad (2.1)$$

Armed with the above we can calculate the "return" one-way light speed:

$$c(\theta+\pi) = \frac{c}{2}\frac{c(\theta)}{c(\theta)-c/2} \quad (2.2)$$

That means that:

$$\lim_{c(\theta)\searrow c/2} c(\theta+\pi) = \infty \quad (2.3)$$

$$\lim_{c(\theta)\nearrow c/2} c(\theta+\pi) = -\infty \quad (2.4)$$

which is obviously a physical impossibility. To further prove the absurdity of considering one-way light speed to be anisotropic, let's take $c(\theta) = 0.8c$. This implies immediately:

$$c(\theta+\pi) = 4c/3 \quad (2.4)$$

In fact, for $\forall c(\theta) \in [c/2, c]$ we have the absurd consequence $c(\theta+\pi) > c$. Even worse, for $\forall c(\theta) \in [0, c/2)$ we have the even more absurd consequence $c(\theta+\pi) < 0$. For $c(\theta) = c/2$ we have a vertical asymptote. The only reasonable outcome is to consider $c(\theta+\pi) = c(\theta) = c$ for all $\theta \in [0,\pi]$. As we can see, assuming that one-way light speed can be anisotropic, leads to unphysical situations. Coupled with the multitude of experiments [3-17] that severely constrain one-way light speed anisotropy, we have to conclude that one-way light speed is, indeed, isotropic.

One Way Light Speed Measurement Experiment Setup Description

In the previous section we have demonstrated that $c(\theta+\pi) = c(\theta) = c$ for all $\theta \in [0,\pi]$. This fact allows us to use Einstein synchronization for two remote clocks separated by an arbitrary distance *L* without any assumption on the value of the one-way light speed and without even having to know the distance separating the clocks. Indeed, if we send a pulse from one clock to the other clock and we reset the second clock upon the signal arrival, followed by reflecting the signal towards the first clock and halving the time accumulated on the first clock we will have the clocks showing the times *L/c* and $L/c(\theta+\pi)$ respectively. We can accomplish the clock synchronization through clock transport as well, The transport doesn't even have to be "slow", any speed will do as long as both clocks are transported with the same speed. Assume that we have two identical high precision clocks mounted on two identical lathe sleds. Both sleds are engaged on a long lead screw, one sled being right threaded while the other sled is left threaded (see figure 1). After a certain number of turns, N, arbitrary but known, the lead screw is stopped, each clock having traveled the same distance:

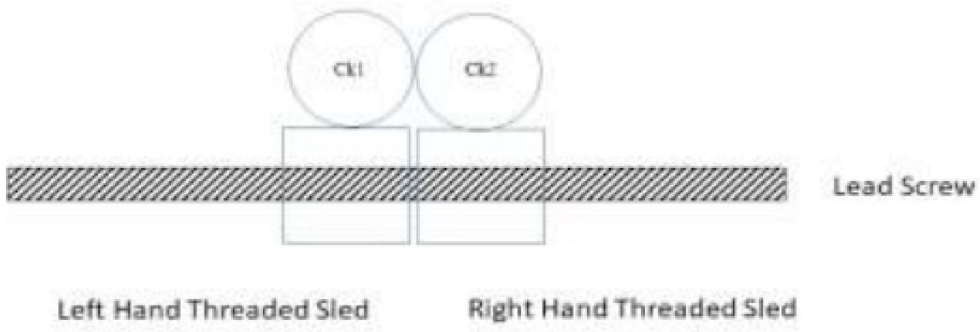

Figure 1: Experimental Setup.

$$L = N * step \qquad (3.1)$$

where "step" is the distance between two consecutive threads, the step of the screw, in other words. During their motion, each of the two clocks has accumulated the same proper time:

$$\tau = \int_0^{L/v} \sqrt{1-\frac{v^2}{c^2}}dt = \frac{L}{v}\sqrt{1-\frac{v^2}{c^2}} \qquad (3.2)$$

Now, if the diameter of the lead screw is *d* and the angular speed of turning it is ω then we have the relationship:

$$step / v = d\omega\pi \qquad (3.3)$$

So:

$$\frac{L}{v} = \frac{L}{step} d\omega\pi = Nd\omega\pi \qquad (3.4)$$

After the time τ the two clocks are separated by the distance (see figure 2):

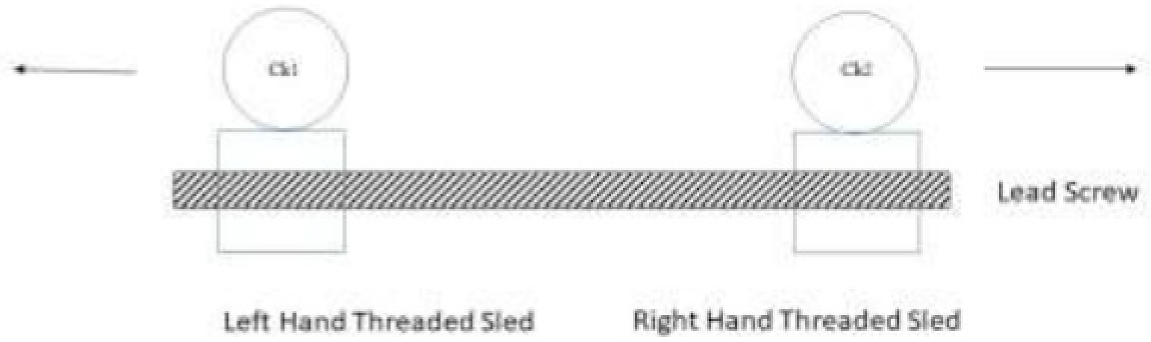

Figure 2: Final Clock Position.

At this point we can now send a light beam from source SRC (see fig.3). When the light beam passes clock CK1 it stops it. Clock CK1 will show the time τ_1 . When the light beam passes clock CK2 it will stop it. Clock CK2 will show the time τ_2 . The one-way light speed is:

Figure 3: One Way Light Speed Measurement.

$$c_{OWLS} = \frac{2L}{\tau_2 - \tau_1} \quad (3.5)$$

We can repeat the experiment while we rotate the whole setup in incremental steps to a full 180 degrees (we do not need to do the whole 360 degrees due to symmetry). As shown in figure 4.

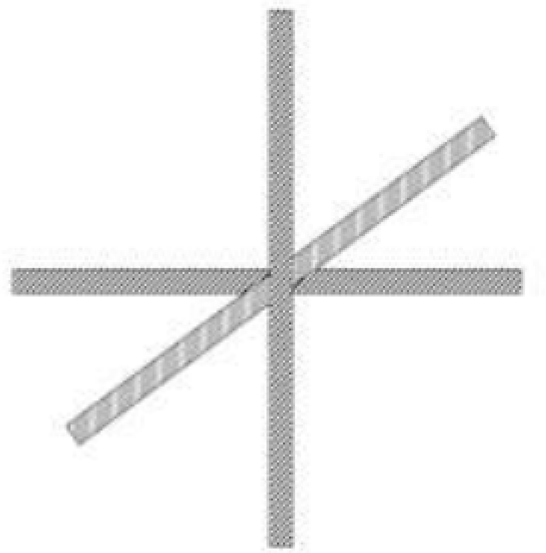

Figure 4: Setup Rotation.

Error Analysis

When we substitute (3.4) into (3.2) we obtain a very interesting result:

$$\tau = Nd\omega\tau\sqrt{1 - \frac{\left(\frac{step}{d\omega\tau}\right)^2}{c^2}} \quad (4.1)$$

The only (very small) desynchronization between the two clocks can only come from a (very small) error in machining the lead screw, more exactly from some variation in the "step" between the threads. We can calculate the desynchronization to be:

$$\Delta\tau = Nd\omega\tau\sqrt{1 - \frac{\left(\frac{step}{d\omega\tau}\right)^2}{c^2}} - Nd\omega\tau\sqrt{1 - \frac{\left(\frac{step+\varepsilon}{d\omega\tau}\right)^2}{c^2}} \quad (4.2)$$

Since $\frac{step}{d\omega\tau} << c$ we can write the desynchronization to be:

$$\Delta\tau \approx \frac{Nd\omega\tau}{2c^2}[\left(\frac{step+\varepsilon}{d\omega\tau}\right)^2 - \left(\frac{step}{d\omega\tau}\right)^2] \quad (4.3)$$

The above can be further approximated as:

$$\Delta\tau \approx \frac{Nstep}{c^2 d\omega\tau}\varepsilon = \frac{L}{c^2 d\omega\tau}\varepsilon \quad (4.4)$$

The error can be minimized by minimizing the distance traversed by the two clocks. Either way, the error will be very small due to the presence of the term in c^2. The above systematic error can be completely cancelled out by inverting the light speed direction, the 180 degrees inversion inverts the sign of the error, and we are thus left to account with only a potential intrinsic one-way light speed anisotropy between the two measurements.

Conclusion

In the current paper we have set the theoretical foundations for justifying the fact that one-way light speed in vacuum has to be isotropic. Once we established the theoretical foundations for one-way light speed isotropy, we proceeded with describing the experimental setup for measuring one-way light speed. We also described two different approaches, one based on Einstein clock synchronization, and one based on clock transport for measuring one-way light speed.

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