Peer Review

Review of: "Entangled Simultaneity: Testing Lorentz and Light Speed Invariance with Quantum and Classical Entanglement"

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Abstract

In this comment, we demonstrate that the claim by Spavieri et al., asserting that Wang et al.'s interferometric experiment disproves the special theory of relativity by revealing that simultaneity must be an absolute concept independent of the observer's state of motion, is based on circular reasoning and therefore constitutes a logical fallacy.

1. Introduction

In Ref.[1], the authors present several arguments against the validity of special relativity. They follow an out-of-the-mainstream tradition started in the 1930s by Albert Eagle[2], pretending to prove that absolute simultaneity is a natural concept imposed on us by rational thinking and experimental facts whose rejection leads to inconsistencies. A quick literature search reveals that this anti-relativistic tradition remains alive in the 21st century[3][4][5][6][7][8][9][10].

One of the leading figures of this tradition was the Italian physicist Franco Selleri, who proposed an argument known among his followers as *Selleri's paradox*.

The argument proposed by Selleri[11][12] never received serious consideration by mainstream physicists, which is probably unfortunate because the clarification of foundational issues restrains the spreading of incorrect scientific ideas among non-experts and the public in general.[2]

Although all the arguments exposed by Spavieri et al. in Ref.[1] can be consistently rebutted according to the orthodox scientific understanding, we shall concentrate only on clarifying their concrete claim stating that

Wang et al.'s interferometric experiment (Wang experiment for short) cannot be consistently explained by special relativity.

The argument is sufficiently compelling as to be considered a paradox. We congratulate Spavieri et al. for conceiving and promoting the paradox. However, there is a difference between a paradox, whose explanation defies intuition, and a true logical inconsistency.

2. The Wang experiment

Ruyong Wang et al.[13][14] carried out an experiment that they conceived as a modified Sagnac interferometer (Fig. 1). In the Sagnac interferometer, a phase shift is produced between two light beams by rotation. In contrast, in the Wang experiment, the phase shift is obtained by linear motion using a device they called *fiber optic conveyor* (FOC) to distinguish it from the usual fiber optic gyroscope (FOG).

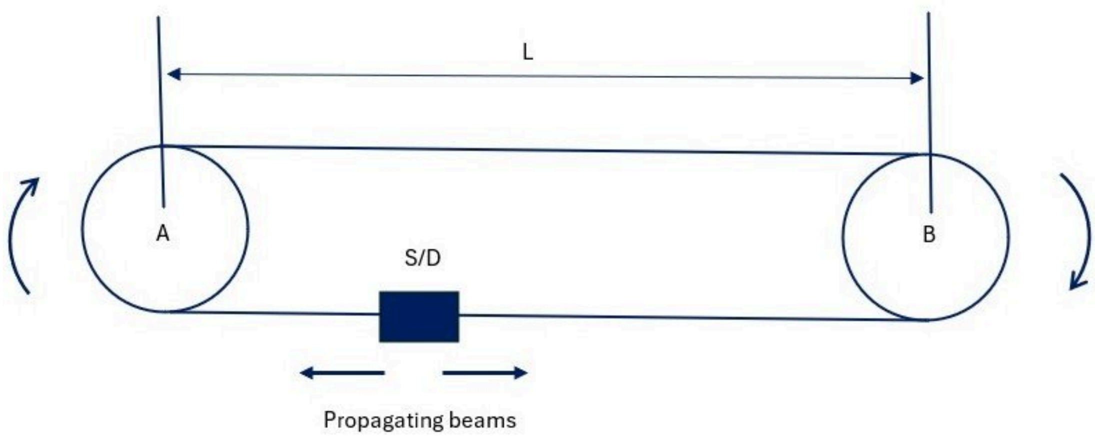

Figure 1. Wang interferometer. Two beams are generated at the source (S) and then detected after returning to the detector (D). The S/D device is fixed to the fiber optic medium, which is assumed to have refractive index $n = 1$ and is set in motion with linear speed ν by the rotating wheels A and B.

The phase shift at D is owing to the time difference in the arrival times of the beams and is readily obtained in the laboratory reference frame (LAB frame) as,

$$\Delta t = \frac{4\nu L}{c^2} \tag{1}$$

where t is the time of the LAB frame. According to relativity, the proper time difference indicated by a clock moving with S/D is

$$\Delta\tau = \frac{\Delta t}{\gamma} \tag{2}$$

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where the gamma factor is $\gamma = 1/\sqrt{1-(\nu/c)^2}$. Since, to first order in v/c, $\gamma \approx 1$, we can ignore the time dilation effect for this experiment.

3. The Inconsistency Claim

According to the authors of Ref.[1], it is well-known that the Lorentz transformation fails to describe light propagation along a closed contour. To prove their claim, they analyze the Wang interferometer and calculate the time it takes the counter-propagating photon ϕ to complete a round-trip, as measured by a clock C^* fixed to the fiber optic and moving with speed ν with respect to the LAB frame (Fig. 2).

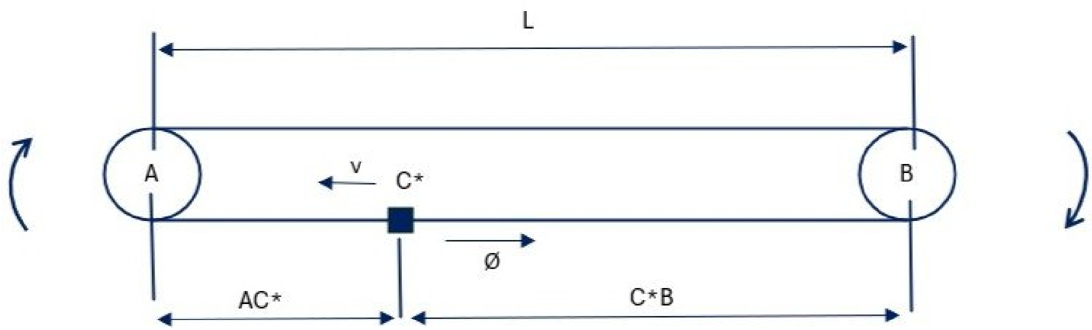

Figure 2. The clock C^* is stationary with respect to the fiber optic and moving with speed ν with respect to the laboratory reference frame

The time registered by C^* is calculated from the LAB frame. Assuming an initial condition where the distances of the clock C^* from A (AC^*) and B (C^*B) are such that when the clock reaches A, simultaneously the photon ϕ reaches B. Then, if t is the laboratory time,

$$AC^* = \nu\, t_{out} \tag{3}$$
$$C^*B = c\, t_{out} \tag{4}$$

Since $AC^* + C^*B = L$, we readily obtain,

$$t_{out} = \frac{L}{c+\nu} \tag{5}$$

Disregarding the curved sections corresponding to the pulleys at A and B, the configuration at $t = t_{out}$ is depicted in Fig. 3.

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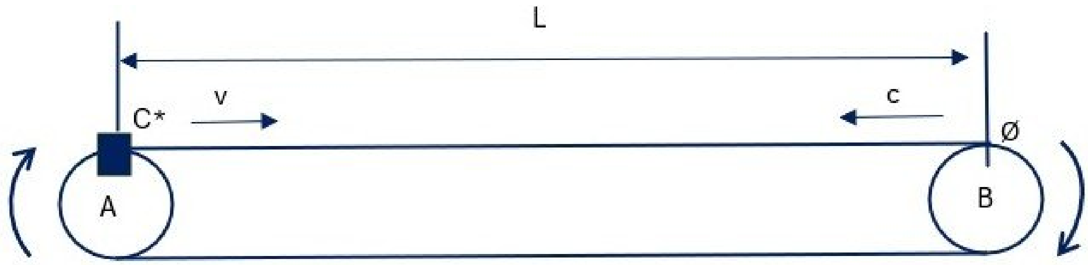

Figure 3. In the LAB frame, the two distant events “the clock is at A” and “the photon is at B” are simultaneous.

At $t = t_{ret}$, the clock and the photon reunite on the upper section; t_{ret} must satisfy the equation $L = \nu\, t_{ret} + c\, t_{ret}$, thence,

$$t_{ret} = \frac{L}{c+\nu} \tag{6}$$

The total time of the photon round-trip, according to the LAB frame time, is

$$T_{LAB} = t_{out} + t_{ret} = \frac{2L}{c+\nu} \tag{7}$$

The proper T time registered by the clock C^* is,

$$T = \frac{T_{LAB}}{\gamma} = \frac{2L}{\gamma\,(c+\nu)} = \frac{2L}{\gamma\, c\,(1+\beta)} \tag{8}$$

where $\beta = \nu/c$.

The presumed inconsistency is revealed when we investigate the ground distance covered by the photon according to the proper time (8) and the fact that the speed of light is c irrespective of the observer. Since the clock C^* is stationary with respect to the fiber optic, we expect that after completing its journey back to C^*, the photon should have traveled the entire length of the fiber optic medium. However, we find that the distance traveled by the photon is,

$$c\,T = \frac{2L}{\gamma(1+\beta)} < 2\gamma L \tag{9}$$

Where $2\gamma L$ is the total proper fiber optic length since the fiber moves with speed ν between the centers of the stationary pulleys and $AB = L$.

The difference

$$\delta d_{\phi} = \qquad 2\gamma L - cT = 2L\gamma - \frac{2L}{\gamma(1+\beta)} = 2\gamma L\beta \tag{10}$$

is the central point of the inconsistency argument.

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According to Spavieri et al., δd_ϕ is a "missing path" which implies a "time gap" $\delta t = \delta d_\phi / c$ constituting an unacceptable breach in spacetime continuity as observed in the reference frame in which the clock C^* remains at rest.

4. Analysis of the "missing path" and "time gap"

In Ref.[1], the authors introduce two reference frames, S'', at rest with respect to the lower section of the fiber, and S', at rest in the fiber's upper section. They correctly reckoned the times T''_{out} and T''_{ret} corresponding to time as measured in the S'' reference frame.

They start with an initial configuration such that, as observed from S'', after the elapsed time T''_{out}, the clock reaches A at the same time the photon arrives at B (Figs. 4 (a) and (b)).

According to the relativistic addition of velocities, S' is moving with speed w with respect to S'', where

$$w = \frac{2\nu}{1+\beta^2} \tag{11}$$

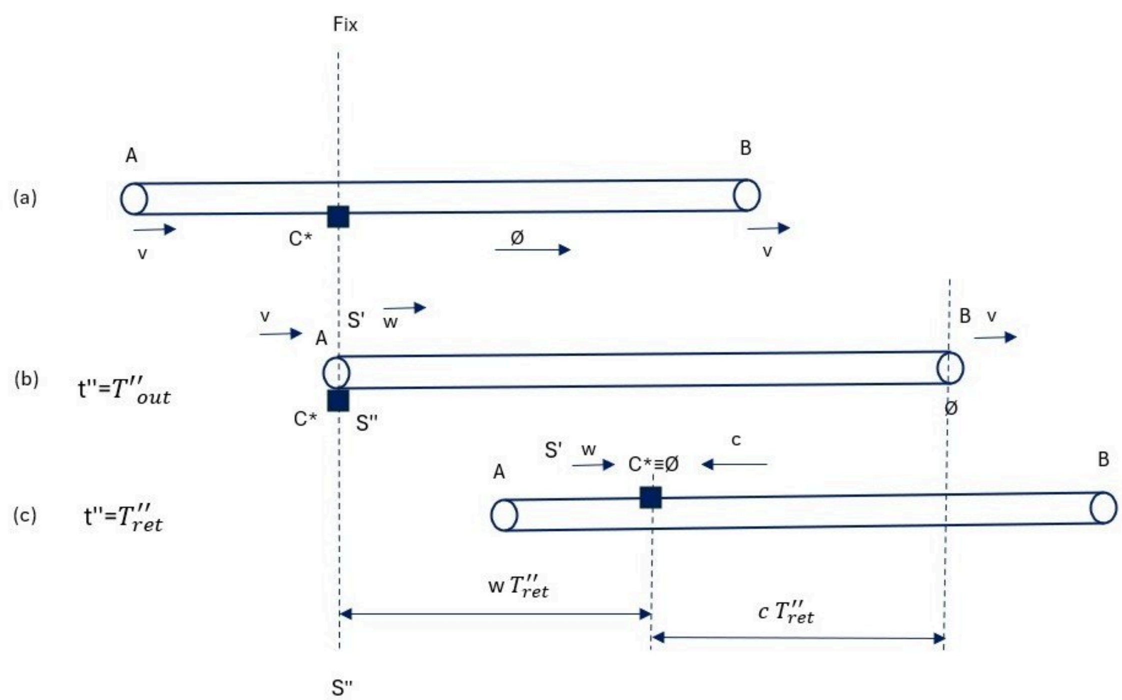

Figure 4. Wang interferometer as seen from S'' where the lower fiber section is instantaneously at rest.

Evaluating the elapsed clock's proper time $T''_{out} + T''_{ret}/\gamma_w$, we find (8) once more, confirming the previous result by a different method,

$$T = T''_{out} + \frac{T''_{ret}}{\gamma_w} = \frac{2L}{\gamma c(1+\beta)} \tag{12}$$

Where,

$$T''_{out} = \frac{L}{\gamma c} \tag{13}$$

$$T''_{ret} = \frac{L}{\gamma c(1+\frac{w}{c})} \tag{14}$$

$$T'_{ret} = \frac{T''_{re}}{\gamma_w} = \frac{L}{\gamma c}\frac{(1-\beta)}{(1+\beta)} \tag{15}$$

Where,

$$\frac{1}{1+\frac{w}{c}} = \frac{1+\beta^2}{(1+\beta)^2} \tag{16}$$

$$\gamma_w = \frac{1}{\sqrt{1-(\frac{w}{c})^2}} = \frac{1+\beta^2}{1-\beta^2} \tag{17}$$

4.1. Missing path according to Spavieri et al.

Here we reproduce the core of the argument presented in[1]. Under the title: **Spatial ground distance covered by the photon according to the LT**, the authors explain that the distance covered in S'' according to (13) is,

$$L'' = cT''_{out} = \frac{L}{\gamma} \tag{18}$$

In the return trip on the upper fiber section, the photon is in the system S', and the distance covered is, according to (15),

$$L' = cT'_{ret} = \frac{L}{\gamma}\frac{(1-\beta)}{(1+\beta)} \tag{19}$$

The total distance covered by the photon is,

$$L'' + L' = \frac{L}{\gamma} + \frac{L(1-\beta)}{\gamma(1+\beta)} = \frac{2L}{\gamma(1+\beta)} \tag{20}$$

The missing path paradox arises because the total proper length of the fiber is $2\gamma L$, so we have a missing path that has not been covered by the photon,

$$\delta d_\phi = 2\gamma L - (L' + L'') = 2\gamma L\beta \tag{21}$$

This result confirms again the value (10) found by another method.

4.2. Explication of the "missing path paradox"

According to the authors of[1], owing to the invariance of the speed of light, the time required by the photon to cover the whole fiber medium is,

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$$(T)_E = \frac{2\gamma L}{c} \tag{22}$$

Since $(T)_E$ is greater than the observed time T given by (8) and (12), the Lorentz transformation purportedly fails to provide a consistent explanation. Spavieri et al. attribute this problem to the relativity of simultaneity.

However, we shall see that the correct application and interpretation of the Lorentz transformation (23) proves that the total time the photon was in motion is indeed $(T)_E$ and that the missing path is inexistent.

Ironically, it is the fact that simultaneity is relative and not absolute that renders the correct explication of the missing path paradox, instead of producing it.

The reference systems $S'(t', x', y', z')$ and $S''(t'', x'', y'', z'')$ are set as in[1]; their origins coincide when the clock C^* is at A (Fig. 4 (b)). The Lorentz transformation is given by,

$$\left.\begin{array}{lcll} t' & = & \gamma_w & (t'' - \frac{wx''}{c^2}) \\ x' & = & \gamma_w & (-wt'' + x'') \end{array}\right\} LT \tag{23}$$

We have two relevant events; the first one is the event $CA \equiv$"the clock is at A." The second one is $PB \equiv$"the photon is at B." We recall here that, according to relativity theory, only the individual events are part of objective reality and that the simultaneity of distant events is not part of objective reality.

The coordinates (t'', x'') and (t', x') of these events in S'' and S' are

$$\begin{array}{lclcccclcccl} CA & : & (& 0 & , & 0 &)_{S''} & \xrightarrow{LT} & (& 0 & , & 0 &)_{S'} \\ PB & : & (& 0 & , & L/\gamma &)_{S''} & \xrightarrow{LT} & (& -\gamma_w wL/\gamma c^2 & , & \gamma_w L/\gamma &)_{S'} \end{array} \tag{24}$$

At $t'' = t' = 0$ the clock C^* is abruptly forced to pass from the system S'' to $S.'$ For the argument's sake, it is irrelevant whether we choose to use another clock already at rest in S', as in Ref.[1], to reckon time intervals.

As shown by (24), in S'', the events CA and PB have the same time coordinates $t''_{CA} = t''_{PB} = 0$ but in S' we find that $t'_{CA} = 0 \neq t'_{PB} = -\gamma_w wL/\gamma c^2$.

Therefore, when the clock is forced to change reference frames at $t' = 0$, we find that the event "$PB \equiv \text{the photon is at B}$" has already taken place in S' at $t'_{PB} = -\gamma_w wL/\gamma c^2 < 0$, before the clock is forced to change systems.

Then, if simultaneity is not absolute, as relativity and the Lorentz transformation require, when C^* passes to S', it finds that, in that reference frame, the photon departed from B in the past and has already traveled the distance

$$c|t'_{PB}| = c| - \gamma_w wL/\gamma c^2| = 2\gamma L\beta = \delta d_\phi \tag{25}$$

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This shows that there is indeed no missing path because the total covered length is given by the distance traveled in S'', equal to L'', plus the total distance traveled in S', equal to L'(after the clock changed frames) plus δd_ϕ (before the clock changed frames), which, according to (21) is,

$$L'' + L' + \delta d_\phi = 2\gamma L \tag{26}$$

Accordingly, the total time the photon was in motion is given by,

$$\begin{aligned} |t'_{PB}| + T &= \frac{\gamma_w w L}{\gamma c^2} + \frac{2L}{\gamma c(1+\beta)} && (27) \\ &= \frac{2\gamma L}{c} && (28) \\ &= (T)_E && (29) \end{aligned}$$

5. Conclusions

We have demonstrated that Spavieri et al.'s "missing path paradox" arises only if we assume that relative simultaneity is false.

The correct explication requires the description from two distinct inertial frames, S'' and S', and the use of the Lorentz transformation taking into account relative simultaneity, in which case no contradiction or inconsistency arises.

When the description of the entire phenomenon is made from only one system, for instance, from the laboratory reference frame, or S'', there seems to be a lost "time gap" or "missing path".

The claimed inconsistency involves circular reasoning because to prove that relative simultaneity is inconsistent, the proof presented in[1] ignores its implications, tacitly assuming that it is false.

Intuition is a good guide when it is supported by strict logic and rigorous rational thinking, but intuition and "common sense" alone can be deceiving, as modern physics, founded in relativity and quantum mechanics, has taught us.

Footnotes

[1] A didactic refutation of Selleri's argument can be found in Ref.[15].

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Declarations

Potential competing interests: No potential competing interests to declare.