Research Article

Length Contraction From Three Experimentally Verified Effects

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Length contraction has reappeared, quite recently, after more than a century of intermittent debate about its mere existence. We start with the verified constancy of the two-way speed of light, requiring the same round-trip travel time measured by an inertial observer. By analyzing a configuration with a stationary and moving system and incorporating the verified effects of the independence of the speed of light from the speed of the emitter and time dilation, it emerges that those two effects are insufficient to account for the invariance of the round-trip speed of light in the moving system. By involving length contraction—so far lacking direct experimental verification—the discrepancy disappears. Length contraction thus emerges as a real effect, a direct consequence of three experimentally verified effects: the invariance of the round-trip speed of light, time dilation, and the independence of the speed of light from the speed of the emitter.

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1. Introduction

The invariance of the round-trip (two-way) speed of light is one of the soundest empirical facts in modern physics. The Michelson–Morley (M&M) famous experiment and M&M's latest results [1] to modern radar and interferometric measurements [2], have consistently found that *the time required for light to propagate back and forth along a closed path is independent of the uniform motion of the apparatus* [3]. The null results of M&M interferometers failed to detect the expected anisotropy in the two-way light speed. In 1889, Fitzgerald, motivated to justify the null result of M&M and inspired by Heaviside (1888), who calculated the shortening of the electron field (later confirmed by Searle) along the direction of motion, [4] proposed length contraction; Lorentz independently proposed the same a couple of years later. Years later, Tolman [5] provided a theoretical explanation using Einstein's light clock, also involving time dilation. Tolman described the distortion of a moving body as "not a physical change in the body itself but a scientific fiction." In contrast, for Poincaré and Lorentz, the contraction was intended as a real physical effect caused by motion through the ether, not merely a "perspectival effect"[6]. Although length contraction lacks direct experimental proof, it has been the subject of a long-standing debate, with renewed interest in recent years [7][8][9]. Time dilation, by contrast, has been directly confirmed in numerous experiments since the 1940s [9][10]. The independence of the speed of light from the speed of the emitter, a very well-known physical fact, is also at the base of the Sagnac effect [11], exploited also in modern laser gyroscopes. This paper addresses the question: *"Is length contraction merely a kinematical consequence of coordinate transformations, or is it a physical effect like the experimentally verified time dilation?"* To answer this question, we analyzed a light-propagation configuration involving a uniformly moving system, explicitly incorporating the experimentally verified effects of time dilation and the law of independence of the speed of light from the emitter. By computing the round-trip light time using a single clock in each system, thereby avoiding distant clock synchronization, we show that time dilation alone is indeed insufficient to preserve the invariance of the two-way speed of light. A further reduction of the effective propagation length in the moving system is required; hence, length contraction emerges naturally. Length contraction is not introduced as an ad hoc hypothesis or inferred from symmetry arguments but arises simply as an operational necessity imposed by experimentally established properties of light propagation. In this sense, length contraction, although indirectly measurable but unavoidable for the internal consistency of observations, confirms the several predictions of its actual existence.

2. The Propagation of Light in Stationary and Moving Systems

The following analysis relies on experimentally established effects and explicitly stated operational assumptions. No appeal is made to synchronization conventions, the prior adoption of Lorentz transformations, or the assumption of the one-way invariance of the speed of light. It is based on the following physical facts:

(E1) The time required for light to propagate back and forth along a closed path is independent of the uniform motion of the apparatus. Experiments measuring the out-and-back propagation time of light along a closed path find that the average speed is equal to c, independently of the uniform motion of the apparatus. This is guaranteed by the invariance of the round-trip light time along a known path length (the same for the same apparatus): $T_{out-back} = T'_{out-back}$

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(E2) Independence of the speed of light from the speed of its emitter: a property of waves.

(E3) Time dilation. Clocks, set at a constant speed v, run slower by a factor $\gamma^{-1} = \sqrt{1 - v^2/c^2}$, as confirmed by high-precision experiments involving unstable particles and Doppler spectroscopy.

We propose an arrangement (Fig. 1) in which a primed structure and a twin structure are at rest relative to the embankment, like Einstein's train-embankment thought experiment and like Tolman's theoretical setup [5]. We will call the ***primed wagon*** the one which can move.

The measured length at rest with the embankment of both structures is L. The aim is to find L', the length of the moving wagon as measured from the embankment.

To avoid the complexities of synchronizing distant clocks, emitters and detectors are co-located at the center of their respective structures. We consider a stationary system (Embankment) with center M unprimed and a primed system Wagon with center M′. Mirrors/reflectors are placed at the extremes (Ra, Ra′, Rb, Rb′). The primed wagon is brought to speed v.

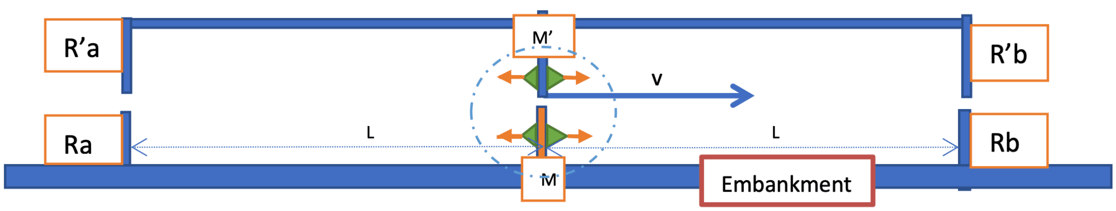

Figure 1. *The structures are aligned and emitters shoot at once*

When **M** and **M′** overlap, light pulses are emitted toward the mirrors. This event, involving the simultaneous emission of four pulses, triggers all the following events. The analysis is performed according to a stationary clock on the embankment; the time intervals of the events are as follows.

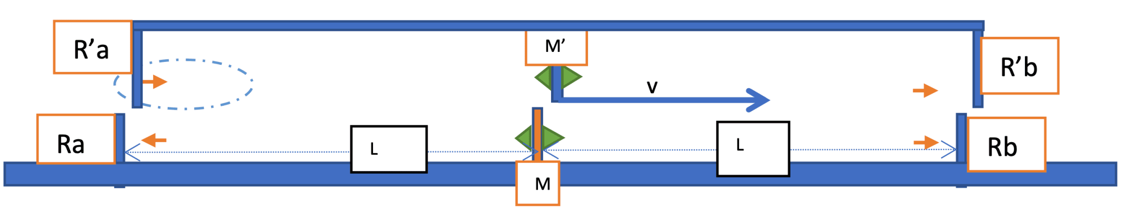

Figure 2. *The first event: a reflection.*

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The FIRST event is a REFLECTION in Ra'; the counter-propagating wave meets the mirror, moving toward it. We consider T_+ the elapsed time between the emission by M' and the reflection on R'a.

By applying **(E2)**, the simple equation of the length crossed $cT_+ = L' - vT_+$ emerges. The elapsed time is then $T_+ = \frac{L'}{c+v}$ (1)

The SECOND event is a simultaneous reflection at Ra and Rb in the embankment frame, occurring after time $\frac{L}{c}$ according to M.

The THIRD event is a reflection at Rb′ (the co-propagating wave "chases" the mirror moving away). Here, by applying (E2) again,

$cT_- = L' + vT_-$; by solving the previous equation, it is $T_- = \frac{L'}{c-v}$ (2)

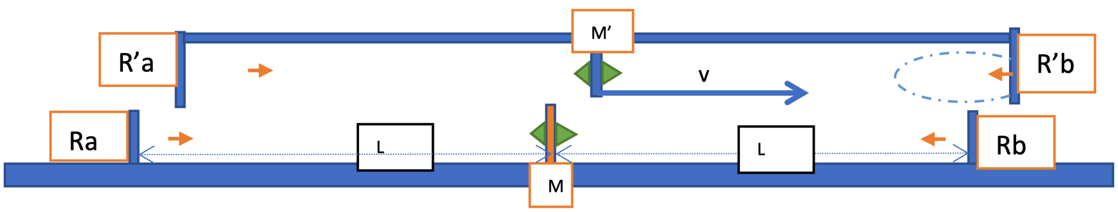

Figure 3. *The third event: a reflection.*

The FOURTH event is the simultaneous absorption by M of the two waves it emitted, occurring after the interval $T_{out-back} = 2L/c$, as required by the constancy of the two-way speed of light in the embankment frame.

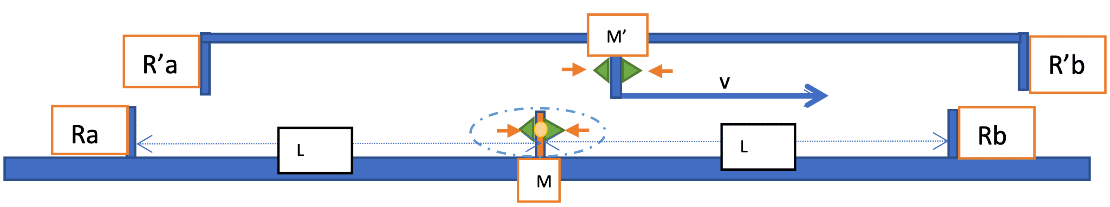

Figure 4. *The fourth event: simultaneous absorption by M.*

The FIFTH event is the simultaneous absorption by M' of its two emitted waves, after intervals (1) and (2).

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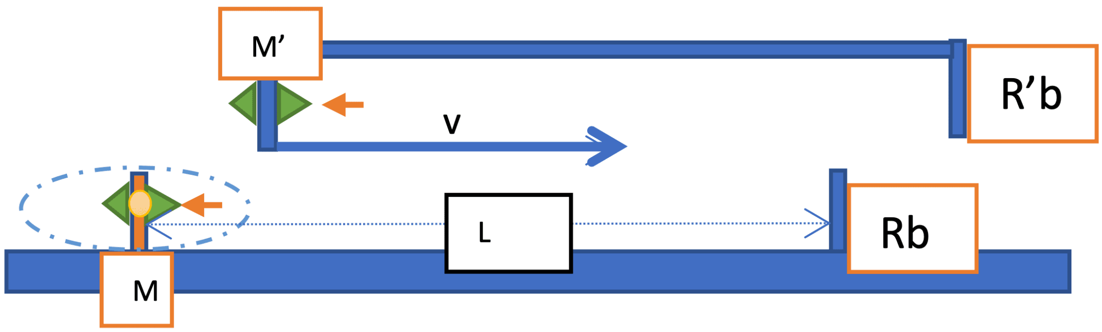
Note that the initial simultaneous emission results in non-simultaneous absorptions (the fourth and fifth events), as predicted in Einstein's original train-embankment configuration. The round-trip time in the moving system, as measured from the embankment clock, is the sum of (1) and (2):

$$T_{M'} = T_{+} + T_{-} = \frac{L'}{c+v} + \frac{L'}{c-v} = \frac{2L'}{c} \cdot \frac{1}{1-v^2/c^2} = 2\gamma^2 \frac{L'}{c} \qquad (3)$$

Since this is an out-and-back arrangement, the result is general and depends only on the invariance of the round-trip light travel time. The problem could be illustrated in each half, as below:



Due to **(E3)**, the comoving clock at M' runs slower by γ^{-1}. Thus, the round-trip time measured by the moving observer must be

$$T'_{out-back} = \gamma^{-1} T_{M'} = 2\gamma \frac{L'}{c} \qquad (4)$$

3. Length Contraction Is a Necessary Physical Effect

By considering $T'_{out-back} = 2\gamma \frac{L'}{c}$ and the compliance with (E1): $T_{out-back} = T'_{out-back}$ where $T_{out-back} = \frac{2L}{c}$, *the only possible solution is* $L' = \frac{L}{\gamma}$ *hence* $T'_{out-back} = 2\gamma \frac{L/\gamma}{c} = \frac{2L}{c}$.

Summarizing:

- From (E2), the independence of SOL on the speed of the emitter gives $T_{M'} = 2\gamma^2 L'/c$.
- From (E3), time dilation reduces that interval for the moving clock to $2\gamma L'/c$.
- From $T_{out-back} = T'_{out-back}$, it must be $L' = \frac{L}{\gamma}$, yielding $T'_{out-back} = 2L/c$.

The length L' of the wagon undergoes a contraction by γ detected from the embankment to preserve round-trip light time invariance within the same system (or in a twin system)— $L' = \frac{L}{\gamma}$ is the Lorentz/FitzGerald contraction. Thanks to that, the observer in the wagon measures the same round-trip speed of light as the one on the embankment. This operational necessity establishes length contraction as a real physical effect. The very recent paper by Gjurchinovski, deriving length contraction from differential simultaneity [12], represents a quite different viewpoint on the topic purely based on theoretical grounding, without experimental evidence, besides the fact that the property is not reciprocal.

4. Conclusions

Length contraction was not assumed but derived from three laws: the constancy of the round-trip speed of light for non-accelerated observers, the independence of the speed of light from the emitter, and time dilation. These experimental facts together provide sound support for length contraction to be a real physical effect. It is also possible to say that the invariance of the round-trip speed of light is guaranteed by the concurrent action of three effects: the independence of the speed of light from the speed of the emitter, time dilation, and length contraction.

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Declarations

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