

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. The verified constancy of the two-way speed of light, requiring the same round-trip travel time measured by an inertial observer, is considered. A configuration involving a stationary system, in which light propagation is assumed isotropic, and a uniformly moving system is analysed. By considering the independence of the SOL from the speed of the emitter and time dilation, 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 a 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. From the famous Michelson–Morley (M&M) experiment and the latest M&M results ^[1] to modern radar and interferometric measurements ^[2], experiments 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 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 as the experimentally verified time dilation?*" To answer this question, we analysed 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 requiring the isotropy of light in one system and computing the round-trip light time using a single clock in each system, thereby avoiding distant clock synchronisation, we show that time dilation alone is indeed insufficient to preserve the invariance of the two-way speed of light-time. 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, is unavoidable for the internal consistency of observations, confirming 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 synchronisation conventions or the prior adoption of Lorentz transformations; it is based on the following facts:

(E1) The time required for light to propagate back and forth is independent of the uniform motion of the same 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. That is guaranteed by the invariance of the round-trip light time (RADAR timing) along a known path length (the same for the same apparatus): $T_{out-back} = T'_{out-back}$

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

(E3) Time dilation. Clocks, set at 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.

A simple arrangement (Fig. 1) is proposed where a primed structure and a twin structure are at rest relative to the embankment, which is always inertial. It recalls Einstein's train-embankment thought experiment and Tolman's theoretical setup [5]. We will call the *primed wagon* the one which is able to move from the embankment.

The measured length at rest with the embankment of both structures is L .

(E4) Light propagation is assumed isotropic, with speed c , in the embankment frame.

The aim is to find L' , the length of the moving wagon as measured from the embankment.

To avoid synchronising distant clocks, emitters and detectors are co-located in a stationary system (Embankment) with M unprimed and in a primed system Wagon M' . Two mirrors/reflectors are placed at the extremes (Rb , Rb'). The primed wagon is brought to speed v .

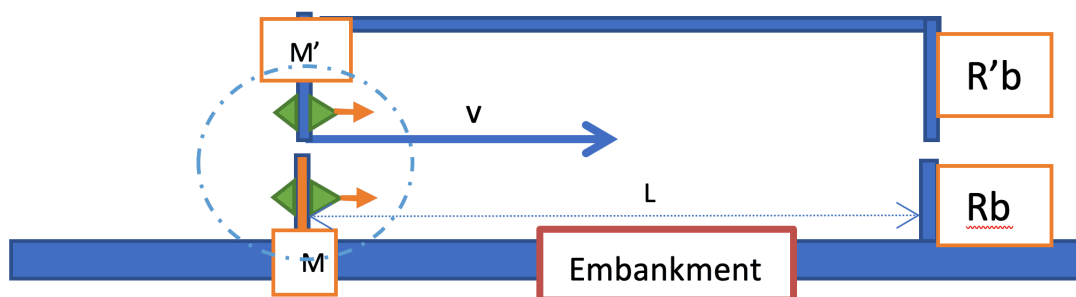


Figure 1. The structures are aligned and emitters shoot at once

When M and M' overlap, light pulses are emitted towards 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.

The reflection at Rb' , by applying (E2) and (E4), is obtained by equating the distances crossed by light and by the emitter. Between emission and reception, the moving emitter-receiver advances by a distance vT during T , while light is unaffected by the speed of the emitter and its path length is cT when it is reflected.

$$cT_- = L' + vT_- \text{ hence, it occurs at } T_- = \frac{L'}{c-v} \quad (1)$$

The absorption by M occurs after the interval $T_{out-back} = 2L/c$, as required by (E1).

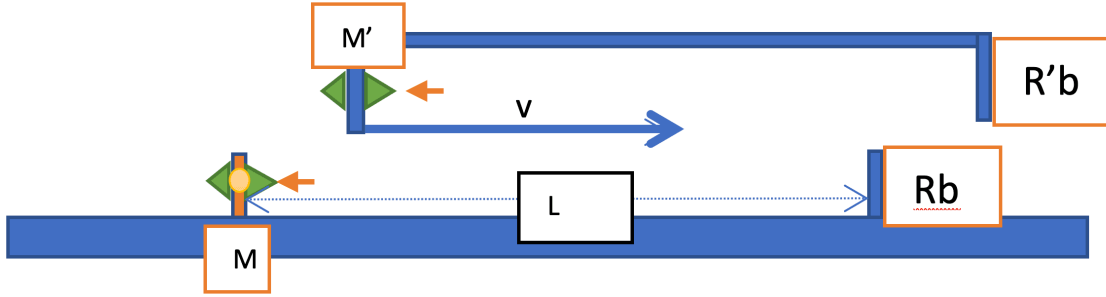


Figure 2. Absorption by M and M'.

The absorption by M' by applying (E2) and (E4) again, is found by solving the equation $cT_+ = L' - vT_+$, the same as the previous except that the interval vT is subtracted, compared to the previous case.

$$\text{The absorption occurs } T_+ = \frac{L'}{c+v} \quad (2)$$

The round-trip time in M', as measured from the embankment clock, is the sum of (1) and (2):

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

The corresponding round-trip time measured by the clock comoving with M' must be independent of the uniform motion of the apparatus, according to E1.

Due to (E3), the comoving clock at M' runs slower by γ^{-1} . Thus, the round-trip time measured by the moving observer would be $T'_{out-back} = \gamma^{-1}T_{M'} = 2\gamma \frac{L'}{c}$ (4)

3. Length Contraction as a Necessary Physical Effect

By considering the Eq (4) the compliance with (E1) imposes that $T_{out-back} = T'_{out-back}$, where $T_{out-back} = \frac{2L}{c}$, only by setting $L' = \frac{L}{\gamma}$ we are compliant with E1 hence $T'_{out-back} = 2\gamma \frac{L/\gamma}{c} = \frac{2L}{c}$

Summarizing

- The independence of SOL on the speed of the emitter and the requested isotropy of SOL in the embankment gives $T_{M'} = 2\gamma^2 L'/c$.
- Time dilation reduces that interval for the moving clock into $2\gamma L'/c$,

- $T_{out-back} = T'_{out-back}$, requires that $L' = \frac{L}{\gamma}$, yielding $T'_{out-back} = 2L/c$.

The length L' of the wagon, undergoes a contraction by γ detected from the embankment where the speed of light has been requested isotropic, 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, same as the observer on the embankment. This operational necessity establishes length contraction as a real physical effect.

The very recent paper of Gjurchinovski, deriving Length contraction from differential simultaneity ^[12], represents a quite different viewpoint on the topic purely based on theoretical grounding, without relying on experimental evidence.

4. Conclusions

Length contraction is not introduced as an independent postulate or derived from coordinate transformations but emerges as a necessary consequence of the combined application of three experimentally established laws: the invariance of the round-trip speed of light, the independence of light propagation from the motion of its emitter, and time dilation. Under the assumption of isotropic light propagation only in the embankment frame, the combined application of these three laws is sufficient to derive the Lorentz–FitzGerald contraction factor.

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