Special relativity without length contractions and time dilations

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Abstract

Path lengths and flight times of light, propagating inside a moving inertial system, are found to physically and measureably change in length according to the inverse of the Lorentz transformations (LT) when observed from a stationary system. The LT reverse those changes, to reproduce by mathematics the original path lengths and flight times of light in the moving system. Only space and time coordinates in the field equations, and the associated flight times and path lengths of light, transform by the LT, not real time and the length of rigid bodies. Consequently, real time is disconnected from the geometrical structure of four-dimensional spacetime. This changes our current concepts of space and time: The real world is three-dimensional and distinct from spacetime, with universal real time common to all inertial systems independent of velocity. The travelling twin never ages more slowly; time travels do not belong to the real world; moving bodies maintain their rest length. This all-optical interpretation of the LT explains the null result in Michelson's experiment, and any other measurements relevant for special relativity, without recourse to time dilation and length contraction as in the current interpretation of the LT.

Key words: Lorentz transformations; special relativity; nature of time
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Introduction

The Lorentz transformations (LT) of space and time variables in Maxwell equations were initially presented [1] as a mathematical approach to make electrodynamics covariant, so that processes involving light propagation inside moving inertial systems could be correctly observed and understood from a stationary platform. Lorentz interpreted the transformations as implying that, due to motion at a velocity v, rigid bodies are reduced in length by a factor $[(1 - (v/c)^2]^{1/2}$, in agreement with his former *ad hoc* explanation [2] of the null result in Michelson's experiment [3]. In the subsequent development of the special theory of relativity (SRT), Einstein [4] introduced a physical interpretation of the LT that is still current, *i.e.*, the rate of time and the length of rigid bodies both decrease by the Lorentz factor in a moving inertial system. That interpretation has been essential in the development of the concept of spacetime [5], with time being relative and part of the geometry of a four-dimensional real world. Here I consider from an experimental point of view the physics involved in observations from outside of optical wave propagation in moving inertial systems. When observed from a stationary platform, light paths inside a moving inertial system will be measured as being either longer or shorter than in the moving system, depending on the direction of light propagation (Fig. 1). With the velocity of light defined as a universal constant [4], flight times of light in the moving system will be similarly changed when measured from a stationary system. I show that those are real physical effects described by the inverse of the LT, and lead to an interpretation in which the LT reverse such changes to recreate the original path lengths and flight times of light inside the moving system, on the basis of the path lengths and flight times measured from the stationary system. Distinct from established teaching [6, 7], therefore, in this interpretation real time and the length of rigid bodies do not transform by the LT, *i.e.*, length contraction [2] and time dilation [4] do not occur. The effects of the LT are purely mathematical, wholly related to optical observations between mutually moving inertial systems, and concern only the space and time coordinates of electromagnetic waves and the corresponding path lengths and flight times. Consequently, such all-optical interpretation of the LT implies that real time is not part of the geometry of spacetime, and so will change our concepts of space and time: The real world is three-dimensional and separate from four-dimensional spacetime, with universal real time and the length of rigid bodies inside moving inertial systems independent of the systems' velocity. This physical interpretation of the LT and its inverse explains the null result in the Michelson [3] experiment, how cosmic ray-generated muons reach down to earth despite their short lifetime, and any other experiment relevant to SRT, without recourse to length contraction and time dilation as in current explanations. On the other hand, SRT and spacetime physics remain largely unperturbed by this interpretation of the LT, except that coordinates in spacetime refer to space and time in the field equations and not to real time and the size of rigid bodies.

The light path

Consider a rod with length L when measured at rest, situated along the x-axis inside an inertial system moving at velocity v parallel to the x-axis of a stationary system, as shown in Fig. 1. In the moving system, a short pulse of light is sent from the rear end A of the rod towards the front end B, where it is reflected back towards A by a mirror situated at B; this is similar to the physical situation considered in Ref. [4]. Inside the moving system light travels a distance L along the body in each direction. When observed from the stationary system, one finds from Fig. 1 that light is measured to travel an increased distance $S_1 = L/(1 - v/c)$ from A to B, and a shorter distance $S_2 = L/(1 + v/c)$ on its return from B to A; this was applied by Michelson [3] when calculating the expected result of his experiment. A simple measurement will demonstrate the reality of those changed light paths: Let photographs be made of the moving rod from the receding and approaching directions in the stationary system, with cameras having near-zero shutter times. Each photograph will show the ends of the rod and the corresponding coordinates along a measuring tape at rest in the stationary system. Crucially, for both cameras light that passes through the camera shutters would have left the far end of the rod - and the adjacent tape markings - sooner than from the near end, and in the meantime the rod moved some distance δS_1 or δS_2. A picture from the approaching side is found to show a length $L_1 = S_1$ while from the receding side the photograph shows a length $L_2 = S_2$. When a moving rod is observed in longitudinal directions, therefore, a stationary observer measures the longer or shorter *light paths* associated with the moving rod, and not the length of the rod itself. The true length of the rod, and the length of light paths in the moving system, are found from $F_1(v)S_1$, with $F_1(v) = (1 - v/c)$ or, equivalently, from $F_2(v)S_2$ with $F_2(v) = (1 + v/c)$, where $F_1(v)$ and $F_2(v)$ may be considered as transforming the measured light paths in the stationary system into the original light paths in the moving system.

For the moving rod, the photographs are just a kind of optical illusion, because the ends of the rod are pictured at different times and rod positions in the stationary system. For electromagnetic waves on the other hand, such lengthened or shortened light paths, and the associated flight times of light, are real physical phenomena that can even be photographed and measured. Those real and concrete effects of optical measurement between moving and stationary inertial systems constitute the physical basis for the proposed all-optical interpretation of the LT, *i.e.*, that the LT recreate the original path lengths and flight times of light in the moving system from the changed path lengths and flight times measured in the stationary system, in analogy with $F_1(v)$ and $F_2(v)$ above. The physics is essentially the same as in the aforegoing classical analysis, while the factors of lengthening or shortening of path lengths and flight times become more complex, as discussed in further detail below.

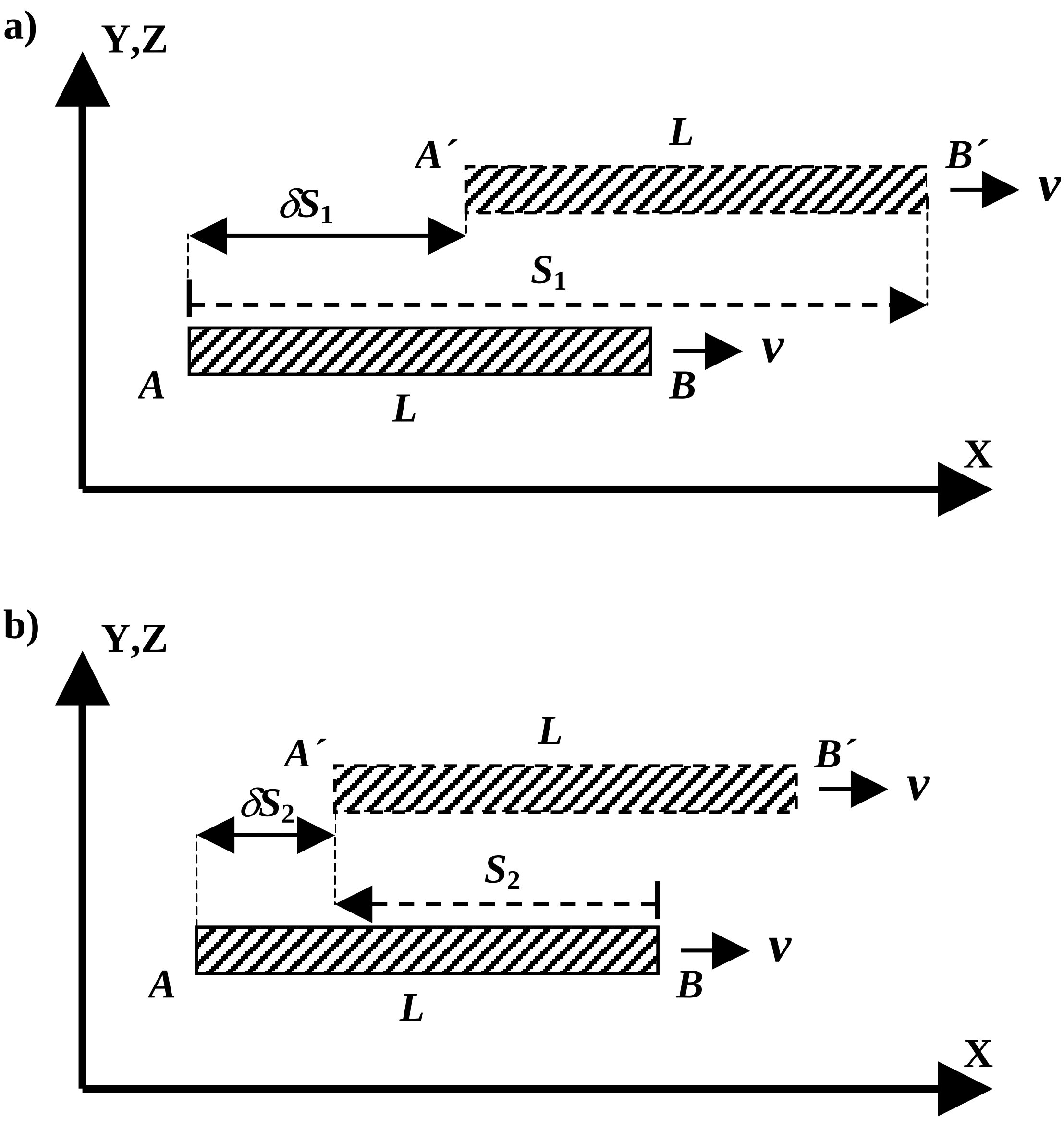

Figure 1. Path lengths S_1 and S_2 of light propagating in the forwards (a) and backwards (b) directions along a rod of length L moving at velocity v with respect to a stationary inertial system, as measured from the stationary system, while the rod moves a distance δS_1 or δS_2.

The Lorentz transformations

Ref. [4] introduced the fundamental idea that the velocity of light c is a universal constant independent of the velocity of the light source. A spherical wave of light emanating from an arbitrary point will be observed from any inertial system - moving or stationary - as being spherical, with velocity c. This implies that an equation (1) which describes the light wave in a stationary system, transforms into a similar equation (2) for the spherical wave when seen from a moving system,

$$x^2 + y^2 + z^2 = c^2 t^2, \tag{1}$$

$$\xi^2 + \eta^2 + \zeta^2 = c^2 \tau^2, \tag{2}$$

where (x, y, z, t) and (ξ, η, ζ, τ) are the coordinates of the light waves measured from their point of origin in the stationary and moving systems, respectively. As remarked in Ref. [4], the condition that Eq. (1) transforms into Eq. (2) allows a simple and straightforward derivation of the LT; *i.e.*, the LT are direct and necessary consequences of the invariance of the velocity of light. When the (ξ, η, ζ, τ) system moves with its ξ-axis along the positive x-axis of the (x, y, z, t) system with velocity v, light propagates in the forwards ξ-direction in the moving system and is observed from the stationary system, as in Fig. 1a, and the origins of the two systems coincide at $t = \tau = 0$, so that all coordinates are measured from zero, the LT have the familiar form

$$\xi = (x - vt)/[1 - (v/c)^2]^{1/2} \tag{3}$$

$$\tau = (t - vx/c^2)/[1 - (v/c)^2]^{1/2}, \tag{4}$$

while the transverse coordinates remain unchanged, $\eta = y$ and $\zeta = z$. Similarly, when the observed light waves propagate in the negative ξ-direction (Fig. 1b), the LT are given by

$$\xi = (x + vt)/[1 - (v/c)^2]^{1/2} \tag{5}$$

$$\tau = (t + vx/c^2)/[1 - (v/c)^2]^{1/2}. \tag{6}$$

Interchanging (x, t) and (ξ, τ) and reversing the sign of v in Eqs. (3) and (4), the associated inverse Lorentz transformations (LT^{-1}), which transform Eq. (2) into Eq. (1) with $y = \eta$ and $z = \zeta$, are found as

$$x = (\xi + v\tau)/[1 - (v/c)^2]^{1/2} \tag{7}$$

$$t = (\tau + v\xi/c^2)/[1 - (v/c)^2]^{1/2}. \tag{8}$$

A pair of light wave coordinates (x_s, t_s) in the stationary system transform by the LT of Eqs. (3) and (4) into coordinates $\xi_m = (x_s - vt_s)/[1 - (v/c)^2]^{1/2}$ and $\tau_m = (t_s - vx_s/c^2)/[1 - (v/c)^2]^{1/2}$ in the moving system. With ξ_m and τ_m substituted for ξ and τ in Eqs. (7) and (8), we find $x = (\xi_m + v\tau_m)/[1 - (v/c)^2]^{1/2} = x_s$ and $t = (\tau_m + v\xi_m/c^2)/[1 - (v/c)^2]^{1/2} = t_s$, thus confirming that the LT^{-1} of Eqs. (7) and (8) are indeed the inverse of the LT of Eqs. (3) and (4). Altogether, Eqs. (3) - (8) specify how space and time variables in the field equations for a certain light wave transform back and forth between moving and stationary inertial systems. The LT (and the LT^{-1}) thereby fulfill their intended mission for the Maxwell equations, so that the various components of the electromagnetic (and related) fields transform correctly between moving and stationary inertial systems.

Physical interpretations

But the LT and LT^{-1} have more to tell. Obviously, as in Eqs. (1) and (2), any particular values (ξ_m, τ_m) and (x_s, t_s) of the coordinates in the LT and LT^{-1} equations measure the corresponding distance from the origin, in space and time, reached by a light wave when observed from the moving or stationary system, respectively. Accordingly, the pairs of coordinates (ξ_m, τ_m) and (x_s, t_s) measure the *path lengths and flight times* of the light wave in one system or the other, with $\xi_m = c\tau_m$ and $x_s = ct_s$. From Eqs. (7) and (8), therefore, a path length ξ_m and flight time τ_m in the moving system, will be measured as path length x_s and flight time t_s in the stationary system, where

$$x_s = \xi_m (1 + v/c)/[1 - (v/c)^2]^{1/2} = \xi_m [1 - (v/c)^2]^{1/2}/(1 - v/c) \qquad (9)$$

$$t_s = \tau_m (1 + v/c)/[1 - (v/c)^2]^{1/2} = \tau_m [1 - (v/c)^2]^{1/2}/(1 - v/c). \qquad (10)$$

Consequently, path lengths and flight times of electromagnetic waves, propagating in the forwards ξ direction inside an inertial system cruising at velocity v along the positive x-axis of a stationary system, increase by a factor $H(v) = [1 - (v/c)^2]^{1/2}/(1 - v/c)$ when observed from the stationary system (Fig. 1a), as given by the LT^{-1} of Eqs. (7) and (8). As was discussed in the preceding analysis, these are real, measureable effects of optical observations between mutually moving inertial systems, that express the physics behind the proposed all-optical interpretation of the LT. Conversely, we find from Eqs. (3) and (4) that the LT will reverse such elongations, by the inverse factor $H(v)^{-1} = [1 - (v/c)^2]^{1/2}/(1 + v/c)$, to reproduce the path lengths ξ_m and flight times τ_m of light in the moving system. Likewise, for light waves propagating in the negative x and ξ directions, the appropriate inverse LT, and the associated changes in path lengths and flight times, follow from Eqs. (7) - (10) by changing the sign of v. For instance, light paths and flight times measured in the stationary system will in that case be shorter than in the moving system by the factor $H(v)^{-1}$ (Fig. 1b). When transformed back into the moving system, by Eqs. (5) and (6), path lengths and flight times in the backwards direction increase by a factor $H(v)$. The factors $H(v)^{-1}$ and $H(v)$ result directly from the LT and the LT^{-1} with $x = ct$ or $\xi = c\tau$ as appropriate, and differ from the classical case by the Lorentz factor $[1 - (v/c)^2]^{1/2}$. When the velocity of the moving system comes close to c, $H(v)^{-1}$ approaches a value given by $H(c)^{-1} = (1/2)[1 - (v/c)^2]^{1/2}$, half the factor of time dilation and length contraction in the current physical interpretation of the LT.

Simultaneity and the synchronization of clocks

In the early pages of Ref. [4], a scheme for synchronization of clocks in stationary and moving inertial systems was developed, which led to the categorical statement that clocks cannot be synchronized between mutually moving systems: Events that are simultaneous in the stationary system will not be simultaneous in a moving system. This was a basic premiss underlying the subsequent developments in Ref. [4], and was made even more explicit in the celebrated example of a train passing through a train station [6]: A man is situated in the midst of a train compartment, whose length we assume to be $2L$, and just as he opposes a person standing on the station platform, a pulse of light is emitted from each end of the coach, observable both inside the compartment and outside along the platform. The argument is made that the person on the platform, being situated at the midpoint of the release of the light pulses, will observe them as being simultaneous, whereas the one on the train will not because he is moving towards the pulse from the front end and away from the light trailing him from the rear. In other words, it would take longer time for light to reach the midpoint inside the compartment from the rear end than from the front, implying that, with distances to the midpoint being the same, the velocity of light as measured by the person inside would differ in the forwards and backwards directions.

But this is misleading, as was discussed by Ushenko [8]. SRT derives its very basis from the idea that the velocity of light is independent of the velocity of the light source relative to the observer. The man on the train therefore will measure both light signals as having the same velocity c, and so, because he is situated at the midpoint of the coach will receive both light pulses at the same time, to observe them as being simultaneous. On the other hand, the person on the (stationary) platform would measure light paths to the midpoint inside the train compartment to be longer than L in the forwards direction and shorter in the backwards direction (RE Fig. 1), as given by the appropriate LT^{-1}. When those light paths observed from the station platform are transformed back into the train compartment, by the LT of Eqs. (3) or (5) for light in the forwards and backwards direction, respectively, both paths have exactly the same length inside the coach, and so for the flight times of the light pulses, too, in support of Ushenko's analysis. In effect, and as remarked by Ushenko, in Ref. [6] light propagation as observed inside the moving train compartment was mistakenly represented by measurements made from the stationary platform. Contrary to established wisdom, the fact that the velocity of light is defined as a universal constant implies that physically simultaneous events will always be found by proper measurement to be simultaneous, from whatever inertial system irrespective of its velocity. Therefore there will also be no problem in synchronizing clocks between mutually moving inertial systems. Moreover, the light pulses will reach both persons at the same instant, the man on the train only having moved a distance $[H(v) - 1]L$ – the relativistic equivalent of δS_1 – further down the railroad when this happens. Should the train velocity v approach light velocity, the distance $[H(v) - 1]L$ could become quite large. Unfortunately, after 60 years Ushenko's analysis has still to be accepted into the physics literature, which continues to treat time and the concept of simultaneity on the basis of Ref. [4].

Relation to experiment

Michelson [3] designed an interferometer to measure any effects on the velocity of light as the earth moves through space at a velocity v = 30 km/s. The interferometer comprised two arms of length L at right angles to each other. Light entered the interferometer through a beam splitter, was reflected by a mirror at the far end of each arm and led to interfere behind the beam splitter. With one arm pointing in the direction of the Earth's motion, any difference in the forwards and backwards velocity of light would cause a phase shift shown as interference fringes, the other arm functioning as a zero reference. No such interference fringes were observed, meaning that light velocity was the same in both directions. Furthermore, in the direction of the earth's motion, light was calculated to travel a length $2L/[1 - (v/c)^2]$ back and forth from the beam splitter, equal to $S_1 + S_2$ from the discussion above. In the transverse arm light travels another distance $2L/[1 - (v/c)^2]^{1/2}$ back and forth, slightly longer than $2L$ due to forwards motion during light propagation. This difference in path lengths between the two arms would show up as interference fringes even in the absence of any differences in light velocity. Surprisingly, the experiment showed zero phase shift. Lorentz, and independently FitzGerald, suggested that the null result could be explained if the interferometer arm lying in the direction of the earth's velocity was shortened due to motion by a factor $[1 - (v/c)^2]^{1/2}$; the phase difference would then cancel exactly. That introduced the concept (and size) of length contraction, which has survived to this day. However, the present all-optical interpretation of the LT and its inverse shows that forwards and backwards path lengths in the arm pointing in the direction of motion, will be measured as being shorter than S_1 and S_2 from the classical calculation by the Lorentz factor $[1 - (v/c)^2]^{1/2}$, as given above by the appropriate LT^{-1} through the factors $H(v)$ and $H(v)^{-1}$. Thus the total path lengths in the two arms are seen to be exactly equal, and the expected phase shift is identically zero. Therefore, length contraction has no place in explaining the null result of the Michelson experiment. Had this optical analysis based on the LT and the LT^{-1} been made in 1904 or 1905, the concept of length contraction would have been dead there and then, and the concept of time dilation might never have been born.

More recent experiments with relevance to the physical interpretation of the LT come mostly from measurements that involve elementary particles moving at velocities close to c. For instance, muons created by cosmic rays colliding with air molecules in the upper atmosphere reach down to earth despite their mean lifetime of 2,2 μs, which would otherwise allow an average travel limited to about 660 m at light velocity. Ground-based observations of such cosmic ray-generated muons are generally taken as evidence that time goes slower inside the muon's rest system due to its very high speed. Instead, and as dictated by the LT^{-1}, the present optical interpretation teaches that path lengths of muons down the atmosphere shall increase by a factor $H(v)$ into tens of km or more at near-light velocities when measured from the ground (compare the train example from above), with observable flight times in excess of 100 μs sufficient for the muons to reach down to stationary earth. Conversely, when observed from the moving system (which would be the stationary system as seen from the muon's point of view), the path length through the countermoving atmosphere would be measured as being shorter than the real atmosphere by a factor $H(v)^{-1}$, in accordance with Fig. 1b, and so can be travelled well inside the lifetime of the muon. The proposed all-optical interpretation of the LT thereby offers a straightforward physical explanation from first principles of those observations and, similarly, for flight times and path lengths of elementary particles in accelerator experiments, without the extraneous introduction of length contraction and time dilation. And then there is Ockham's razor.

Conclusions

From its inception [4], time in SRT was defined as (light path)/(light velocity), with light velocity as a universal constant. Time in SRT thus is a derived variable, the more fundamental variable being the light path - which is also the more tangible variable. Therefore I consider the measurement of *light paths* between moving and stationary inertial systems, instead of focusing on time as in Ref. [4]. In view of Fig. 1 and Eqs. (3) - (8), the crucial insight is to realize that the space and time variables in the LT and LT^{-1} equations, as in the electrodynamic field equations, are connected by $x = ct$ and $\xi = c\tau$. By these means I obtain an all-optical interpretation of the LT which can be stated as follows:

- When observed from a stationary system, path lengths and flight times of light inside a moving inertial system become either lengthened or shortened, by a factor $H(v) = [1 - (v/c)^2]^{1/2}/(1 - v/c)$ or $H(v)^{-1} = [1 - (v/c)^2]^{1/2}/(1 + v/c)$, respectively, depending on the direction of light propagation.
- These are real, concrete and measureable physical effects described by the LT^{-1}.
- Optical observations between mutually moving inertial systems become symmetric, from each system observers will make corresponding measurements about optical propagation inside each other's system.
- On the other hand, the function of the LT is purely mathematical, in correcting - by the appropriate inverse factor $H(v)^{-1}$ or $H(v)$ - the path lengths and flight times measured in the stationary system, to reproduce the original path lengths and flight times of the electromagnetic waves propagating inside the moving system. Accordingly all real physical effects are given by the LT^{-1}, the LT have no physically real consequences for any space or time coordinates, *i.e.*, length contraction and time dilation in a moving inertial system do not occur in the real world.

The interpretation proposed here differs, of course, from the current and long established physical interpretation of the LT, which was given in Ref. [4] and has been essentially unchanged since then:

- The rate of time and the length of a rigid body are both reduced by the Lorentz factor $[1 - (v/c)^2]^{1/2}$ inside a moving inertial system. These are acknowledged as fundamental but otherwise inexplicable properties of the underlying nature of time and matter, discovered by Einstein [4] as physically real and measureable effects of motion, and all known experiments with relevance to SRT are understood to support this interpretation of the LT. On the background of what is presented here, however, it remains a mystery how Einstein could favour such a strange interpretation, to the neglect of the simple and straightforward all-optical interpretation. Apparently he was misled by his introductory but erroneous analysis in Ref. [4], repeated more explicitly in Ref. [6], that time cannot be synchronized between moving and stationary inertial systems, and so arrived (by further erroneous measures) at an interpretation of the LT which appeared to confirm that conclusion as well as the Lorentz-FitzGerald contraction of moving bodies. But we shall never know. Suffice it to say that the all-optical physical interpretation of the LT and its inverse has solid experimental support, by connecting the LT and LT^{-1} directly to the physically concrete and measureable light paths as observed between mutually moving inertial systems; *vice versa*, this also supports the correctness of the LT. Furthermore, the all-optical interpretation of the LT and the LT^{-1} is corroborated by its immediate resolution of the null result in the Michelson experiment [3], and by its explanation of the extended life times observed for elementary particles moving at near-light velocities, without the need for length contraction and time dilation.

It follows that real time and the length of real rigid bodies do not transform by the LT, as currently taught, and so are not subject to the four-dimensional geometry of spacetime. We are obliged, therefore, to distinguish between spacetime and the real world: The real world is three-dimensional, with time and the length of rigid bodies inside an inertial system independent of the system's velocity. In particular, the optical interpretation of the LT proposed here will have implications for the age-old discussions about the nature of time. SRT identified real time with time in spacetime, which is subject to the LT, so time as such has been understood to be relative and part of the geometrical structure of a four-dimensional spacetime world [5]. On the other hand, Gödel [9, 10] reasoned that real objective time does in fact not exist inside a relativistic spacetime. The all-optical interpretation of the LT resolves those questions about time, in a format consistent with relativistic physics and experiments, except that our concepts of space and time will change: Real time exists and operates in the three-dimensional real world of real rigid bodies, different from time in spacetime and unaffected by the LT, and is absolute and universal for all inertial systems in the real world irrespective of their velocity of motion, the travelling twin never ages more slowly. This also negates the idea that simultaneity and the synchronization of clocks cannot be defined between moving inertial systems. Time travel, too, disappears as a real-world option; real, universal time is unrelated to the geometry of space and flows unidirectionally forwards to leave the past behind forever. Except for such hypothesized effects on time and rigid bodies, SRT and spacetime physics remain largely unperturbed by this interpretation of the LT. Spacetime loses its identity as representing the real world, yet retains its essential function as a model coordinate system for the invariant treatment of the fundamental physical fields and forces, with coordinates in spacetime subject to the LT and referring to space and time variables in the field equations. Spacetime led to the geometrization of physics. With real time removed from the geometry of space, as in this all-optical interpretation of the LT, questions could again be asked about the role of real time in fundamental physics; such perspectives might warrant further attention.

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