Simultaneity and the Constancy of the Speed of Light: Normalization of Space-time Vectors in the Lorentz Transformation

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One of the main consequences of Einstein's derivation of the Lorentz transformation (LT) was the conclusion that a given event may not occur simultaneously for two observers in relative motion. It is pointed out that the constancy of the speed of light in free space is not sufficient in itself to completely specify the relationship between space-time vectors in different rest frames, as first noted by Lorentz in 1899. The LT results by assuming that distances measured perpendicular to the line of two observers must be equal ($\mathrm{d}y = \mathrm{d}y'$ and $\mathrm{d}z = \mathrm{d}z'$), and it is this assumption that produces the non-simultaneity characteristic of the resulting equations. If one forgoes the latter assumption, it is possible to impose simultaneity ($\mathrm{d}t = \mathrm{d}t'$) as an alternative normalization condition for the space-time vectors. The

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resulting set of equations is referred to as the alternative Lorentz transformation (ALT). It leads to exactly the same velocity addition formula as is derived from the LT. One of the hallmarks of the ALT is that it does not require that measurement be symmetric, for example, that two clocks can both be running slower than one another or that two measuring rods are each shorter than the other. Under the circumstances, there is no need to abandon the ancient principle of rationality of measurement (PRM) in the ALT formulation of relativity theory. Instead, it is assumed that clocks actually do slow down upon acceleration and that the magnitude of the time dilation must be assessed with reference to a definite (objective) rest frame from which to apply Einstein's formula, contrary to what has consistently been assumed on the basis of the LT. The relativity principle retains its validity in all inertial frames, but one needs to recognize that the units of time, energy and distance can vary with both the state of motion of the observer and his position in a gravitational field. Finally, it is noted that *in an objective theory* the constancy of the light speed in free space can only be rationalized with time dilation if one assumes that distances *expand isotropically* by the same fraction as clocks slow down and inertial masses/energies increase upon acceleration of objects from a given rest position.

Keywords: objectivity of measurement, absolute simultaneity, alternative Lorentz transformation (ALT), objective rest system (ORS), isotropic length expansion, time dilation

I. Introduction

The possibility that an event does not occur simultaneously for observers in relative motion seems to have first been raised by Poincaré [1]. The idea gained considerable momentum from Einstein's original paper [2] on the special theory of relativity, and has long since been regarded as dogma by the physics community.

Yet in every-day life we regard it as a matter of practical certainty that no event occurs earlier for one person than for any other. Clocks are painstakingly synchronized to ensure that a unique time and date can be ascribed to any occurrence after one takes proper account of the time zone in which it took place. The immensely popular GPS navigation technology relies on the assumption that the exact time of emission of a light signal from a satellite is the same there as it is on the Earth's surface [3]. One simply has to take into account the fact that not all clocks run at the same speed and make appropriate corrections based on independent experimental and theoretical information.

The present work reviews the arguments that have previously been given to support the concept of non-simultaneity of events. The discussion centers on the two main transformations of spatial and temporal coordinates, the Galilean and the Lorentz transformations, which have been used over the years to come to grips with the fact that the measured speed of an object is generally dependent on the state of motion and also the position in a gravitational field of the observer.

II. Derivation of the Galilean Transformation

The main motivation for introducing the Lorentz transformation (LT) was the failure of the Galilean transformation (GT) to explain the fact that the speed of light is the same for observers in relative motion, as first demonstrated by the Michelson-Morley experiments [4]. The model for the GT is illustrated in Fig. 1. A coordinate system is assumed with two origins, O and M, which are in motion with respect to one another. One of them (O) is fixed in time, whereas the other (M) moves along the x axis with speed u. The position of an object is determined relative to both origins at times $t = 0$ and $t = \mathrm{d}t$. A key

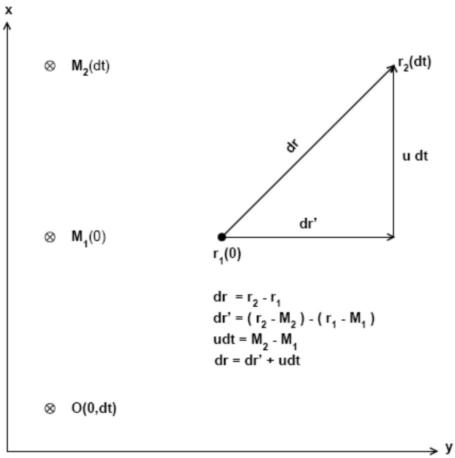

Fig. 1. Diagram illustrating the derivation of the Galilean transformation. An object moves between positions r1 and r2 in elapsed time dt at the same time that observer M travels from M1 to M2 with speed u relative to a fixed origin O. The change in the location of the object relative to M is denoted as dr', which is related by the Galilean transformation to the corresponding change dr relative to O. Note that the same unit of length is employed throughout.

element in Newton's derivation of the GT is that time has an absolute quality in this discussion. All observers anywhere in the universe can agree in principle as to when the time $t = 0$ and $t = \mathrm{d}t$ actually occur. In a word, any event is **simultaneous** for all observers, a position that was wholly consistent with daily experience.

The relative position of the object is clearly different for the two origins. To quantify these relationships it is agreed that the two (Cartesian) coordinate systems are simply displaced from one another along the x axis, as indicated in Fig. 1. The choice of the latter axis for this purpose is clearly arbitrary and does not detract in any way from the generality of the following analysis. At $t = 0$ the object is located at $\boldsymbol{r}_1$ relative to O and it has moved to $\boldsymbol{r}_2$ from his vantage point $\mathrm{d}t$ s later. The distance moved is defined by the three-dimensional vector $\mathbf{d}\boldsymbol{r} = \boldsymbol{r}_2 - \boldsymbol{r}_1$. The expressed purpose of the GT is to use this information to obtain the corresponding position and distance vector relative to the (moving) origin M. Using ordinary vector analysis, it is assumed that the position of the object at any given time *relative to M* can be determined by subtracting the corresponding position in O's reference frame from that of the current location of origin M in the same coordinate system. The assumption of simultaneity is essential for this analysis to proceed in an unambiguous manner. The corresponding distance vector relative to origin M is thus $\mathbf{d}\boldsymbol{r}' = \boldsymbol{r}_2' - \boldsymbol{r}_1' = (\boldsymbol{r}_2 - \mathbf{M}_2) - (\boldsymbol{r}_1 - \mathbf{M}_1)$.

The above definitions lead directly to the GT in vector notation:

$$\mathbf{d}\boldsymbol{r} = \mathbf{d}\boldsymbol{r}' + \boldsymbol{u}\mathrm{d}t\ . \tag{1}$$

Recalling that $\boldsymbol{u}$ is pointed along the x direction allows one to write down the corresponding equations for each of the distance components as

$$\mathrm{d}x = \mathrm{d}x' + u\mathrm{d}t \tag{2a}$$

$$\mathrm{d}y = \mathrm{d}y' \tag{2b}$$

$$\mathrm{d}z = \mathrm{d}z'. \tag{2c}$$

A few remarks are worthwhile in this context. First, because of the assumption of simultaneity, it is not necessary to have two different time variables in the GT. A simple way to express this relationship is to add a fourth equation, namely

$$\mathrm{d}t = \mathrm{d}t', \tag{2d}$$

that will have greater significance when the discussion turns to the derivation of the LT. Secondly, it is assumed implicitly that the **units** of distance and time are the same for the primed and unprimed variables. Thirdly, it is not necessary that the x and x' axes coincide in order to arrive at eqs. 2a-c since only differential quantities are involved. As long as the two sets of axes can be made to coincide by a simple translation, the results of the analysis based on Fig. 1 will be the same. Finally, there is no requirement that $\boldsymbol{u}$ be constant. It is permissible to look upon the GT as describing the spatial relationships of the GT over an infinitesimal amount of time even when either the object or origin M or both are accelerating relative to O. Indeed, it is perfectly straightforward to obtain analogous equations relating the instantaneous velocities and accelerations of the object relative to the two origins, namely as:

$$\boldsymbol{v} = \frac{\mathrm{d}\boldsymbol{r}}{\mathrm{d}\boldsymbol{t}} = \frac{\mathrm{d}\boldsymbol{r}'}{\mathrm{d}\boldsymbol{t}} + \boldsymbol{u} = \boldsymbol{v}' + \boldsymbol{u} \tag{3a}$$

$$\frac{\mathrm{d}^2\boldsymbol{r}}{\mathrm{d}\boldsymbol{t}^2} = \frac{\mathrm{d}^2\boldsymbol{r}'}{\mathrm{d}\boldsymbol{t}^2} + \frac{\mathrm{d}\boldsymbol{u}}{\mathrm{d}\boldsymbol{t}}, \tag{3b}$$

that is, by dividing eq. (1) by dt.

III. Derivation of the Lorentz Transformation

The problem of fitting the results of the Michelson-Morley experiments [4] into the framework of the GT led to much consternation among 19th century physicists. It gradually became clear [5] that the constancy of the speed of light for different observers in relative motion could not be understood on the basis of eq. (3a). Voigt [6] was the first to write down an alternative set of equations that was consistent with the light speed experiments. It differed from the LT by a constant factor. Larmor [7] wrote an essay in 1898 in which he introduced the exact form of the LT [8] that was later to be used as the cornerstone of Einstein's special theory of relativity [2]:

$$\mathrm{d}x = \gamma(u)\left(\mathrm{d}x' + u\mathrm{d}t'\right) \tag{4a}$$

$$\mathrm{d}t = \gamma(u)\left(\mathrm{d}t' + \frac{u\mathrm{d}x'}{c^2}\right) \tag{4b}$$

$$\mathrm{d}y = \mathrm{d}y' \tag{4c}$$

$$\mathrm{d}z = \mathrm{d}z', \tag{4d}$$

where c is the speed of light in free space (2.9979x10^8 m/s) and γ (u) = $(1-u^2/c^2)^{-0.5}$. In the following year Lorentz [9] published a more general version of this transformation,

$$\mathrm{d}x = \varepsilon\gamma(u)(\mathrm{d}x' + u\mathrm{d}t') \tag{5a}$$

$$\mathrm{d}t = \varepsilon\gamma(u)\left(\mathrm{d}t' + \frac{u\mathrm{d}x'}{c^2}\right) \tag{5b}$$

$$\mathrm{d}y = \varepsilon\mathrm{d}y' \tag{5c}$$

$$\mathrm{d}z = \varepsilon\mathrm{d}z', \tag{5d}$$

which differs from Larmor's by a scale or normalization factor (ε) in each of the four equations (Voigt's equations [5, 6] have ε equal to $\frac{1}{\gamma}$). The reason for this distinction is quite important for the following discussion. The key point is that the condition of the constancy of the speed of light by itself only allows one to define the relationships between the two sets of space-time variables **to within a constant factor**. For the special case of a light pulse, one obtains upon squaring:

$$\mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 - c^2\mathrm{d}t^2 = 0 = \varepsilon^2\left(\mathrm{d}x'^2 + \mathrm{d}y'^2 + \mathrm{d}z'^2 - c^2\mathrm{d}t'^2\right), \tag{6}$$

which clearly holds for any value of ε.

Einstein's derivation [2] of the LT had advantages over those of his predecessors in that it was no longer predicated on the existence of an ether. He assumed with Larmor that $\varepsilon = 1$ in eqs. (5, 6). This choice has two main consequences. First of all, it means that eqs. (2b, 2c) of the GT are taken over unchanged in the LT, i.e. eqs. (4c, 4d).

Goldstein [10] justifies this choice with the following remark: "The directions perpendicular to the motion are obviously left unaffected by the transformation ... for they do not participate in the motion and are effectively at rest." The other consequence is the lack of simultaneity in the LT caused by its eq. (4b). The $\varepsilon = 1$ choice has been justified by another somewhat more sophisticated argument as well [2, 11, 12], as will be discussed in detail in Sect. VI.

IV. The Alternative LT: Simultaneity as Condition

Non-simultaneity is not a necessary consequence of the constancy of light speed, contrary to what has been widely assumed in the literature. Instead of setting $\varepsilon = 1$ in eqs. (5a-d), as both Larmor [7] and Einstein [2] did, one can determine the value for this quantity by insisting that the condition of simultaneity for all events be rigorously satisfied. We therefore combine Lorentz's eq. (5b) with the implicit relation of eq. (2d) of the GT:

$$\mathrm{d}t = \varepsilon\gamma(u)\left(\mathrm{d}t' + \frac{u\mathrm{d}x'}{c^2}\right) = \mathrm{d}t', \tag{7}$$

with the result:

$$\varepsilon = \frac{\mathrm{d}t'}{\gamma\left(\mathrm{d}t' + \frac{u\mathrm{d}x'}{c^2}\right)} = \left(\gamma\left(1 + \frac{u\mathrm{d}x'}{c^2\mathrm{d}t'}\right)\right)^{-1} = \frac{\eta}{\gamma}, \tag{8}$$

that is, using the following definition ($\boldsymbol{v}' = \frac{\mathbf{d}\boldsymbol{r}'}{dt}$; see Fig. 1):

$$\eta(\boldsymbol{u}\bullet\boldsymbol{v}') = \left(1 + \frac{\boldsymbol{u}\bullet\boldsymbol{v}'}{c^2}\right)^{-1} = \left(1 + \frac{u\mathrm{d}x'}{c^2\mathrm{d}t'}\right)^{-1} \tag{9}$$

On this basis we obtain the following alternative Lorentz transformation (ALT):

$$\mathrm{d}x = \eta\left(\mathrm{d}x' + u\mathrm{d}t'\right) \tag{10a}$$

$$\mathrm{d}y = \frac{\eta \mathrm{d}y'}{\gamma} \tag{10b}$$

$$\mathrm{d}z = \frac{\eta \mathrm{d}z'}{\gamma}, \tag{10c}$$

$$\mathrm{d}t = \mathrm{d}t'. \tag{10d, 2d}$$

It is easy to show that this set of equations is still consistent with Einstein's second postulate, that is, it guarantees that the speed of light is the same in both rest frames $\left(\frac{\mathrm{d}r}{\mathrm{d}t} = \frac{\mathrm{d}r'}{\mathrm{d}t} = c\right)$. For example, if the light pulse moves along the *x* axis (the direction of relative motion for the two rest frames; see Fig. 1), then $\eta = \left(1 + \frac{u}{c}\right)^{-1}$ in eq. (9) since $\frac{\mathrm{d}x'}{\mathrm{d}t'} = c$ in this case. According to eq. (10a), $dx = \eta \mathrm{d}t'\left(c + u\right) = c\mathrm{d}t' = cdt$, where the condition of simultaneity of eq. (10d) has been used in the last step. If it moves along the *y* axis, then $\eta = 1$ since $\frac{\mathrm{d}x'}{\mathrm{d}t'} = 0$ in eq. (9). One then obtains $\mathrm{d}x = u\mathrm{d}t'$ and $\mathrm{d}y = \frac{c\mathrm{d}t'}{\gamma}$ from eqs. (10a, b), from which follows: $\mathrm{d}r^2 = \mathrm{d}x^2 + \mathrm{d}y^2 = \left(u^2 + \frac{c^2}{\gamma^2}\right)\mathrm{d}t'^2 = c^2\mathrm{d}t'^2 = c^2\mathrm{d}t^2$ (recall that

$\gamma^{-2} = 1 - \frac{u^2}{c^2}$). For the general case of a light pulse moving in any direction, let $\mathrm{d}x' = A\cos\theta$, $\mathrm{d}y' = A\sin\theta\cos\varphi$, $\mathrm{d}z' = A\sin\theta\sin\varphi$ and $\mathrm{d}t' = \frac{A}{c}$ using polar coordinates. These input values give the result of $\eta = \left(1 + \frac{u\cos\theta}{c}\right)^{-1}$, so that eqs. (10a-c) are changed to $\mathrm{d}x = \eta A\left(\cos\theta + \frac{u}{c}\right)$, $\mathrm{d}y = \frac{\eta A\sin\theta\sin\varphi}{\gamma}$ and $\mathrm{d}z = \frac{\eta A\sin\theta\sin\varphi}{\gamma}$. Squaring and adding the latter results therefore gives $\mathrm{d}r^2 = \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 = A^2$. Since $\mathrm{d}t = \mathrm{d}t' = \frac{A}{c}$, it follows that $\frac{\mathrm{d}r}{\mathrm{d}t} = \frac{\mathrm{d}r'}{\mathrm{d}t'} = c$, as desired. *The simultaneity condition requires that the distance traveled by the light pulse in both the* S *and* S' *rest frames must be the same in order to be consistent with Einstein's second postulate*, and this is guaranteed by the ALT whereas it is simply violated in the LT.

One of the most common examples of non-simultaneity that has been discussed [13] considers how two light pulses on an airplane are viewed from the ground. In a typical case, one light pulse moves toward the front of the plane, while the other goes the same distance (A) in the opposite direction. For an observer on the plane, both light pulses must arrive at the same time at their respective detectors. In the first case, $\mathrm{d}x' = A$ and $\mathrm{d}t' = \frac{A}{c}$, whereas in the second, $\mathrm{d}x' = -A$ and $\mathrm{d}t'$ again is equal to $\frac{A}{c}$ [assuming the light pulses move parallel to the direction of relative motion of the plane (S') to the ground (S)]. The non-simultaneity argument [3, 13] then proceeds by using eq. (4b) of the LT. Accordingly, the elapsed time for the forward light pulse for the observer on the ground is $\mathrm{d}t = \dfrac{\gamma A\left(1+\dfrac{u}{c}\right)}{c}$, whereas that of the backward pulse is $\mathrm{d}t = \dfrac{\gamma A\left(1-\dfrac{u}{c}\right)}{c}$. Therefore, the observer on the ground finds that the light pulses do not arrive at their respective detectors at the same time when the LT is used. The ALT [eqs. 10a-d)], on the other hand, simply finds that $\mathrm{d}x = A$ for the forward pulse and $-A$ for the backward pulse, exactly the same values as observed on the plane, as demonstrated explicitly in the previous paragraph. The corresponding elapsed times are $\mathrm{d}t = \mathrm{d}t' = \dfrac{A}{c}$ in both cases as a result, so both pulses move at the speed of light for the ground observer, as required by Einstein's second postulate, but they also arrive at their respective detectors at exactly the same time. **It is therefore clear that non-simultaneity is not an essential consequence of Einstein's postulate.** The condition of simultaneity is guaranteed by the ALT, while still remaining consistent with the assumption that the speed of light of a given pulse is the same in both S and S'.

V. Time Dilation and Fitzgerald-Lorentz Length Contraction

Thus far we have only considered applications of the ALT for light pulses. Einstein [2] also used the LT to derive a number of interesting phenomena for other objects such as clocks and measuring rods, however, and so it is important to see if these effects are compatible with the simultaneity condition embodied in the ALT. To begin with, let us take the case of a clock at rest on a rocket ship (S') moving at speed u relative to the ground (S). By construction, $\mathrm{d}x' = \mathrm{d}y' = \mathrm{d}z' = 0$, so according to eq. (4b) of the LT, the elapsed times measured in the two rest frames must have the relationship: $\mathrm{d}t = \gamma \mathrm{d}t'$. This equation has been interpreted to imply that the clocks on the rocket ship run γ times slower than on the ground, and one refers to this phenomenon as time dilation. In this connection, it is important to recognize that the LT can be inverted by simply setting $u = -u$ in eqs. (4a-d) and interchanging the primed and unprimed symbols:

$$\mathrm{d}x' = \gamma(u)(\mathrm{d}x - u\mathrm{d}t) \tag{11a}$$

$$\mathrm{d}t' = \gamma(u)\left(\mathrm{d}t - \frac{u\mathrm{d}x}{c^2}\right) \tag{11b}$$

$$\mathrm{d}y' = \mathrm{d}y \tag{11c}$$

$$\mathrm{d}z' = \mathrm{d}z\,. \tag{11d}$$

By the same logic as used above, one comes to the conclusion that time dilation is *symmetric.* In other words, if the clock is at rest in S so that $\mathrm{d}x = \mathrm{d}y = \mathrm{d}z = 0$, it follows that $\mathrm{d}t' = \gamma \mathrm{d}t$, which must be interpreted to mean that the clock on the ground is running slower than the one on the rocket ship.

Goldstein [14] has summarized this situation with the following sentence: "Thus no one system is singled out as the stationary one and the other the moving one—the motion is only relative; all (uniformly moving) systems are completely equivalent." Einstein [2] nonetheless pointed out that the symmetry implied in the above derivation is broken if one of the rest frames has been accelerated relative to the other. In this case, one can clearly distinguish S and S' in the present example because a force had to be applied to the rocket ship in order to propel it to its current velocity relative to its point of origin on the ground. Time dilation has been observed in a number of different experiments, including observations of the transverse Doppler effect (TDE [15,16]) and of clocks mounted on high-speed centrifuges [17], the decay of high-speed muons created in the upper atmosphere or in the laboratory [18], and also for atomic clocks located on airplanes [19], rockets [20] or GPS satellites. These results support Einstein's prediction but they also raise questions about their relationship to the LT. As mentioned above, the latter clearly indicates that the effect should be symmetric for two observers in relative motion.

In order to avoid a possible contradiction between theory and experiment, it has generally been argued that one can *only* apply the time-dilation formula from the vantage point of an inertial system (IS). For example, Hafele and Keating [19] found that their empirical timing results could be explained by assuming that Einstein's formula can only be directly applied for reference clocks located on the Earth's polar axis and not from the vantage point of identical clocks located on airplanes or elsewhere on the Earth's surface. While this position agrees with the facts, it still leaves open a number of key questions. Since the Earth is constantly accelerating around the Sun, for example, why is it permissible to consider the clocks on the polar axis as IS? More generally, can we really make a meaningful distinction for objects moving at constant velocity on the basis of whether they were always IS or instead have previously undergone an acceleration phase to reach their current state of motion?

When eqs. (10a-d) are used to describe the motion of a clock that is stationary in S', the result for the observer in S is simply: $dx = u dt$ and, of course, $dt = dt'$. There is no hint of time dilation in the ALT, but this does not mean that the latter transformation is contradicted by the occurrence of this phenomenon. One has to recall that the units of time and distance employed therein are the *same* for both the S and S' frames. If the clock in S' slows by a factor of γ because of its acceleration relative to S, as Einstein assumes in his original work [2], this means the unit of time actually used by the observer in S' is γ s [21]. Therefore, if the observer in S measures an elapsed time of dt s, his counterpart in S' must obtain the smaller value of $\frac{dt}{\gamma}$ s in order to maintain the condition of simultaneity required by the ALT. The key point is that there is absolutely no information in the ALT itself to lead one to conclude that the clocks in the two rest frames are running at different rates. In fact, it is clear from the Hafele-Keating experiments [19] that the ratio of the time units in different rest frames moving at relative speed u to one another is not always equal to $\gamma(u)$. According to the empirical formula obtained in the latter study, the desired ratio for two airplanes is obtained by inserting their respective speeds u_E and u_W relative to the polar axis into Einstein's formula for time dilation and dividing the resulting two values of $\gamma(u)$, that is, the ratio (after correction for the gravitational red shift) is found to be $\frac{\gamma(u_E)}{\gamma(u_W)}$. One can understand this result by assuming that the clock on the polar axis serves as an objective rest system (ORS [22]) for determining the rate by which each of the airplane clocks has slowed as a result of its acceleration. Because of the

Earth's rotation around its polar axis, it is not possible to obtain this result from the vantage point of a clock located off the polar axis because it has itself been accelerated due to the Earth's rotation.

The guiding principle is the same as in Einstein's original work [2], namely that the slowing of a given clock's rate is caused by the acceleration from its original rest position. The relationships are not symmetric, however. The clock on a given airplane actually does run slower than its counterpart at the North or South Pole. Measurement of time is both *objective and rational* according to the results of actual experiments [19-20]. There is no essential role of an IS in this interpretation. One simply has to know the *instantaneous* speed of a given clock relative to the Earth's polar axis to determine its rate. It doesn't matter if the clocks are accelerating or not at the time of the actual determination. Most importantly in the present discussion, the fact that clocks in relative motion may run at different rates in no way violates the condition of simultaneity inherent in the ALT. It simply means that elapsed times measured by different clocks need to be adjusted to account for the effects of time dilation. This fact is rigorously taken into account in the GPS navigation method, as will be discussed in more detail in Sect. IX.

The Fitzgerald-Lorentz length contraction effect (FLC) was also derived from the LT. It was first suggested by Fitzgerald [23] and then later independently by Lorentz [24] as a means of explaining the constancy of the speed of light **within the context of the GT**. Einstein [2] obtained the same result by setting $\mathrm{d}t = 0$ in eq. (11a) of the LT, which leads to $\mathrm{d}x' = \gamma \mathrm{d}x$. This has been interpreted to mean that the lengths of objects stationary in S' along the direction of relative motion to S appear contracted to an observer in the latter reference frame. Again, the analogous result [$\mathrm{d}x = \gamma \mathrm{d}x'$] measured in S' for an object that is stationary in S may be obtained by setting

$\mathrm{d}t' = 0$ in eq. (4a), so it has also been assumed [10] that this effect is *symmetric* for two IS, similarly as for time dilation based on the same theory. Because of eqs. (4c, 4d), however, there is thought to be no contraction along perpendicular directions to the relative motion of S and S', exactly as in the original version of the FLC. It should be noted, however, that contrary to time dilation, **there has never been a confirmed experimental observation of the FLC**. Indeed, it has been speculated that the effect can *never* be observed because of the impracticality of measuring both ends of the object at exactly the same time, i.e. for $\mathrm{d}t = 0$ in the first case.

Since $\mathrm{d}t = \mathrm{d}t'$ in the ALT, it is impossible to derive the FLC from the latter formulation of relativity theory. First and foremost, this is because dt=dt'=0 has no meaning when one applies these equations to motion. If no time elapses, by definition, no motion occurs. What Einstein did in deriving the FLC was to change the meaning of the space-time variables relative to the model on which his derivation of the LT is based [25]. Accordingly, $\mathrm{d}x$ ($\mathrm{d}x'$) is said to be the *length* of an object rather than the distance traveled by it (cf. Fig. 1) in a given time $\mathrm{d}t$ ($\mathrm{d}t'$). If one goes ahead anyway and tries to apply the ALT under this condition ($\mathrm{d}t' = 0$), the resulting value of η in eq. (9) is null because $\frac{\mathrm{d}x'}{\mathrm{d}t}$ is infinite, which therefore leads to a value of $\mathrm{d}x = 0$ regardless of the corresponding value for $\mathrm{d}x'$. It is therefore clear that the ALT is not consistent with the FLC, but a quite different possibility presents itself because of the fact that clocks in S' run slower than those in S, as discussed above in the present section. Once one assumes that measurement is objective and rational [26], consistent with the results of the Hafele-Keating [19] and Vessot-Levine [20] experiments, there is no choice other than to assume that the lengths of objects actually **expand** upon acceleration. Since the observer in S' measures the same value for the speed of light in free space as his counterpart in S even though his clock runs slower by a factor of γ, it follows that *he must also measure distances* traveled by the light to be **smaller** by the same factor. This must occur in all directions as well. In order for this to happen and still remain consistent with the principle of objectivity and rationality of measurement (PRM [26]), it is absolutely necessary that **the measuring rod employed in S' be γ times longer than that in S**, and this in all directions, that is, the unit of length in S must be smaller than that in S' by this factor [3]. This is **isotropic length expansion,** not the anisotropic contraction effect envisioned in the FLC. We will return to this subject in Sect. IX when experimental tests that can distinguish between the ALT and the LT are considered further.

VI. Mathematical Conditions for the Space-time Transformation

Even before Einstein's paper [2], mathematical physicists tried to discover conditions that would uniquely specify the new relativistic space-time transformation [12]. To this end Poincaré [11] made the following argument that has been repeated many times since. He first assumed that the normalization constant ε in Lorentz's eqs. (5a-d) must only be a function of the relative speed u of S and S': $\varepsilon(u)$. He then argued that the corresponding constant for the inverse transformation is necessarily $\varepsilon(-u)$, which leads to the following condition:

$$\varepsilon(u)\varepsilon(-u)=1. \tag{12}$$

A rotation of 180° around an axis perpendicular to the direction of motion (Fig. 1) simply amounts to a change in the definition of the coordinate system, and thus:

$$\varepsilon(u) = \varepsilon(-u), \tag{13}$$

from which follows the unique solution: $\varepsilon(u) = 1$. This result is quite attractive because of its simplicity, and above all, for the fact that it satisfies the condition of Lorentz invariance in eq. (6).

There is nonetheless a problem with this derivation. There is no *a priori* reason for assuming that ε is not also a function of the velocity of the object ($\boldsymbol{v}$ or $\boldsymbol{v}'$) of the observations, in particular of its scalar product ($\boldsymbol{u}\bullet\boldsymbol{v}$ or $\boldsymbol{u}\bullet\boldsymbol{v}'$) with the relative velocity $\boldsymbol{u}$ of S and S'. The condition of eq. (12) is actually a statement of the fact that successive applications of the transformation equations in the forward and reverse directions must lead back to the original state of the system. Acknowledgement of this complicating feature requires that the latter relation take on the more general form:

$$\varepsilon(u, \boldsymbol{u}\bullet\boldsymbol{v}')\varepsilon(-u, -\boldsymbol{u}\bullet\boldsymbol{v}) = 1, \tag{12'}$$

with $\varepsilon(u, \boldsymbol{u}\bullet\boldsymbol{v}') = \dfrac{\eta(\boldsymbol{u}\bullet\boldsymbol{v}')}{\gamma(u)}$ for the ALT, for example. The use of $\boldsymbol{v}'$ in one case and $\boldsymbol{v}$ in the other is necessary because the forward and reverse transformations are made from the vantage points of different observers, that in S in the first case and that in S' in the second. This extended condition is of course satisfied by the former value of $\varepsilon = 1$, but it is no longer a unique solution.

The inverse of the ALT can be obtained by algebraic manipulation of eqs. (10a-d):

$$\mathrm{d}x' = \eta(\mathrm{d}x - u\mathrm{d}t) \tag{14a}$$

$$\mathrm{d}y' = \frac{\eta \mathrm{d}y}{\gamma} \tag{14b}$$

$$\mathrm{d}z' = \frac{\eta \mathrm{d}z}{\gamma}, \tag{14c}$$

$$\mathrm{d}t' = \mathrm{d}t . \tag{14d}$$

In this case, $\eta = \eta(-\boldsymbol{u}\bullet\boldsymbol{v})$ according to the definition of eq. (9), consistent with the fact that the respective observers in S and S' exchange positions when applying the inverse transformation. The inverted equations are obtained from the original ALT of eqs. (10a-d) by setting u to $-u$ and interchanging all primed and unprimed symbols, exactly as for both the GT and the LT. Both eqs. (12', 13) are satisfied as a result [$\eta(\boldsymbol{u}\bullet\boldsymbol{v}')\eta(-\boldsymbol{u}\bullet\boldsymbol{v}) = \gamma(u)^2$], and thus these conditions do not allow one to make a definite choice as to whether the LT or the ALT is the correct relativistic space-time transformation. It is clear, however, that satisfaction of the simultaneity condition ($\mathrm{d}t = \mathrm{d}t'$) prevents the ALT from being Lorentz invariant precisely because $\varepsilon \neq 1$ in this case (ALT matrices also do not satisfy the properties of a group). This does not mean that the ALT is not consistent with Lorentz invariance elsewhere in relativity theory, however, as will be discussed in Sect. VIII.

VII. Expressing the ALT in Local Units

The original intent of both the GT and the LT is to relate the space-time measurements of two observers for the motion of the same object (see Fig. 1). The ALT of eq. (10) doesn't really accomplish this goal directly because it requires that both observers express their measured results *in the same set of units*. As discussed above, this condition inevitably requires that at least one of them use a different set of units than that based directly on his local clocks and measuring rods. It also carries with it the danger of missing the distinction between eqs. (2d) and (10d) in the GT and the ALT, respectively; because of time dilation, there is a crucial difference between what is meant by the $\mathrm{d}t = \mathrm{d}t'$ provision in the two theories.

The form of the space-time equations should also emphasize that there is a definite symmetry inherent in the way the two observers view their surroundings. A notation should be employed that distinguishes between the two without destroying this essential equivalence. In the following this will be accomplished by referring to the observers as O and M, respectively, and including this identification in parentheses for each of their locally measured values; for example, $\mathrm{d}t(\mathrm{O})$ is the elapsed time measured by observer O expressed in his local unit. The difference in units employed by the two observers can then be conveniently introduced by designating a particular rest frame as reference. Clock-rate parameters α_M and α_O are then defined as the ratios of the periods of atomic clocks in the respective rest frames O and M to those of the reference system. Measured elapsed times are then inversely proportional to the clock-rate parameter in a given case. As discussed in Sect. V, the same ratios must be used for measured distance values in order to satisfy Einstein's second postulate. For the sake of concreteness, the unprimed symbols in eqs. (10a-d) are associated with O's adjusted measured values and the corresponding primed values with M's adjusted results: for example, $\mathrm{dt} = \alpha_\mathrm{O}\, \mathrm{dt}\,(\mathrm{O})$. The result is:

$$\alpha_\mathrm{O} \mathrm{d}x(\mathrm{O}) = \alpha_\mathrm{M} \eta \left[\mathrm{d}x(\mathrm{M}) + u \mathrm{d}t(\mathrm{M}) \right] \tag{15a}$$

$$\alpha_\mathrm{O} \mathrm{d}y(\mathrm{O}) = \frac{\alpha_\mathrm{M} \eta \mathrm{d}y(\mathrm{M})}{\gamma} \tag{15b}$$

$$\alpha_{\mathrm{O}}\mathrm{d}z(\mathrm{O})=\frac{\alpha_{\mathrm{M}}\eta\mathrm{d}z(\mathrm{M})}{\gamma} \tag{15c}$$

$$\alpha_{\mathrm{O}}\mathrm{d}t(\mathrm{O})=\alpha_{\mathrm{M}}\mathrm{d}t(\mathrm{M}). \tag{15d}$$

Note in particular that both η and γ are unaffected by the change in units because of the requirement that length and time scale in exactly the same manner.

The form of these equations makes clear that we don't really need a specific reference frame to define the standard units. In making the desired comparisons it is sufficient to know the ratio $R=\frac{\alpha_{\mathrm{M}}}{\alpha_{\mathrm{O}}}$ to completely define the ALT for observers O and M. This definition simplifies the transformation to the following:

$$\mathrm{d}x(\mathrm{O})=R\eta\left[\mathrm{d}x(\mathrm{M})+u\mathrm{d}t(\mathrm{M})\right] \tag{16a}$$

$$\mathrm{d}y(\mathrm{O})=\frac{R\eta\mathrm{d}y(\mathrm{M})}{\gamma} \tag{16b}$$

$$\mathrm{d}z(\mathrm{O})=\frac{R\eta\mathrm{d}z(\mathrm{M})}{\gamma} \tag{16c}$$

$$\mathrm{d}t(\mathrm{O})=R\mathrm{d}t(\mathrm{M}). \tag{16d}$$

Two remarks are important. First, we can recognize that the new equations can be obtained directly from the general Lorentz form of eqs. (5a-d) by setting $\varepsilon=\frac{R\eta}{\gamma}$. Secondly, the ratio R has the same value as that used to compute the time-dilation adjustment for GPS clocks. It means that the pre-corrected clock must run R times faster (after taking account of gravitational effects) on the satellite than its uncompensated clock in the same rest frame. It also should be mentioned at this point that R can be determined directly from measurements of the TDE [15, 16], as will be discussed in Sect. IX.

The most common value for R in previous expositions of relativity theory is γ. It has been emphasized above (Sect. V) that this is by no means the only value that occurs in practice, however, as demonstrated by the results of the Hafele-Keating experiments [19] when comparing the rates of clocks located on different airplanes or at various latitudes on the Earth's surface. Nonetheless, in view of the ubiquitous nature of the $R = \gamma$ condition in laboratory experiments, it is worthwhile to consider the explicit form of the ALT in this case:

$$\mathrm{d}x(\mathrm{O}) = \eta\gamma\left[\mathrm{d}x(\mathrm{M}) + u\mathrm{d}t(\mathrm{M})\right] \tag{17a}$$

$$\mathrm{d}y(\mathrm{O}) = \eta\mathrm{d}y(\mathrm{M}) \tag{17b}$$

$$\mathrm{d}z(\mathrm{O}) = \eta\mathrm{d}z(\mathrm{M}) \tag{17c}$$

$$\mathrm{d}t(\mathrm{O}) = \gamma\mathrm{d}t(\mathrm{M}). \tag{17d}$$

This form has the perhaps attractive feature of expressing time dilation explicitly with the usual factor γ in eq. (17d). The similarity to the description of time dilation in the LT ends there, however, as can be seen by making the analogous substitutions in the inverted eqs. (14a-d):

$$\mathrm{d}t(\mathrm{M}) = \frac{\mathrm{d}t(\mathrm{O})}{\gamma}, \tag{18}$$

which in turn results quite simply from algebraic manipulation of eq. (17d). The latter result is a direct consequence of the assumption of rationality of measurement (PRM [26]). One needs more than algebra to go from $\mathrm{d}t = \gamma \mathrm{d}t'$ to $\mathrm{d}t' = \gamma \mathrm{d}t$, as demanded by the symmetry principle of STR and the LT [2, 10] which denies the validity of the PRM. In the general case, one has

$$\mathrm{d}t(\mathrm{M}) = \frac{\mathrm{d}t(\mathrm{O})}{R} \tag{19}$$

as the inverted form of eq. (16d). The key point is that the relationship between the two measured values for elapsed times and other quantities is *reciprocal*, not symmetric, as has been demonstrated in experiments with airplanes and rockets [19, 20] as well as in the GPS technology.

VIII. The Energy-Momentum Four-vector Relations

The question to be considered in this section is how the normalization condition that leads to the ALT affects the key relationships between energy $\mathrm{d}E$ and momentum $\mathrm{d}\boldsymbol{p}$ in relativity theory. The transformation properties of the latter quantities can be obtained in a completely analogous manner as for the space-time variables $\mathbf{d}\boldsymbol{r}$ and $\mathrm{d}t$ on the basis of Hamilton's equation for velocity: $\frac{\mathrm{d}E}{\mathrm{d}p} = v$. For the case of light in free space, we again set $v = c$ for both inertial systems S and S', with the result:

$$\mathrm{d}E = \gamma(u)\left(\mathrm{d}E' + u\mathrm{d}p_x'\right) \tag{20a}$$

$$\mathrm{d}p_x = \gamma(u)\left(\mathrm{d}p_x' + \frac{u\mathrm{d}E'}{c^2}\right) \tag{20b}$$

$$\mathrm{d}p_y = \mathrm{d}p_y' \tag{20c}$$

$$\mathrm{d}p_z = \mathrm{d}p_z', \tag{20d}$$

where the direction of relative motion of S and S' is along the x axis and the corresponding speed is u. These equations are very similar to those of the LT in eqs. (4a-d). It is again possible to generalize them by multiplying each term on the right-hand side of these equations with a common factor ε [see eqs. 5a-d], because the light speed condition, $\frac{\mathrm{d}E}{\mathrm{d}p} = \frac{\mathrm{d}E'}{\mathrm{d}p'} = c$ is not sufficient in itself to fix the value of this quantity. It is easy to see what this condition must be in the present case, however, by looking at the limiting situation for low relative speed u when the object is **stationary** in S': $\mathrm{d}E = \mathrm{d}E' + \frac{\mu u^2}{2}$, where μ is the inertial mass of the object, that is, $\mathrm{d}E$ differs from $\mathrm{d}E'$ by the classical non-relativistic kinetic energy. The latter (rest energy) is assumed to be the same for observers in both S and S' in the non-relativistic theory, i.e. with $u << c$. For this special case, $dp_x' = 0$, and thus eq. (20a) leads to the result: $\mathrm{d}E = \gamma \mathrm{d}E'$, or more generally, $\mathrm{d}E = \varepsilon\gamma \mathrm{d}E'$, when one takes account of the normalization condition as in eqs. (5a-d).

To proceed further, it is helpful to invert eqs. (20a-d), with the result:

$$\mathrm{d}p_x' = \gamma(u)\left(\mathrm{d}p_x - \frac{u\mathrm{d}E}{c^2}\right). \tag{21}$$

Since $\mathbf{dp}' = 0$ in the present case, i.e. because the object is stationary in S', it follows that

$$\mathrm{d}p_x = \mathrm{d}p = \frac{u\mathrm{d}E}{c^2}, \tag{22}$$

from which we infer Einstein's famous mass/energy equivalence relation [2] because of the definition of momentum as the product of inertial mass d*m* and velocity ***u***:

$$\mathrm{d}E = \mathrm{d}mc^2\,, \tag{23}$$

where d*m* is the relativistic inertial mass. Since the object is stationary in S', its corresponding inertial mass in this IS equals the rest (or proper) mass value μ used in the classical kinetic energy expression given above, so that $\mathrm{d}E' = \mu c^2$ from eq. (23) on this basis.

We can therefore determine the value of the normalization factor ε by setting γ equal to its low-velocity limit of $1+\frac{u^2}{2c^2}$:

$$\mathrm{d}E = \varepsilon\gamma\mathrm{d}E' = \varepsilon\left(1+\frac{u^2}{2c^2}\right)\mu c^2 = \varepsilon\left(\mathrm{d}E'+\frac{\mu u^2}{2}\right) = \mathrm{d}E'+\frac{\mu u^2}{2}\,, \tag{24}$$

from which it follows that ε= 1 in this case. The latter value for ε insures that the Lorentz invariance condition holds for d*E* and d***p*** in eqs. (20a-d), namely:

$$\mathrm{d}E^2 - \mathrm{d}p^2c^2 = \mathrm{d}E'^2 - \mathrm{d}p'^2\,c^2\,. \tag{25}$$

This result is essential for the relativistic Dirac equations and quantum electrodynamics, and comes about in a natural way by simply demanding that the above equations hold at the low-velocity limit [3]. The fact that $\varepsilon \neq 1$ in eq. (6) for the space-time variables is in no way contradicted by this result, and so it is seen that **simultaneity is compatible with Lorentz invariance of the $\boldsymbol{E}, \boldsymbol{p}$ four-vector and also of the electromagnetic field**. One has to recognize that the two conditions stemming from Einstein's second postulate [2], namely

$\frac{\mathrm{d}r}{\mathrm{d}t} = \frac{\mathrm{d}r'}{\mathrm{d}t} = c$ on the one hand and $\frac{\mathrm{d}E}{\mathrm{d}p} = \frac{\mathrm{d}E'}{\mathrm{d}p'} = c$ on the other, are independent of one another.

The key point is that the normalization factor ε does not affect relationships between velocities of the object measured in S and S', respectively. The latter equations can be obtained quite simply from the ALT by dividing eqs. (10a-c) by $\mathrm{d}t = \mathrm{d}t'$. The result is:

$$v_x = \frac{\mathrm{d}x}{\mathrm{d}t} = \eta\left(\frac{\mathrm{d}x'}{\mathrm{d}t} + u\right) = \eta\left(v_x' + u\right) \tag{26a}$$

$$v_y = \frac{\mathrm{d}y}{\mathrm{d}t} = \frac{\eta \mathrm{d}y'}{\gamma \mathrm{d}t} = \frac{\eta v_y'}{\gamma} \tag{26b}$$

$$v_z = \frac{\mathrm{d}z}{\mathrm{d}t} = \frac{\eta \mathrm{d}z'}{\gamma \mathrm{d}t} = \frac{\eta v_z'}{\gamma}, \tag{26c}$$

with η defined as in eq. (9). Note that these equations are exactly the same as derived from the LT directly [27]. This is a critical point since many of the confirmed experimental verifications [28] of special relativity are actually verifications of the above velocity component relations rather than of the LT itself.

There is an aspect of the derivation of the energy-momentum relations of eqs. (20 a-d) that requires further consideration, however. Hamilton's equation itself is derived from Newton's Second Law and the definition of energy/work as the scalar product of an applied force $\boldsymbol{F}$ and the distance $\mathbf{dr}$ through which it acts:

$$dE = \boldsymbol{F} \bullet \mathbf{dr} = \frac{\mathbf{d}\boldsymbol{p} \bullet \mathbf{d}\boldsymbol{r}}{\mathrm{d}t} = \mathbf{d}\boldsymbol{p} \bullet \boldsymbol{u} = u\mathrm{d}p, \tag{27}$$

that is, with $\boldsymbol{u} = \frac{\mathbf{d}\boldsymbol{r}}{\mathrm{d}t}$. The last step follows from a geometrical argument [29]. The formula for the kinetic energy of an object proceeds from this relationship, both in non-relativistic theory and special relativity [2, 29]. Implicit in this definition is the condition that the velocity $\boldsymbol{u}$ attained by the object occurs as the direct result of application of the above force. Moreover, the velocity $\boldsymbol{u}$ is *defined relative to the rest position from which the object was initially accelerated* as a result of the applied force $\boldsymbol{F}$. What this means in simple terms is that the energy of the accelerated object is actually greater than when it was at its initial rest position.

This situation is **inconsistent with the symmetry principle** mentioned above in connection with the time dilation and FLC effects. An identical object left behind at the point in which $\boldsymbol{F}$ was applied appears to have γ times **less** energy than its accelerated counterpart from the vantage point of an observer co-moving with the

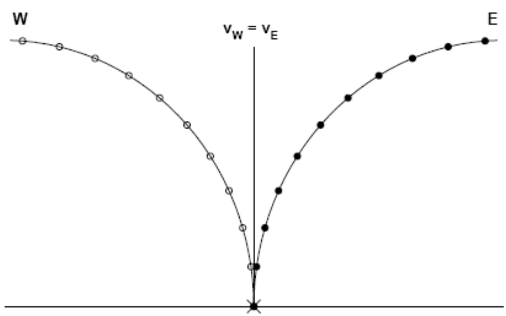

Fig. 2. Diagram showing two rockets leaving the same position in a gravity-free region of space. Their speed relative to the departure position is the same for both at all times, even though the respective directions of velocity are always different. The symmetric relationship of their trajectories indicates that the rates of their respective onboard clocks are always the same. This remains true even for the termini of the trajectories shown, in which case the rockets are both a) inertial systems (each traveling at constant velocity) and b) in relative motion to one another at that point.

latter. The rest frame in which the acceleration first occurs qualifies as an ORS [22]. This rest frame is unique in that only from this vantage point is it possible to apply Einstein's $E = \gamma E'$ rule correctly [30]. The latter in turn is identical with eq. (25) under these conditions, i.e when $\mathrm{d}p' = 0$, as can be seen by squaring both sides and using eq. (22) to specify the relation between dE and $\mathrm{d}p = \mathrm{d}p_x$. Concretely, this means that the energies of two identical objects that have been accelerated to the same speed from the ORS are equal, independent of whether they are moving in different directions or not, as indicated explicitly in Fig. 2. An observer in the ORS finds that both objects have γ times the (rest) energy E' they had in their original positions prior to being accelerated. The easiest way to understand these relationships is to assume that the **unit** of energy has increased by this factor in the rest frames (airplanes or rockets) $\mathrm{S_E}$ and $\mathrm{S_W}$ in which the two objects are located [30-32]. Hence, even though the ORS observer finds that each of the objects has energy $E = \gamma E'$, observers in $\mathrm{S_E}$ and $\mathrm{S_W}$ find that both of them still have the rest energy value $E = E'$, **even though one of the objects is moving at high speed relative to one of these observers in each case**. In other words, it is not correct to simply insert the relative speed v of $\mathrm{S_E}$ and $\mathrm{S_W}$ into Einstein's $E = \gamma(v)E'$ relation for thispurpose, contrary to what is invariably claimed in the literature on the basis of the relativistic symmetry principle. Instead, the PRM [26] needs to be applied, which states that since the energies of the two objects are equal for an observer in the ORS, they must also be the same for any other observer, regardless of his state of motion or position in a gravitational field.

Experimental evidence for the above conclusions will be considered in the following section. There is another clear indication that the eqs. (20a-d) are only valid when S' has been accelerated to speed u relative to S by virtue of an applied force in the latter rest frame, however. If these equations were perfectly general, then it must be possible to obtain the velocity components v_x, v_y, and v_z of eqs. (26a-c) by simply dividing dE on the left-hand side of eq. (20a) by $\mathrm{d}p_x$, $\mathrm{d}p_y$ and $\mathrm{d}p_z$, respectively, from eqs. (20b-d). One does indeed find that $\frac{\mathrm{d}E}{\mathrm{d}p_x}$ is equal to v_x of eq. (26a) when this is done, that is, by using Hamilton's equation and setting $\frac{\mathrm{d}E'}{\mathrm{d}p_x'} = v_x'$. This procedure leads to a false result for v_y and v_z, however: for example, $v_y = \gamma(u)\left(v_y' + \frac{u\mathrm{d}p_x'}{\mathrm{d}p_y'}\right)$ instead of eq. (26b) [The same problem occurs when one multiplies two LT matrices that correspond to velocities that are not parallel to one another]. These results can be understood quite easily when one assumes that S' has been accelerated along the x axis relative to S. When the object is imparted momentum $\mathrm{d}p_x'$ **in the same direction** relative to S', one can consider this as a continuation of the original acceleration process relative to S in which only the magnitude of the applied force has been changed. Note that only $u\mathrm{d}p_x'$ is assumed to contribute to the total change in energy dE from the vantage point of S, not $u\mathrm{d}p_y'$ or $u\mathrm{d}p_z'$. When the object's acceleration in a perpendicular direction relative to S' is considered, the situation becomes more complicated. The momentum change of the object does not contribute to dE and thus the ratio (derivative) of dE to $\mathrm{d}p_y$ or $\mathrm{d}p_z$ can no longer be equated with the respective velocity component in that direction. By contrast, ratios of distance to time are simply definitions of the corresponding velocity components and thus are not subject to any conditions regarding the cause of the object's motion relative to a given observer.

Before closing this section, it is important to briefly discuss the relevance of the above conclusions to the treatment of electromagnetic interactions. A more detailed description of this general subject is given elsewhere [33], but several general points are worth noting in the present context. First of all, the Lorentz expression for the force on a charged particle is invariant to the ALT of eq. (10a-d), so there is no need to change the standard (covariant) relativistic theory on this basis. Lorentz [9] wrote about the possibility of inserting an arbitrary constant ε in the transformation of eqs. (5a-d) for the expressed purpose of pointing out that such a degree of freedom was inherent in his theory of electromagnetism. His theory makes use of the Maxwell field equations [34] as a law of motion for the electromagnetic field, but it is certainly worth pointing out that other competing theories exist [35]. A discussion of this important topic is beyond the scope of the present work, however.

The PRM [26] plays an analogous role for the electromagnetic force law as it does for the E,p four-vector already discussed, however, so some key distinctions between Einstein's covariant theory and the present version based on the ALT need to be pointed out. In particular, the speed u to be inserted in the field equations is that which is measured for the charged particle *relative to the laboratory from which it has been accelerated*. An observer in motion relative to this laboratory must measure the same forces as his counterpart at rest there according to the PRM, albeit by using a different set of units. The manner in which the units of electromagnetic quantities vary with both the motion of the observer (kinetic scaling) and his position in a gravitational field (gravitational scaling) has also been discussed in a companion article [36]. The electromotive force itself is completely independent of the kinetic scale factor for physical units, for example [31]. In this sense, *it is not correct to say the ALT version of the theory is fully covariant*. The laws of physics must nonetheless be invariant to any such change of units, consistent with Einstein's first postulate [2], and this is accomplished in a straightforward manner by insisting that the uniform scaling be consistent with experimental observations, as is easily done [31, 32].

IX. Experimental Tests of Simultaneity and of the Rationality of Measurement (PRM)

The focus of the present work is on the compatibility of the principle of simultaneity of measurement and Einstein's postulates for the special theory of relativity. Despite the fact that previous discussions of this point have claimed that non-simultaneity is an essential feature of relativity theory, there has never been an experimental verification of this phenomenon, although many Gedanken experiments have been constructed to highlight the unusual consequences of non-simultaneity that would occur in everyday life. Instead, one has simply pointed out the notable successes of the LT in explaining various types of observations that cannot be explained consistently within the framework of the GT, starting with the Michelson-Morley experiments [4] themselves, with the implication that any unobserved predictions of the same theory must be correct as well. Realization that it is a simple matter to construct an alternative space-time transformation [the ALT of eqs. (10a-d)] which enforces simultaneity but is also consistent with all of the above experimental findings underscores the fact that it is essential to resolve this question in an empirical manner, however.

In this connection it is important to consider the underlying assumptions of the GPS navigation technology. Light signals are sent from three satellites to a position P on the Earth's surface. Since the locations of the satellites are always known to a high degree of accuracy, it is only necessary to know the distance each of the light signals travels in order to determine the ground position in question. It is assumed first and foremost that light travels at speed c on its way to the Earth, that is, by neglecting the refraction effects of the atmosphere and also the gravitational variation of the light speed in free space. The distance L to the ground position in a given case is determined by multiplying the elapsed time ΔT it takes for the signal to arrive from the satellite by c. The key point is that in order to obtain an accurate measurement of ΔT, one must rely on information supplied by an atomic clock located on the satellite. The time of emission of the signal T_S is then compared with its time of arrival T_G at P. Two further assumptions are needed [3] to determine ΔT from the latter two values, however. The most critical one in the present context is that the signal departs the satellite **at exactly the same time** for an observer there as for his counterpart on the ground. If this condition of simultaneity were not satisfied to at least a very good approximation, there would be no point in even measuring T_S on the satellite because what is actually needed is the time of emission **from the vantage point of the ground observer.**

Even with this assumption, however, it is still not possible to obtain ΔT on the ground by simply subtracting T_S from T_G. Instead, one must take into account the experimental fact that the clock on the ground generally does not run at the same rate as the one on the satellite. The latter is speeded up because of the gravitational red shift but a suitable correction can accurately be made since the satellite's altitude is known. More interesting in the present context is the effect of time dilation. In this case one assumes that the satellite clock is slowed by a factor of $\gamma(v)$, where v is the current speed of the satellite relative to the ground. The value of T_S is measured on the satellite, however, so according to the special theory of relativity the clock there is actually running **faster** than its counterpart on the ground (LT symmetry principle). One can take the position that the time dilation formula is not valid for an observer on the satellite because it is not an IS and thus ignore the symmetry principle in this case, as Hafele and Keating have done in their interpretation of their own experiments with circumnavigating airplanes [19]. It as at least difficult to argue this point given the weightlessness of objects carried onboard the satellite, however.

The ALT has a quite different interpretation of time dilation, as discussed in Sect. V. Accordingly, a) measurement is assumed to be objective and rational (PRM), therefore excluding the possibility that two clocks can both be running slower than each other at the same time, and b) the slower rate of clocks on the satellite is a direct result of their acceleration to speed v relative to their original position on the ground. The Earth's polar axis serves as an ORS for determining the relative rates of clocks on the basis of Einstein's formula [2]. One has to clearly distinguish time dilation from non-simultaneity. If two people disagree on the time of a given event, the reason is invariably because they have either not been paying attention or their respective clocks are not suitably synchronized. If we know that clock A is slower than clock B by a specific ratio R, then it is simply necessary to adjust the elapsed time measured on A by this factor in order to bring the two values into coincidence. This is exactly what is done in the GPS technology [3]. One assumes that the time of departure of the light pulse from the satellite is the same for everyone. The value

T_S is adjusted by multiplying it with $\gamma(v)$ and then making the corresponding gravitational correction in order to ensure that the elapsed time ΔT can be accurately obtained by subtraction, that is, as $\Delta T = T_G - \gamma T_S$. The method works quite well and this can be seen as an important verification of the underlying assumptions on which it is based. The latter are perfectly compatible with the ALT of eqs. (10a-d) *but not with either non-simultaneity or the symmetry principle of the LT.*

The lack of objectivity in the special theory is also essential in its treatment of the relativistic Doppler effect. The standard derivation [37] assumes that the phase of an electromagnetic wave in free space is Lorentz-invariant. The key point is that the phase velocity $\frac{\omega}{k}$ is equal to c for observers in different IS, where ω is the circular frequency of the radiation and $\boldsymbol{k}$ is the corresponding phase vector. As before with the LT and the energy-momentum four-vector relations, this condition is only sufficient to define the transformation properties of these quantities to within a common factor ε, however:

$$\omega' = \varepsilon\gamma(u)(\omega - uk_x) \tag{28a}$$

$$k_x' = \varepsilon\gamma(u)\left(k_x - \frac{u\omega}{c^2}\right) \tag{28b}$$

$$k_y' = \varepsilon k_y \tag{28c}$$

$$k_z' = \varepsilon k_z\ . \tag{28d}$$

The conventional procedure [37] then simply sets $\varepsilon = 1$ and makes conclusions on this basis. For example, it follows that a wave moving transverse to the direction of motion of the two observers ($k_x = 0$)

satisfies the condition: $\omega' = \gamma\omega$. By taking the inverse of the above equations, however, it is also possible to obtain the *symmetric* result: $\omega = \gamma\omega'$. Ives and Stillwell [15] were the first to observe this *transverse* Doppler effect (TDE). They found that the wavelength emitted from a moving source is γ times larger than that when it is at rest in the laboratory. These results have always been considered to be a verification of the above prediction, but note that this can only be said to be true if one associates the *in situ* frequency with ω' rather than ω.

As before with the energy momentum-four vectors (Sect. VIII), however, it is not necessary to give up the principle of rational measurement (PRM) in this case either. Instead, one can assume that the decrease in frequency observed in the TDE experiments [15, 16] is the direct result of time dilation in S' [38] by virtue of its acceleration relative to the laboratory S. In other words, **the clocks in S' are physically running γ times slower than in S**. On this basis, one would expect the observer in S' to measure an **increase** in frequency for light emitted from a source at rest in S by the same factor. According to this interpretation, measurement is rational and not symmetric. Furthermore, the ratio of the two frequencies ω and ω' need not equal γ. If light signals are exchanged between the two airplanes in Fig. 2, for example, it is expected that **no** shift in (transverse) frequency would be observed in either case because both sets of onboard clocks run at exactly the same rate under these conditions. This also means that the normalization factor ε in eqs. (28a-d) can take on any value consistent with the relative rates of clocks in S and S'. In all cases the condition $\omega = kc$ will be satisfied. Observers in S and S' will simply find that their respective values for this quantity (ε) are not the same (contrary to what the symmetry principle requires) but are rather the **reciprocal** of one another. The distinction between these different interpretations of the TDE can be tested experimentally by exchanging light signals from identical sources between laboratories located at different latitudes on the Earth's surface. This is because the experiments with clocks located on airplanes [19] and rockets [20] indicate that their rates decrease in a well-defined manner as they are moved from one of the Poles to the Equator. More details concerning this experiment may be found elsewhere [39]. If measurement is rational and not symmetric, the frequencies of light signals from identical sources measured at the Equator will always be larger than those at higher latitudes once the necessary gravitational corrections have been made to account for differences in altitude of the various laboratories.

Another major distinction between the ALT and LT formulations exists with respect to their attitude toward length contraction [FLC]. In this connection it is important to consider the experimental relationship between time dilation and the constancy of the speed of light in free space. Specifically, one needs to ask the following question: **how can two observers with clocks that have different rates still manage to agree on the value of the light speed?** The answer is quite simple. If observer A's clock is running slower than B's, this means that he will measure a smaller elapsed time for a light pulse to travel between two points in space. He therefore must also measure a **smaller** value for the distance between these points, and by **exactly the same factor** as for their respective elapsed times. In order for this to happen, however, his measuring rod must be **larger** than B's, not smaller as is often assumed. Furthermore, since time dilation is independent of the direction of A and B's relative motion, it follows that the ratio of the lengths of their measuring rods must also be the same in all directions [3]. This is **isotropic length expansion** in A's rest frame, not the anisotropic length contraction foreseen in the FLC.

The above conclusion is perfectly consistent with the GPS methodology. If the observer on the Earth's surface finds that it has taken ΔT s for the light signal to travel from the satellite, his counterpart in the latter's rest frame must find that it has only taken $\frac{\Delta T}{\gamma}$ s (after correcting for the gravitational redshift). Since the speed of light is the same for both observers, it therefore follows that the satellite observer will conclude that the light signal has traveled only $\frac{1}{\gamma}$ times as far as the observer on the Earth's surface determines. This conclusion is completely unaffected by the direction that the light pulse travels. It simply results from the fact that the period of the onboard atomic clocks on the satellite is **greater** than for those on the ground, which in turn is directly proportional to the unit of length employed to make the corresponding distance determinations [3].

Further experimental support for the isotropic length expansion hypothesis comes from the TDE [15, 16]. The faster the source moves relative to the laboratory, the smaller is the frequency ω of the light detected there because of time dilation at the source. In the experiments carried out by Ives and Stillwell [15], however, the wavelength of the light was measured rather than the frequency, and it was found that this wavelength was **larger** than in the rest frame of the source. This result is necessary in order to be consistent with Einstein's second postulate [2] since the speed of light is the product of frequency and wavelength. Hence, it constitutes a verification of the conclusion that time dilation is accompanied by length expansion, not length contraction. It is interesting that the frequency decrease in the TDE is often used as an example of time dilation [37, 38] without mentioning the obvious conflict with the FLC that the accompanying increase in measured wavelength represents.

The only way to avoid the above contradictions and still retain the LT is to give up the principle of rationality of measurement (PRM). One simply claims that observers in relative motion do not actually measure the same object. The symmetry principle of special relativity [10] is completely in line with this assertion, making it possible for the observers to disagree as to which line segment is greater or which clock is running slower. One of the main consequences of this approach is that it greatly restricts the possibilities of logical argumentation. The ALT on the other hand leaves open the distinct possibility that the only reason two observers disagree on the measured value for a given quantity is *because the respective units they employ to express their result are not the same*, not that the quantity itself changes with the state of motion of the observer. The underlying assumptions of the GPS technology are perfectly consistent with this view [3] since they rely on the fact that the clock on the satellite actually runs slower than its identical counterpart on the ground. It makes sense then to talk about different units of time, distance and energy for different rest frames. One of the main goals of the resulting theory of relativity is therefore to determine how these units vary from one rest frame to another [31-32].

X. Postulates of Relativity

The above discussion has indicated that acceleration plays a key role in relativity theory and that it is responsible for both the slowing down of clock rates and energy-mass dilation. This possibility was already pointed out in Einstein's original work [2], namely by stating that an applied force destroys the symmetry that otherwise exists between inertial systems. The two postulates he enunciated on which to base his new relativity theory do not actually reflect the role of acceleration, however. They simply state that the laws of physics are the same in all inertial systems and that the speed of light is independent of the state of motion of the observer and light source.

It has been shown in Sects. III and VI, however, that there is actually a hidden postulate ($\mathrm{d}y = \mathrm{d}y'$ or alternatively, the Lorentz invariance condition) in Einstein's formulation of the theory that is also essential in order to derive the Lorentz transformation (LT). The main consequence of the latter assumption is that it rules out the principle of simultaneity of events, since the LT leads to the conclusion that measured times ($\mathrm{d}t$ and $\mathrm{d}t'$) depend on the relative position ($\mathrm{d}x'$) of a given observer to the object [see eq. (4b)]. While this result has been hailed as one of the key advances of relativity theory, the fact is that the predicted non-simultaneity is contradicted by experience with the GPS navigation technology [3]. Thus, there is a need to reconsider the underlying structure of conventional relativity theory (STR [2]) to bring it into line with the results of this and other experiments that have been carried out since its inception in 1905.

One can best start this exercise by restating Einstein's two postulates:

1) **The laws of physics are the same in all inertial systems (Relativity Principle), but the units in which they are expressed vary systematically depending on their history of acceleration and position in a gravitational field.**
2) **The speed of light in free space is a constant, independent of the source and the observer.**

As discussed at the end of Section II, an addendum is required for the Relativity Principle to emphasize the experimental finding that clocks slow down upon acceleration and also that other physical quantities are changed as well. The resultant variation in properties is uniform within any rest frame, and so it amounts to a simple change in units in each case. Since the laws of physics are mathematical equations in every instance, such a **uniform scaling** clearly does not alter the laws themselves [31-32]. The effect is the same as if one converts from one system of standard units to another, such as going from feet to meters of length or from s to ms of time. One of the primary goals of relativity theory is to establish how these units change upon acceleration and change of position in a gravitational field. Two additional postulates are required to specify these relationships for the "kinetic" scaling of units [31].

Rather than give up the principle of simultaneity of events, as Einstein did in 1905 [2], it is necessary to insist upon it as the condition for completely specifying the required space-time transformation that is consistent with his second postulate:

3) Every physical event occurs simultaneously for all observers, independent of their state of motion and position in a gravitational field (Simultaneity Principle).

When this postulate is combined with that of the constancy of the speed of light in free space, the result is the ALT of eqs. (10a-d). Instead of $\mathrm{d}y = \mathrm{d}y'$ and $\mathrm{d}z = \mathrm{d}z'$ as in the LT [2], one has eq. (10d) to insure simultaneity. Dividing eqs. (10a-c) by $\mathrm{d}t = \mathrm{d}t'$ leads to exactly the same velocity transformation as for the LT, thereby insuring not only adherence to Einstein's second postulate but also agreement with a number of other key experimental results such as the Fizeau light drag effect and the aberration of light from stars that ultimately cemented the reputation of STR.

The ALT also frees one from the necessity of assuming that two clocks can both be running slower than one another, which is the prediction of the symmetry principle of STR [2, 10]. Equations such as $\mathrm{d}t = \gamma \mathrm{d}t'$ and $\mathrm{d}t' = \gamma \mathrm{d}t$ can be derived in a straightforward manner from the LT, whereas the only possibility for the ALT is that there is a definite ratio between the rates of clocks in any pair of inertial systems. As a result, one can add a fourth postulate that upholds another ancient principle:

4) The ratio of any two physical quantities of the same type is the same for all observers, independent of their state of motion and position in a gravitational field (Principle of Rational Measurement or PRM).

The latter postulate is the antithesis of the symmetry principle of STR. The PRM is in perfect agreement with the results of the Hafele-Keating experiments [19] and is also one of the underlying assumptions, in addition to the third postulate above (simultaneity), which allows the GPS navigation technology to produce reliable measurements of distance [3]. It becomes feasible to introduce "conversion" factors for relating the results of measurements in different inertial systems. In GPS technology, for example, one simply assumes that any measurement of elapsed time on a satellite can be adjusted so as to provide the corresponding value that would be measured by a clock on the ground. If there were disagreement about which clock runs more slowly, the one on the satellite or its counterpart on the ground, such a procedure would be groundless, or at least would require a quite different set of logical assumptions than are used in actual practice to achieve the desired results.

Finally, the conventional version of STR [2] assumes that one can simply use the LT and the related energy-momentum four-vector relations to derive information about the ratios of measured values for two observers in relative motion. In this case, a few additional remarks are necessary to clarify the situation when the ALT is used instead. Time dilation cannot be derived from the latter because of the simultaneity condition of eq. (10d). The light speed hypothesis is sufficient to derive energy-mass dilation, but as discussed above, the speed v to be used in applying Einstein's original formula, i.e.

$E = \gamma(v)E'$, in this instance must be taken relative to a particular rest frame, the ORS [22, 30]. In Sect. IX evidence has been cited to show that elapsed times scale in exactly the same manner with speed relative to a given ORS as do energy and mass. The latter result does not follow directly from the first four postulates given above, however, and hence a fifth postulate is required to complete the framework of the theory:

5) The unit of time in a given inertial system changes in direct proportion to those of energy and inertial mass.

The PRM [26] plays a key role in the scaling relationships. Consistent with the Hafele-Keating experiments [19], once the change in units has been established for two rest frames S and S' relative to their common ORS as $\gamma(v)$ and $\gamma(v')$, respectively, it follows that the conversion factor between their own units is given by the corresponding ratio $R = \frac{\gamma(v)}{\gamma(v')}$, as discussed in detail in Sect. VII. Measurement is completely rational and objective. There is no question about which clock is slower than the other on this basis, nor by what factor, exactly as is required in the GPS timing procedure.

No additional postulate is needed for the scaling of distances. They must also vary in direct proportion to elapsed times because of the light speed constancy [3]. This means that time dilation is accompanied by isotropic length expansion [31, 32], however, and not Fitzgerald-Lorentz length contraction. The main experimental evidence for this conclusion comes from observations of the transverse Doppler effect [15, 16]. They show unequivocally that the period of electromagnetic radiation varies in direct proportion to its wavelength, independent of the source's direction of motion relative to the observer. The increase in period is a clear example of time dilation in the rest frame of the light source, and the corresponding increase in wavelength is no less an experimental proof for isotropic length expansion. The only way to avoid this conclusion is again to allow for violations of the PRM, as is done in STR [2], but not in the above formulation of relativity theory (Postulate 4). A further consequence of the last two postulates is that the *relative* velocities of two objects must be the same for all observers (also forces because of the proportionality of the energy and length scaling factors), not just the speed of light in free space.

XI. Conclusion

Since Einstein's original paper on the special theory of relativity [2], it has generally been assumed that non-simultaneity is the inevitable consequence of the constancy of the speed of light in free space. It has been overlooked thereby that this result, which is embodied in the Lorentz transformation (LT), is only obtained when another, hidden, postulate is employed, namely that distances measured perpendicular to the direction of motion of two observers must be equal ($\mathrm{d}y = \mathrm{d}y'$ and $\mathrm{d}z = \mathrm{d}z'$). Lorentz [9] pointed out in 1899, however, when he first introduced his own space-time transformation, that a normalization condition is required in order to completely specify the desired relationships. This is because velocity is a ratio and thus is unaffected when the respective distance and time coordinates are multiplied by a common factor. In the present work, it has been shown that one can satisfy Einstein's postulate of the constancy of the light speed by using a different normalization factor than for the LT and requiring instead that $\mathrm{d}t = \mathrm{d}t'$, that is, that events are always simultaneous for observers in different rest frames. The resulting alternative transformation (ALT) is given in eqs. (10a-c). It leads to the same velocity addition formula as is obtained from the LT, and thus stands in agreement with all the experimental phenomena in which comparisons of the velocity of an object in different rest frames have been obtained, such as light aberration from stars, the Fresnel drag effect and the Michelson-Morley observations. Interestingly enough, the latter formula does not find that velocity components in perpendicular directions to the line of relative motion are the same, making it far less compelling to assume in the LT that the corresponding distance components must be equal.

Enforcing the condition of simultaneity in the ALT also frees one from the necessity of claiming that two clocks can be running slower than each other at the same time or that two measuring rods are each shorter than one another depending on one's state of motion (relativistic symmetry principle). Instead, it makes it possible for relativistic theory to subscribe to the ancient principle of rational measurement (PRM), whereby the ratio of any two physical quantities of the same type (distances, times, energies and masses) is assumed to be the same for all observers. Accordingly, the only acceptable reason for there to be disagreement regarding a given measured value is because different units have been employed to express the same result (making an error in measurement can also be looked upon as changing units unwittingly).

Both the PRM and simultaneity are essential for the success of the GPS navigation technology. One has to assume that the time of emission of a light signal from a given satellite is exactly the same there as on the Earth's surface. There would be no point in using the time measured on the satellite if this were not the case. The fact that clocks on the ground and on the satellite do not run at the same rate should not be confused with lack of simultaneity anymore than if two judges at rest in the same arena disagree on the value of an elapsed time for a race just because their clocks are not properly synchronized. The GPS methodology assumes that such timing measurements are perfectly objective. After correction for the gravitational redshift is made, it is assumed that the clock on the satellite runs physically slower because of relativistic time dilation and needs to be adjusted accordingly in order to have an accurate measurement for the elapsed time required for the light signal to pass from there down to the Earth's surface. Again, if there was disagreement on which clock was running slower, as the relativistic symmetry principle derived from the LT claims, there would be no means of achieving the level of synchronization of these clocks needed for a suitably reliable measurement of this elapsed time. The ALT is perfectly consistent with the assumptions of the GPS technology, and hence the latter's success can be taken as a striking verification of this version of the relativistic space-time transformation.

The ALT also leads to a different view of the nature of the time dilation effect itself. Its $\mathrm{d}t = \mathrm{d}t'$ condition obviously cannot be used to derive this phenomenon in the same way as occurs with the LT. That does not mean that the ALT is inconsistent with time dilation, however. Instead, it forces one to go back and look at the available experimental evidence for this effect and come up with a different explanation which does not violate the simultaneity condition. When this is done, it is found that in every instance the clock that has undergone acceleration is found to run slower than its counterpart left behind at the original rest system. This empirical result is perfectly consistent with Einstein's original prediction of the phenomenon, in which he emphasized the fact that the symmetric relationship between rest frames must necessarily be broken by the application of a force to one of them. His time dilation formula therefore can only be applied correctly from the vantage point of the rest frame from which the acceleration occurs. In the experiments with airplanes [19] and rockets flying above the Earth's surface [20], it was found empirically that this *objective* rest system (ORS) [22, 30] is the polar axis. One has to determine the speed relative to the ORS of a given clock and insert this value into the time dilation formula in order to accurately predict the factor by which the latter clock's rate has slowed relative to a standard clock located on the polar axis. The easiest way to understand this result is to assume that the unit of time in the accelerated rest frame has changed by the above factor. The simultaneity condition, $\mathrm{d}t = \mathrm{d}t'$, assumes that **the same unit of time has been employed in both rest frames**. When comparing the actual measured values, however, it is necessary to apply a correction that takes account of the quantitative difference in units employed by the different observers, whereby a gravitational correction also needs to be applied when the clocks are located at different gravitational potentials. This procedure is again consistent with both simultaneity and the PRM and has never been contradicted in experimental tests thus far carried out. The role of the IS is greatly diminished in applying the time dilation formula in this manner, since the quantity u in eqs. (10a-c) is simply interpreted as the instantaneous relative speed of the two rest frames, similarly as in the classical GT formulation (see Fig. 1).

The situation with length contraction (FLC) is even more critical. The value of $\mathrm{d}t = \mathrm{d}t' = 0$ cannot be used in eqs. (10a-c) because the derivative $\dfrac{\mathrm{d}x'}{\mathrm{d}t'}$ in eq. (9) is not properly defined in this case. Once again, however, it is possible to deduce the correct relationships by insisting that the PRM is also valid for distance measurements. The units of time and distance must vary in direct proportion in order to satisfy the condition that the measured light speed be the same in all rest frames. This means that isotropic length expansion must accompany the slowing down of clocks, not anisotropic length contraction. Only in this way can one be assured that the modern definition of the meter as the distance traveled by a light pulse in 1/c s is valid in all rest frames. Accordingly, an observer on a satellite employed in the GPS technology must find that all distances are smaller from his vantage point than for his counterpart on the ground. In effect, his measuring rod has increased in length because the period of his onboard clocks has increased by the same fraction and one can only assume that the same deduction applies for the actual lengths of objects carried onboard the satellite. The fact that the periods of electromagnetic waves increase in direct proportion to their respective wavelengths is also clearly consistent with this interpretation. Indeed, the wavelength of light was previously used to define the meter before it was agreed to use light frequencies for this purpose.

It is not possible to prove that all events occur simultaneously for different observers, anymore than one can be absolutely certain of energy conservation or the constancy of the speed of light in free space. In the absence of any confirmed observation to the contrary, however, there is certainly merit in constructing a relativistic theory of motion that employs simultaneity as a fundamental postulate. The same also holds true for the principle of the rationality or objectivity of measurement (PRM). It is not possible to achieve this goal within the framework of the LT, but there is no problem when the ALT is used in its place. The experimental evidence for time dilation indicates strongly that an addendum be made to Galileo's relative principle (RP), which Einstein has used as his first postulate. While it is true that the laws of physics are the same in every inertial system, it needs to be emphasized that the units in which their respective variables are expressed can vary with the state of motion of the observer. In addition, time dilation is an integral part of the theory, the details of which also need to be specified by means of a postulate. The indication from experiment is that the fractional change in clock rates is the same as for energy and inertial mass. Isotropic length expansion follows directly from this postulate and the constancy of the speed of light in free space. The manner in which the units of other physical properties vary can be deduced [31,32] simply by knowing their composition in terms of the above fundamental quantities of time, distance and energy or inertial mass. The hidden postulate in the LT that requires distances perpendicular to the direction of relative motion to be the same for all observers needs to be discarded because it is inconsistent with the simultaneity postulate.

From the philosophical point of view, the main distinguishing feature of the ALT *vis-à-vis* the LT is that it allows a return to the Newtonian view that space and time are fundamentally different entities. Since $\mathrm{d}t = \mathrm{d}t'$, exactly as in the GT, there is no reason to regard the coordinates of space and time as interchangeable aspects of a single physical quantity. Observers in relative motion can disagree about the distance traveled by a given object, but not about the elapsed time it took to arrive at its final destination. That this is an intuitively attractive philosophical position is underscored by the fact that it became dogma at a very early stage in the development of physical theory. The only way it can be legitimately overturned is by experiment, but to date no such definitive evidence has ever been found.

References

[1] H. Poincaré, "La mesure du temps", *Revue de métaphysique et de morale* **6** (1898) 1-13.

[2] A. Einstein, "Zur Elektrodynamik bewegter Körper", *Annalen der Physik* **322(10)** (1905) 891-921.

[3] R. J. Buenker, "The Global Positioning System and the Lorentz Transformation", *Apeiron* **15(3)** (2008) 254-269.

[4] A. Michelson and E. W. Morley, "Relative motion of earth and luminiferous Ether", *American Journal of Science* **34** (1887) 333-345.

[5] A. Pais, *'Subtle is the Lord ...' The Science and the Life of Albert Einstein*, Oxford University Press (1982) p. 119.

[6] W. Voigt, "Ueber das Doppler'sche Princip", *Göttinger Nachrichten* **7** (1887) 41-51.

[7] J. Larmor, *Aether and Matter*, Cambridge University Press (1900).

[8] A. Pais, *'Subtle is the Lord ...' The Science and the Life of Albert Einstein*, Oxford University Press (1982) p. 126.

[9] H. A. Lorentz, "Electromagnetic phenomena in a system moving with any velocity smaller than that of light", *Proceedings of the Royal Netherlands Academy of Arts and Sciences* **6** (1904) 809-831; P. Zeeman and A. D. Fokker, eds., *Collected Papers*, Vol. 5, Nijhoff (The Hague, 1935-1939) 172pp.

[10] H. Goldstein, *Classical Mechanics*, Addison-Wesley Publishing Co. (Reading, Massachusetts, 1950) p. 189.

[11] H. Poincaré, "Sur la dynamique de l'électron", *Rendiconti del Circolo Matematico di Palermo* **21** (1906) 129-175; *Oeuvres*, Vol. 9, Jacques Gabay (1995) p. 494.

[12] A. Pais, *'Subtle is the Lord ...' The Science and the Life of Albert Einstein*, Oxford University Press (1982) p. 136.

[13] W. Rindler, *Essential Relativity*, Springer Verlag (New York, 1977), p. 28.

[14] H. Goldstein, *Classical Mechanics*, Addison-Wesley Publishing Co. (Reading, Massachusetts, 1950), p. 193.

[15] H. E. Ives and G. R. Stilwell, "An Experimental Study of the Rate of a Moving Atomic Clock", *Journal of the Optical Society of America* **28(7)** (1938) 215-219 (contd. in **31(5)** (1941) 369-374); G. Otting, "Der quadratische Dopplereffekt", *Physikalische Zeitschrift* **40** (1939) 681-687; H. I. Mandelberg and L. Witten, "Experimental Verification of the Relativistic Doppler Effect" *Journal of the Optical Society of America* **52(5)** (1962) 529-535.

[16] W. Kündig, "Measurement of the Transverse Doppler Effect in an Accelerated System", *Physical Review* **129(6)** (1963) 2371-2375.

[17] H. J. Hay, J. P. Schiffer, T. E. Cranshaw, and P. A. Egelstaff, "Measurement of the Red Shift in an Accelerated System Using the Mössbauer Effect in Fe^{57}" *Physical Review Letters* **4(4)**, (1960) 165-166.

[18] D. S. Ayres, D. O. Caldwell, A. J. Greenberg, R. W. Kenney, R. J. Kurz, and B. F. Stearns, "Comparison of π^+ and π^- Lifetimes" *Physical Review* **157(5)** (1967) 1288; A. J. Greenberg, Thesis, Berkeley (1969).

[19] J. C. Hafele and R. E. Keating, "Around-the-World Atomic Clocks: Predicted Relativistic Time Gains", *Science* **177(4044)** (1972) 166-168.

[20] R.F.C. Vessot and M. W. Levine, "A test of the equivalence principle using a space-borne clock", *General Relativity and Gravitation* **10(**3) (1979) 181-204.

[21] R. D. Sard, *Relativistic Mechanics*, W. A. Benjamin (New York, 1970) p. 95.

[22] R. J. Buenker, "Resolution of Open Questions in Special Relativity by Employing the Concept of an Objective Rest System," submitted for publication.

[23] G. F. Fitzgerald, "The Ether and the Earth's Atmosphere" *Science* **13(328)** (1889) p. 390.

[24] H. A. Lorentz, "The Relative Motion of the Earth and the Ether." *Koninklijke Akademie van Wetenschappen te Amsterdam. Wis- en Natuurkundige Afdeeling. Verslagen der Zittingen* **1** (1892–93) 74–79; P. Zeeman and A. D. Fokker, eds., *Collected Papers*, Vol. 4., Nijhoff (The Hague, 1935-39) p. 219–223.

[25] R. J. Buenker, "Logical Principles and the Special Theory of Relativity," to be published.

[26] R. J. Buenker, "Relativity Theory and the Principle of the Rationality of Measurement," to be published.

[27] R. D. Sard, *Relativistic Mechanics*, W. A. Benjamin (New York, 1970) p. 104.

[28] A. Pais, *'Subtle is the Lord …' The Science and the Life of Albert Einstein*, Oxford University Press (1982) p. 144.

[29] R. D. Sard, *Relativistic Mechanics*, W. A. Benjamin (New York, 1970) p. 156.

[30] R. J. Buenker, "Use of an Objective Rest System to Determine Energy and Momentum Relationships for Observers in Relative Motion," to be published.

[31] R. J. Buenker, "The Relativity Principle and the Kinetic Scaling of the Units of Energy, Time and Distance," to be published.

[32] R. J. Buenker, "Gravitational and Kinetic Scaling of Units", *Apeiron* **15(4)**, (2008) 382-413.

[33] R. J. Buenker, "The Role of Acceleration in the Relativistic Theory of Electromagnetism," to be published.

[34] R. D. Sard, *Relativistic Mechanics*, W. A. Benjamin (New York, 1970) p. 355.

[35] T. E. Phipps, Jr., *Old Physics for New - A Worldview Alternative to Einstein's Relativity Theory*, Apeiron (Montreal, 2006) p. 109.

[36] R. J. Buenker, "The Kinetic and Gravitational Scaling of the Units of Electricity and Magnetism," to be published.

[37] R. D. Sard, *Relativistic Mechanics*, W. A. Benjamin (New York, 1970) p. 362.

[38] W. Rindler, in *Essential Relativity*, Springer Verlag (New York, 1977) p. 55.

[39] R. J. Buenker, "On the Asymmetry in Relativistic Doppler Shifts Caused by Time Dilation," to be published.