Nonequivalence of ether theories and special relativity

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The role played by clock synchronization procedures for coordinate transformations which account for time dilation and length contraction is discussed. Special relativity is here compared with the ether theory based on the Tangherlini transformations. These transformations are shown to be theoretically distinguishable from the Lorentz ones by means of an internal synchronization procedure which makes use of rods kept in contact with a rotating disk. This procedure makes it possible, in principle, to measure the one-way velocity of light and to test the theories. First-order experiments confirm special relativity and rule out the ether theory.

I. INTRODUCTION

The question concerning the empirical equivalence between special relativity (SR) and an ether theory (ET) taking into account length contraction and time dilation has been debated[1] at length in the last decades.

It is well known that the classical ET based on Galileo's transformations had to be abandoned in favor of SR a long time ago. However, even today problems concerning the ether are still relevant, mainly for the following reasons.

First of all there has been an evolution in the concept of ether. A modern ether is no longer the naive fluid conceived in the past century. It would, rather, consist of electromagnetic fields radiated by all the atoms of the universe. This electromagnetic background would be the zero-point radiation which constitutes the basis of a classical theory called stochastic electrodynamics.[2] By means of this theory many quantum results have been obtained in a classical way. The vacuum of SR is thus replaced by a physical vacuum (the ether) which, hopefully, could provide a more understandable description of phenomena such as, e.g., the slowing down of moving clocks.[3]

Furthermore, new coordinate transformations, called generalized Galileo transformations,[4,5] are now associated with the concept of modern ether. These transformations can take into account length contraction and time dilation and, therefore, can explain the physical phenomena related to these effects. Besides, modern ether theories can be a basis for the interpretation of the observed cosmic, background-radiation anisotropy,[6] and of some data from quasars and compact radiogalaxy radiation.[7]

The role played by synchronization in SR was discussed first by Poincaré[8] and Einstein.[9] Recently it has emerged[3,10,11] that the choice of the procedure used for the synchronization of clocks is essential for the measurement of physical quantities. Although length contraction and time dilation are considered real effects, it is generally believed[11,12] that it is impossible, in principle, to measure the one-way velocity of light. If this were true, then it would be equally impossible to corroborate experimentally the very first hypothesis on which SR stands, the constancy of the speed of light.

We have found, however, as will be shown later, that there is a synchronization procedure by which the one-way velocity of light can still be measured in principle.

In view of all the above considerations, we believe that the polemic about the equivalence between ET and SR should be reconsidered in the light of the new synchronization procedure.

II. COORDINATE TRANSFORMATIONS AND SYNCHRONIZATION PROCEDURES

As also in Refs. 10 and 11, let us consider general coordinate transformations of the type

$$x' = a(x - vt)\,,\qquad y' = ey\,,\qquad t' = jt + \epsilon x'\,, \tag{1}$$

between the ether frame $S(x,y,t)$ and frame $S'(x',y',t')$ moving with velocity $v_x = v$ with respect to S, and discuss the role played by the parameter ϵ in the procedure of clock synchronization.

Here, we would like to remind the reader that before considering specific coordinate transformations, it is generally assumed, although not explicitly stated, that the clocks of each reference frame are previously (internally) synchronized. Thus, adopting, e.g., Einstein's synchronization procedure,[9] we may synchronize any two distant clocks of S by sending a light signal from one clock to the other and back.

The same procedure must be adopted to synchronize the clocks at rest in frame S'. Finally, the readings of the clocks of S can be related to those of S' by setting, e.g., $t = t' = 0$ for the two clocks at the origin of S and S', respectively.

Once the clocks have been synchronized, the parameters of the coordinate transformations (1) do not depend on synchronization, and they can be determined on the basis of physical hypotheses. For example, if we require space isotropy and light-speed invariance we obtain[13] $a = j^{-1} = \gamma = (1 - v^2/c^2)^{-1/2}$, and $\epsilon = -v/c^2$, i.e., the Lorentz transformations (LT). However, if, e.g., the clocks of S' are not previously (internally) synchronized, the speed of light in S' is now not necessarily given by c as in S.

In fact, if the clocks of S' are synchronized according to, e.g., Einstein's procedure, when a light signal sent from the origin O' at $t'=0$ reaches the clock C'_B at $x'_B=d'$ the reading of C'_B is $t'=d'/c$. While, with, e.g., a different, merely conventional synchronization, the reading of C'_B is now $t^{*'}\neq t'$ for the same event. Thus, the velocity of light is now $c^{*'}=d'/t^{*'}\neq c$. Since the velocity of light in S' depends on the (conventional) synchronization procedure, if the clocks of S' are not synchronized we can no longer use the invariance of c to determine the parameters of (1).

It is as if space is isotropic in the frame S where the ether is at rest, and anisotropic in the frame S' moving with respect to the ether. However, Sjödin[11] has shown that, apart from the arbitrary parameter ϵ which depends on the choice of the synchronization, the other parameters of (1) can be determined by requiring that the round-trip velocity of light be independent of the direction and of the inertial frame. In this case, we obtain from (1),

$$\begin{aligned} x'&=\gamma(x-vt)\ , \\ y'&=y\ , \\ t'&=\gamma^{-1}t+\epsilon x'\ . \end{aligned} \tag{1'}$$

Apparently independently of the synchronization parameter ϵ, transformations (1') predict length contraction and time dilation. If we choose Einstein's synchronization, then $\epsilon=-v/c^2$ and we obtain the LT. If we choose the so-called absolute synchronization ($\epsilon=0$), then we obtain the Tangherlini[14] transformations (TT).

Lately, Mansouri and Sexl[10] (MS) considered transformations (1) and analyzed the role played by ϵ in the procedure of clock transport synchronization. They show that slow clock transport and Einstein's synchronizations are equivalent internal synchronization procedures for an ET based on the TT. This result was foreseeable considering that the TT predict the same time-dilation effect as the LT. Assuming implicitly that any other internal synchronization procedure must be undistinguishable from Einstein's synchronization, MS conclude that the ET considered is kinematically equivalent to SR, i.e., the TT are equivalent to the LT, regardless of the conventional value of the synchronization parameter ϵ.

In other words, MS state that for an ET based on (1'), which implies the same length contraction and time dilation as SR, any internal synchronization procedure turns out to be equivalent to Einstein's. Thus, the synchronization parameter in (1') must take the value $\epsilon=-v/c^2$ and this ET coincides with SR. Furthermore, transformations (1') with $\epsilon\neq-v/c^2$ must be equivalent to the LT because the arbitrary change in the synchronization convention does not alter physical effects.

If this were true, i.e., if any internal synchronization were equivalent to Einstein's, then, considering that in (1') Einstein's procedure implies the constancy of the speed of light and vice versa. Podlaha[12] would be right in claiming the impossibility of measuring the one-way velocity of light. In fact, if we use Einstein's procedure (any other would be equivalent anyway) to synchronize two distant clocks, a logical circularity arises when we use these clocks to measure the velocity of a light signal previously used to synchronize the same clocks.

However, Marinov,[15] Vargas,[16] and Chang[5] have considered the ET based on the TT in a realistic sense as a different, nonequivalent, and alternative theory to SR. The problem of the equivalence between the LT and the TT has then been reconsidered by Podlaha,[12] Sjödin and Podlaha,[11] Cavalleri and Spinelli,[3] Rembelinski,[17] and Flidrzynski and Nowicki.[18]

On the other hand, MS point out that the equivalence between LT and TT does not hold for phenomena involving the electrodynamics of bodies moving with respect to the ether because, in this case, extra assumptions are necessary for the development of the ET.

Moreover, Rembelinski[17] and Flidrzynksi and Nowicki[18] maintain that the LT and TT can be discriminated when applied to dynamical processes because, in this case, the TT mark the absolute frame.

It should be noted that there are other transformations that, like the TT, are a special case of the generalized Galileo transformations, which are based on the absolute synchronization of clocks. These transformations are not equivalent to the LT and can be associated to ether theories which make use of models of the ether different from the one considered here. Such is the case of the modern version of the Stokes-Planck ET considered by Spavieri[4] in connection with the invariance of the wave equation under general coordinate transformations, and by Spavieri and Contreras[19] in order to interpret the experiment of Arago.

Although in the specific case of the TT, MS showed that clock transport is equivalent to Einstein's synchronization, this fact cannot be taken as a general proof that any internal synchronization must lead necessarily to a value of ϵ corresponding to that of Einstein's.

In this paper we reconsider the problem of internal synchronization and we show that length contraction and time dilation alone cannot fix *a priori* the value of the synchronization parameter. In the case of internal synchronization by means of a moving rod the arbitrariness of ϵ is related to the arbitrariness of the value of the Thomas precession of the moving rod.

Moreover, we are able to devise a new internal synchronization procedure, consisting of two rods moving in contact with a rotating disk, which is equivalent to Einstein's only in the case of the LT. In effect, the new procedure does not depend on length contraction and time dilation, and when clocks of frame S and S' are synchronized by means of this new procedure the parameters of (1) and of (1'), including ϵ, do not depend on synchronization. In this case, different values of ϵ represent different physical realities.

Since the new procedure is not, *a priori*, equivalent to Einstein's, it follows that it is, in principle, possible to measure the one-way velocity of light.

In the case of the TT the new procedure, which is not equivalent to clock transport, leads to absolute synchronization as a result of internal synchronization. If this new synchronization procedure is used, then an ET based on the TT cannot be equivalent to SR, and the TT can be tested with the experiments against the LT. Neglecting second-order terms in v/c, the LT and the TT differ essentially for the value of the parameter ϵ which now is no longer conventional. Thus, first-order tests can be used to estimate the value of ϵ. Contrary to the results of Vargas's[20] analysis, the experimental data confirm that ϵ corresponds to Einstein's synchronization parameter and rules out the TT.

III. INTERNAL SYNCHRONIZATION BY MEANS OF A MOVING ROD: ARBITRARINESS OF THE SYNCHRONIZATION PARAMETER

Let us consider a rod parallel to the x' axis and initially at rest in frame S' at a given distance below the origin O'. Actually, the rod can be thought of as being aligned along the x axis of an auxiliary frame having originally its axes parallel to those of S'. The auxiliary frame, initially at rest with the frame S', is being accelerated, keeping its abscissa axis parallel to the x' axis for S', until it reaches the uniform velocity $\mathbf{u}(u_x,u_y)=\mathbf{u}(v,u_y)$ with respect to S, as shown in Fig. 1.

Because of length contraction in the direction of motion the axes of the moving auxiliary frame are no longer orthogonal for S. In fact, they open by an angle $\Delta\phi_0=\gamma u_x u_y/c^2$ and cannot be both kept parallel to the corresponding axes of S. From a kinematical point of view, the consequence of length contraction is such that the orientation of the auxiliary frame, as judged by S, is kept the same as if there were no length contraction except for a rotation by an angle $\Delta\phi \leq \Delta\phi_0$ about the direction of motion.

Once the auxiliary frame has reached the constant velocity u_y', we find thus that it can be arbitrarily oriented,

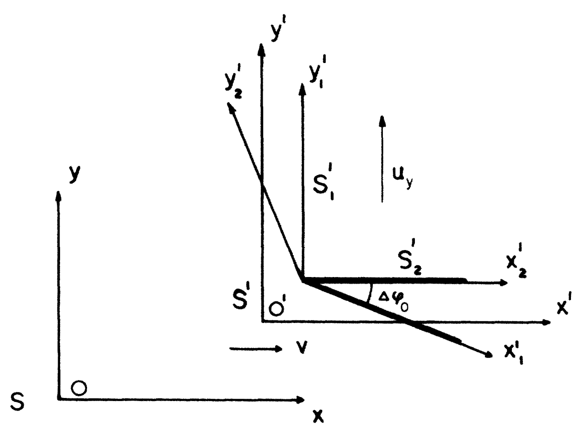

FIG. 1. A rod, initially parallel to the x' axis and at rest with respect to S', is set in motion and reaches a uniform velocity u_y when it crosses the x,x' axes. The rod can be aligned along either the x_1' axis or the x_2' axis depending on the initial acceleration mechanism. The four frames S, S', S_1', and S_2' coincide with one another if $u_y=v=0$.

with respect to S, between two extreme positions: either that of frame S_1' which has kept the y_1' axis parallel to the y,y' axes, or else that of frame S_2' which has kept the x_2' axis parallel to the x,x' axes. The specific orientation depends on the acceleration procedure which in turn involves the dynamical properties of bodies moving through the ether.

It should be noted that the four frames S, S', S_1', and S_2' have all their axes respectively parallel if $u_y'=v\to 0$. However, the moving frames S_1' and S_2' are rotated one with respect to the other by the angle $\Delta\Phi_0$ related to the Thomas precession.

Since the same considerations must apply to the rod, if we use this to synchronize two clocks of S',O' at $x'=0$, and A' at $x'=L_0$, i.e., setting $t_{O'}'=t_{A'}'=0$ when the rod crosses the x' axis, we find then that there is an arbitrariness in the value of ϵ, related to the arbitrariness of the angle of rotation of the auxiliary frame. In order to calculate ϵ we have to use the transformations

$$x_1'=\gamma_x(x-u_x t)\ ,\qquad y_1'=\gamma_0[\gamma_x^{-1}y+\gamma_x(u_x u_y/c^2)x-\gamma_x u_y t] \tag{2}$$

from S to S_1', and

$$x_2'=\gamma_0[\gamma_y^{-1}x+\gamma_y(u_x u_y/c^2)y-\gamma_y u_x t]\ ,\qquad y_2'=\gamma_y(y-u_y t) \tag{3}$$

from S to S_2'.

In (2) and (3), we have $\gamma_0=(1-u^2/c^2)^{-1/2}$, $u^2=u_x^2+u_y^2$, $\gamma_x=\gamma=(1-u_x^2/c^2)^{-1/2}$, $u_x=v$, and $\gamma_y=(1-u_y^2/c^2)^{-1/2}$.

Transformations (2) and (3) can be obtained from either the LT or the TT, applied to two frames moving with relative velocity u along their abscissa axes. Then, the first frame is rotated by an angle ϕ, with $\tan\phi=u_y/u_x$, and identified with frame S. If the second frame is rotated by an angle ϕ', with $\tan\phi_1'=\gamma u_y/u_x$, its y_1' axis is kept parallel to the y axis and we obtain S_1', while with $\tan\phi_2'=\tan(\phi_1'+\Delta\phi_0)=u_y/\gamma u_x$, its x_2' axis is kept parallel to the x axis and we obtain S_2'.

In this procedure, the effect of time dilation plays only a secondary role, while the length contraction effect plays a primary role. These roles are interchanged in the case of the clock transport procedure.

According to (1) the value of ϵ, with $j=\gamma^{-1}$ and $t_{O'}=t_{O'}'=0$, is given by the condition

$$\Delta t'=t_{A'}'=\gamma^{-1}t_{A'}+\epsilon L_0=0\ , \tag{4}$$

where $t_{A'}$ represents the time evaluated in S when the rod, i.e., the x_1' or the x_2' axis, respectively, intersects clock A'. The time $t_{A'}$ must satisfy the relation (position of A')

$$x=\gamma^{-1}L_0+vt\ . \tag{5}$$

The condition of intersection of A' by the x_1' axis of S_1 is $y=y_1'=0$, i.e., from (2),

$$(u_x/c^2)x-t=0\ . \tag{6}$$

From (6), (5), and (4) we obtain

$$\epsilon=-v/c^2\ . \tag{7}$$

Therefore, the internal synchronization by means of the rod aligned along the x'_1 axis of S'_1 leads to (7), i.e., to Einstein's synchronization.

If the rod is along the x'_2 axis of S_2, the condition of intersection of A' by x'_2 is $y=y'_2=0$, i.e., from (3)

$$t=t_{A'}=0 \; . \tag{8}$$

As a result of (8) relation (4) yields

$$\epsilon=0 \; . \tag{9}$$

Then, with the rod aligned on the x'_2 axis, this procedure leads to the absolute synchronization given by (9).

In the considered internal synchronization procedure, we have already taken into account the kinematical effects of the length contraction and time dilation. Still, choosing arbitrarily the synchronization procedure leading to (9), it is possible to discriminate between the LT and TT.

However, the arbitrariness of this choice might disappear if we introduce in the ET extra physical hypotheses related to the modalities of accelerating the auxiliary frame keeping its x' axis parallel to that of S'.

In fact, the rod, or the auxiliary physical frame, is initially at rest with S' and can be accelerated only by applying a force to it. In order to know the effect of this force, we would have to proceed beyond purely kinematical considerations, and would have to develop the dynamics of this ET, which could mark the absolute frame.[17,18]

To avoid discussing the dynamical properties of bodies moving through the ether, we present, in the following section, a new, internal synchronization procedure which involves rods in uniform motion only.

IV. INTERNAL SYNCHRONIZATION PROCEDURE CONSISTING OF TWO MOVING RODS IN CONTACT WITH A ROTATING DISK

An alternative method for internal synchronization is provided by a long moving rod in contact with a spinning disk whose center is at rest in frame S' as shown in Fig. 2. When the rod moves with uniform constant velocity, the disk spins with constant angular velocity ω' without sliding on the rod. In this circumstance the velocity of the rod can be measured by only one clock O' and is given by $u'=\omega' R'=2\pi R'/T'$, where R' is the radius of the spinning disk, measured in y' direction, and T' is the period of revolution. Clock A' will, then, be synchronized when the point D marked on the rod for this purpose, after passing by O' at $t'_{O'}=0$, reaches A' at $x'=L_0$, at $t'_{A'}=L_0/u'$.

Notice that the eventual shrinking of the circumference of the disk is compatible with the noncontraction of the radius, as shown in the solution of Ehrenfest's paradox by Cavalleri.[21]

Actually, it is not even necessary to measure u' for synchronizing two distant clocks. In fact, a clock B', placed at $x'=-L_0$, can be synchronized with A', i.e., by setting

$$\Delta t'=t'_{A'}-t'_{B'}=0 \; , \tag{10}$$

when a similar mark E on a second rod, moving with

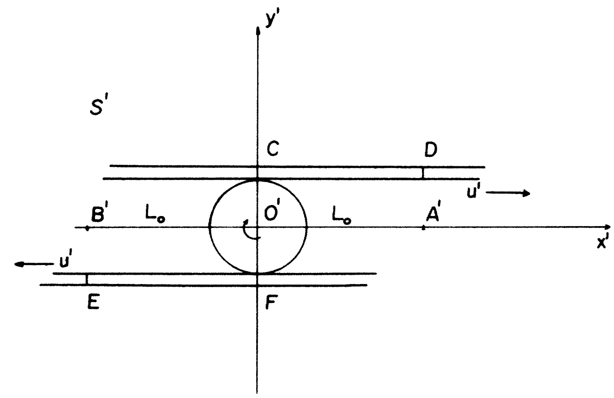

FIG. 2. Two long rods move in opposite directions, running without sliding on a rotating disk. After a complete revolution of the disk the rods have moved an equal distance $d'=CD=FE$, respectively.

velocity $u'_x=\bar{u}'=-u'$, reaches B'. The second rod is running in contact with the lower part of the same rotating disk and the mark E crosses the origin O' at the same time $t'_{O'}$ of D.

The condition imposed on the disk motion of rolling without sliding assures us that the rods move with equal and opposite velocities regardless of the values of ω' and R'. In fact, after a complete revolution, the disk is in contact with points C and F now at the origin O', and, for S', the rods have traveled an equal distance, $d'=CD=EF$, respectively, in opposite directions and in the same period of time. Although we might know d' in S', we do not know the relationship between d' and the corresponding rest lengths of CD or EF. Nor do we know the relationship between d' and the length of CD or EF evaluated in S, because these relationships depend on the type of coordinate transformations.

The time difference for the two events A' and B' can be evaluated in S considering that point D reaches A' at the time $t_{A'}$ such that $ut_{A'}=\gamma^{-1}L_0+vt_{A'}$, while point E reaches B' at the time $t_{B'}$ such that $\bar{u}t_{B'}=-\gamma^{-1}L_0+vt_{B'}$, where u and $\bar{u}$ are the velocities of the two moving rods, respectively. Thus, we obtain

$$\Delta t=t_{A'}-t_{B'}=\gamma^{-1}L_0\left[\frac{1}{u-v}-\frac{1}{v-\bar{u}}\right] . \tag{11}$$

If we use for u and $\bar{u}$ the velocity transformations obtained from the TT, expression (11) yields

$$\Delta t=0 \; .$$

Calculating instead u and $\bar{u}$ according to the LT we obtain

$$\Delta t=2\gamma L_0 v/c^2 \; . \tag{12}$$

However, if the LT and the TT are equivalent, then, taking into account time dilation and length contraction, (11) must necessarily lead to result (12). This situation is impossible because we cannot obtain (12) from (11) unless we assume additional physical hypotheses about the behavior of the moving rods.

Our conclusion is not surprising if we consider that, as mentioned also by MS, in order to describe phenomena involving bodies in motion through the ether extra assumptions are necessary for the development of the ET, and these do not necessarily coincide with the assumptions of SR. For example, if we perform an internal synchronization in S' by means of sound signals propagating in a medium at rest in S', and therefore moving though the ether, the corresponding sound velocity with respect to S can be obtained only by means of extra hypotheses. Thus, in principle, the ET can be discriminated from SR.

In the particular case of synchronization with light signals, we can exploit the original hypothesis that frame S is at rest with the ether, so that the light must travel in every direction with the same speed. Thus, we would have $u=-\bar{u}=c$, and in this case (11) would lead to Einstein's procedure (12). However, in the case of moving rods, we only know that $|u'|=|\bar{u}'|$ in frame S' allowing for the internal synchronization (10), while we do not know the values of u and $\bar{u}$ in frame S.

In order to stress the difference between the above S' internal synchronization procedure and another S' synchronization procedure which would be equivalent to Einstein's procedure for S, we consider now the following synchronization procedure. Two rods of equal rest length, i.e., with $(CD)_0=(EF)_0=d_0$ are moving in opposite directions as in the previous case. The velocities of the two rods are taken to be the same in S' if they are such that, being D and E at the origin of S' at a given time, at a later time the other two ends C and F reach O' simultaneously, as shown in Fig. 3. Clocks A' and B' are thus synchronized as before when they are reached by the rod ends D and E, respectively. If D and E are at the origin $O\equiv O'$ of S at $t=0$, C and F will cross the origin O' at the time t such that

$$ut=d_0/\gamma_u+vt \tag{13}$$

and

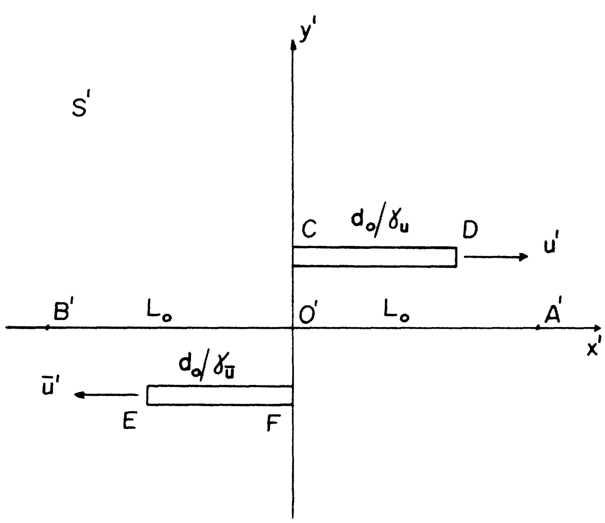

FIG. 3. Two rods of equal rest length $d_0=(CD)_0=(FE)_0$ move in opposite directions in S'. Their velocities are taken to be the same if, D and E having crossed the origin O' at the same time, C and F later cross O' again simultaneously.

$$\bar{u}t=-d_0/\gamma_{\bar{u}}+vt ,$$

where ut and $\bar{u}t$ are the positions of D and E, respectively, at the time t. In this case we can find, eliminating t from (13), the relationship between u and $\bar{u}$ which turns out to be

$$\frac{u-v}{1-uv/c^2}=-\frac{\bar{u}-v}{1-\bar{u}v/c^2} . \tag{14}$$

Expression (14) is precisely the relativistic transformation of $u'=-\bar{u}'$, and if (14) is substituted in (11) we obtain result (12). Thus once more, this synchronization procedure is equivalent to Einstein's procedure.

In the previous case of Fig. 2, once the length d' of the circumference of the disk has been defined in S', we must have

$$CD=ED=d' . \tag{15}$$

However, in the rest frames of the rods we might obtain different lengths for the circumference, $(CD)_0\neq(EF)_0$, because the disk might translate here with different velocities.

V. EXPERIMENTAL DETERMINATION OF THE SYNCHRONIZATION PARAMETER

Considering that clocks of S and S' can be internally synchronized according to the procedure presented in Sec. IV, the value of the synchronization parameter ϵ is no longer a mere question of convention. Therefore, the LT and the TT are not equivalent as they lead to different physical predictions. If the Earth moves with respect to the ether, the TT predict that the velocity of light is not constant. As pointed out by MS the clocks contributing to UTC (Universal Time Coordinated, the universal time emitted by coordinated radio stations) are synchronized with the help of radio signals, the propagation delays of which are measured with the help of clock transport. Then, if S' is a frame of rest with the Earth, the time delay for the radio signals to travel from O' to A', is, on account of (1), given by

$$t'=L_0/u'=L_0\Big/\left[\frac{a(u-v)}{j+\epsilon a(u-v)}\right] . \tag{16}$$

The time delay measured with the help of clock transport is equivalent to that given by Einstein's synchronization, i.e., $t'_E=L_0/c$.

Actually the clock transport can be provided by the Earth's rotation. In this case light travel times of about 5×10^{-2} sec are involved, and no diurnal changes in clock synchronization between Europe and the United States are observed at the 10^{-6}-sec level. Thus, at first order in v/c, with $a\simeq j\simeq 1$, $u=c-v(1+\epsilon c^2/v)$, (16) yields

$$(t'-t'_E)/t'=\frac{v}{c}\left[1+\frac{\epsilon c^2}{v}\right]\leq 10^{-5} . \tag{17}$$

From (17) we obtain (7), i.e., $\epsilon=-v/c^2$ within a precision of about $10^{-5}c/v$. On the other hand, in order to account for result (17) with (9), i.e, with $\epsilon=0$, the Earth's velocity with respect to the ether cannot be greater than $v=3$ km/sec.

Furthermore, if we take into account the results of recent experiments on the transversal Doppler effect, we obtain, in agreement with MS analysis,

$$v(1+\epsilon c^2/v) \le 5 \text{ cm/sec} \tag{18}$$

for Isaak's[22] data. In this case Einstein's value of ϵ is confirmed with an accuracy of about $10^{-10}c/v$, while, for the ET, the velocity of the ether wind at the Earth's surface must be less than 5 cm/sec. However, if the ether is practically at rest with respect to the Earth, this ET cannot explain the phenomenon of aberration of starlight. In fact, this phenomenon can be explained by an ET, which makes use of an ether isotropic and uniform everywhere in the rest frame S, only if the Earth moves with respect to S, with a velocity $v \ge 30$ km/sec.

VI. CONCLUSIONS

From a purely kinematical point of view the synchronization parameter of transformations (1), for an ET which takes into account the same length contraction and time dilation of SR, i.e., with $a=\gamma=j^{-1}$, is not bound to assume the value corresponding to Einstein's synchronization. In fact, when an internal synchronization procedure, based on moving rods, is performed in frame S' moving with respect to the ether, the value of ϵ may vary from $\epsilon=0$ to $-v/c^2$, depending on the choice of the orientation of the rod, the arbitrariness of which is related to the Thomas precession.

Furthermore, we propose a new internal synchronization procedure, consisting of two rods which move in opposite directions with the same speed by running on the same disk. This mechanism is actually based on the same principle as the automobile speedometer. Again this internal procedure is not necessarily equivalent to Einstein's for the ET considered. Thus, transformations (1), with $a=\gamma=j^{-1}$, and $e=1$, represent different physical realities for different values of ϵ. Therefore, it is possible to discriminate theoretically between the LT and the TT. From an experimental point of view, first order tests in v/c allow us to determine the value of ϵ. These experiments do not provide, as erroneously believed by MS, a way to test the value of the time-dilation factor j. In fact, it was rather puzzling to conceive that their test theory led to a verification of the value of j with an accuracy of about 1 in 10^7 by first-order experiment, while the value of a, which is of the same order of j, is verified, by second-order experiment, with an accuracy of only a few percent.

Contrarily to the conclusions of Vargas,[20] who did not take into account the most recent and precise experiments, the determination of ϵ by first-order tests confirm the LT, i.e., SR, and rules out the ET associated to the TT.

Finally, since the synchronization procedure based on rods moving in contact with a disk is not, *a priori*, equivalent to Einstein's procedure, it is possible, in principle, to measure the one-way velocity of light.

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