On the Consistency between the Assumption of a Special System of Reference and Special Relativity

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In a previous work, we have shown that the null result of the Michelson–Morley experiment in vacuum is deeply connected with the notion of time. The same is true for the postulate of constancy of the two-way speed of light in vacuum in all frames independently of the state of motion of the emitting body. The argumentation formerly given is very general and has to be true not only within Special Relativity and its "equivalence" of all inertial frames, but as well as in Lorentz-Poincaré scenario of a preferred reference frame. This paper is the second of a trilogy intending to revisit the foundations of Special Relativity, and addresses the question of the constancy of the one-way speed of light and of the differences and similarities between both scenarios. Although they manifestly differ in philosophy, it is debated why and how the assumption of a "special system of reference experimentally inaccessible" is indeed compatible with Einstein's Special Relativity, as beautifully outlined and discussed by Bell [Speakable and Unspeakable in Quantum Mechanics (Cambridge University Press, Cambridge, 1988)]. This rather trivial statement is still astonishing nowadays to a big majority of scientists. The purpose of this work is to bring such assertion into perspective, widening the somewhat narrow view of Special Relativity often presented in textbooks and scientific papers.

KEY WORDS: special relativity; synchronization; one-way speed; conventionality thesis; absolute space.

1. INTRODUCTION

In 2005, the whole world celebrated the 100th anniversary of Albert Einstein's annus mirabilis. Of course the articles Einstein published in 1905

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had a marked influence on Physics and Philosophy. But, more important, Einstein's thoughts and his works keep feeding the scientific community, promoting debates, eventually some controversy, and compelling a permanent and comprehensive discussion of the foundations of physics.

In a previous contribution,[1] we have shown that the roots of both the null result of Michelson–Morley experiment and of the postulate of the constancy of the *two-way* speed of light in vacuum in all inertial frames, independently of the state of motion of the emitting body, rest firmly on the very notion of time. In particular, we have explained that both can be obtained under three very reasonable assumptions: (i) that all good clocks can be used to measure time, independently of the periodic physical phenomena they are built upon; (ii) that time is measured in the same way in all inertial frames, i.e., if a particular clock can be used to measure time in the "rest system," a similar clock can be used to measure time in "moving" inertial frames; (iii) that a limit speed exists in the "rest system." We noted in Ref. 1 that the arguments given are valid *both* in the pre-relativistic Lorentz-Poincaré scenario of a preferred reference system and within Einstein's relativity and its "equivalence" of all inertial frames. It is now time to address the question of a possible constancy of the *one-way* speed of light, which appears to be related to differences between these two scenarios.

Our reflection is essentially motivated by Bell's analysis from Ref. 2. He has noted the following (italics added in one sentence).

> Many students never realize, it seems to me, that this primitive attitude, admitting a special system of reference which is experimentally inaccessible, is consistent.
> (...) The approach of Einstein differs from that of Lorentz in two major ways. There is a difference of philosophy, and a difference of style.
> The difference of philosophy is this. Since it is experimentally impossible to say which of two uniformly moving systems is *really* at rest, Einstein declares the notions of "really resting" and "really moving" as meaningless. For him only *relative* motion of two or more uniformly moving objects is real. Lorentz, on the other hand, preferred the view that there is indeed a state of *real* rest, defined by the "aether," even though the laws of physics conspire to prevent us identifying it experimentally. *The facts of physics do not oblige us to accept one philosophy rather than the other.* And we need not accept Lorentz's philosophy to accept a Lorentzian pedagogy. Its special merit is to drive home lessons that the laws of physics in any *one* reference frame account for all physical phenomena, including the observations of moving observers.

From our experience, this is not a question of students only, as *most scientists* never realize it either. It is striking the unease revealed by many colleagues when discussing the foundations of Special Relativity and confronted with the compatibility between Einstein's results—based on the notion of *relative* motion—and the possibility of existence of a preferred reference frame—with its associated idea of *absolute* motion.

In this journey into the foundations of Special Relativity, our aim is to use Lorentz's philosophy to explore the simple example of time dilation and to consider the constancy of the one-way speed of light, in such a way that no doubts can subsist on the formal compatibility of Lorentz and Einstein philosophies in what concerns the description of the physical phenomena. For this reason, the paper is written in a language corresponding to Lorentz's philosophy. Notice that our message is rather close to the one transmitted by Selleri.[3,4] Nevertheless, there are evident differences in the presentation, which we have tried to keep extremely simple. Moreover, the key notion of *Einstein speed* is introduced.

The structure of the article is as follows. In the next section, the Lorentz-Poincaré view is established, together with its "natural" way of clock synchronization and the corresponding laws for transformation of coordinates between inertial frames. By doing so, the Mansouri and Sexl theory,[5] which is still excluded from most textbooks, is introduced in a pedagogical and straightforward way. Time dilation is illustrated in this framework. Sections 3 and 4 introduce a formal Galileo transformation and the Lorentz transformation, respectively. The description of time dilation is made again with the help of these transformations of coordinates. In Sect. 5, the question of the constancy of the one-way speed of light is discussed, using all the previously presented coordinate transformations. As they describe one and the same reality, they are obviously all mathematically equivalent, thus emerging the compatibility between Einstein and Lorentz-Poincaré views in physical terms, although not in philosophical ones. Finally, the last section summarizes the main conclusions of this work.

It is worth to stress that all the analysis from Ref. 1 and herein developed is made in vacuum, so that the consistency between the assumption of a special system of reference and special relativity is being argued to hold only in this case. Notice that in the last few years, Consoli[6,7] and Cahill[8–10] have been systematically analyzing the available historical experimental data and the more recent and sophisticated versions of the famous experiment performed by Michelson and Morley more than 100 years ago. The experiment is usually said to have given a "null-result," as it should be according to special relativity, but this was not actually the case. It gave a small result, distant from what was expected, but not a null one. It was assumed at the time that this small result was simply within the error margin of the procedure and could be taken as zero. However, the successive repetition of the experiment by several authors, starting with Morley and Miller between 1902 and 1906, passing through the exceptional work of Miller in the 1920s[11] and continuing up to now, seems to have confirmed the original non-null result. A short discussion of this

issue can be found in Ref. 12, where an experiment capable of confirming or denying Consoli and Cahill claims was also proposed.

One interrogation imposes itself at the present stage: if the two-way speed of light in vacuum is in fact c in any inertial frame and if there is a space contraction, how is it possible that the experiments had not given a null result after all? Cahill–Kitto and Consoli–Costanzo have shown this is a consequence of the fact that light is not propagating in vacuum, but in earth's atmosphere. The main idea is that the outcome of an interferometer experiment may depend on the refraction index of the gas, a view that is supported by and consistent with at least seven experiments, as pointed out by Cahill in 2004.[10] Moreover, it is possible to remove "earth's air" to a big extent, by performing the experiments in high-vacuum chambers. In this case of light propagating in vacuum, the Michelson–Morley experiment should give a null result, although it gives a non-null result when light propagates in the air. This discussion goes far beyond the purpose of the present paper, and can be found in Refs. 6–10, 12 and 13. Nevertheless it gives, of course, an important argument in favor of Lorentz-Poincaré philosophy.

2. EXTERNAL SYNCHRONIZATION AND THE SYNCHRONIZED TRANSFORMATION

Within Lorentz-Poincaré view, the rest system is the system in which the one-way speed of light in empty space is c in any direction, independently of the velocity of the source emitting the light. This system is unique. For the point we are trying to make here, it is irrelevant if this system is experimentally inaccessible or not, as the discussion is essentially an academic discussion of principles, and not of direct practical interest. Let us assume for now we do know which is the rest system. The consequence of not knowing it does not change the conclusions of this work and is examined in Sec. 6.

The clocks from the rest system can be synchronized with the usual Einstein procedure involving light rays,[14] since the one-way speed of light is known in this system. Next, in order to perform time measurements in a moving inertial frame (a frame moving with constant speed in relation to the rest system), it is necessary to synchronize the moving clocks. This cannot be done in the way used in the rest system, since in the moving frame the one-way speed of light is not known *a priori* (recall we are using the language of Lorentz's philosophy). Nevertheless, it can easily be done with the help of the clocks at rest, because these clocks have already been synchronized. Hence, the moving clocks can be synchronized simply by
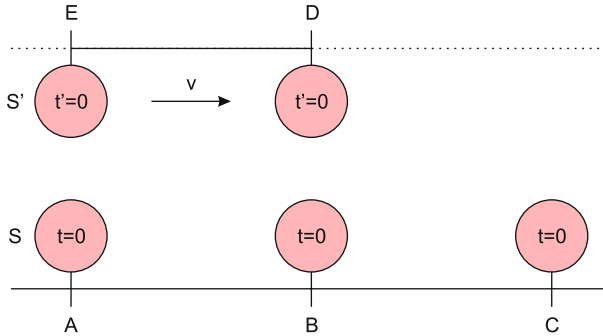
Fig. 1.   Synchronization of clocks in a moving system: the moving clocks D and E are synchronized with the help of the previously synchronized clocks at rest A and B.

adjusting them to zero whenever they fly past a clock at rest that shows zero as well. From that moment on the moving clocks remain synchronous between themselves, thus establishing the common time of the moving system. Evidently, this synchronization procedure is not the standard one. We shall not start here any discussion around the "conventionality of synchronization," which has ample literature available and is only briefly addressed bellow. A more comprehensive analysis of the subject is left for our final paper.

Let S denote the rest system and S' the moving one. For simplicity, assume the axis of both frames are aligned, and that the origin of S' moves along the x-axis of S with a certain speed v, in the positive direction. The primed and non-primed quantities correspond to measurements made with the rulers and clocks of S' and S, respectively. The synchronization procedure just delineated corresponds simply to the statement that $t = 0$ implies $t' = 0$, as it is shown in Fig. 1. Of course this synchronization method is an *external* one, as noted by Mansouri and Sexl,[5] since to synchronize the clocks from S' one has to use the clocks from S.

The phenomenon of time dilation can be deduced in the usual way, such as presented in the classic textbooks from Refs. 15 and 16, using a light clock placed in S' aligned along the y-axis. The well-known result

$$\Delta t = \gamma t', \tag{1}$$
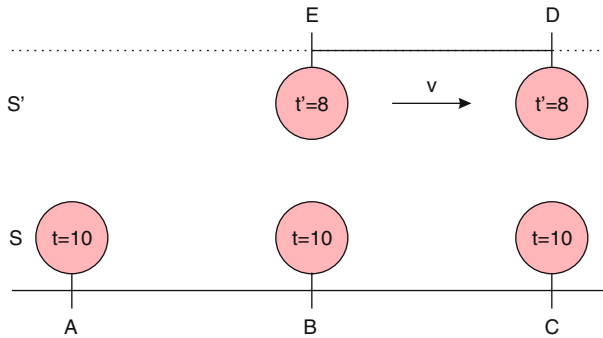
with

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}, \tag{2}$$

Fig. 2. Evolution of the situation from Fig. 1 after 10 ms. All times in the figure are expressed in ms.

expresses the fact that "moving clocks run slower." *Each* of the moving clocks experiences time dilation. Referring to Fig. 1, if $v = 0.6c$ (so that $\gamma = 1.25$) and if the distances between clocks A and B and between clocks B and C are the same, L, and equal to 1800 km, the situation depicted in Fig. 1 evolves to the one depicted in Fig. 2 at $t = 10$ ms. Always within Lorentz's philosophy, the effect is considered to be induced by absolute motion and clearly there is no reciprocity of time dilation.

The phenomenon of space contraction can be deduced as well in the usual way, using a light clock placed in S' aligned along the x-axis. The well-known result

$$L' = \gamma L, \tag{3}$$

expresses the fact that "moving rulers are shorter." Referring to Figs. 1 and 2, the distance in S' between clocks D and E is $L' = \gamma L = 1.25 \times 1800$ km $= 2250$ km. Again, the effect is considered to be induced by absolute motion and clearly there is no reciprocity of space contraction.

The transformation of coordinates between S and S' can now be readily obtained. If the origins of both frames are considered to be at clocks A and E, the position x' of clock D in S' is simply given by

$$x' = L' = \gamma L = \gamma (x - vt), \tag{4}$$

being x its position in S. Consequently, the relations between space and time coordinates providing the translation from the description in the rest

system to the one in a moving frame are just given by

$$x' = \gamma(x - vt),$$
$$t' = \frac{t}{\gamma}, \tag{5}$$

where γ is given by Eq. (2) and v is the absolute speed (i.e., the speed measured in the rest system) of the moving frame.

Expressions (5) form the *synchronized transformation* and are very adequate to analyses made within Lorentz's philosophy. They were obtained by Mansouri and Sexl[5] and have been emphasized by Selleri,[3,4] who named them as *inertial transformations*. Interestingly enough, the synchronized transformation is not symmetrical, as the inverse transformation, expressing x' and t' as functions of x and t, is given by,

$$x = \frac{1}{\gamma}(x' + \gamma^2 vt'),$$
$$t = \gamma t'. \tag{6}$$

Notice that the position of the origin of S, $x = 0$, is given in S' by $x' = -\gamma^2 vt'$. This means that S' sees S passing with speed $v' = -\gamma^2 v$, and not just $-v$ as one could think at first sight. One factor γ accounts for the fact that rulers are shorter in S', while the second γ factor comes from the fact that clocks run slower there.

It is not difficult to derive that if an object goes with absolute speed w, then its relative speed, w_v, in relation to a frame S' moving with absolute speed v, is given by

$$w_v = \gamma^2(w - v) = \frac{w - v}{1 - v^2/c^2}. \tag{7}$$

Thus, it is possible to calculate the one-way speed of light in a moving frame. If a light ray is emitted and travels in the positive direction of the x-axis, we know it propagates in the rest system with speed c, independently of the speed of the source emitting the ray. In S', the one-way speed of this light ray is given by (7) with $w = c$,

$$c_v^+ = \gamma^2(c - v). \tag{8}$$

If the light ray is emitted in the negative direction of the x-axis, $w = -c$ and its speed is given, in absolute value, by

$$c_v^- = \gamma^2(c + v). \tag{9}$$

Therefore, following Lorentz's philosophy, in the moving frame the one-way speed of light is not the same in different directions and c_v^- is always bigger than c. And yet the two-way speed of light is always c, as the reader can easily verify.

Besides absolute time dilation and absolute space contraction, the synchronized transformation exhibits as well absolute simultaneity. How can these statements be compatible with Special Relativity? The answer is given in the next two sections.

3. A FORMAL GALILEO TRANSFORMATION

Once the effects of time dilation and space contraction have been obtained, we can do something rather funny: since it is known that moving clocks run slower, it is easy to "correct" the mechanisms of these clocks, so that they do not get delayed! It is enough to tell the moving clocks D and E to mark always a factor γ in advance of what they would mark without correction.

Suppose, for simplicity, that one "tic-tac" of the clocks in S corresponds to "1 s" (in S). Since in the present example $\gamma = 1.25$, one can simply *define* one tic-tac from the clocks in S' as to be 1.25 s in S'. That being so, if t_G' denotes the "time" given by these corrected clocks—that we shall name *Galilean clocks*—then we simply have

$$t_G' = t, \tag{10}$$

exactly as in the standard Galileo transformation. With Galilean clocks, the situation represented in Figs. 1 and 2 is now depicted in Fig. 3. Galilean time *appears* to be an absolute time, since it is the same in all inertial frames.

Of course Figs. 1 and 2 show precisely the *same reality* as Fig. 3, which is simply *described* in a different way. Nothing prevents the observers in S' from describing all events using Galilean clocks. There are a couple of problems, though. The first one is that a clock working in a certain frame cannot be taken to another frame and be expected to work well. It will mark wrong Galilean times. Before it can be used it must be corrected with the appropriate γ factor, corresponding to the speed of the new frame. Only then it can be utilized as a Galilean clock. The second question is related to the *meaning* of the quantities measured with Galilean clocks. Time itself, for a start. "Time" given by Galilean clocks can be simply called "time," but of course this does not correspond to our intuitive notion of time and may originate some misunderstandings.
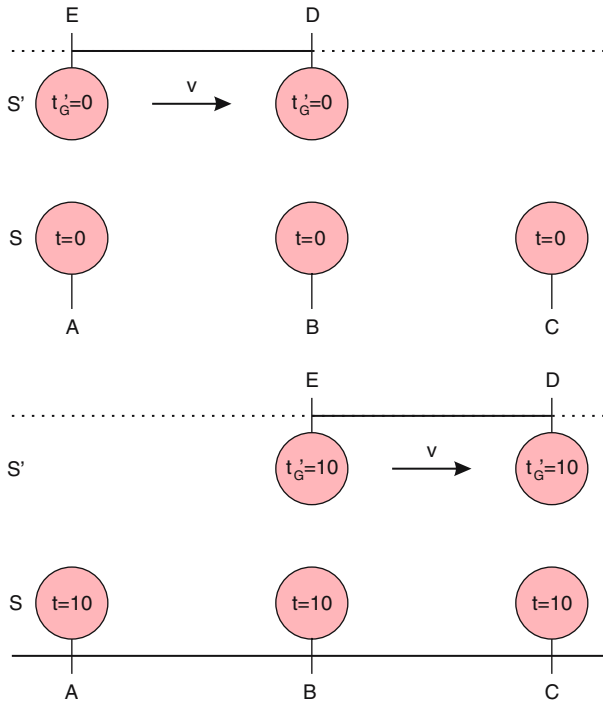
Fig. 3.   "Time dilation" with synchronized Galilean clocks. All
times expressed in "miliseconds".

What has been done with clocks and time intervals can be done with rulers and lengths. We know that moving rulers are shorter. It is thus possible to correct the moving rulers so that they do not give shorter lengths. It is enough to tell the moving rulers to mark always a factor γ less than what they would mark without correction. If a working ruler is taken from S to S', the mark for "1 m" should be replaced by $1/\gamma$ m. That being so, if L_G' denotes the "length" given by these corrected rulers—that we shall name *Galilean rulers*—then we simply have

$$L_G' = L, \tag{11}$$

exactly as in the standard Galileo transformation. Once more, nothing prevents the observers in S' from describing all events using Galilean rulers. This does not change the reality of what is being observed.

As with Galilean clocks, Galilean rulers have also to be corrected by the appropriated factors if they are taken from one inertial frame

to another before they can be used. Moreover, the generalization of the results from a 1+1- to a 3+1-dimensional case requires some care, as a correction of the reference unit lengths under rotation of the measuring rods in the same frame is necessary. The problem is conceptually simple, but can be extremely complicated from a practical point of view, in particular for the study of rotating systems. As a matter of fact, for those systems one could not use rigid rods attached to the rotating frame as direct measuring devices, in the sense that the marks for "1 m" in the rods would very rarely correspond to the defined Galilean meter.

It is still possible to *define* a *Galileo speed*, v_G, as the "speed" measured with Galilean clocks and Galilean rulers,

$$v_G = \frac{\Delta x_G}{\Delta t_G}. \tag{12}$$

From the expressions given in Sec. 2, it is easy to show that the "Galileo speed" of an object whose absolute speed is w, measured in an inertial frame S' going with absolute speed v, is just given by

$$v_G = w - v \tag{13}$$

as in Galileo transformation. The "Galileo speeds" of light are therefore

$$c_G^+ = c - v \tag{14}$$

and

$$c_G^- = c + v \tag{15}$$

for light rays propagating in the direction of the movement of S' and in the opposing direction, respectively. With Galilean clocks and Galilean rulers, the transformation of coordinates between S and S' reduces formally to the Galileo transformation,

$$\begin{aligned} x_G' &= x - vt, \\ t_G' &= t, \end{aligned} \tag{16}$$

where v is the absolute speed of S'.

It may be somehow surprising that this Galileo transformation is *mathematically equivalent* to the synchronized transformation (5). Hence, in some sense it does not matter which of the transformations is used to *describe* the same reality. If we know the Galilean coordinates of a certain

event, then we can immediately know its synchronized coordinates, and vice versa, as long as the absolute speed of the moving frame is known. The important question is not to assign an erroneous meaning to the measurements that are being made.

Two peculiarities of the Galileo transformation are still very interesting to note. The first one is that, contrary to the synchronized transformation, Galileo transformation is *symmetrical*. As a matter of fact, the quantities in the rest system can be expressed as a function of the Galilean ones by inverting (16), resulting

$$x = x_G' + vt_G',$$
$$t = t_G'. \tag{17}$$

This set of equations is the same as (16), simply interchanging the roles of the quantities in both frames and replacing v by $-v$. The position of the origin of S, $x = 0$, is given in S' by $x_G' = -vt_G'$, so that S' sees S passing with *Galileo speed* $-v$. In what concerns "Galileo speeds," there is no difference in the ways "S sees S'" and "S' sees S." The second observation is that if a second inertial frame S'' goes with absolute speed w, then the transformation of Galilean coordinates between S' and S'' *takes the same form* as between the rest system and a moving inertial frame,

$$x_G' = x_G'' + v_G t_G'',$$
$$t_G' = t_G'', \tag{18}$$

where $v_G = w - v$ being the *relative* Galileo velocity between both moving frames. These two facts could eventually suggest all moving inertial frames are equivalent to the rest system and only relative motion is of importance. If that would be the case, the rest system would not be a privileged frame after all. But this "equivalence" is purely formal. It emerges as a consequence of using Galilean clocks and rulers.

4. THE LORENTZ TRANSFORMATION

According to Lorentz's philosophy, all the remarks made in the previous section for the formal Galileo transformation can be made for the Lorentz transformation. The latter provides only another way to relate the space and time coordinates of the rest system S to the ones of a moving inertial frame S', but does not have any fundamental privileged role. Once the clocks in both frames have been synchronized as described in

Sec. 2, the Lorentz transformation can be easily obtained by "correcting" in a particular way the time readings of the moving clocks.

In the previous section, Galileo transformation was attained by defining shorter seconds for the moving clocks. Now the rhythm of the clocks will not be changed, only the clocks will start from a different condition. Instead of adjusting the moving clocks to mark $t' = 0$ when $t = 0$ (see Fig. 1), we shall do that to one clock of S' only, which identifies the position $x' = 0$. The remaining moving clocks will be delayed by a factor that is proportional to their distance x' to the reference position $x' = 0$, which is given by $\frac{v}{c^2}x'$ (if x' is negative, this corresponds actually to advancing the clock). We shall denote the clocks altered in this way by *Lorentzian clocks*, and their time readings, t_L', by Lorentzian times. We thus have

$$t_L' = t' - \frac{v}{c^2}x'. \tag{19}$$

Why, following Lorentz's philosophy, should someone be interested in "desynchronizing" clocks according to (19) is related to the problem of performing an *internal* "synchronization" of the moving clocks. This will be fully clarified in the last paper of this trilogy. Anyway, as it is well known, the resulting Lorentz transformation (see below) is the natural transformation of coordinates used assuming an equivalence between all inertial frames. Again we shall drop the "" signs in the word "synchronization," which from now on denotes the external synchronization delineated in Sec. 2.

Referring to Fig. 1, suppose clock E defines the position $x' = 0$. Then, clock E marks $t' = 0$ when $t = 0$. Since clock D is located at $x' = 2250$ km and $v = 0.6c$, it must be delayed $(v/c^2)x' = (0.6/c) \times 2250 \times 10^3 \simeq 0.0045$ s $= 4.5$ ms. Therefore, at $t = 0$ clock D reads $t_L' = -4.5$ ms. Notice that the moving clocks D and E are exactly equal to clocks at rest A, B, and C, only they are not synchronized as to mark all $t = t_L' = 0$ at some arbitrary instant. The situation is shown in the upper part of Fig. 4. Since the moving clocks are precisely the same as in Figs. 1 and 2, they exhibit strictly the same time dilation as shown in those figures. Their *rhythms* are affected by time dilation exactly as before. The only difference is that now their starting condition was set in a different way. Hence, when 10 ms have passed in S, only 8 ms elapsed in S'. More precisely, at $t = 10$ ms clocks D and E mark $t_L' = -4.5 + 8 = 3.5$ and $t_L' = 0 + 8 = 8$ ms, respectively, as represented in Fig. 4.

With Lorentzian times, the expressions for transformation of coordinates between the rest system and the moving frame are easily found by substituting t' and x' given by the synchronized transformation (5) into
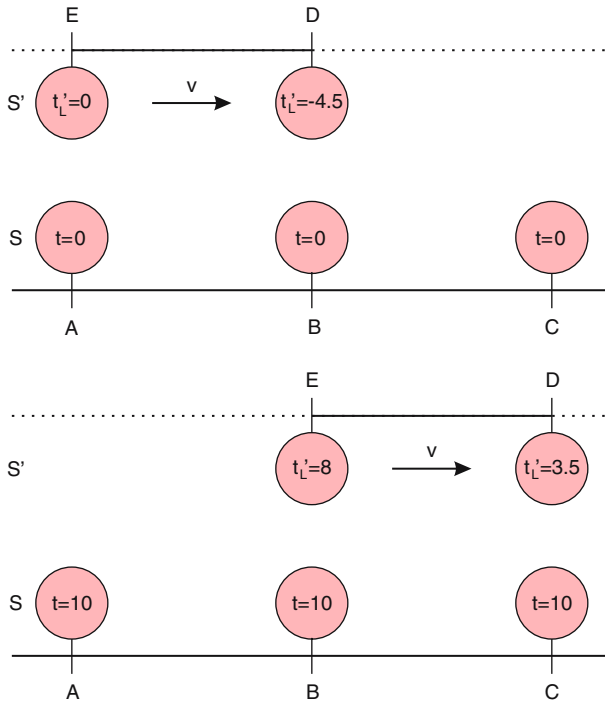
Fig. 4.   Time dilation with de-synchronized and equal clocks. All times expressed in ms.

(19). The *Lorentz transformation* is finally obtained,

$$x' = \gamma(x - vt),$$
$$t_{\mathrm{L}}' = \gamma\left(t - \frac{v}{c^2}x\right) \tag{20}$$

with γ given by (2) and v denoting the absolute speed of S'.

As with "Galileo speed" (12), it is possible to *define* an *Einstein speed* (this speed could be named "Lorentz speed" as well; however, we prefer to call it Einstein speed, since it was defined and used by Einstein in his theory of relativity), v_{E}, as the "speed" measured with Lorentzian clocks (and ordinary rulers),

$$v_{\mathrm{E}} = \frac{\Delta x}{\Delta t_{\mathrm{L}}}. \tag{21}$$

The time interval is calculated as the difference of the "time reading of a clock located at arrival position" with the "time reading of a clock located

at departure position." Since Lorentzian clocks are de-synchronized, "Einstein speeds" are of course different from the "true speeds" (which can be calculated by $v = \Delta x/\Delta t$ when the time intervals and distances are measured with synchronized clocks and ordinary rulers, respectively). Nevertheless, two-way speeds of any object are the same with both types of clocks, since they are measured with one clock only and, that being so, any de-synchronization of distant clocks has no effect in the measurements.

Finally, the "Einstein speed" v_E, measured in a frame moving with absolute speed v, of an object which has absolute speed w, is

$$v_E = \frac{w_v}{1 - vw_v/c^2} = \frac{w - v}{1 - vw/c^2}. \tag{22}$$

The "Einstein speed" of light, c_E, exhibits a very interesting property. As a matter of fact, since the absolute speed of light is always c, c_E is obtained directly from (22) with $w = c$:

$$c_E = \frac{c - v}{1 - v/c} = c. \tag{23}$$

Therefore, *the "Einstein speed" of light is always c in any moving inertial frame, independently of the speed of the moving frame.*

Notice that the remarks made about Galilean times, lengths, and speeds can be repeated here. Of course Figs. 1–4, show precisely the *same reality*, which is simply *described* in a different way. Even assuming Lorentz's philosophy, nothing prevents the observers in S' from describing all events using Lorentzian clocks. But this has to be done with care. For instance, two clocks placed in distinct locations working well in a certain frame cannot be "transferred" to another frame and be expected to work well. They will mark wrong Lorentzian times. Before they can be used they must be corrected with the appropriate de-synchronization factors. Only then they can be utilized as Lorentzian clocks.

It may be somewhat surprising that the Lorentz transformation (with its associated "relativity of simultaneity," "relativity of time dilation," and "relativity of space contraction"!) is *mathematically equivalent* to the synchronized transformation (5). That being so, *any phenomenon described by the Lorentz transformation can be described as well by the synchronized transformation*, which is the natural transformation of coordinates in the Lorentz-Poincaré scenario of a preferred frame. As a matter of fact, if we know the Lorentzian coordinates of a certain event, then we can immediately know its synchronized coordinates, and vice versa, as long as the

absolute speed of the moving frame is known. Reality is obviously independent of the choice of coordinates made to describe it. The important question is not to assign an erroneous meaning to the measurements that are being made.

As with the formal Galileo transformation, the Lorentz transformation is symmetrical (in what concerns "Einstein speeds," there is no difference in the ways "S sees S'" and "S' sees S") and the transformation of coordinates between two moving inertial frames takes the same form as between the rest system and a moving inertial frame (with v_E in the place of v). But in Lorentz's philosophy this equivalence is purely formal. It simply emerges as a consequence of using Lorentzian clocks.

5. THE ONE-WAY SPEED OF LIGHT

The discussions about the "constancy" of the one-way speed of light in all frames can now be easily understood. Not only it is necessary to be careful with what is meant by "constancy" (see Ref. 1), but also with what is meant by "speed"! This should be already clear and can be illustrated without effort with a simple example.

Suppose, that the moving frame S' is equipped with all three types of clocks previously introduced (synchronized, Galilean and Lorentzian), and that at $t = 0$ a light ray is emitted from point E to point D, as shown in Fig. 5. At what instant does the light ray reach D? In the "rest system," S, light propagates with speed c, independently of the velocity of the source emitting the light. Since clock D advances with speed v, the relative speed (in S) of light and the clocks in D is $c - v$, so that light takes $t = L/(c - v) \simeq 1800 \times 10^3/(0.4 \times 3 \times 10^8) = 0.015$ s. Therefore, when the light ray reaches D, the synchronized clocks in S mark 15 ms. During this time interval, clocks at D have advanced a distance $vt \simeq (0.6 \times 3 \times 10^8) \times (15 \times 10^{-3}) = 2.7 \times 10^6$ m, i.e., one and half times the distance between clocks B and C. It is still desirable to know which time readings the moving clocks show. The synchronized clocks are affected by time dilation, hence marking $t' = t/\gamma = 15/1.25 = 12$ ms. Galilean clocks have been corrected for the time dilation factor, and simply mark the same time as the rest clocks, $t'_G = 15$ ms. Finally, each of the Lorentzian clocks has advanced the same 12 ms as the synchronized clocks. That being so, Lorentzian clocks E and D mark $0 + 12 = 12$ and $-4.5 + 12 = 7.5$ ms, respectively. The situation corresponding to the arrival of the light ray at D is represented in Fig. 6.

Now, what is left is to check the "speeds" of light measured with the different sets of clocks, according to the definition of speed as ratio
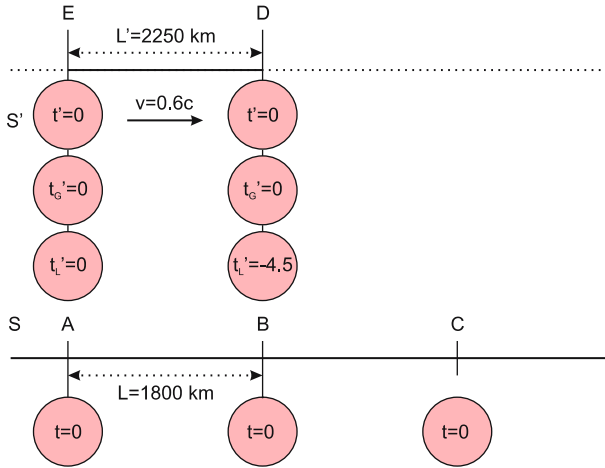
Fig. 5.   Speed, "Galileo speed" and "Einstein speed." A light ray
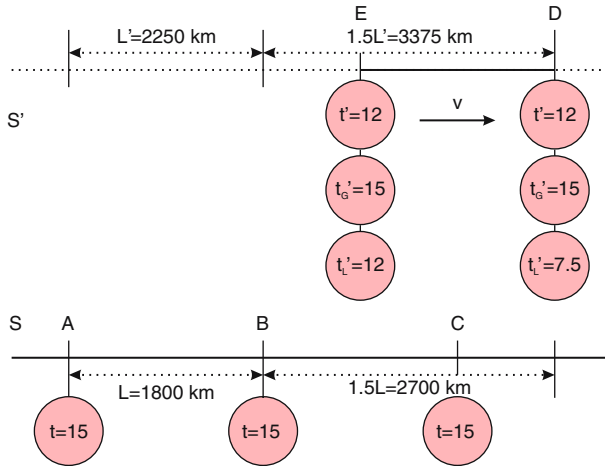departs from point E toward D at $t = 0$...

Fig. 6.   ... and arrives at point D at $t = 15\,\text{ms}$. All times in the
figure are expressed in milliseconds.

between the "length of the trip" with difference of the "time reading of a
clock located at arrival position" with the "time reading of a clock located
at departure position". In S, the speed of light is of course c,

$$v_S = \frac{(1800 + 2700)\,\text{km}}{(15 - 0)\,\text{ms}} = 3 \times 10^8\,\text{m/s} = c. \qquad (24)$$

In S' the speed of light should be given by Eq. (8), $\gamma_v{}^2(c - v) = 1.25^2 \times (0.4c) = 0.625c \simeq 1.875 \times 10^8$ m/s. Do the synchronized clocks from Figs. 5 and 6 provide this value? Indeed, since the distance light travels in S' is just $L' = 2250$ km,

$$v_{S'} = \frac{2250\,\text{km}}{(12 - 0)\,\text{ms}} = 1.875 \times 10^8\,\text{m/s}. \tag{25}$$

With Galilean clocks and rulers, the "Galileo speed" of light is given by (14), $v_G = c - v = 0.4c \simeq 1.2 \times 10^8$ m/s. Is that really so? Since Galilean rulers are corrected for space contraction, $L_G{}' = L = 1800$ km and the "Galileo speed" calculated from Figs. 5 and 6 is in fact

$$v_G = \frac{1800\,\text{km}}{(15 - 0)\,\text{ms}} = 1.2 \times 10^8\,\text{m/s}. \tag{26}$$

Finally, "Einstein speed" of light is obtained from the two figures as

$$v_E = \frac{2250\,\text{km}}{(7.5 - 0)\,\text{ms}} = 3 \times 10^8\,\text{m/s} \equiv c \tag{27}$$

in accordance with the result (23). Notice that clock D is showing only 7.5 ms at the arrival of the light signal, but it was clock E (and not D) that was marking $t_L{}' = 0$ at the departure of the signal. Once more, it is meriting to emphasize that there is one and the same reality—in this example a light ray emitted from point E to point D—that is, simply being described in three different ways. This reality is of course independent from the chosen description: they are all mathematically equivalent and it is easy to pass from one description to another.

What this example teaches us is the following: first, that the constancy of the one-way speed of light is a trivial statement regarding the "Einstein speed" of light; and second, that such constancy is fully compatible with a non-constant one-way speed of light as measured with the synchronized clocks. The Lorentz and Einstein philosophies correspond to assigning the word "time" to the time coordinates given by the synchronized transformation and by the Lorentz transformation, respectively. The philosophies are different, but they are fully compatible in physical terms.

6. SUMMARY AND CONCLUSION

The compatibility between Special Relativity and Lorentz-Poincaré view of a preferred reference system experimentally inaccessible was shown

to hold in a very simple and direct way, and was exemplified with the case of time dilation. The consistency of both scenarios is thoroughly discussed in Ref. 13, where many other classic examples are illustrated, such as the "reciprocity" of time dilation and space contraction, the "relativity of simultaneity," the twin paradox, the problem of Bell's accelerating spaceships, the propagation of spherical electromagnetic waves and the electric field of a moving point charge.

The key point is that reality can be described in many different ways, for instance using "synchronized," "Galilean" or "Lorentzian" clocks, which are all mathematically equivalent. However, a change in the *description* does not change reality itself. The question of the "constancy" of the one-way "speed" of light is essentially an issue of *language*, related to which description is being used. Therefore, when presenting or discussing Special Relativity we must keep in mind the precise meaning in which words like "speed" and "simultaneity" are used. Notice that this remark goes deeper than the *conventionalist* thesis and a vision of physics based on *operationalism*. Together with a discussion of the Principle of Relativity, these matters will be the subject of our third and final paper on the foundations of Special Relativity.

The (eventual) impossibility of detecting experimentally the "rest system" does not change anything in Lorentz's philosophy. Within its framework, one would simply have to admit he does not know the "absolute speed" of an object, but this does not promote the "Einstein speed" to the status of "true speed." They remain different notions. Consequently, the scenario of a preferred frame keeps being consistent even if this frame cannot be identified. Although, of course, its usefulness can then be questioned.

Besides the works by Selleri,[3,4] there is another very nice article with a message relatively similar to the one conveyed here, published by Leubner *et al.*[17] After developing a non-standard synchronization, which they named "everyday synchronization" (and actually corresponds to the synchronized transformation for the particular case $v = -c$), they conclude:

> After these educational benefits of studying the set of standard 'relativistic effects' also in everyday coordinates, we are of course happy to drop again 'everyday' synchronization before proceeding to less elementary aspects of relativistic physics. For these aspects, we certainly prefer the more symmetric coordinate representations of expressions resulting from Einstein synchronization, but on purely practical grounds, and not on philosophical ones.

We subscribe both Bell's and Leubner's ideas, and hope in the near future physics textbooks and articles will regularly include an analysis of Lorentz's philosophy and of its consistency, assuming without any prejudice that "the facts of physics do not oblige us to accept one

philosophy rather than the other." Regardless of the philosophy adopted, such approach has various pedagogical advantages. Eventually, practical and even philosophical arguments can be invoked in favor of one philosophy. But, for strong and elegant they may be, they remain practical and philosophical ones.

Our own view is that the standard interpretation of special relativity corresponds to a minimalist operational procedure to study relative motion without the knowledge of which is the rest system. Nonetheless, it can easily be explained and interpreted, as a special case, within a theory of absolute motion, as outlined here. Thus, one should not speak about "two philosophies," as they are different aspects of one and the same theory. This latter point was also raised by Michael Duffy.[18] To deepen such considerations goes far beyond the scope of the present paper, and is left for another opportunity.

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