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On the Experimental Determination of The One-Way Speed of Light

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Abstract
In this paper it is considered the physical meaning of the one-way speed of light. Usually in the standard Special Relativity what is considered is the Einstein one-way speed of light that has been introduced by Einstein in the 1905 article by definition. In the standard interpretation the one-way speed of light it is not considered since the Einstein speed of light is considered to be the speed of light. However, in our previous work we have shown that this is a terminological confusion. Now we explain why this is so with a very simple example using two methods of synchronization, with rods and with light signalling, that shows the physical meaning of absolute simultaneity and also the physical meaning of Einstein simultaneity in connection with the two concepts "speed of light". As a result of this analysis an experimental method for the determination of the one-way speed of light emerge.

1. Introduction

In our previous works a broad approach of Special Theory of Relativity (SR) has been formulated [1-13]. The implications of this approach in the interpretation and experimental determination of the one-way light speed will be discussed in the present paper. In Special Relativity the problem of the physical meaning and the experimental determination of the one-way speed of light has been debated since the emergence of the theory when Maxwell discovered the wave equation in his equations of the Electromagnetic Field. The similitude of the value of the speed of propagation of the waves obtained theoretically with the experimental value early obtained by Römer, Bradley, Fizeau, Foucault naturally convinced Maxwell that the speed of light must be related with the theoretically description he obtained. This is the origin of the idea of the independence of the speed of light of the speed of the source sometimes misinterpreted as implying that the speed of light is the same in every frame.

For sure one of the postulates of SR based on experience and theoretical reasoning is that the speed of light is isotropic in vacuum independently of the speed of the source in one frame that we previously designate by Einstein Frame (EF) [5]. Another postulate of special relativity based on the experience of Michelson-Morley-Miller is that the two-way speed of light in every frame is the same in every direction in vacuum with the value c obtained experimentally (although the experiment has been originally performed in air and does not give a null result, but it has been assumed initially that air does not interfere (see Irvine experiment)) [14]. Therefore, the value of the one-way speed of light in EF is also c. From these postulates without invoking the constancy of the one-way speed of light.

Special Relativity has been constructed initially by Fitzgerald, Larmor, Poincaré and Lorentz with a constructive theory based on experience interpreted with the assumption of a privileged frame where the one-way speed of light has the value c [4-11,14,15]. In our previous works based on these postulates we conciliate the analysis of Einstein based on a Principle theory with the Lorentz-Poincaré approach [1-13,16]. Recently several works point out the importance of this discussion about the foundations of Special Relativity [11-14,17-52].

In section I we consider several configurations of three rods designated by S, S´ and S´´ moving relatively to each other longitudinally.

In Ia we consider the rod S' with length l_1 moving with speed v_1 in relation to EF where is located rod S with proper length l_0. The rods are moving longitudinally in the same direction defined by the rods. Since the rod S´ is Lorentz contracted (S is the EF, see IB.) we know l1 when the extremities of the rods pass by each other simultaneously [1]. This is the most primitive notion of simultaneity that Special relativity does not rule out [1-3]. Therefore, we can calculate the one-way speed of light in S´ confirming that it is not c. Of course, Einstein one-way speed of light is c by definition since the Lorentz clock at the extremity of the rod is desynchronized of the clock synchronized, the clock has been desynchronized conveniently with the condition that light arrives to the extremity of the rod where a clock is waiting marking l_1/c. Therefore, both values of the "speed of light" are true and must be observed if not the theory collapse.

In Ib we consider another rod S´´ moving with speed v_2 in relation to EF (S). We obtain the length l_2 that satisfies the condition of simultaneity with bar S with length l0 and the relation between l2 and l_1. We previously discovered that this relation is no more the Lorentz-Fitzgerald contraction although a relation formally identical exist and originates a novel spatial gap of "synchronizations" as previously pointed out by Mansouri and Sexl with a similar but not completely equivalent approach [1-3,9,11,27].

In section II we conceive a method to determinate the one-way speed of light using rods S´ and S´´ defined at IB without previous knowledge of EF. This method is based on the results obtained in section I through the discovered of the synchronization as a limit for the preservation of the condition two way-speed of light with value c for a given v_1.

2. One-Way Speed of Light

2.1. One of the Rods is at Rest in the EF

Consider a rod S' with proper length l1 moving with speed v_1 in relation to EF where is located another bar S with proper length l0 (Fig.1).

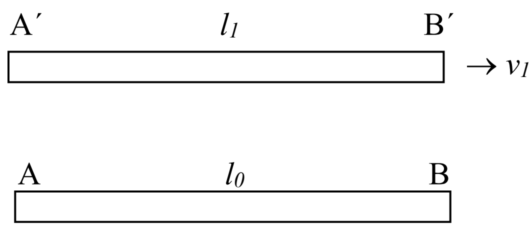

Figure 1: Rod S´ is Moving with Speed v_1 In Relation to Rod S at rest in EF. The extremities of the rods coincide simultaneously And, therefore, can synchronize clocks at A, A´ and B, B´

The rod S´ is moving with speed v_1. Since the bar S´ is Lorentz contracted (since S is at rest in the EF) we know l_1 when the extremities of the rods pass by each other simultaneously, when A´ coincide with A and B´ with B as represented in the figure 1. This is the most primitive notion of simultaneity that Special Relativity does not ruled out. However standard interpretation induce to think that it is impossible to synchronize clocks because it is not possible to send a signal from A´ to B´ with infinite speed and since the one-way speed of light was not known in frame S´ Einstein postulate that the one-way light is *c*. In this context this affirmation must be ruled out.

Indeed, we can calculate the one-way speed of light at S´.

We have

$$l_1 = \frac{l_0}{\sqrt{1-\frac{v_1^2}{c^2}}} \qquad (1)$$

From the origin of S´ (A´) it is emitted a ray of light in the direction of the extremity B´ of S' when A´ pass by A. This ray of light moves in the EF with speed c. Therefore, we can calculate the coordinate x where the ray of light intercepts the extremity B´

$$x = l_0 + v_1 t \qquad (2)$$

$$x = ct \qquad (3)$$

$$t = \frac{l_0}{c-v_1} \qquad (4)$$

Since S´ is moving with speed v_1 in relation to EF we have the Larmor time dilation [15].

$$t' = t\sqrt{\left(1 - \frac{{v_1}^2}{c^2}\right)} \qquad (5)$$

From (4) and (5)

$$t' = \frac{l_0}{c - v_1}\sqrt{\left(1 - \frac{{v_1}^2}{c^2}\right)} \qquad (6)$$

Therefore, we obtain the one-way speed of light in S´

$$c_+ = \frac{l_0}{\sqrt{\left(1 - \frac{v_1^2}{c^2}\right)}} \times \frac{c - v_1}{l_0} \times \frac{1}{\sqrt{\left(1 - \frac{v_1^2}{c^2}\right)}} \qquad (7)$$

$$c_+ = \frac{c - v_1}{1 - \frac{v_1^2}{c^2}} = \frac{c}{1 + \frac{v_1}{c}} \qquad (8)$$

As expected, the one-way speed of light is not c. Only in a first order approximation is c and we obtain the Galileo approximation ($c - v_1$) for a second order approximation.

Consider now Einstein's one-way speed of light. By definition Einstein has defined "Einstein synchronization" by a clock at x´ (the generic coordinate of B´) marking x'/c and awaiting the arrival of the ray of light emitted at $x' = 0$, $t_L' = 0$. This time is the Lorentzian time t_L' and of course $x'/t_L' = c$, it cannot be otherwise [1-3]. Since $t' = x'/c + = (x'/c)\,(1 + v_1/c)$ we have $t_L' = t' - (v_1/c_2)\, x'$. Since the clocks marking t' are synchronized the clocks marking t_L' are desynchronized. Note that the one-way speed of light that preserve the value c for the two way of light is the harmonic mean of c´+ and c´ [26, 27, 30-32, 52]. given by

$$c'_{\pm} = \frac{c}{1 \pm \alpha\frac{v_1}{c}} \qquad (9)$$

with $\alpha \in [0, 1]$.
Lorentz was right, t_L' is the local time and SR can be formulated with the synchronized time [9,11,27].

2.2. Two Rods Moving in Relation To EF

We introduce now a third rod S´´ with length l_2.

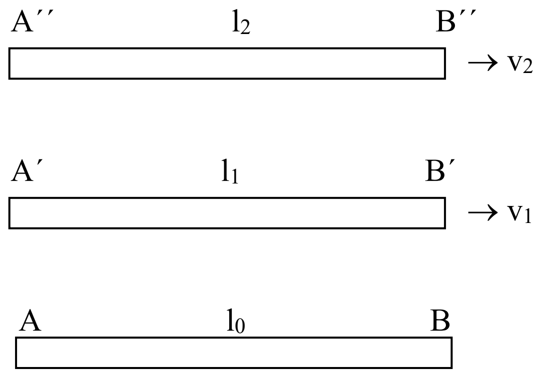

Figure 2: A Third Rod S´´ Is Moving with Speed v_2 In Relation To EF

The rod S´´ is moving with speed v_2 in relation to EF. The rod has proper length l_2
l^0

$$l_2 = \frac{l_0}{\sqrt{(1-\frac{v_2^2}{c^2})}} \qquad (10)$$

From (1) we have

$$l_2 = l_1 \frac{\sqrt{(1-\frac{v_1^2}{c^2})}}{\sqrt{(1-\frac{v_2^2}{c^2})}} \qquad (11)$$

It easy to obtain from (11)

$$l_2 = \frac{l_1}{\sqrt{\left(1-\frac{v'^2_E}{c^2}\right)}}\left(1 + \frac{v_1 v'_E}{c^2}\right) \qquad (12)$$

since Einstein's speed of rod S´´ in relation to S´ is given by [9, 11]

$$v'_E = \frac{v_2 - v_1}{1-\frac{v_1 v_2}{c^2}} \qquad (13)$$

The correct evaluation of the distance l_2 is crucial as we pointed out in several previous works [1,5,12,13]. and used to solve the Twin Paradox in a one-way trip analysing the approach of Φ. Grϕn [9,13,28].

We see from (12) that we can consider two lengths

$$l_2 = \frac{l_1}{\sqrt{\left(1-\frac{v'^2_E}{c^2}\right)}} \qquad (14)$$

and

$$l_2 = \frac{l_1}{\sqrt{\left(1-\frac{v'^2_E}{c^2}\right)}}\left(1 + \frac{v_1 v'_E}{c^2}\right) \qquad (15)$$

When $v_1 = 0$ S´ is at rest in EF we have only for 12 the value given by (14). However, there are several values of l_2, a gap, between the values given by (14) and (15).

We can define these several values introducing α

$$l_2 = \frac{l_1}{\sqrt{\left(1 - \frac{v'^2_E}{c^2}\right)}} \left(1 + \alpha \frac{v_1 \, v'_E}{c^2}\right) \qquad (16)$$

with $\alpha \in [0, 1]$ and in the following figure 3 l_2 for $\alpha = 0$ correspond to Einstein synchronization.

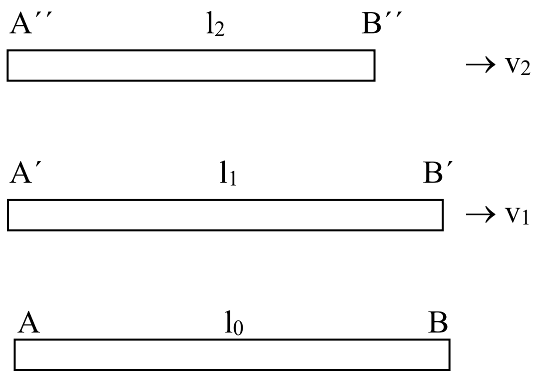

Figure 3: S´´ With the Proper Length L_2 (A $=0$) That "Synchronize" A Lorentzian Clock Located At B´ Marking Zero When B´´ Pass By B´

Indeed when $t_L{}' = 0$ at B´ (l2 is given by (14)) B´´ coincide with B´ [29]. Since we know $v_E{}'$ we know l_2 for $\alpha = 0$. This eventually can be experimentally tested with the other method of "synchronization" by light signalling. When A´´ pass by A´ light is emitted from A´ to B´. Since B´ has been previously "synchronized" ($t_L{}' = 0$ at B´) by the passing of B´´ if the theory is correct the arrival of light at B´ is $t_L{}' = x'/c$. This method of synchronization corresponds to an external "synchronization" [9,11,18,19,27-32]. Rod S´´ establish the connection with the EF, rod S, the "external synchronization" [27].

3. A Method to Determinate Experimentally the One-Way Speed of Light

The crucial matter is what is revealed by Fig. 4

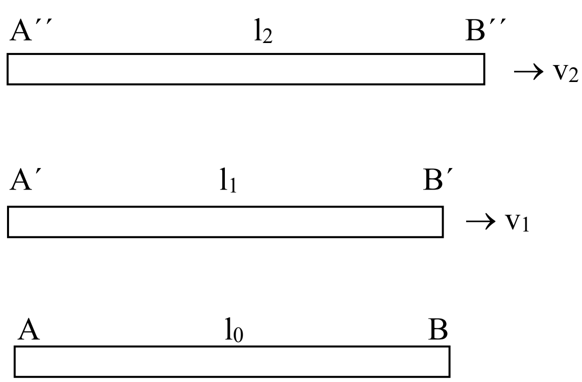

Figure 4: Bar s´´ has proper length that exceeds the range of "synchronizations"

From the previous analysis corresponding to Einstein synchronization but now by rods (figure 3) we can increment the length l2 (for several values of $\alpha > 0$) but it has no meaning $\alpha > 1$ (figure 4). For these values the extremity B´´ pass by B´ previously to the passing of A´´ to A´. This violates the principle of causality corresponding to a speed of signalling "superior to infinity" that has no meaning (Fig.

4). Therefore, we can conceive the tentative determination of the condition $\alpha = 1$ and corresponding value of v_1 that satisfies the value c for the two-way of light for a given v_1. We can begin incrementing the length of rod S´´ from the length given by (14).

The clock at B´ is set to zero and begin working when B´´ pass by B´. When A´ pass by A´´ light is emitted to B´ that measure the arrival of light with the clock previously "synchronized". Similarly, when B´ pass by B´´ light is emitted to A´ that measure the arrival of light with the clock A´ previously "synchronized". When this measurements with the clocks located at A´ and B´ does not satisfy the c condition for the two-way speed of light for a given v_1 we obtain synchronization with the corresponding measurement of the one-way speed of light. Indeed when the length of rod S´´ exceed the gap if light emitted from B´ (when B´´ pass by B´) arrive at A´ when the clock at A´ is not yet working because A´´ has not arrived yet at A´(see fig 4.) we can detect this condition at B´. The length of rod S´´ exceed the length given by (12) the limit of the gap, $\alpha = 1$. This excess of length d´´ can be quantified. The speed of light from B´ to A´ is given from (9)

$$c'_{-} = \frac{c}{1-\frac{v_1}{c}} \qquad (17)$$

Therefore, the travel time for light (B´A´) is given by

$$\frac{l_1}{c}\left(1-\frac{v_1}{c}\right) \qquad (18)$$

Since any point of S´´ has the same speed v' through S´ the distance d´ in S´ that correspond to d´´ is

$$d' = v'\frac{l_1}{c}\left(1-\frac{v_1}{c}\right) = \frac{v'_E}{1+\frac{v_1 v'_E}{c^2}}\frac{l_1}{c}\left(1-\frac{v_1}{c}\right) \qquad (19)$$

where the speed $v'$is given by [9, 11, 13]

$$v' = \frac{v_2 - v_1}{1-\frac{v_1^2}{c^2}} = \frac{v'_E}{1+\frac{v_1 v'_E}{c^2}} \qquad (20)$$

Since

$$\frac{d''}{d'} = \frac{l_2(\alpha=1)}{l_1} = \frac{1+\frac{v_1 v'_E}{c^2}}{\sqrt{1-\frac{v'^2_E}{c^2}}} \qquad (21)$$

$$d'' = \frac{l_1}{\sqrt{1-\frac{v'^2_E}{c^2}}}\frac{v'_E}{c}\left(1-\frac{v_1}{c}\right) = \frac{l_1}{\sqrt{1-\frac{v'^2_E}{c^2}}}\frac{v'_E}{c} - \frac{l_1}{\sqrt{1-\frac{v'^2_E}{c^2}}}\frac{v_1 v'_E}{c^2} \qquad (22)$$

Therefore $d'' \to 0$ when $v'_E \to 0$. Note that the gap (inexistent when $v_1 = 0$)

$$\frac{l_1}{\sqrt{1-\frac{v'^2_E}{c^2}}}\frac{v_1 v'_E}{c^2} \qquad (23)$$

tend to zero when v_E' tend to zero (however, the time for the trip of B´´ in S´ correspondent to the Lorentz synchronization is only dependent of v_1, $l_1\frac{v_1}{c^2}$ (see fig. 3) as expected). With this novel method of synchronization emerge the physical meaning of the two-way speed of light measured with the harmonic mean of the "speeds" for a given v_1 (eq. (9)) and of course this does not contradict that the two-way speed of light is c measured with one clock in a two-way trip after reflection that is completely independent of the "synchronizations" and independent of v_1 [26,50].

Another way to check the theory is considering $v_2 = -v_1$. Indeed when $v_2 = -v_1$ equations (11), or (12) and (13), gives synchronization with $l_2 = l_1$ when the speeds of light are the same in both frames, only dependent of v_1.

This novel method based on the existence of the spatial gap reveals why standard special relativity is unable to conceive the determination of the one-way speed of light since standard interpretation only consider $v_1 = 0$ and, therefore, Special Relativity is undetermined [9,11]. It is crucial to solve experimentally this indeterminacy.

"Our inability to detect absolute motion is a result of experiment and not a result of plain thought (...). There is a philosophy which says that one cannot detect any motion except by looking outside. It is simply not true in physics. True, one cannot perceive a uniform motion in a straight line, but if the whole room were rotating, we would certainly know it (...). It is only uniform velocity that cannot be detected without looking outside.

Uniform rotation about a fixed axis can be" (Feynman quotation [9]). The problem is what is "looking outside" as our and other analysis reveal in the context of the meaning of "The Principle of Relativity" [4,5,7,9,11-13,19,27,33-36,44-52].

4. Conclusion

It is our firm belief that physics should assume itself as the heir of natural philosophy. And thus question, with no fear nor prejudice, the postulates or hypothesis at the origin of each theory. Only in this way is it possible to claim that to understand a physical theory goes much beyond the simple knowledge of how to perform the calculations. Unfortunately, special relativity is presented in most textbooks by passing too swiftly over the discussion of its postulates [1-52].

In section 2 we consider several configurations of three rods designated by S, S´ and S´´ moving relatively to each other longitudinally. The idea is that rods moving in relation to each other can reveal the movement in relation to the frame where the one-way speed of light is isotropic with value c, the frame that we designate by Einstein Frame (EF) because the movement of the rods in relation to EF can affect differently each rod and this effect can be observable. A similar idea has been defended recently by Espen Haug [18,29,34] with several pertinent questions in relation to the difficulty to conceive absolute simultaneity.

In section 2.1. we consider a rod S´ moving with speed v_1 in relation to EF where rod S is at rest. Since S´ is Lorentz-Fitzgerald contracted it is easy to obtain the one-way speed of light in the frame of S´. The Einstein's one-way speed of light is c by definition.

In section 2.2. we consider a third rod moving with speed v_2 in relation to EF and we obtain the relation between the proper lengths of rods that reveals a gap of possible "synchronizations" that preserve the value c for the two-way speed of light for a given v_1. A deeper analysis of this "synchronizations" will be given separately in a future publication.

In section 3 based on the results obtained in 2.2. we describe a novel method of synchronization that permit to conceive the experimental determination of the one-way speed of light.

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