An inconsistency between light speed invariance and causal relations

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Abstract

If the speed of light is independent of the movement of its source, then it should make no difference at all when clocks are synchronized using light sources at rest or moving ones. It seems it does. When clocks are synchronized in two reference frames, moving relatively to one another, the causal relations between two particular events will depend on whether sources at rest or moving ones have been used. This inconsistency will appear solid evidence that the speed of light can never be invariant.

Si la vitesse de la lumière est indépendante du mouvement de sa source : alors il ne devrait y avoir aucune différence si les horloges sont synchronisées, utilisant des sources lumineuses en mouvement ou immobiles . Pourtant il semblerait y avoir une différence. Quand des horloges sont synchronisées dans deux référentiels, en mouvement l'un par rapport à l'autre, la liaison causale entre deux événements particuliers dépendra du fait si des sources lumineuses en mouvement ou immobiles ont été utilisées . Cette incohérence sera l'évidence que la vitesse de la lumière ne peut jamais être absolue.

Key words

Causality ,One-way speed of light, Distant simultaneity, Special relativity

1 Introduction

When we are moving toward a source of light, then surely that light must strike us with a higher speed than to an observer for which the light source is at rest . How can it be otherwise? Indeed, in classical mechanics all speeds, whether of solid bodies or of light, are different for observers moving relative to one another. On the other hand, Maxwell's equations seem to imply that the speed of light c cannot change and is a direct result of basic laws of nature i.e. $c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$

Einstein " resolved" this conundrum by critically analyzing the operations involved in synchronizing clocks. Convinced that the propagation mode of electromagnetic radiation is described by Maxwell's equations, Einstein developed Special Relativity theory accordingly. He postulated the speed of light being independent of the movement of its source and concluded that simultaneity must be relative. He therefore insists that absolute time (simultaneity), assumed in classical mechanics , must be abandoned. What has been overlooked though, is that simultaneity and causality are closely linked. They both concern the concept "time" whereby the causal relations are definitely absolute. When the speed of light is indeed independent of the movement of its source, then it should make no difference at all when clocks are synchronized using light sources at rest or moving ones. It does make a difference.

In the argument , I will describe two similar situations in which clocks are synchronized in two reference frames moving relative to one another. In the former , only one light source is used which obviously must be moving with respect to at least one of the reference frames. In the latter, the signal sources are at rest with respect to the clocks. At first sight , both synchronization procedures yield identical results . However, the causal relations between two particular events will depend on whether signal sources at rest or moving ones have been used. This inconsistency will appear conclusive evidence that the speed of light could never be invariant, despite the many experimental results which seem to suggest otherwise. [i]

To fully appreciate the argument, some concepts have to be addressed first ; causality , and the one-way speed of light leading to Einstein's definition of simultaneity

2 Causality and simultaneity

Pick any two events in the history of the universe and call them X and Y . Then one of three things will always be true . Either X could be a cause of Y, or Y could be a cause of X, or neither could be a cause of the other. For example, let event e_1 denote the emission of a signal from some place in space and event e_2 the arrival of that signal at a distant place, then e_1 and e_2 are said to be causally related. Because signals with infinite propagation speed do not exist, causally connected events are never simultaneous events. Their time sequence , the succession of cause and result, is absolute and unambiguous. Furthermore, in the classical world of arbitrarily fast signals, every pair of events which are not happening at the same time are potentially causally connected. Only simultaneous events are guaranteed to be causally unrelated . This last is different in Special Relativity theory . Causally unrelated events do not necessarily happen simultaneously and if they don't , their time ordering is ambiguous and depend on the movement of the observer.

As we can see, simultaneity and causality are closely linked. Causally related events are never simultaneous events, while simultaneous events can never be causally connected . The causal relations are a powerful tool because they enable one-way light speeds to be compared without the need to know their numerical magnitudes. As we'll see next, the magnitude of the one-way speed of light cannot be determined at all without introducing a definition of simultaneity. In this way, one-way speeds are always more or less conventional. The causal relations can avoid this conventionality aspect while still be able to establish the (in)equality of multiple one-way light speeds.

3 The circular reasoning and the one-way speed of light.

At a first sight, it would seem that the experimental determination of the one-way speed of light is a single task. It is only necessary to have a source of light emitting from point A and let the light travel the path of length L to arrive at point B. Then, by measuring the time the light takes to travel from point A to B it seems possible to obtain the one-way speed of light simply by dividing the length L by the time difference measured by the two clocks. Still this appearance of simplicity is only an illusion. To measure the initial time, the time of departure of the pulse of light from point A we need a clock placed at that point. To determine the arriving time, the final time, another clock must be placed at point B. The transit time will then be the time difference of the two readings, if and only if the two clocks are synchronized.

Now the problem is, to synchronize clocks, one needs to know the one- way velocity of light, but to determine the one-way velocity of light, one requires synchronized clocks .

Aware of this circular reasoning , Einstein wrote in his famous 1905 paper on Special Relativity[ii] : "we have not defined a common 'time' for A and B, for the latter cannot be defined at all unless we establish by definition that the time required by light to travel from A to B equals the time it requires to travel from B to A" .

$$t_B = t_A + 1/2\left(t'_A - t_A\right) \qquad (1)$$

whereby $t'_A - t_A$ denotes the proper time interval measured at A which determines the two-way or round-trip velocity of light c : $c = \frac{2\overline{AB}}{t'_A - t_A}$

Einstein's definition (1) is deceptively simple: postulate the invariant light velocity to start with and define simultaneity accordingly . In this way , inertial frames in relative motion have different definitions of simultaneity, but are guaranteed to get the same value for the one-way speed of light in every measurement , as will be illustrated in the argument.

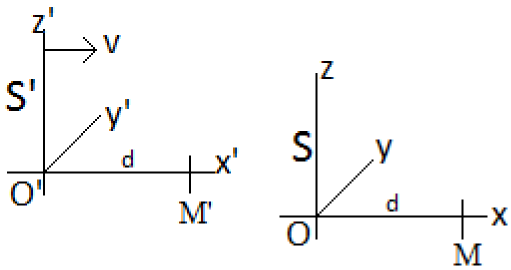
THE ARGUMENT

4 : Synchronizing clocks using a single light source

Let’s consider the following situation:

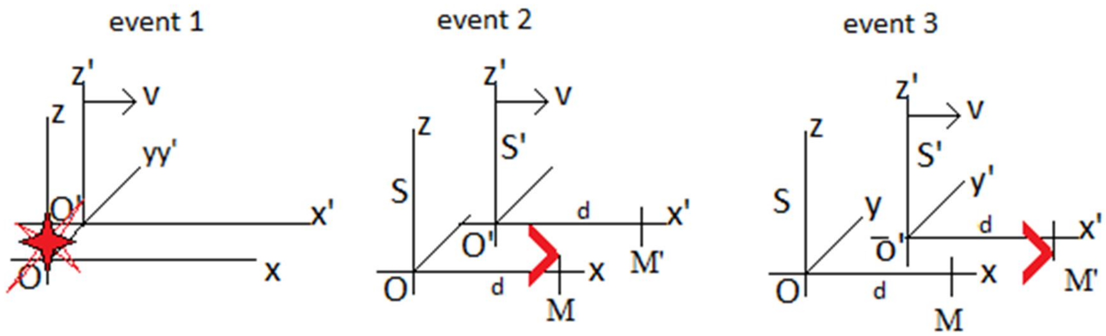
Two inertial frames S and S’ in standard configuration are moving at speed v with respect to one another along their common x – x’ axes . Let observer M be at rest in S at a distance d from the origin O on the x- axe and another observer M’ at rest in S’ at the same distance d from O’ on the x’- axe. Both distances are measured at rest in the relevant frames.

Figure 1 : the relatively moving frames S and S’



Let’s assume at time $t_0 = t'_0$ a flash of light is emitted from the point in space where O and O’ momentarily coincide and call this event 1 . Event 1 will cause the two particular events mentioned in the abstract.

Figure 2 : the succession of the events 1, 2 and 3



The flash of light must pass M (i.e. event 2) on the way to M’ and upon arriving at M’ (i.e. event 3) can hold information that event 2 already has happened . The two events are connected by a signal, hence , the events are guaranteed to be causally related. Therefore, their time ordering is unambiguous. From this fact , one can deduce that the time interval T the light took to travel from O to M must be less then the time interval T’ the light took to go from O’ to M’ . Logical sense suggests that the one-way speed of light c_S in S, is different and exeeding from to the one-way light speed $c_{S'}$ in S’:

$$T < T' \Rightarrow \frac{\overline{OM}}{T} > \frac{\overline{O'M'}}{T'} \quad or \quad c_S > c_{S'} \qquad (2)$$

Naturally, if the speed of light is absolute, a way must be found to make *T* equal to *T'*. To illustrate how Einstein's definition of simultaneity (1) solved this problem, let's finish the synchronization procedure :

When the flash of light reaches M , i.e. event 2, he sets his clock to read $t_M = t_0 + d / c$ in order to synchronize (according (1)) his clock to the one at O

And when the flash of light reaches M', i.e. event 3 , M' sets his clock to read $t'_{M'} = t'_0 + d / c$ in order to synchronize (according (1)) his clock to the one at O' .

We get : $$T = t_M - t_0 = T' = t'_{M'} - t'_0 = d / c \qquad (3)$$ and

$$T = T' \Rightarrow d / T = d / T' \quad or \quad c_M = c_{M'} \qquad (4)$$

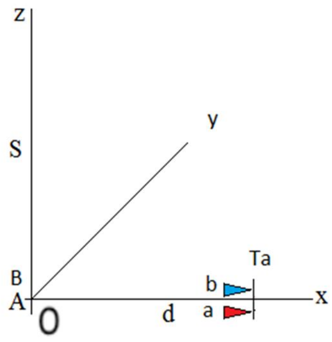
We see that synchronizing clocks Einstein's way guarantees that the one-way speed of light c_M as measured by M equals the one-way speed of light $c_{M'}$ as measured by M' ! We must bear in mind though that the "measured" light speeds are in fact defined speeds assuming light speed invariance . Therefore, equation (4) must be considered but a convention and as such is neither true nor false .

I's clear from figure 2 that a single flash of light can never reach M and M' simultaneously and will appear the fundamental reason why the speed of light can never be invariant.

5 Synchronizing clocks using signal sources at rest

For the synchronization of clocks in inertial reference frames, one obviously can use alternative signals . An observer could shoot standard bullets from standard shot guns at time t_0 . When this bullet passes another observer at rest at a distance d from the first , its clock is set to read $t_0 + d / u$, *u* being the muzzle velocity of the shot gun. Obviously, this synchronization is equivalent to that using light , since it would be so in absolute space, and since in SR every inertial frame is as good as absolute space. So, let's have two standard shot guns A and B with equal muzzle velocities $u_A = u_B$. This equality is established by the following procedure : a target Ta is set at a distance d from the shot guns . Without knowledge of the magnitudes of u_A and u_B , two bullets a and b ,fired simultaneously from the two guns , will reach that target simultaneously.

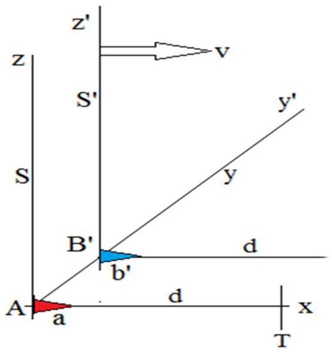
Figure 3 : the simultaneous arrival of the two bullets at Ta, hence $u_A = u_B$



Let gun B , henceforth B' be placed in an inertial reference frame S' which is moving relative and parallel to the x-axe of the rest frame S of gun A . According to the relativity principle , the muzzle velocity $u_{B'}$ will not have changed. Another target Ta' is placed in S' at the same distance d from gun B' on the x' axe. Both distances d are measured at rest in the relevant frames.

At time $t_0 = t'_0$, the guns coincide and they are fired simultaneously as depicted below and call this event *I*:

Figure 4 : event *I*



Again, we consider the next two particular events:

Event *II* : bullet a reaches Ta and a clock at Ta is set to read $t_{Ta} = t_0 + d / u_A$

Event *III* : bullet b reaches Ta' and a clock at Ta' is set to read $t'_{T'a} = t'_0 + d / u_{B'}$

The crucial question is : are the events *II* and *III* causally related or not ?

First of all, the events happen at the different places in space. We can imagine an observer halfway between these two events who sees them happening simultaneous. Another observer moving relative to the first, will perhaps see event *II* before event *III*. Yet another might see event *II* later then event *III* . In SR, these observers will conclude that the time ordering of the two events *II* and *III* is ambiguous and depends on the state of motion of the observer. As we have seen, the existence of an ambiguity in the time ordering of events proves that the events can never be causally related to one another. We also have seen that causally unrelated events are guaranteed to happen simultaneously in the classical sense, hence one may conclude: the time interval T bullet a took to cross the distance d in frame S equals the time interval T' bullet b took to cross the same distance d in frame S' :

$$T = T' \quad \text{hence,} \quad d / T = d / T' = u_A = u_{B'} \qquad (5)$$

(recall , both distances d are measured at rest in the relevant frames)

The similarity between the equations (4) and (5) is striking and from the perspective of light speed invariance , an absolute necessity . However, the former synchronization procedure leads to causally related events yielding $T < T'$ while in the latter , the relevant events are causally unrelated leading to the conclusion that $T = T'$. The fundamental reason for this difference can now be formulated :

Because the muzzle velocities are equal, $u_A = u_B$, the relevant events can never be causally related to one another. It follows , if the one-way light speeds in both frames were equal i.e. $c_S = c_{S'}$, a causal relation between event 2 and event 3 should not exist either. It's obvious (fig 2) that the flash of light will reach M before M' and never simultaneously . Therefore, the causal relation is guaranteed to exist and proves that the one-way light speeds in the frames S and S' are different ; $c_S \neq c_{S'}$ according to equation (2) whereby, in casu $c_S > c_{S'}$

The conclusion seems inescapable : the speed of light from a single source or any signal whatsoever is guaranteed to be different for observers moving relative to one another .

The postulated invariant light speed in Special Relativity theory leads inevitably to the relativity of simultaneity . As has been demonstrated, the speed of light can never be invariant, hence simultaneity must be absolute . Thus, the transition of the future into the past happens at the same time throughout the universe, rendering its age universal for all observers. Furthermore, absolute simultaneity prevents causality ever to be violated and renders time travel, with all the intrinsically potential paradoxes , impossible.

Select bibliography

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[ii] Einstein . Albert , Zur Elektrodynamik bewegter Körper. Annalen der Physik 17 . 1905