Dissecting's Einstein's Lightning Strike Example:

Proof That His Light-speed Constancy Postulate Is Untenable

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Abstract

The example of two lightning strikes on a train given by Einstein is reviewed. He used his light-speed postulate (LSP) to prove that events which occur simultaneously for one observer will not be so for another who is moving relative to him. It is shown that the LSP fails to correctly predict the speed of light emitted from a source which passes the observer at the same time that the light is emitted. The correct value is obtained when the Galilean Velocity transformation (GVT) is used, however, as shown by adding the distances traversed at any later time T by the light relative to its source and the source relative to the observer (cT + vT). When the GVT is applied instead in the train example, it is found that the lightning strikes do occur simultaneously for both the observer on the train and his counterpart at rest on the platform. Moreover, it is shown that the prediction of remote non-simultaneity (RNS) by the Lorentz transformation (LT) is not consistent with the Law of Causality. The latter requires that the rate of an inertial clock must remain constant for an indefinite period of time, thereby indicating that the *ratio* Q of the rates of any two such clocks (such as those used in the LT and the train example) must have a constant value. As a consequence, the following proportionality must exist for the elapsed times for a given event measured by the two clocks Δt'=Δt/Q. This relation, which is referred to as Newtonian Simultaneity, clearly eliminates any occurrence of RNS since Δt' and Δt must either both have null values or both non-null values on this basis. A replacement (Newton-Voigt transformation or NVT) for the LT is obtained by incorporating Newtonian Simultaneity with Einstein's two postulates of relativity.

Keywords: Galilean velocity transformation (GVT), vector addition, Relativistic velocity transformation (RVT), Newtonian Simultaneity, Newton-Voigt transformation (NVT)

I. INTRODUCTION

The example of two lightning strikes on a passing train was used by Einstein [1] to illustrate a controversial prediction of the Lorentz transformation [2]. Specifically, it is claimed that two events may be observed to occur simultaneously in one rest frame without being so in another. This prediction runs counter to the longstanding belief promulgated by Newton in the 17th century whereby any two events throughout the universe must occur simultaneously for all observers regardless of their state of motion. Poincaré pointed out [3], however, that there had never been an experiment which verified Newton's conjecture.

In formulating his version of relativity theory, Einstein agonized [4] over the definition of a postulate which correctly described the observation of light-speed constancy. He concluded that the speed of light in free space has the same value c for all observers independent of their state of motion as well as that of the source of the light. It will be shown in the following how his postulate leads directly to the conclusion that the lightning strikes on the train could not possibly be simultaneous for both an observer there and one who is stationary on the platform.

II. PIVOTAL ROLE OF THE GALILEAN VELOCITY TRANSFORMATION

The Galilean velocity transformation (GVT) takes its name from the founder of the Relativity Principle [5], but its true origin is uncertain. It is nothing more than an application of a the well-known procedure of mathematics referred to as *vector addition*. Consider the example of a car and a truck traveling along a road in the same direction. If the observer on the street measures the speed of the car to be v and a second observer in the car reports that the speed of the truck relative to his position is w, then it can safely be assumed that the speed of the truck relative to the street observer is the sum of these two values, namely v + w. The relationship is not restricted to a single dimension, but can be applied to any two velocity vectors by simply following the rules of vector addition in three-dimensional space.

There is a crucial application in the field of astronomical observations. Bradley used it in 1767 [6] to account for the aberration of starlight arriving on the Earth's surface. In this case, the velocity vector of light originating from the Sun, for example, is combined with the corresponding vector describing the motion of the Earth relative to the Sun at any particular time. The phenomenon can be perceived in everyday life by noting the motion of raindrops as they fall on the windshield of a speeding car.

A turning point came with the discovery of the light-drag effect introduced in 1818 [7] by Fresnel. He proposed that if a liquid with refractive index n moves through a tube with speed v, a light beam traveling through it in the same direction would have a velocity of $c' = c/n + v(1-n^{-2})$. It is clear that the GVT would lead to a different result, namely $c' = c/n + v$. Fizeau verified Fresnel's prediction [8] to a reasonable approximation in 1851. This result shows at the very least that the GVT is not generally applicable to all experiments dealing with light.

Fresnel's light-drag effect prediction was made in reaction [7,8] to the supposition of the existence of an aether through which light must move through space. Michelson and Morley [9] used their newly discovered interferometer to see if the proposed aether could be detected by comparing the speeds of two light beams moving perpendicularly to another. It had been argued that a frequency difference of varying magnitude would occur at different times of the year, but instead a null interference effect was observed. Voigt [10] concluded on this basis that the speed of light in free space might be the same in all rest frames. He suggested that the GVT could be amended to lead to this prediction by the mixing of its space and time coordinates. His new set of equations was the precursor of the LT [11,12], which Einstein later used as the cornerstone of his version of relativity theory published in 1905 [1,13]. He derived the Relativistic velocity transformation (RVT) by dividing the respective spatial coordinates of the LT by the corresponding time coordinate. It should be noted that the RVT can also be derived using the same procedure from Voigt's original space-time transformation [10]. The RVT was used later by von Laue [7] to derive the Fresnel light-drag formula, thereby giving the RVT increased credibility. Einstein [13] viewed the GVT as simply being the *low-velocity limit* of the RVT, and as such he concluded therefore that it was not applicable to the description of the motion of light rays.

III. COMPARISON OF THE RVT AND GVT IN EINSTEIN'S LIGHTNING STRIKE EXAMPLE

Relegation of the GVT to the realm of low-energy physics has its price, however. Belief in the LT and Einstein's light-speed postulate (LSP) forces one to accept the doctrine of remote non-simultaneity (RNS). Accordingly, two events which occur simultaneously for an observer in one rest frame may not necessarily be simultaneous for someone who is in motion relative to him. Einstein was aware that there is no experimental verification for RNS [4], even though what Poincaré [3] had to say on the subject is just as true, namely that there is also no proof from experiment that all events must occur at the same time for all observers in the universe.

In order to deal with his own uncertainty on this subject, Einstein came up with an example [1] which should demonstrate without doubt that RNS is a fact of Nature. He asked his readers to consider the case in which two lightning strikes occur on a passing train. They are measured to occur simultaneously for an observer O_p who is at rest on the station's platform. He argued that if the two strikes occurred on opposite sides of the position M of O_p which both were separated by a distance of L from him, then light emanating from them would necessarily arrive at M simultaneously. The time T_p required for this to occur is L/c, where c is the speed of light in free space.

He further assumed that the passing train was moving at a constant speed v relative to the platform as the lightning strikes occurred. On the basis of his LSP, an observer O_t who is at rest on the train at the same position M when the two lightning strikes occur, cannot find that they would also occur simultaneously for him. This is because O_t must find that the light pulse moving in the opposite direction as the train would move a distance of cT toward him at any time T while he has moved a distance of vT during the same period. The light would therefore arrive at O_t's momentary position at time $T_1=L/(v+c) < T_p$. Meanwhile the light pulse travelling in the opposite direction would also move a distance of cT by virtue of the LSP, whereas O_t would have moved a distance of vT away from this pulse. The time required for this light pulse to "catch up" with O_t is thus $T_2= L/c\text{-}v>T_p$. Clearly, $T_2>T_1$, so the light pulses do not arrive simultaneously for O_t when the LSP is used, as Einstein wished to show [1].

Consider the following example, however. A truck moving with speed v passes an observer at rest on the street corner. At the same time, the observer on the truck reports that there is a car moving at speed w in the same direction. After time T has elapsed, the truck has moved a distance vT away from the street corner, while the car has moved a distance of wT away from the truck. This means that the distance the car has moved away from the street corned during this period is equal to vT + wT. By definition, the speed of the car relative to the street corner is thus equal to v+w, exactly the result expected from the GVT.

Next consider the analogous situation when the car is replaced by a light pulse which was emitted from a light source on the truck at the original time. Assume, as is believed to be generally true, that the speed of the light pulse is c relative to the light source/truck. The *distance* travelled by the light pulse relative to the street corner in this period is thus measured to have a value of vT + cT. Again, by definition, this means that the speed of the light pulse relative to the street corner/origin is v+c, which is the same value predicted by application of the GVT, but *not* the value of c expected on the basis of Einstein's LSP. As a consequence, it is clear that the *LSP fails* to predict the correct speed of the light pulse in this case, whereas the GVT is successful in this example.

This doesn't change the fact that the GVT fails to correctly predict the light speed in the Fresnel/Fizeau experiment, whereas the RVT does, as shown by von Laue in 1907 [7]. There is a simple way out of this dilemma, but before presenting that, let us consider how the substitution of the GVT for the RVT in Einstein's example of two lightning strikes [1] changes the result.

Assume as before that the light from the two strikes reaches the observer O_p located at the midpoint M of the platform simultaneously at time $T_p = L/c$. After time T has elapsed, the sources of the strikes have moved to positions 2L+vT and vT, respectively, taking account of the speed of the train relative to the platform. The speed of the first light pulse relative to O_t is c + v in the negative direction according to the GVT, so at time T this pulse is located at 2L + vT – (v+c)T= 2L-cT. Meanwhile, the speed of the second pulse toward O_t is c-v according to the GVT. As a result it is located at vT + (c-v) T = cT at time T. Therefore, the two light pulses will meet when 2L-cT = cT. The corresponding time is $L/c=T_p$, the same as for O_p on the platform. In summary, the arrival time is simultaneous for O_t as well when the GVT is used. It is thus clear that there is no RNS in this case, contrary to what one must assume when the LSP is assumed instead.

It is worth noting that the RVT can be used to show that the light pulses do at least arrive simultaneously for the train observer O_t [2]. It can be seen, however, that when the RVT is assumed, that they do not reach O_t when he is located at M, as is known to be correct based on O_p's experience, but rather at L +vT= L(1+ vc^{-1}). Hence, it is clear that the RVT does not give a completely accurate prediction of the motion of the two light pulses, whereas the GVT has been shown to produce the correct result.

It is therefore obvious from the above discussion that there are some experiments involving light which can be understood within the context of the GVT but not when the RVT is used in its place. The opposite is also true. Some experiments can be understood using the LSP and the RVT, but not when the GVT is used instead. In short, the range of application of the two velocity transformations is *mutually exclusive.* The RVT performs well for the Fresnel-Fizeau light-drag experiment, but not in the train example discussed above in which observers in two different rest frames must find that the speed of light is different from their perspectives.

The goal is therefore to be able to decide on a definitive basis which of the two transformations is applicable in a given case. The solution is quite simple [6]. When *two observers in different rest frames* are to compare their measurements for the same light pulse, they must use the GVT to obtain the correct answer. By contrast, the RVT is valid when *only a single observer makes separate observations under two different conditions,* for example, namely v=0 and v≠0 for the relative speed of the medium in the Fresnel-Fizeau experiment [7]. Another example for which the RVT is essential involves the acceleration of electrons in electromagnetic fields. The objective in this case is to cause an electron to attain faster-than-c speed. As in the Fresnel light-drag experiment, there is but one observer who performs measurements under two different conditions, before and after the field is applied. The assignments of velocities in the RVT in the two cases are made on this basis. The assumption of light-speed constancy is justified because of the limiting case where the magnitudes of the two velocities each approach a value of c, i.e. one starts with the electron moving with a speed very close to c and ends up with a new velocity after application of the field with a magnitude which is only infinitesimally greater but is still less than c. This example cannot be explained on the basis of the GVT.

Another important example where the RVT is essential but for which the GVT cannot be used successfully is in deriving the theoretical explanation of the phenomenon of Thomas spin precession [14, 6]. This case has some similarities to that discussed above regarding attempts to accelerate an electron to faster-than-c speed. The focus in both of these cases is on the state of motion of the electron in two different situations, before and after application of a field, from the *vantage point of a single observer*. Consequently, the application of the GVT is ruled out in this case as well. On the other hand, the GVT can be used to illustrate that all events do occur simultaneously for observers who are in relative motion to each other, including those which do not involve light [6]. In this analysis of Einstein's lightning-strikes example, the LSP is avoided entirely, however. It is replaced by the considerably less restrictive postulate which states that *the speed of light in free space is equal to c relative to its light source.* This form of the postulate is seen to be entirely consistent with the results of the Michelson-Morley experiment [9].

IV. ABSOULTE SIMULTANEITY AND THE NEWTON-VOIGT TRANSFORMATION

There is a more straightforward means [15-19] of proving that Einstein's lightning-strikes example [1] is not consistent with his claim of remote non-simultaneity (RNS). To this end, one must only recognize that the clocks used in this example are *inertial* objects, that is, they are not subjected to any unbalanced external force. In analogy to the velocity of an inertial object in Newton's First Law of Motion (Law of Inertia), the Law of Causality precludes any change in the rates of these clocks or in any other physical property connected with them [16]. As a consequence, the *ratio* of the rates of two inertial clocks, such as those on the train and on the station platform in Einstein's example, *must be constant over all time*. This means that any time differences measured by the two clocks must always be measured to have the same ratio. In other words, if the time differences are denoted as Δt' and Δt, respectively, the following equation must be satisfied, namely:

$$\Delta t' = \Delta t / Q,$$

where Q is the above ratio of clock rates.

It is therefore clear that if two events occur simultaneously, that is, if Δt'=0, for example, then they must also occur simultaneously (Δt'=0) based on the other clock. Accordingly, one must conclude that RNS is excluded from the realm of possibility in the lightning-strike example. This conclusion is thus perfectly consistent with the discussion in Sect. III for the case when the GVT is used to deduce the velocities of the light rays emitted by the two lightning strikes.

Inertial clocks are idealized systems that do not occur in actual practice, but experiments that were carried out with circumnavigating atomic clocks by Hafele and Keating [20] are consistent with the proportionality relation given above (which is referred to as Newtonian Simultaneity). It was found that the rates of the clocks decreased with their speed relative to the Earth's center of mass (ECM). As a result is was found that clocks flying eastward ran slower than those left behind at the origin of the flight, which in turn ran slower than their counterparts flying in a westerly direction around the globe. The following relation could therefore be obtained after correcting for the effects of gravity on the rates of the clocks [21]:

$$\Delta t' \gamma (v') = \Delta t' \gamma (v'),$$

where $\gamma(v) = (1-v^2c^{-2})^{-0.5}$. An analogous relation was found for the periods of x-rays emanating from clocks which were rotating at high speeds [22], in which case the speeds v were measured relative the laboratory rest frame. Consequently the above relation is referred to as the Universal Time-dilation Law (UTDL) [23-25], whereby the speeds in general are measured relative to what is referred to as the Objective Rest Frame (ORS) [26]. Einstein [13] gave a related example in his 1905 paper of an electron moving in a circular trajectory in which case the ORS is the rest frame in which the accelerating force was applied. He also gave another example of this type in which he argued that a clock located at the Equator would run slower than one located at the Pole. The UTDL is used to adjust rates of atomic clocks carried on the orbiting satellites of the Global Positioning System [27,28]. The motivation for such adjustments is to ensure these clocks run at the same rate as their counterparts located on the Earth's surface. It needs to be recognized that such adjustments only make sense when it is assumed that events always occur simultaneously for both clocks, so this experience serves as an everyday experimental refutation of RNS [21].

The way in which the proportionality relation of Newtonian Simultaneity is derived shows unequivocally that the LT is inconsistent with the Law of Causality. The LT needs to be rejected as a consequence and replaced by a different space-time transformation which is consistent with physical reality. To achieve this end it is necessary to evaluate the constant Q in the proportional relation on as general a basis as possible. This can be done by combining it with the UTDL. Accordingly, for a given ORS with respect to which speeds of the clocks are to be determined, the following experimental determination of Q is obtained:

$$Q= \gamma (v')/\gamma (v).$$

One can then obtain the desired space-time transformation by adding the Newtonian Simultaneity relation to Einstein's original two postulates, the Relativity Principle and his LSP.

As such it is only valid for situations in which the RVT can be used successfully, as discussed in Sect. III, i.e. for cases in which a single observer makes his measurements under two different sets of circumstances. The resulting set of space-time relations is given below and is referred to as the Newton-Voigt transformation (NVT) [29,30]:

$$\Delta t' = \frac{\Delta t}{Q}$$

$$\Delta x' = \eta\left(\Delta x - v\Delta t\right)$$

$$\Delta y' = \frac{\eta \Delta y}{\gamma Q}$$

$$\Delta z' = \frac{\eta \Delta z}{\gamma Q}$$

with η (it appears in the RVT as well) defined above as $\left(\frac{1 - \mathrm{vc}^{-2}\Delta\mathrm{x}}{\Delta\mathrm{t}}\right)^{-1}$. Note that Newtonian Simultaneity is used directly as the first equation, thereby excluding any possibility of RNS in the results. The constant Q needs to be obtained from experiment in any given case, which means the UTDL must be followed and a specific ORS must be designated.

A point which was not considered in Einstein's description [1] is the possibility that the rates of the clocks on the platform are different than for those on the station platform. Assume, for example, that the clock on the train is running slower than that on the platform by a factor of Q. This relationship clearly does not change the conclusion of whether there is simultaneity in either locale. It is merely a matter of deciding what unit of time to use in each case. According to the proportionality relation (Newtonian Simultaneity) for times, $\Delta t' = \frac{\Delta t}{Q}$, it is clear that either Δt and Δt' for the lightning strikes are both equal to zero or that both are not equal to zero. Just changing the rate of either clock cannot change this relationship.

It is still necessary to consider what effect any rate change will have on the speed of light measured in either locale. Obviously, changing the unit of time by itself will cause a change in the latter quantity. It is equally clear, however, that the value of the light speed will not change if proportionately *the same change is made in the unit of length.* As a consequence, it must be true that there is an analogous proportionality relationship for the respective values of the distances (Δr and $\Delta r'$) travelled by the light, namely:

$$\Delta r' = \Delta r/Q.$$

This equation is clearly at odds with two of Einstein's predictions based on the LT [13]. Time dilation in an accelerated rest frame is accompanied by an *increase* in the values of measured lengths, and by the same fraction in all orientations of the object, not the type of asymmetric length contraction predicted by the FitzGerald-Lorentz length contraction effect (FLC). Moreover, the prediction that two clocks can both be running slower than one another at the same time, and also that two lengths can each be shorter than one another at the same time (Einstein Symmetry Principle) are shown to be invalid as a result of the above two proportionality relations.

What evidence is there for the constancy of the speed of light in free space, however? It is not possible in practice to confirm this with a direct measurement, but it can be confirmed indirectly by combining results of wavelength and frequency measurements on different objects. The Ives-Stilwell experiment [31,32] indicates that the wavelength λ of light from a source accelerated with speed v relative to the laboratory satisfies the relationship: $\lambda=\gamma$ (v) λ', where λ' is the standard value when the light source is at rest. This experiment is limited to radiation of relatively long wavelength (visible light) for which it is not possible to measure the corresponding light frequency ν. Hay et al. [22,33] were able to measure the frequency of x-rays in a rotor moving with a relatively small speed v and found the following relationship: $\nu= \nu'/\gamma$ (v). Assuming that the same proportional relationships would hold if the corresponding measurements could be made with satisfactory y accuracy in each case therefore leads to the following result: $c=\lambda\nu= \lambda'\nu'$. On this basis, it can be inferred with high probability that the light speed has the same value c for all light sources. One can also infer that the analogous equality hold for all *relative* speeds, i.e. v=v'. It is helpful to use the following notation for this result, namely $v'= v= Q^0 v$, which underscores the fact that all three of the relationships for time, distance and speed involve proportionality factors which are integral multiples of the constant Q in the Newton Simultaneity relationship. Experiments with accelerated electrons [34] also indicate that inertial mass adheres to the same proportional relationship as elapsed times and distances. The above examples are illustrative of the Uniform Scaling procedure which is discussed in detail in previous work [23,35,36].

V. CONCLUSIONS

The clear purpose in Einstein's lightning-strike example was to bolster support for the Lorentz transformation (LT). The latter predicts unequivocally that two events which differ in location and occur simultaneously for one observer cannot also be simultaneous for another who is moving relative to the first. This LT prediction has been referred to as remote non-simultaneity (RNS). Einstein assumed that the speed of the light emanating from the lightning strikes would be independent of the state of motion of an observer on the train. This assumption is consistent with the light-speed postulate (LSP) he used to derive the LT.

There is a simple example which proves that the LSP is unphysical, however. Consider a light source which passes an observer with speed v at the same time that it emits a light beam in the same direction. After time T, the light source will have travelled a distance of vT whereas the light will have moved a distance of cT relative to the source. The corresponding distance the light has moved relative to the observer is therefore vT + cT, which therefore is proof that the speed of light relative to him is not c, as assumed with the LSP, but rather c+v. The latter is the same as is predicted by the Galilean velocity transformation (GVT), which is simply an example of the commonly used procedure in mathematics generally referred to as *vector addition.* According to the LSP, the light has moved a distance of cT relative to both the source and the observer, which therefore leaves unexplained how the distance vT travelled by the source relative to the observer can be accounted for. This proves that the RNS computed in Einstein's example is simply an artefact of the LSP.

There is another way to prove that the LT prediction of RNS is false. The clocks in the train example are inertial, that is, they are not influenced by any external unbalanced force. The rate of any inertial clock therefor cannot change over time. This is a consequence of the Law of Causality, which is also a factor in the formulation of Newton's First Law of Motion. This means that the ratio of the rates of any two inertial clocks must itself be a constant. As a consequence, when two such clocks are used to measure an elapsed time, their corresponding values must differ by the same ratio Q as their rates: $\Delta t' = \Delta t/Q$. This equation is referred to as

Newtonian Simultaneity. When applied to the lightning-strikes example, it leads to the conclusion that the lightning strikes occur simultaneously ($\Delta t' = \Delta t = 0$), in agreement with the conclusion above obtained based on application of the GVT.

A key question arises because of the above discussion, namely when is it imperative to use the GVT in comparing relative velocities and when it is not allowed, in which case the RVT must be used in its place. If the object is to compare the speeds of an object, including light, from the vantage point of *two observers who are moving relative to one another*, the GVT must be used. This is because the vector addition of distances, which is the underlying principle for using the GVT, is involved in all such cases. This is the situation in the lightning-strikes example, since the speed of light is required from the vantage point of both the light source and the observer on the train. The LSP must be avoided for this purpose. If the goal is to compare speeds of an object relative to a single observer under two different circumstances, the GVT must be eschewed in favour of the RVT. This is the case in the Fresnel/Fizeau light-speed damping experiment as well as in several other well-known examples cited in Sect. III.

The LT has been shown to be inconsistent with the Law of Causality, in particular with its prediction of "space-time mixing." An alternative space-time transformation is obtained by incorporating the proportionality between elapsed times obtained by two observers: $\Delta t' = \Delta t / Q$. The constant Q is required in all four equations. It is referred to as the Newton-Voigt transformation (NVT) and is given explicitly in Sect, IV. On this basis, each of the unphysical predictions of the LT is removed. These include RNS, FitzGerald-Lorentz length contraction Einstein's Symmetry Principle, according to which two clocks can both be running slower than another at the same time, as well as the possibility of time reversal.

Finally, there is an analogous proportionality relation for all physical properties. This group of Laws is referred to as Uniform Scaling. The proportionality constants can conveniently be looked upon as *conversion factors* for each property which allow the results obtained by an observer in one rest frame to be changed over to those of his counterpart in another rest frame.
The conversion factor for elapsed times is used in the operation of the atomic clocks of the Global Positioning System (GPS).

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