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A revised light-speed postulate and the applicability of the Galilean velocity transformation in relativity theory

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Abstract
The history of the assumption of the equality of light speeds in free space for observers in different rest frames is reviewed. The classical (Galilean) velocity transformation (GVT) is unable to explain the results of various experiments such as Fresnel-Fizeau light-damping in moving fluids, but this failure is shown to leave open an important class of experiments for which its application is essential. Einstein's light-speed postulate (LSP) is shown to be unviable by considering a case in which a light source passes by a stationary observer at the same time that it emits a light pulse in the same direction. The fact that the relativistic velocity transformation (RVT) has many successful applications, despite its apparent reliance on the LSP, is attributed to the fact that in all such cases it only considers the results of a single observer made under two different conditions. By contrast, the GVT is applicable when the objective is to deduce the relationship between the velocity measurements of two observers in relative motion.

A revised light-speed postulate is introduced which states that the speed of light relative to its source, as well as relative speeds of objects in general, is the same for all observers. This is because the unit of speed is the same in all rest frames. The application of the revised postulate to the Michelson-Morley experiment is considered in detail.

Keywords: Relativistic velocity transformation (RVT), Galilean velocity transformation (GVT), vector addition, fresnel-fizeau light-damping experiment, michelson-morley null interference effect

1. Introduction

Questions about the value of the speed of light measured by observers in different rest frames have plagued the physics community for at least 200 years. It started with an experiment in which the speed of light was measured in an apparatus filled with water in free flow. It was concluded by many that the results could not be explained on the basis of the classical (Galilean) velocity transformation (GVT). In addition, there was evidence from the Biot-Savart Law and Maxwell's equations that the speed of light had the same value in every inertial system. There followed a frantic search for a so-called "aether" which played the same role for light as the rest frame in which sound waves are generated. Finally, Michelson and Morley carried out an experiment with their newly invented interferometer which seemed to provide conclusive evidence that the speed of light in free space is the same for all observers, independent of their state of motion relative to the light source. A review of the theoretical attempts to reconcile these developments is given below.

2. The Relativistic Velocity Transformation (RVT)

The relationship between the speeds of a moving object measured by two different observers who are themselves in relative motion to another had for centuries been described in terms of the classical (Galilean) velocity transformation (GVT). Accordingly, if the object moves along the same (x,x') axis as the two observer are separating from each other at speed v, the two respective speeds u' and u are described by the equation:

$$u'=u+v. \quad (1)$$

Fresnel had predicted [1] that if a liquid with refractive index n moves through a tube with speed v relative to an aether and a light beam filled with water traverses the tube in the same direction, the speed of the light c' obeys the following relationship:

$$c' = c/n + v\,(1 - 1/n^2). \quad (2)$$

The term $(1-1/n^2)$ is referred to as the light-damping coefficient. Fizeau verified eq. (2) to a reasonable degree of accuracy for water [2] in 1851. Comparison with the GVT relation in eq. (1), shows that if u'=c' and u=c/n, the expected value of the speed of light in the liquid medium would be:

$$c' = c/n + v \quad (3)$$

This result shows that the GVT does not successfully predict the experimental value of the light speed in this case.
Moreover, if eq. (2) is evaluated for the case of n=1, i.e. free space, it becomes simply c'=c.
This result is consistent with other observations related to Maxwell's equations such as the Law of Biot and Savart [3]:

$$\varepsilon_0\mu_0 c^2=1 \quad (4)$$

(ε_0 is the electric permittivity in free space and μ_0 is the magnetic permeability). Since the latter two values are the same in every rest frame, it follows that the speed of light must also be the same in every rest frame as well. This result is therefore consistent with the c=c' relation based on eq. (2) for light in free space. Michelson and Morley [4] then carried out an interferometry experiment in which light waves were sent back and forth in two perpendicular directions. A null interference effect was found which the authors argued was proof that an aether could not be used to explain the c=c' result.
Rather than keep looking for an aether to explain matters, Voigt [5] made an innovative suggestion, namely to amend the GVT in such a way as to make it consistent with the c'=c condition. A few years later, Larmor [6] and Lorentz [7] independently derived what has come to be known as the Lorentz transformation (LT). Einstein showed [8] that division of the spatial coordinates in both transformations leads to the relativistic velocity transformation (RVT). The corresponding equation connecting the velocities u' and u in two inertial rest frames separating with speed v in the mutual x.x' direction is given below:

$$u' = (u+v)/(1+uv/c^2) \quad (5)$$

It was shown by von Laue in 1907 [9] that substitution of v = c/n in eq. (5) gives:

$$u' = c' = (c/n + v)/(1 + v/cn) \approx (c/n + v)\,(1- v/cn) = c/n + v\,(1- 1/n^2), \quad (6)$$

which is the same as the Fizeau result for light-damping given in eq. (2).

3. Successful Application of the GVT for Light

Two things are clear from the discussion in Sect. II. The GVT is not applicable for clarification of the light-damping experiment and the RVT is. This does not mean, however, that the GVT cannot be applied for other situations involving light. Consider the example of someone standing on a street corner while a truck with a light source is passing by with speed v. At the same time, a light pulse is emitted in the same direction with speed c. According to Einstein's theory [8], the GVT is not applicable in this case for determining the speed of the light pulse w relative to the street corner. In order to check this position, consider what happens after a certain time T has elapsed. The distance of the light source from the street corner is now vT, while the corresponding distance of the light pulse relative to the light source is cT. The total distance that the light pulse has travelled relative to the street corner is clearly vT + cT, i.e. the sum of the latter two partial distances. On the basis of the definition of speed as the ratio of distance travelled to the corresponding elapsed time, it therefore follows that the speed of the light pulse relative to the street corner is equal to c+v, which is exactly the same value predicted by the GVT.
Moreover, this result stands in direct contradiction to the corresponding prediction of the RVT in eq. (5) if u=c:

$$u' = (c+v)/(1+v/c) = c, \quad (7)$$

which is not equal to the value of the speed computed above, namely c+v. Hence, this example proves that the GVT can be successfully applied in a case involving light in free space, while at the same time contradicting the result obtained by the RVT in the same set of circumstances.
There is a clear distinction that can be made for the two applications [10]. In the light-damping experiment, the goal in the theory is to compare the speed of light for two different conditions, i.e. with the liquid at rest or flowing through the apparatus with speed v relative to the rest frame of the laboratory. In the other example, the goal is to relate the values of the light speed obtained by two observers who are moving with speed v relative to each other.
One doesn't need to hypothesize that an aether must be involved in order to explain the light-damping experiment. The same is true in the experiments which have been carried out with electrons in an attempt to accelerate them sufficiently in the laboratory by applying an electromagnetic force to attain a speed which is greater than c., Again, there are two separate conditions, before and after the force is applied, The GVT cannot be applied in this case either, but the RVT can be used successfully in its place.
The GVT in eq, (1) is an example of vector addition in mathematics. It can be extended accordingly to apply to three dimensions [10], as was done by Bradley in the early 18th century to predict the amount of the aberration of light observed at the zenith by earth-bound telescopes.
Einstein [8, 11] claimed on the basis of the RVT that Bradley's formula for the angle of aberration needed to be modified by a factor of γ (v); this was necessary to account for the fact that the speed of light measured in the rest frame of the earth emanating from the sun must supposedly be the same as that measured there. Since observers in two different rest frames are involved, however, the RVT must be eschewed in this case in favor of the GVT.

4. True Light-speed Postulate

According to Einstein's light-speed postulate (LSP) which he used to derive the LT [8], the speed of light in free space is equal to c independent of the states of motion of the observer and the light source. It has been shown [12, 13] by using the distance reframing procedure discussed in Sect. III that this version of the postulate is untenable. In the example considered there, the LSP would predict that the speed of the light pulse would have the same value of c relative to both the light source and the street corner. After time T had elapsed, the light pulse would therefore be separated by a distance of cT from both the light source and the street corner. This is impossible because the light source is no longer located at the street corner; the LSP ignores the fact that the light source has moved a distance vT away from the latter position and so the light pulse must be separated by a distance of vT + cT from the street corner, not cT.

Examination of all the experimental results which seemed to be properly described by the LSP shows that there is a simple alternative, namely to assume that light always moves with speed c relative to its source in free space. The LT and RVT, as well as Voigt's original transformation [5], assume that two observers in different rest frames will agree that the speed of light is equal to c. It is necessary to satisfy a key condition for this to be the case, however, namely the unit of speed must be exactly the same in both rest frames. Otherwise, they would measure different values even though the absolute value of the light speed is actually the same for both.

Consistency with the RP requires that observers in different rest frames also agree on the values of the relative speeds of objects. If there were an exception to this rule, an observer in an inertial rest frame would be able to distinguish his state of motion by measuring the value of the relative speed v of two objects; he would find that the value of the speed differs from one rest frame to another if the RP did not hold.

The GVT is consistent with the above postulate. For example, if two observers are separating from each other with velocity v, their measured values u_1 and u_2 for an object's velocity would satisfy the following vector equation:

$$u_2 = u_1 + v \qquad (8)$$

If there are two such objects A and B with measured velocities u_{2A} and u_{2B}, respectively, for one observer and u_{1A} and u_{1B} for the other, the corresponding relative velocities must be related as follows:

$$u_{2A} - u_{2B} = (u_{1A} + v) - (u_{1B} + v) = u_{1A} - u_{1B}, \qquad (9)$$

i.e. the relative velocity of A and B is the same for both observers, consistent with the above postulate.

The maximum value of the difference in speeds is 2c. This value is attained when two light beams approach each other in opposite directions; each has a speed of c, so vector addition leads to the conclusion that their relative speed is 2c. According to eq. (9), any observer independent of his velocity relative to either of the respective light sources will measure the same value of 2c for the relative speed and direction of the two light beams.

Finally, the above relationships will be applied to the Michelson-Morley experiment [4]. If an observer approaches the laboratory with speed v, he will find that the speed of the light beam in the forward direction is v+c, whereas the value in the reverse direction is v-c. If the observer approaches at an angle with velocity v relative to the laboratory, the corresponding velocities will be v+c and v-c, whereby the direction of the light beam is now included explicitly in the definition of its velocity c. Corresponding values will be obtained for the second light beam in the experiment, in which case the direction of c is different/perpendicular than for the first.

By applying vector addition in both cases, however, it is possible for the observer to deduce the velocities of the two light beams in both directions in the rest frame of the laboratory. On this basis, he will be able to conclude correctly that there will be null interference in the experiment as long as the distance travelled by both light beams in the back-and-forth direction is exactly the same.

5. Conclusion

Consideration of the distance travelled by a light pulse after some time has elapsed (distance reframing procedure) proves that Einstein's light-speed postulate (LSP) in not viable. It shows that the distance separating the light pulse from the position from which it was emitted would be the same as for the light source according to the LSP; this is an impossibility since the light source is no longer at the origin at this time. The same argument also shows that the classical velocity transformation (GVT) is applicable for light, contrary to what has been claimed because of belief in the LSP.

A clear distinction is underscored between cases where the GVT can be successfully applied and others where it cannot. The relativistic velocity transformation (RVT) is effective in cases such as the Fresnel-Fizeau light-damping experiment where only a single observer is involved who makes measurements under two different conditions (with and without liquid flowing through the apparatus). Application of the GVT is called for when there are two observers comparing their respective values of the light speed, or any other object for that matter. It is simply necessary to use vector addition to obtain the results. The ranges of applicability for the RVT and GVT are seen to be mutually exclusive as a result. For example, in the example of stellar aberration, there are two rest frames of interest from which the speed of light is to be compared: the earth and the sun. The same is true for Einstein's example of two lightning strikes on a moving train. In this case the two observers are located on the station platform and the moving train, respectively.

The success of the RVT in various applications is based on the assumption that the speed of light in free space has the same value of c for observers in different rest frames. This can only be the case if the two observers use the same unit of speed on which to base their measured values. It is therefore possible to replace Einstein's LSP with the assumption that the speed of light relative to its source is always equal to c. This is consistent with the deductions based on Maxwell's equations. The proposed alternative version states that observers in all rest frames must agree on the value of the light speed relative to the source. It is also clear on this basis that the values of the relative speed of any two objects must also be the same for all observers. Any deviation from this result would stand in contradiction to Galileo's RP since this would agive observers a way to distinguish their various rest frames from another

The GVT is consistent with the revised postulate. The results of vector addition of velocities require that two observers in motion must agree on the relative speed of any two objects. The postulate is clearly consistent with the null interference result of the Michelson-Morley experiment. Accordingly, the speed of light in the forward and reverse directions relative to a specific light source is independent of the direction of emission. Therefore, if the distance the light beams travel in the experiment is the same, it follows that the time for return to the location of the interferometer will be exactly the same independent of the emission direction.

Application of vector addition enables an observer who is moving relative to the apparatus to deduce both the speed and direction of each light beam that is measured in the laboratory rest frame.

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