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One fundamental principle of physics is all observers concurrently measuring the output of an experiment must have identical or equivalent results, especially when the recorded data are transformed to one inertial frame. Einstein claimed that the one-way time interval using light from one end of a uniformly moving rod to the other end was equal to half of the roundtrip for light originating from the rod's end and reflecting from the other end toward the origination, forming Einstein's time synchronization method. For an observer stationary relative to the rod, light traverses one rod length in either direction with equal transmission time intervals between ends. For an external inertial observer monitoring the one-way distances, light traverses a longer distance than the rod length to overtake the receding end and a shorter distance when intercepting the approaching end, making the total roundtrip greater than two rod lengths. The roundtrip distance increases with a faster uniformly moving rod. Length contraction from special relativity undercompensates for this extra distance. Assuming a universal speed of light, theory predicts unequal transmission intervals for the external inertial observer witnessing the uniformly moving rod. In all ultraprecise lab measurements, the observed light speed is the same quantity and satisfies Einstein's time synchronization convention when the distance between the light source and detector is always fixed. For the external observer to witness the same output as the observer fixed with the rod, light must obey vector velocity addition for the external observer to have equal transmission time intervals over both directions (as required by Einstein's time synchronization convention) and measure the standard speed of light between the ends of the uniformly moving rod. The Laser Interferometer Gravitational-Wave Observatories (LIGO) consortium verifies these conditions as the ends of each LIGO arm move at different velocities due to Earth's rotation, making all one-way light paths different in inertial space, yet null results are output for all observers, whether accelerated on Earth's surface or in an inertial reference frame.

One key equation in the evaluation corrects a mathematical error in the distance that light traverses toward an approaching object in five previous papers by the author. An appendix in this paper contains the errata to correct the corresponding equations and replaces inaccurate summaries to correct the results and conclusions in those five papers.

Keywords: length contraction, time dilation, time synchronization, light speed, special relativity, michelson-morley interferometer, and Kennedy-Thorndike test.

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I. EINSTEIN'S TIME SYNCHRONIZATION AND RELATIVITY PRINCIPLE

In his groundbreaking 1905 manuscript on special relativity, Einstein defined his concept of time synchronization in the first section of that paper. He first illustrated the time of an event is always a judgment of simultaneous events. In his example, "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events", meaning "That train arrives here at 7 o'clock." He further emphasized, "It might appear...the definition of 'time' can be overcome by substituting 'the position of the small hand of

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my watch' for 'time'." [1, §1, lines 15-20]. What he meant is that within an acceptable neighborhood encompassing both the train and pocket watch, the train arrived at 7 o'clock, else the train would crush the pocket watch upon arrival. An observer at point A can time events in the immediate vicinity of A by coordinating the positions within the neighborhood of the clock as being simultaneous. If a remote location at point B is far outside of the neighborhood of A, then time recorded by an identical clock near B would indicate for an observer at B the timed events in the immediate neighborhood of B. Einstein stated it is impossible without further definitions to compare 'A time' with 'B time', because there is no master time or common time between A and B. Surprisingly, Einstein made the following claim without evidence, "The latter time can now be defined by requiring that *by definition*[1] the 'time' necessary for light to travel from A to B be identical to the 'time' necessary to travel from B to A. Let a ray of light start at the 'A time' t_A from A toward B, let it at the 'B time' t_B be reflected at B in the direction of A, and arrive again at A at the 'A time' t'_A. The two clocks run in synchronization by definition if

$$t_B - t_A = t'_A - t_B \qquad (§1.1)$$

We assume this definition of synchronization to be free of any possible contradictions applicable to arbitrarily many points." [1, §1, lines 41-48]

"In addition, in agreement with experience we further require that the quantity

$$\frac{2AB}{t'_A - t_A} = c \qquad (§1.2)$$

be a universal constant (the velocity of light in empty space)." [1, §1, lines 61-63]

This is known as the Einstein synchronization convention, which assumes that the one-way time of transmission of light is the average of two transmission intervals from A to B and from B to A. The immediate equation above defines c as a constant, which is also the average roundtrip velocity between A and B. As shown later in this paper, there is a contradiction between an external inertial observer recording light bouncing between points A and B of a rod moving at a constant velocity and another observer stationary relative to that rod. It is important to know that this synchronization process has no verified, empirical data to support this assumed convention. It is simply a stipulation that alludes to one's experience, which often is misleading using casual observations. For example, it has taken millennia to refute the illusion that Earth is the center of the universe, as the cosmos always appears to rotate around us without noticeable vibrations. Equation §1.1 is Einstein's stipulation that light transmission is the same in either direction, but the roundtrip excursion can be the same if light's velocity is $c/2$ in one direction and infinite on the return, or infinite in the initial direction and $c/2$ on the return, or anything between [2]. Einstein chose this option that the transmission interval of light between A and B is identical in either direction with no evidence to justify his choice. He later wrote, "That light requires the same time to traverse the path $A \rightarrow M$ as for the path $B \rightarrow M$ is in reality neither a supposition nor a hypothesis about the physical nature of lights, but a stipulation which I can make of my own freewill in order to arrive at a definition of simultaneity." [3, page 27] So, Einstein's synchronization convention is very subjective and must be scrutinized.

Another problem is Einstein often equated simultaneity and synchronization, which are not identical. The author defines simultaneity as two or more phenomena that either split, divide, separate, etc., or merge, collide, overlap, join, mix, fuse, coalesce, unite, combine, etc. at one point at one instant of time. An observer is effectively a point in space. So, communications of events arriving at the same time instant at the observer's location are simultaneous for that observer. Einstein required that a clock is needed to assign a time at the coordinate position within some acceptable neighborhood for all phenomena in that neighborhood (i.e., coordinate time). To make any meaningful timescale for all such clocks

[1]Original italics implying a convention: Die letztere Zeit kann nun definiert werden, indem man *durch Definition* festsetzt, daß die „Zeit", welche das Licht braucht, um von A nach B zu gelangen, gleich ist der „Zeit" welche es braucht, um von B nach A zu gelangen.

within the domain of a reference frame, those clocks must be synchronized to a master clock, preferably using light to communicate the time tags between clocks. Einstein required that the interval to transmit time from A to B be the same from B to A for synchronizing clocks to a master timepiece for a standard timescale. The author defines synchronization as two or more separated events or phenomena as having the same coordinate time at different locations. Much like a team competes in synchronized swimming, the parallel actions do not interfere between team members. Such competitions are not called simultaneous. An example of a simultaneous event is the collision of two cars in an intersection. All observers witness this event as simultaneous, whether they are stationary, move at a uniform velocity, or accelerate relative to the intersection. All such observers saw by way of light and heard by way of sound the simultaneous collision of vehicles. This underscores the most fundamental principle of physics: all observers concurrently measuring the output of an experiment must have identical or equivalent results, especially when the recorded data are transformed to one reference frame. Even in a court of law, all credible witnesses of an event testify to the same outcome. A corollary to this fundamental principle is that any theory failing to predict the same outcome for all observers concurrently witnessing an event is inconsistent and needs revision.

Einstein tried to demonstrate that a simultaneous event in one inertial frame is not necessarily simultaneous in another inertial frame [3]. He considered a thought experiment where two lightning strikes hit points A and B synchronously on the ground equidistant from a ground observer and a train passenger collocated at a midpoint M (i.e., both observers are located on the perpendicular bisector to the line AB with the ground observer abreast with the train passenger at the instant of the lightning, but the passenger is moving at a constant velocity). Einstein did not consider the physical limitations of the human eye, because the standard frame rate of movies is 24 per second. One can embellish the thought experiment with ultrahigh speed video cameras and attachments to serve as suitable observers recording the events. All railcars can be equipped with synchronized clocks, lightning rods and cables touching the rails to conduct the lightning into the ground. On the ground, there are synchronized clocks beside tall lightning rods at A and B. The train is moving at a constant velocity V in a direction parallel from A to B. One lightning bolt branched to strike lightning rods at A and A' simultaneously (i.e., lightning rod A stands on the ground and A' is on the railcar, but both are in the same neighborhood), and another bolt hits both lightning rods of B and B' simultaneously. The times of the ground clocks and train clocks were recorded when current in the cables conducted electricity into the ground, and the comparison reveals that the twin lightning bolts occurred synchronously (i.e., same coordinate time) between A and B and between A' and B'. The ground camera at M records simultaneous reception of light from A and B, but in the finite time for light to traverse toward M, which would be in microseconds, the camera located at M' on the train has moved slightly closer to B, causing the moving camera to record light from B' sooner than A'. Einstein considered the twin bolts to strike simultaneously in the ground frame, not synchronously, because the distances traversed were identical and, with a constant light speed, the ground observer saw simultaneous light from both bolts at M. In the train, Einstein considered the train observer still saw light from B earlier than A, but with equal distances of $A'M'$ and $B'M'$ and a constant light velocity of c, Einstein inferred the train observer must decide that the bolt struck B' sooner than the bolt at A'. Thus, Einstein concluded this demonstrated that events may be simultaneous in one inertial frame and not in another inertial frame [3]. He did not have a rigorous definition for simultaneous and overlooked another possibility. His inference that the train observer concludes the bolt struck B' sooner than the bolt at A' contradicts his initial requirement that both bolts struck synchronously. The alternate explanation is the effective light speed (and sound speed) is faster because the train observer is moving toward the lightning bolt (and thunder) from B and receding from the A bolt, which creates a slower net velocity. His dual lightning strike illustrates the net velocity of light obeys vector addition of velocity between the source and observer.

Einstein never explained how this paradox occurs in select frames. In this embellished version, both cameras are identically at the midpoint at the onset of the dual lightning strikes. In the ground frame, the ground camera at M records simultaneous reception of lightning. With still air, the camera also records audio that would register simultaneous sounds of thunder. The train camera at M' moved toward B while light approached the train's camera. This camera will record light from B' sooner than A' as well as thunder from B' before recording thunder from A'. However, in the inertial train frame, the equal distances of $A'M'$ and $B'M'$ are maintained, and an examination of the time logs would show the dual lightning strikes occurred synchronously by the train clocks. Even length contraction of both $A'M'$ and $B'M'$ would still maintain equal distances. Time dilation would only make the train clocks mutually slower than the ground clocks, but it would not disturb the synchronization between the train clocks. With a universal light speed for all inertial frames, theory would predict simultaneous reception for the train camera at M'. This contradiction implies one or more assumed concepts may be incorrect. This thought experiment is a precursor for examining whether Einstein's stipulated clock synchronization procedure and assumed relativity postulate are consistent or contradictory. In any case, physics is the science that explains how nature operates with the goal of combining similar phenomena under one explanation.

II. EINSTEIN'S THOUGHT EXPERIMENT: REFLECTING LIGHT BETWEEN ROD ENDS

Einstein defined his second postulate of relativity, "Any ray of light moves in the 'resting' coordinate system with the definite velocity c, which is independent of whether the ray was emitted by a resting or by a moving body. Consequently, velocity = (light path)/(time interval) where time interval is to be understood in the sense of the definition in §1. Consider a rigid rod at rest whose length is L when measured by a measuring rod which is also at rest. We now imagine the axis of the rod lying along the x-axis of the resting coordinate system, and that a uniform motion of parallel translation with velocity v along the x-axis in the direction of increasing x is then imparted to the rod. [1, §2, lines 10-17]...We imagine further that at the two ends A and B of the rod, clocks are placed which synchronize with the clocks of the resting system—that is, that their indications correspond at any instant to the 'time of the resting system' at the places where they happen to be. Consequently, these clocks are 'synchronous in the resting system'. We imagine further that with each clock there is a moving observer, and that these observers apply to both clocks the criterion established in §1 for the synchronization of two clocks. Let a ray of light depart from A at the time t_A, let it be reflected at B at the time t_B, and reach A again at the time t'_A. Taking into consideration the principle of the constancy of the velocity of light, we find that

$$t_B - t_A = \frac{r_{AB}}{c-v} \text{ and } t'_A - t_B = \frac{r_{AB}}{c+v}$$

where r_{AB} denotes the length of the moving rod—measured in the resting system. Observers moving with the moving rod would thus find that the two clocks were not synchronous, while observers in the resting system would declare the clocks to be synchronous." [1, §2, lines 41-54].

Einstein's formula produces (time interval) = (light path)/c. The following analysis will determine the path length that light with its finite velocity c took to overtake the receding end B of the moving rod and the path length to intercept the approaching end A after reflecting from B. It is emphasized here that simultaneous events in one reference frame transform to equivalent coordinate points and time instants in another reference frame. In Einstein's thought experiment, the light leaving A at the instant t_A is a simultaneous event (i.e., atoms located in the neighborhood of A emit photons at one instant of time, separating a photon from an atom), which is a single point at an instant of time in mutually overlapping reference frames. The reflection of light at B is also simultaneous, as it is the absorption and emission of photons with atoms of the reflective surface in the neighborhood of B occurring at a point in a virtual instant of time. There are two observers: one fixed relative to the rod moving at a uniform velocity $v < c$ along the positive x-axis of the stationary frame and the other observer fixed in the stationary frame. Let the moving rod be attached to an inertial laboratory frame. The laboratory observer measures a rod of length, L, for the one-way light path, calculates the roundtrip light path is $2L$, and determines that the time interval of $A \rightarrow B$ is the same as $B \rightarrow A$ when light speed has a fixed velocity, which conforms to Einstein's synchronization convention. The transformation between the laboratory frame and the stationary frame is a simple Galilean conversion, which is $x' = x_o + v(t - t_o)$, $y' = y$, $z' = z$, and $t' = t - t_o$ where the primed terms apply to the laboratory frame and unprimed terms apply to the stationary frame.

In the stationary frame, the light paths will be derived for the separate legs of $A \rightarrow B$ and $B \rightarrow A$. This is identical to Zeno's paradox of Achilles and the tortoise, who convinced Achilles that he would always be behind the tortoise after a head start, even after an infinite number of time intervals elapsed, implying Achilles would never catch up to the tortoise and would lose the race. The ancient Greek mathematicians did not understand that a finite time interval could be divided into an infinite number of subintervals, allowing Achilles eventually to overtake the tortoise and win the race. Similarly, a light beam emitted at A in the stationary frame overtakes the receding end of the moving rod, B, at some point B' in the stationary frame. Assume the speed of light is c in the stationary frame. When the emitted beam travels the distance L over the time interval L/c, the receding rod end, B, has traveled a further distance, $\xi(1)$. When that beam travels the extra distance $\xi(1)$, B has moved a further distance $\xi(2)$ over the same time interval of $\xi(1)/c$. Over n repetitions of this, the rod moved a distance of $L + \xi(1) + \xi(2) + \ldots + \xi(n)$ where $\xi(1) = v \times (L/c)$ and $\xi(i+1) = v \times \xi(i)/c$. Substitute the individual terms with $v < c$, and the series is:

$$L + v\frac{L}{c} + v\frac{\frac{Lv}{c}}{c} + \cdots + v\frac{\frac{Lv^{n-1}}{c^{n-1}}}{c} =$$

$$L + L\frac{v}{c} + L\frac{v^2}{c^2} + \cdots + L\frac{v^n}{c^n} = \frac{L(1-v^n/c^n)}{1-v/c}$$

$$L_{\rightarrow} = \lim_{n\to\infty} \frac{L(1-v^n/c^n)}{1-v/c} = \frac{L}{1-v/c} = \frac{cL}{c-v} > L \qquad (1)$$

This is the length of the light path to intercept the receding end of the moving rod, B, at some point B' in the stationary frame. After reflection, the beam travels a shorter distance than L as the rod end, A, approaches it. Note that the velocity of the reflected beam is opposite the direction of the moving rod, so that the ratio of v/c is negative. Substitute this into the series (1) to find the distance from B' to intercept the rod's A end at A' in the stationary frame using v and c as speeds.

$$L - L\frac{v}{c} + L\frac{v^2}{c^2} - \cdots + (-1)^n L\frac{v^n}{c^n} = \frac{L(1-(-1)^n v^n/c^n)}{1+v/c}$$

$$L_{\leftarrow} = \lim_{n\to\infty} \frac{L(1-(-1)^n v^n/c^n)}{1+v/c} = \frac{L}{1+v/c} = \frac{cL}{c+v} < L \qquad (2)$$

The roundtrip light path in the stationary frame is

$$L_{\rightarrow} + L_{\leftarrow} = \frac{cL}{c-v} + \frac{cL}{c+v} = \frac{2L}{1-\frac{v^2}{c^2}} > 2L \qquad (3)$$

Algebra can verify (1) and (2). Solve for D in $D/v = (L+D)/c$ and replace it in $L_{\rightarrow} = L+D$, where D is the distance in the stationary frame that end B of the rod moved until light from end A intercepted B. Similarly, solve d in $d/v = (L-d)/c$ to substitute in $L_{\leftarrow} = L-d$ where d is the distance in the stationary frame that end A of the moving rod advanced toward the light reflected from end B until interception. Define $\gamma = (1-v^2/c^2)^{-0.5}$. Then (3) in the stationary frame has a roundtrip path of $2\gamma^2 L$. If one invokes length contraction from special relativity because the rod is moving, then length contraction replaces L as L'/γ, resulting in the roundtrip path of $2\gamma L'$ for the stationary observer versus $2L$ for the laboratory observer. This still does not resolve the disparity in the magnitude of the light paths predicted in the laboratory or stationary frames. The Lorentz transformation for length converts L in the laboratory frame to L/γ, which predicts equal lengths for light to travel $A \to B$ and $B \to A$. However, the stationary observer records that $L_{\to} > L_{\leftarrow}$, a difference of

$$L_{\to} - L_{\leftarrow} = \frac{cL}{c-v} - \frac{cL}{c+v} = \frac{2vcL}{c^2-v^2} > 0 \tag{4}$$

This result is a major discrepancy between observers. These are simultaneous events when the observers concurrently witness the phenomena. Light is emitted from its light source at A, which is common to both laboratory and stationary frames. Light is reflected at B in the laboratory frame and at B' in the stationary frame (i.e., photons are absorbed and then emitted in the opposite direction by the atoms on the reflecting surface at the virtual point in either frame according to Snell's law). Finally, the light beam is absorbed at the rod's end at point A in the laboratory frame, which must be the same point location as A' in the stationary frame. The roundtrip light paths measured precisely in both frames are not equal, especially after all measurements are transformed to a common reference frame. The corollary from the fundamental principle of concurrent observation reveals some theoretical concepts are inconsistent and need updating.

As cited above, Einstein believed his dual lightning test demonstrated simultaneity for the ground observer, but nonsimultaneity for the train observer, who would conclude lightning at B struck earlier than lightning at A. [3, p. 30], which contradicts the test requirement that both strikes occurred synchronously in both frames. For example, a pedestrian standing on the corner of an intersection witnesses two cars collide upon entering an intersection simultaneously, but a moving driver approaching the intersection reports nonsimultaneous entry of the two cars, which results in no collision. This is absurd, and the corollary requires some theoretical concept must be revised. Einstein never included criteria showing which inertial observers concurrently witness synchronized or nonsynchronized events. Einstein's concepts of simultaneity and universal light speed are imprecise or inconsistent, which is unacceptable for rigorous physics experimentation.

The speed of light cannot be the universal value of c, as the transmission intervals along the moving rod are unequal in the stationary frame, but equal in the inertial laboratory frame fixed with the moving rod. Simply divide c into $L_{\to}$ and $L_{\leftarrow}$, getting unequal results that violate the synchronization convention. On closer examination, two different sets of photons are involved with this thought experiment. One set of photons is emitted from end A, traveling parallel with the moving rod to end B until absorption by the atoms of the reflective surface at end B. The other set of photons are emitted by the reflective atoms at end B, moving antiparallel to the moving rod until absorbed by the atoms at end A. Because two different sets of photons are involved, designate $c_{\to}$ for the light speed from $A \to B$ and $c_{\leftarrow}$ for light speed moving $A \leftarrow B$. However, the stationary observer can synchronize identical clocks at points A' and B' to match the master clock A^* before the test (A^* is collocated at the rod's A at $t_o = 0$). Attach two identical clocks to the ends of the rod (i.e., the rod's A and B) and set those two clocks to match the master time t at A^* in the stationary frame (e.g., $t_o = 0$ in the Galilean transformation). Impart a velocity v to the rod and the laboratory fixed with the rod. As required by Einstein's synchronization convention, the transmission intervals for light to travel $A \to B$ and $B \to A$ in the laboratory frame must be equal using the clocks at the ends of the rod. The stationary observer compares the times of the clocks when B of the rod is at B' and later when the rod's point A is at A'. As stipulated by Einstein, if a clock at B is synchronized to a clock at A, then the clock at A is synchronized to the clock at B, and if a clock at A is synchronized to clocks at B and at C, then the clocks at both B and C are synchronized with each other [1, §1, lines 50-53]. The stationary observer records equal time intervals of transmission for the two separate legs with $A^* \to B'$ and $B' \to A'$, as all five clocks are synchronized. The formula is (time interval) = (light path)/(light speed), and the two legs defined by a moving rod have unequal light paths in the stationary frame, yet the time intervals of transmission are equal.

To resolve this apparent dilemma, rewrite (1) and (2) for the light paths with the generalized light speeds where $c_{\rightarrow}$ is parallel to the rod's velocity in the initial traverse and $c_{\leftarrow}$ is antiparallel in the reflected traverse.

$$L_{\rightarrow} = \frac{c_{\rightarrow}L}{c_{\rightarrow}-v} > L \qquad (1')$$

$$L_{\leftarrow} = \frac{c_{\leftarrow}L}{c_{\leftarrow}+v} < L \qquad (2')$$

Divide by the appropriate light speed for that leg of the roundtrip into the light path and equate the time intervals as required by Einstein's time synchronization equation §1.1.

$$t_B - t_A = \frac{L}{c_{\rightarrow}-v} = \frac{L}{c_{\leftarrow}+v} = t'_A - t_B \qquad (5)$$

Equation (5) is valid only if the denominators are identical, nonzero constants and light speed varies. This means $c_{\rightarrow} = c + v$ and $c_{\leftarrow} = c - v$ with c being a nonzero constant. When the laboratory observer is fixed relative to the light source, then the speed of light is apparently constant in the laboratory frame as $v = 0$. In the stationary frame, the stationary observer records different light paths and different light speeds such that the time of transmission is the same for either leg. Thus, light's speed obeys the magnitude of vector velocity addition.

The speed of light in a vacuum could not be a universal constant for inertial frames by comparing the synchronization convention against an assumed constant light speed. Even special relativity can not transform a measured speed of light in one inertial frame into the same numerical quantity in another inertial frame that has a uniform velocity relative to the first frame. Let the numerical value of c be 299792458 m/s in the stationary frame. Before measuring light, the laboratory is at rest in the stationary frame, so that the laboratory has an identical meter standard and a synchronized clock maintaining the second as the stationary observer's master clock. Accelerate the laboratory to a fixed velocity so that the laboratory observer can concurrently measure light speed with the stationary observer. According to special relativity, the moving observer has a shorter meter for length and a longer second for time (i.e., $\Delta L_S = \gamma \Delta L_{Lab}$ and $\gamma \Delta\tau_S = \Delta\tau_{Lab}$). The Lorentz transformation would cause concurrent measurement of light speed in different inertial frames to be:

$$c_{Stationary} = (c)\frac{meter}{second} = \left(\frac{\#\ length\ units}{1\ time\ unit}\right) \times \frac{\gamma \Delta L_{Lab}}{\Delta\tau_{Lab}/\gamma}$$

$$= (c\,\gamma^2)\frac{\Delta L_{Lab}}{\Delta\tau_{Lab}} = (c')\frac{\Delta L_{Lab}}{\Delta\tau_{Lab}} = c_{Lab} \qquad (6)$$

Numerically, $c = c_{Stationary} \neq c_{Lab}$ as $\gamma > 1$. For example, light speed is now defined as 299792458 m/s, which can be converted into yards/minute where yard < meter (illustrating length contraction) and a minute > second (demonstrating time dilation). In this example, the laboratory's numerical number is larger than the standard c number. According to special relativity and with today's high precision in metrology, some variation in the numerical value of light speed should be observed in a laboratory by varying velocity as Earth rotates and revolves about the Sun relative to outer space. Again, light speed appears constant only if the observer is fixed relative to the source of light (i.e., $\gamma = 1$ if $v = 0$) and if light's velocity obeys vector addition of velocity.

The clock synchronization convention is only valid when the distance between remote clocks remains constant during the calibration. Einstein assumed a constant r_{AB} between clocks on the moving rod during the whole synchronization process. In the example of a stationary observer with a master clock at A^* in the stationary frame (i.e., colocation of the moving rod's A at $t = 0$) and the clock at B on the moving rod, it would be impossible to calibrate clock B using the synchronization convention when the distance changes between A^* and B during a light transmission.

III. EXPERIMENTAL EVIDENCE FOR LIGHT'S CHANGING VELOCITY

The previous section theoretically demonstrates that light's speed obeys the magnitude required in vector velocity addition, which also mandates that photons must move in the required direction.

A simple test would demonstrate that emitted photons acquire the added velocity in the direction supplied by the photon emitter. Set a laser to point horizontally at a partially silvered mirror that is angled at 45 degrees relative to the local plumb line. The reflected beam is aimed vertically to a hemisphere mirror that is a distance, d, of about 10 meters above the partially silvered mirror, so that the hemisphere is centered along the light beam. The vertical beam is reflected from the hemisphere of 2 cm radius, r, to the partially silvered mirror below, and some light is transmitted through it to the floor below. Observe if the impact point varies over time as Earth rotates. If there is a sideway displacement of the vertical light path due to the velocity $\boldsymbol{v}$ of Earth around the Sun, the beam should miss the nadir of the hemisphere mirror by an angle of $\theta \approx \sin(\theta) = v\Delta t/r = vd/(cr)$ in radians. The reflected beam from the hemisphere mirror should touch the floor about $d\ \theta$ = 50 cm from the plumb line assuming $v \approx 30000$ m/s for Earth's orbital velocity. Even assuming the orbital speed is 15000 m/s from the cosine projection onto the 10 m arm, this would still cause a 25 cm displacement from the plumb line. If no noticeable displacement from the vertical plumb line over a day is detected within the laboratory frame fixed on Earth, this demonstrates that photon velocity obeys angular vector direction in some stationary frame fixed in outer space. In the elapsed time that photons move from the hemisphere mirror to the floor, Earth's revolution has displaced the floor in a varying direction relative to the initial plumb line in the external inertial frame and imparts a varying distance to the floor (like the moving ends of the rod previously discussed). As multiple photons over hours keep impacting the same point on the floor, this demonstrates that the light source (e.g., the hemisphere mirror) imparts an additional vector velocity to the photons in the external inertial frame while the floor is fixed relative to the hemisphere mirror.

Such a null result has been demonstrated repeatedly with the Michelson-Morley interferometer tests with equal arms and Kennedy-Thorndike interferometer tests with unequal arms. Einstein never published any analysis of the Michelson-Morley experiment, even in his book, which he deferred to Lorentz, who "showed that the result obtained at least does not contradict the theory of an aether at rest". [3, p.168] "Lorentz and FitzGerald rescued the theory from this difficulty by assuming that the motion of the body relative to the aether produces a contraction of the body in the direction of motion, the amount of contraction being just sufficient to compensate for the difference in time mentioned above." [3. p. 59] During any interferometer testing, no one has reported that one beam moved off the reflection mirror or the recombination point.

The problem with the analysis that Lorentz and others ignored is there are two components of velocity, V_x and V_y, parallel respectively to the x-axis and y-axis of an interferometer—not just one component velocity—after combining all velocities of the laboratory relative to the cosmos. Define γ_x using the velocity V_x, and γ_y using V_y, and define L_x for the length of the x-axis arm and L_y for the y-axis arm. The Lorentz analysis works if $V_y = 0$ so that $\gamma_y = 1$. In general, $V_y \neq 0$ so that L_x $L_x = \gamma_y L_x'$, which undermines the Lorentz analysis that requires the x-axis arm to remain at length L_x, not the shorter L_x'. Comparing the unequal roundtrip paths over both arms and the assumed constant speed of light, special relativity would predict destructive interference, contrary to the observations [4].

The most sensitive version of the Michelson-Morley interferometer is the Laser Interferometer Gravitational-Wave Observatory (LIGO), which two observatories are located near Hanford, Washington, and Livingston, Louisiana. Both have 4 km long arms within nearly perfect vacuum chambers allowing laser beams to detect gravity waves. Virgo is a similar observatory in Italy that has recently joined the search for gravitational waves. LIGO uses a continuous laser beam that is amplified from 40 watts to 750 watts with power reflecting mirrors. LIGO has enhanced vibration absorption mechanisms to remove ground vibrations, tremors, solid Earth tides, etc. to isolate the signals. To increase the arm lengths from 4 km, Fabry-Perot cavities are installed near the beam splitter and near the hanging reflection mirror at the end of each arm so that 300 reflections inside the cavities increase the effective arm length to almost 1200 km. A virtually perfect vacuum is maintained so that any gaseous molecule is removed promptly to avoid interference or extraneous reflections with the light beams. Also, one of the split signals is inverted to create complete destructive interference when recombining the two beams [5]. The original Michelson-Morley interferometer produced constructive interference, but this enhancement allows far easier detection of any light against an absolute black background, while it is hard to detect any light variation against a bright background, much like the inability to see sunspots when looking at the Sun. "At its most sensitive state, LIGO will be able to detect a change in distance between its mirrors 1/10,000th the width of a proton." [5]

The following table lists the locations in latitude and longitude of each observatory and the azimuths of each observatory's x-axis and y-axis relative to due east in a counterclockwise direction [6]. No altitude was listed, and no map datum was defined. So, a precise calculation to determine the actual radius of latitude for each arm end is not possible.

Table 1: Directional Azimuths of LIGO Axes.

Observatory	Latitude	Longitude	Azimuth (x-axis)	Azimuth (y-axis)
Hanford	46°27′ 19″N	119°24′28″W	126°	216°
Livingston	30°33′ 46″N	90°46′27″W	198°	288°
Virgo	43°37′ 53″N	10°30′16″E	71°	161°

At each observatory, the x-axis and y-axis arms are joined at a common point where the laser light is split. The reflecting mirror at the opposite end of either arm is suspended on cables. Designate A for the common point of the arms, B for the end of the x-axis arm, and C for the end of the y-axis arm. The LIGO observatories are stationary in the Earth-Centered, Earth-Fixed (ECEF) frame. Consider a sufficiently inertial frame that is freely falling with Earth's center of mass, but without rotation. Let R_A, R_B, and R_C be the radii of the latitude circles through the respective A, B, and C points of the arms. The Earth's rotation, ω, imparts a tangential velocity to the ends of the arms that is ωR_i in the falling frame. The event of splitting the light beam at point A, the event of light touching and reflecting off the mirror at point B, the event of light touching and reflecting off the mirror at point C, and the event of combining the two beams at point A occur at different instances of time. These are four separate simultaneous events seen by the ECEF observer on Earth's surface and by the observer fixed in the falling frame.

The combined beams arrived simultaneously at A with complete synchronization (i.e., destructive interference due to one beam being inverted). The output is witnessed by both observers to be the same. All LIGO observatories are currently in the northern hemisphere. Note that the ECEF observations are accelerated due to Earth's rotation, but the output is the same as if the ECEF frame was nonrotating. Photons emitted by atoms at points A, B, and C travel at their initial speed, due to nearly perfect vacuum in the tunnels. Any arm with an azimuth less than 180 degrees will have point A as the southernmost point and B or C as the northernmost. If the azimuth is between 180 and 360 degrees, then B or C is the southernmost and A is the northernmost point. Each arm is displaced eastward due to Earth's rotation. As derived in equations (1′) and (2′) for the moving rod, the endpoints of the arm are displaced by the cosine projection of the tangential velocity multiplied by the time of transmission of light over the arm. In the freely falling frame, the photons traverse the arm in the one-way distance of $cL/[c \mp \omega R_i \cos(\text{azimuth})]$ where i represents A, B, or C for the photons emitted at A, B, or C, and $\mp$ is chosen as photons move parallel or antiparallel in the arm. The light speed can not be a constant c in the falling frame for the LIGO observatories and still combine light beams at A to be synchronized with equal times of roundtrip transmission. All one-way distances for both x-axis and y-axis arms are unequal in the nonrotating frame and the tangential velocities are unequal (i.e., $\omega R_A \neq \omega R_B$, $\omega R_B \neq \omega R_C$, and $\omega R_A \neq \omega R_C$ because the latitudes of the endpoints are different). The theory only agrees with the observed complete synchronization of the merged beams at A when light speed obeys addition of vector velocities where photon velocity equals the standard velocity of light plus the velocity of the light source (i.e., $c' = c \pm v$ in (1′) and (2′)).

If light obeys vector velocity addition, then a different interpretation of the Sagnac effect is needed. Light is inserted into a ring interferometer and splits in opposite directions at entry. The beams exit the ring at the entry point and undergo interference. The destructive interference determines how much the ring interferometer rotated after the beams were split. The diagram on the left of Figure 1 [7] shows a nonrotating ring of radius R would output constructive interference as each beam would travel the same length of $2\pi R$ and exit at the same time. If the ring interferometer rotated as shown on the right side of Figure 1, one beam would travel further than the other, so both beams would exit with destructive interference.

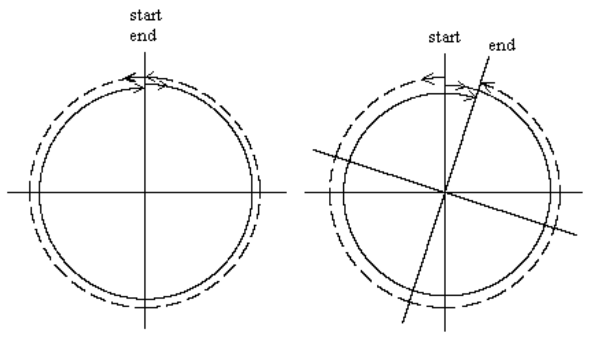

Figure 1: Sagnac effect in circular loops

It is easy to see as an external observer that one beam takes a longer trip than the oppositely traveling beam when the interferometer rotates. The rotating interferometer is a frame that is sufficiently inertial when comparing the constant angular velocity ω with the speed of light. The ring is a conduit, which is accomplished with fiber optics, that bends both beams to traverse in a circular path. A perpendicular acceleration is required to force the light beams to traverse a circle in the rotating interferometer. Such an acceleration is no different than the perpendicular gravity that exists for the Mickelson-Morley interferometer, as any acceleration to the linear paths will be equal to both beams, so the gravitational effects cancel out when combining the two beams.

One common application of the Sagnac effect is found in inertial navigation systems where the interference measurement device is fixed at the exit or end of the rotating ring gyroscope. If an observer is fixed with the rotating ring, special relativity requires that each beam originates with the same constant light speed, c, and each beam travels the circumference of $2\pi R$ inside the inertial rotating frame. This set of assumptions of special relativity for the ring's rotation undergoing constant angular velocity, ω, would predict both beams exit simultaneously (i.e., constructive interference in the output), but reality contradicts that theoretical prediction.

In an external frame, the beams are bent in circles, and the difference in distance is (4). Externally, light speed is c, and the time difference between the exiting beams in the external frame when substituting $L = 2\pi R$ and $v = \omega R$ into (4) is [7]:

$$\Delta t = \frac{2\pi R}{c}\left[\left(\frac{c}{c-\omega R}\right) - \left(\frac{c}{c+\omega R}\right)\right] = \frac{4\pi\omega R^2}{c^2-\omega^2 R^2} \qquad (7)$$

Inside the interferometer, the two beams traverse identical distances of $2\pi R$ in the internal frame, and the output must be identical as (7). The speed of the corotating beam is $c-\omega R$, and the speed of the counterrotating beam is $c+\omega R$ by (7). The identical observed interference [7] of output is witnessed in both inertial rotation frames (i.e., $\omega = 0$ in the stationary rotation frame and a constant $\omega > 0$ for the rotating frame that is fixed with the rotating ring interferometer). Even internally, an observer fixed to an inertial rotation frame can detect rotations via the output. Thus, light obeys vector velocity addition in both linear and rotational frames.

IV. RAMIFICATIONS

It will take time for others to verify the results of this research, but if the velocity of photons does obey vector velocity addition, then several concepts of physics must be addressed. The finding that light's speed in a vacuum can vary generalizes light's behavior to be the same in a vacuum and in transparent materials. The speed of light in a vacuum is faster than in any transparent material medium, and the index of refraction is the ratio of light's speed in a vacuum compared to the medium. The frequency of light in the medium is the same frequency of light in a vacuum when light enters or exits the medium. The number of waves passing through the material is the same as the number arriving at its surface. Waves cannot pile up and collect anywhere. If light's speed depends on the velocity of the emitting atoms, then $c' = c + v = f\lambda'$. The vast cosmos consists of empty space that is virtually a vacuum. The observed wavelength, λ, could well indicate the opposite that Doppler shifts would predict when assuming light in a vacuum is always the constant c. Since no medium is involved in the transmission of light through a vacuum, the principle of relativity asserts that it can be only the relative velocity of an approaching light source, v, that reduces the Doppler formulas when $c \gg v$ to $\Delta f = (v/c)f$ and $\Delta\lambda = -(v/c)\lambda$. For example, if the spectral lines of hydrogen in a star are longer in wavelength making $\Delta\lambda > 0$, then the standard Doppler formula implies $v < 0$, indicating that star is receding. If c' can vary in outer space and $\lambda' > \lambda$ with no change in frequency, this causes $c' > c$ and $v > 0$, which indicates the star is approaching. This means that all observed galaxies have reversed velocities, which will affect all cosmological models.

Readers will recall that most textbooks state that no particle travels faster than the speed of light in a vacuum. Countless electromagnetic experiments seem to demonstrate this. One of the best videos of a rigorous test using a linear accelerator demonstrated that electromagnetic fields do not accelerate free electrons faster than c [8]. As the electromagnetic energy was increased to accelerate the free electrons, the velocity of the electrons approached an asymptote of c. The film verified the timing cables were calibrated. It also showed that the colliding electrons did impart heat to the target that nearly equaled the total energy given to the electrons, but the speed of the electrons approached c. The test is just as valid today as then. Unfortunately, the conclusion has been overgeneralized to state that nothing can go faster than the speed of light. Photons generated by electromagnetic fields are limited to the standard light speed as emitted from the molecules to impart increases in momentum to the charged electrons. The free electrons can be nudged forward by momentum transfer if slower than the moving photons. Once free electrons obtain the limit of the standard light speed, the photons can no longer transfer momentum to nudge the free electrons any faster, although more energy can be given to the electrons. Such tests prove that an electrodynamic force alone does not accelerate charged particles faster than the standard light speed in a vacuum relative to the electromagnetic source. Note that the electromagnetic field produced by the linear accelerator, and the timing devices were stationary relative to each other in the laboratory frame. In this case as demonstrated by the video [8], the electrons can not be accelerated any faster than the standard light speed when the accelerator, the electromagnetic field, the timing sensors, and the target are fixed at the same distances throughout the test.

This paper demonstrates that the measured speed of light will be the standard speed when light sources and detection equipment are mutually fixed. However, when the source has an additional velocity relative to the detector, then Maxwell's equations must be modified to allow c to vary outside of the laboratory frame. This means that Einstein's assumptions for the axioms of special relativity theory are indeed excellent approximations, but not exactly accurate. For example, the last section of Einstein's 1905 paper contained the dynamics of the slowly accelerated electron [1, §10]. He derived that longitudinal mass would differ from transverse mass. No test has confirmed this even exists—directly or indirectly. No one has shown Einstein's derivation has any mathematical flaw concerning this subject. This unverified topic should have raised doubts about the accuracy of these two postulates of relativity. Most electrodynamic experiments do not approach the precision in significant digits to test Maxwell's equations when the sources are moving independent of the detectors.

Some may argue that prior tests measured the same standard speed of light emitted by moving stars external to Earth. In one case, Brecher [9] took the pulses observed from binary x-ray sources to test whether light speed $c' = c + v$. Brecher wrote “The projected radial velocity (toward the observer) will then vary with time as $v(t') = v \cos\omega t'$, where t' is measured in the source frame. Now consider a pulse emitted at the time t' in the source frame.” In that paper's equation (2), the denominator is $(c + kv \cos\omega t')$, which means ω as $\omega(t')$ and v as $v(t')$ are in the star's source units, else one is mixing units in the cosine argument. Brecher should have used primed terms in the equations to represent variables and units in the source frame, instead of mixing the variables between the Earth and the source frames. In that paper, a total derivative was attempted, not a partial derivative, of the time t' that the pulse would arrive in Earth time t. The derivative, equation (4) in that paper, ignored any differentials of $d\omega(t')$ and $dv(t')$, and the star's speed of light $c(t')$ in its time unit was treated identically in the derivative as $c(t)$ in the Earth frame. Brecher's proof is flawed with an incorrect differentiation, and it assumes beforehand in that paper's equation (4) what is eventually claimed that $c' = c$ in only time t units.

Tests have been made to measure emitted photons from high-speed particles by laboratory devices. For example, γ rays from the decay of π^o mesons with more than 6 GeV were detected with lead converters, a scintillator, and a lead-glass Cerenkov counter. [10]. The test was intended to measure $c + kv$, and the result was $k = (-3\pm13)\text{x}10^{-5}$ for mesons moving near light speed ($\gamma>45$). The team used two light detectors spaced 31.450 m and two additional detectors spaced 4.5 m from the other detectors for verification to measure the time interval the γ rays traveled. Photons are absorbed initially and emitted by the atoms of the material. The first detector absorbed the photons from high-speed γ rays and then emitted new photons at the standard speed of light. The measured speed recorded by the second detector after photons were emitted by the first detector was the standard light speed with a fixed distance between the detectors. This and similar tests must be reexamined carefully to ensure that the photon speeds were directly measured without interception to eliminate misinterpretations of the results.

Others may recall that Ives and Stillwell [11] measured a transverse Doppler effect with canal rays of hydrogen in the parallel and antiparallel directions to see if the average of the blue and red shifted lines were equally spaced from the normal emission line. The shifted lines were equally distant from the center emission line and measured within experimental limits as predicted by the relativistic transverse Doppler effect. The cathode ray tube and the detector were stationary in the experiment, forcing any measurement of light speed to be the standard light speed, c, by the analysis in the earlier section. From a classical treatment using geometry only, the full classical transverse Doppler effect will be the same as the relativistic derivation. Assume the moving hydrogen ions in the laboratory emit light perpendicular to their velocity in Figure 2 with $L = c\ \Delta t$ over the length L marked as AB. In the external ‘stationary’ frame, the light traverses the hypotenuse $A'B$ where $D = c'\Delta\tau$. The perpendicular length AB moves constantly to the right in Figure 2 to create the triangle $AA'B$. The light originates at point A' and the perpendicular length moves sideways to the right at a constant velocity V. Light reaches the end at B. In the laboratory frame, light could travel the length AB in the time interval of Δt, but light actually travels the longer distance of the hypotenuse in $c'\Delta\tau$. Light reaches B when the base A' is directly below B at point A after the time interval $\Delta\tau$. The Pythagorean theorem [12] produces the equation:

$$\Delta\tau = \frac{\Delta t}{\sqrt{\left(\frac{c'}{c}\right)^2 - \left(\frac{v}{c}\right)^2}} \tag{8}$$

Immediately, $c' = c \Leftrightarrow \Delta\tau = \Delta t/\sqrt{1 - v^2/c^2}$. This is a classical derivation valid in three dimensions without length contraction. Length contraction is unnecessary, but if included, the total relativistic effect will be increased to γ^2, similarly as (6) shows. This derivation shows that the time dilation effect must be included in the classical transverse Doppler effect if the speed of light is assumed to be the standard speed c, which Ives and Stillwell assumed in their derivation [11].

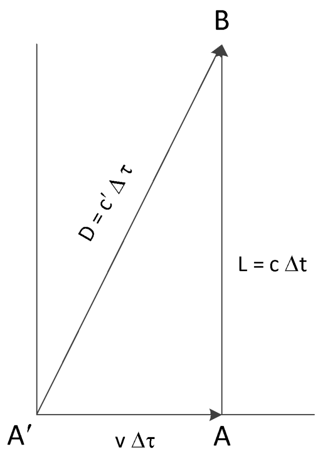

Figure 2: Constancy of light and time dilation.

Some standards of physics will need to be restored. The meter is now defined in terms of the time span it takes light to traverse a meter. This paper shows that photon velocity is affected by the velocity of the light source, and acceleration, such as gravity, can alter that additional velocity at emission. The International System (SI) definition does not define the environment that the meter is calibrated when using the speed of photons, but it states "The metre is the length of the path travelled by light in vacuum during a time interval of 1/299792458 of a second. It follows that the speed of light in vacuum is exactly 299792458 metres per second, c_0 = 299792458 m/s." [13]. One problem is this is a circular definition, which renders it useless. The definition of light speed does not change even if one can repeatedly measure light speed to more precision than 9 significant digits. As a meter is now defined as a time unit, all displacements, velocities, and accelerations are reduced into time units. Philosophically, the universe is collapsed into one dimension instead of four dimensions. This is at best bizarre and illogical at worst as time has no known vector direction to set spatial axes perpendicular to the time axis and is impossible to revisit the starting point or epoch in a time scale for recalibrations or setting the origin of a reference frame by time alone. It is impractical when replacing a length as a time unit, which converts velocities into unitless numbers with unit vectors, making a velocity indistinguishable and equivalent to a position in a reference frame. Such definitions solidify mistaken concepts by changing the original definition with the intention of improving accuracy. For example, the nautical mile is defined now as exactly 1852 meters [13], but the original nautical mile was defined as 1 arcminute on the equator. Since 1984, the International Union of Geodesy and Geophysics (IUGG) [14] and the Global Positioning System (GPS) [15] have accepted the equatorial radius as 6378137 meters, which would make the nautical mile to be 1855.328 meters as an arcminute. This SI definition is almost 40 years old, illustrating that erroneous definitions are not readily updated or verified against the original definitions. A varying light speed should reestablish the physical meter standard as the international unit of length. Some other standards may need similar reexamination.

General relativity shows that gravity waves and light waves have the same universal speed [16, chapter 5]. "The existence of gravitational waves is an immediate consequence of special relativity and, to some extent, the experimental discovery of gravitational waves would merely confirm the obvious." [16, p. 242] If photons can move at different speeds in a vacuum, then gravity waves could have different speeds than the universal *c* speed. This may explain why the LIGO collaboration observes 10 to 100 daily detections with no physical explanation for most of these data. LIGO observations have been made in 3 long runs, and about 50 detections of gravitational waves have been announced. Maintenance and upgrades of the detectors are made between runs. The first run, O1, which ran from 12 September 2015 to 19 January 2016, made the first 3 detections—all black hole mergers. The second run, O2, ran from 30 November 2016 to 25 August 2017, which made 8 detections—7 black hole mergers, and 1 neutron star merger. The third run, O3, began on 1 April 2019 to 30 September 2019, and resumed from 1 November 2019 to 27 March 2020 until stopped due to the COVID-19 pandemic. At the time of this writing, LIGO had made 56 candidate detections, which may well change after this publication [17, 18].

By 2 November 2019, 41 events were announced (8 were later retracted) with 10 identified as neutron star-neutron star mergers or neutron star-black hole mergers [19]. Such events should have some type of electromagnetic emission, but no independent telescopic observation has confirmed any LIGO announcement. Ignoring or discarding the 10 to 100 daily detections as glitches without explanation is not the best science, which concerns a few relativists [19]. Adding the Virgo observatory and other similar facilities into the LIGO collaboration, three-dimensional gravity wave detections should locate the electromagnetic sources in the cosmos. This is straightforward when implementing in reverse the Very Long Baseline Interferometry (VLBI) method for Earth orientation relative to pulsars using concurrent observations. As galaxies move independently to Earth, any observed gravitational waves are probably not at the standard light speed. The actual detections between LIGO observatories may have different time delays than expected, because the speed of light associated for each gravity wave may be a nonstandard speed.

If photons have velocities other than c, then the standard model for particle physics may need to be updated. According to special relativity, energy, E, is related to mass, m, of a particle to the speed of light, c, in a vacuum through Einstein's energy equation $E = mc^2$. In the standard model, the electron, the muon, and the tau particles are identical in all properties except mass, according to the energy equation. If c can vary and increase, then m may be unchanging while E increases in distinct steps. In the standard model, each higher member of a generation has greater mass than the corresponding particles of lower generations. A single particle type would simplify the standard model, but it still leaves an unanswered question: Why are there three generations for each type of particle? It could be that particles are emitted at three discrete energy levels, which may be like Planck's discovery that black body radiation is emitted in discrete quanta.

If energy in particle physics can vary in discrete quanta, then the constants that incorporate energy units may not be constant when the energy source and the detectors move independently of each other. For example, Planck's constant, h, has units of Joule second (Js), and Boltzmann's constant, k, is in units of Joule/Kelvin degree (J/K). Consider the burst of a solar flare, which consists mostly of hydrogen and some helium, heading toward Earth. Does the spectral radiation change as light speed is increased due to the kinetic velocity of the emitting atoms in the flare approaching Earth? For example, Planck's spectral radiation law gives power P_λ in W/m^2 per $m\mu$ for the wavelength, λ, and temperature, T, as

$$P_\lambda = \frac{2\pi hc^2}{\lambda^5(e^{hc/\lambda kT} - 1)}$$

In some references, the term hc^2 is referred as the 'first radiation constant' and hc/k as the 'second radiation constant' [20]. If c can change due to the motion of the photon emitter, some 'constants' are no longer constant. The unit J is defined in terms of $kg\ m^2/s^2$, and if light velocity in m/s can change its numerical quantity, which would affect the photon energy in J, then it may be possible that Planck's constant and Boltzmann's constant would be affected as well. If the speed of light in a vacuum, c, can vary in general, then either the fine structure constant, a, or Plank's constant, h, or both, must vary.

A varying light speed would imply that the Lorentz time dilation is incorrect for many precise timing applications. Hafele and Keating claimed they demonstrated time dilation precisely using four atomic clocks flown in commercial aircraft in westward (275±21 ns) and eastward (40±23 ns) circumnavigation of the world [21]. Essen, one of two horologists at the National Physical Laboratory (NPL) who operated the original cesium clock in the 1955-1958 calibration effort that defined the current atomic second, had reviewed the Hafele-Keating report and concluded the alterations in drift rates of the atomic clocks were useless [22].

The author examined the clock rates in Tables 1 and 2 [23] of the Hafele-Keating report released in 1972. The drift rates of 3 of the clocks varied significantly before and after each circumnavigation in that paper's Table 1, This completely casts doubt that any average of the ensemble demonstrated relativistic time changes, as 3 of 4 clocks did not individually drift according to relativistic predictions. Table 2 of their paper proves the stability of those 3 clocks was not maintained throughout the test. Hafele had released his results at a 1971 conference, which Hafele even doubted his own test. He admitted, "Most people (myself included) would be reluctant to agree that the time gained by any one of these clocks is indicative of anything…." [24, p.273]. By averaging the time gain with 4 clocks, Hafele did get the average eastward circumnavigation with error bounds to agree with the predicted theoretical result, but there was no such fit between theory and the westward time gain [24, p. 282]. Keating later worked with Hafele to write the second report with claims that they verified time dilation [21], but careful examination uncovers many discrepancies.

The author's numerical findings on the Hafele-Keating drift rates were duplicated earlier by A. G. Kelly [25]. Kelly obtained the original raw data from the US Naval Observatory (USNO) to review against the published 1972 report and found several data in the tables differed significantly from raw data with no explanation. Kelly determined Clock #120 performed very irregularly. He wrote, "Discounting this one totally unreliable clock, the results would have been within 5ns and 28ns of zero on the Eastward and Westward tests, respectively. This is a result that could not be interpreted as proving any difference whatever between the two directions of flight". Kelly was not condemning relativity, but he was critical that the flight tests were not rigorous, and the claims were unverifiable based on the actual USNO raw data. If light speed is not a universal constant, then clocks may exhibit different time effects than the Lorentz time dilation, which would warrant a more rigorous retesting.

This is an incomplete list of possible ramifications if light speed is not a universal constant. In any case, it will take time to review the results of this paper.

V. CONCLUSION

Einstein stipulated the conditions to synchronize clocks in his definition, which were the distance between clocks must be fixed during the process and that the time interval to transmit electromagnetically is the same in either direction between the clocks, which is known as the Einstein time synchronization convention. However, no evidence was offered to support it. Einstein often interchanged the terms of simultaneity and synchronization, which are not identical. Simultaneous events occur when two or more phenomena separate or combine at one point at one instant of time. Synchronized events occur at separate points at the same coordinate time, which is maintained by separate clocks within acceptable neighborhoods around each location that have been synchronized by Einstein's convention to a master clock and that are stationary relative to that master.

Einstein further required that the speed of light be a universal constant based on experience, which is valid for the laboratory observer fixed to a uniformly moving rod and measuring light speed along the rod in either direction. It is shown that this leads to a contradiction with an external inertial observer viewing a uniformly moving rod of length L with clocks attached to both ends of the rod. By two separate techniques, the distance that light traverses to overtake the receding end of the moving rod is greater than L, and the distance to intercept the approaching end is less than L, but the sum of both legs is greater than $2L$. Assuming the same constant light speed for the external inertial observer will produce unequal time spans of transmission, contradicting Einstein's time synchronization convention. The requirement for a universal constant light speed is an excellent approximation due to the high speed of light compared to other typical velocities in physics. However, the laboratory observer, who is fixed relative to the rod, records equal lengths of L for the parallel and antiparallel traverses and predicts equal time intervals of transmission with a constant light speed. The events of light emission from end A, absorption and emission by reflection at B, and final absorption at A are all individual points occurring at separate time instants, which require that the laboratory and stationary observers witness each point simultaneously in concurrent measurements. This means that the external, stationary observer must also record equal time spans of transmission between A and B by the time synchronization convention.

In his 1905 paper, Einstein obtained two ratios describing the time transmission intervals between the two clocks previously synchronized on each rod's end for the external stationary observer relative to the moving rod. In the translation, he wrote, "Observers moving with the moving rod would thus find that the two clocks were not synchronous, while observers in the resting system would declare the clocks to be synchronous." [1, §2, lines 53-54].

If Einstein equated the two intervals for the two one-way transmissions as required by his time synchronization convention, he would have obtained (5), which reveals that the velocity of light obeys vector addition of velocity. Instead, Einstein stated the two time spans showed simultaneity in one inertial frame, but nonsimultaneity in another inertial frame. This directly contradicts his stipulations of the time synchronization convention. There is no velocity between the rod and the laboratory observer, so the ratios reduce to L/c in either direction. Equation (5) reveals that light speed must vary precisely for the external observer as $c_{\rightarrow} = c + v$ for the parallel beam and $c_{\leftarrow} = c - v$ for the antiparallel beam, which (5) obtains $(c + v) - v = c = (c - v) + v$. Thus, light speed appears to be a constant in all directions for both observers when the light source and light detector are at a fixed distance relative to each other and when light's velocity obeys vector addition of velocities.

The LIGO consortium provides evidence that light obeys vector addition of velocity. The observatories are giant versions of the Michelson-Morley interferometer that have two perpendicular arms of four km lengths with virtually pure vacuum chambers containing the beams, so that no free molecule interferes with the beam transmissions between the ends. Each observatory is at a different latitude, and the arms are oriented uniquely in azimuth relative to the local east direction. Relative to a freely falling Earth frame that is not rotating (e.g., an inertial frame with its origin at Earth's center of gravity), each arm end is located at different latitudes. The northernmost end is moving slower than the southernmost end from Earth's rotation in this inertial frame. The cosine projection of velocity parallel to an arm displaces each arm like a moving rod in the inertial frame. Let V_A be the rotational velocity at the combination point A for both arms, V_B for the endpoint B of the x-axis arm and V_C for the endpoint C of the y-axis arm. Equations (1′) and (2′) give the one-way distances the photons traverse, but the sum of the distances for the x-axis and y-axis are not equal since $V_C \neq V_B$. If light's velocity is a universal constant, the output of the merged beams would not be synchronized. The output of LIGO observatories is always synchronized after months of continuous operations over three extended periods (excluding the data detections). The principle of concurrent observation requires all observers in the accelerated observatory frame, in the ECEF frame, and the freely falling, nonrotational frame must witness the same synchronization. Einstein's synchronization convention requires that (5) is mandated, so that all time spans for light to traverse between mutually fixed pairs of points must be equal. This means $c_{\rightarrow} = c + v$ and $c_{\leftarrow} = c - v$, which demonstrates that light obeys addition of vector velocities.

It was shown that the Sagnac effect [7] using a ring laser gyroscope in the form of a circular interferometer operates according to (7). An external observer easily sees a constant rotation of the gyroscope causes the corotating beam to travel a longer distance than the counterrotating beam. The output of destructive interference measures the angular distance the gyroscope rotated. The same output is observed by an internal observer fixed with the gyroscopic frame, but the circumference is preserved, so that the internal observer concludes the corotating light beam went slower by $c-\omega R$ and the counterrotating beam by $c+\omega R$ according to (7). This makes the theoretical predictions between external and internal observers consistent. Thus, light's velocity obeys vector addition of velocities in both linear and rotational frames, where c is the standard light velocity.

To obtain very precise measurements of light speed to eight or more significant figures, the light source and the light detector are stationary relative to each other in a laboratory. To employ only one ultraprecise timing device, a roundtrip test of a light emission is standard [2]. This restricted linear testing will produce the standard light speed, but it is not universal. With this new interpretation of light velocity, light now behaves the same in a transparent medium and in a pure vacuum with unchanged frequency (i.e., $c' = c \pm v = f\lambda' = c/n$).

If others verify that light obeys vector velocity addition, then several physics concepts will need to be revised. Previous test results should be reviewed to determine if updates are necessary, but the precision in significant figures will generally not change most results. Several ramifications have been listed in the paper, such as old standards would need to be reestablished, such as the physical meter in the current SI standards, if light speed is not a fixed, exact numerical constant in all reference frames or external environments.

Other axioms of physics, concepts, or physical models may need future revisions. In particular, the definitions and implementations involving time and clock synchronization may well require an overhaul since light speed in a vacuum is not a constant in general applications and the distance between the source and receiver is not usually fixed during the synchronization. Thus, this research indicates more updates in physics.

Appendix: Errata for Previous Papers

In five previously published papers, the author erroneously assumed that light speed moving antiparallel to the direction of the observer, rod, conduit, or racetrack does not affect the ratio of v^n/c^n in the series derivation. Unfortunately, in vector mathematics, the ratios are $(-1)^n v^n/c^n$ in the series when using speed for the velocity magnitude, which the author discovered in this writing. The derivation of equation (2) reveals the error, and the roundtrip distance in (3) makes the total distance longer than $2L$. Thus, corrections to the relevant equations and conclusions in those papers are given in this section.

A.1: Timing in Simultaneity, Einstein's Test Scenario, and Precise Clock Synchronization [26]

Replace (2) with (2) from this paper so that $L_{BP} = Lc/(c+v)$. Then, replace (4) with $\Delta T_{BP} = L_{BP}/c = L/(c+v)$ when dividing by c. Then, $c_{AP} = c-v$ and $c_{BP} = c+v$ without invoking $v<<c$. Replace (7) with (3) in this paper to establish that the roundtrip distance in the stationary frame is greater than $2L$.

The summary needs revision stating that the speed of light does vary by vector velocity addition when the observer or detector is not fixed relative to the light source. The total roundtrip that light traverses for an external observer is greater than $2L$. The roundtrip distance is $2L$ as perceived by the observer fixed with the light source, When the distance is fixed between the source and detector, the time interval for light to traverse either leg is the same, because the speed of light obeys vector velocity addition to precisely compensate for the difference in the light paths within the reference frame that the roundtrip test is conducted.

Two Way Satellite Time and Frequency Transfer (TWSTFT) may be improved to validate precise times between timing laboratories under 1 ns by including the one-way speed of light between the ground stations and the satellite in common view of the stations. The one-way light speed must account for the motion of the satellite's velocity along the cosine projection of the transmitted signal along the line of sight of each transmission. Currently, the Sagnac effect is employed to account for the changing distance between the monitoring equipment and the satellite during transmission using only the standard light speed.

A.2: Generalized Equations for the Collinear Doppler Effect [27]

Several equations must be updated due to equations (2) and (3) derived in this paper. Although the diagrams are correct, too many changes are needed, which would be hard to logically follow. This text will be a terse recapitulation and summary.

For simplicity, vibrations of still air are considered with horizontal propagation to avoid changes in density from altitude. The generalized Doppler equation will be developed in the collinear direction. Any transverse effect can be derived with trigonometry to get a perpendicular propagation.

The source produces waves of frequency, f, and wavelength, λ, with a positive speed of $V = f\lambda$. If the source moves at a uniform velocity, V_s, on the positive x-axis, the wavelength is shorter, but not the wave speed, so that $(V-V_s) = f\lambda_s$. An observer collects waves in one time unit by $1(V-V_o) = f_o\, \lambda$. Then, $f_o = (V-V_o)/\lambda = f_s\,(V-V_o)/(V-V_s)$, which is the standard Doppler equation found in introductory physics textbooks, but the velocities are positive parallel to the positive x-axis. The observed wavelength, $\lambda_o = (V-V_o)/f_o = (V-V_o)/(V-V_s) = (V-V_o)(V-V_s)/((V-V_o)f_s) = (V-V_s)/f_s$. The standard Doppler equation leads to the incorrect conclusion that the observed wavelength is only determined by the source's velocity and transmitted frequency. Any test of a stationary siren with still air would have a broadcast of $f = f_s$ and λ, but a moving observer with velocity, V_o, would collect fewer waves per unit time and would stretch out the observed wavelength. Although adequate, the standard Doppler equation needs to be updated.

Equation (3) is correct for the parallel propagation along the x-axis, which is $\lambda_o = \lambda\, V/(V-V_o)$. Based on (2) in this paper, the correct formula for the antiparallel propagation for Equation (4) is now $\lambda_o = \lambda\, V/(V+V_o)$ when V_o is in the negative x-axis direction. Keeping the velocity direction as a vector, the + sign in Equation (4) can be replaced, making Equation (3) the general form. For the moving source through the medium, $\lambda_s = \lambda = (V-V_s)/f_s$. As the observed λ is modified by the motion of the source and observer and using V_s and V_o as vector velocities parallel to the x-axis, the general Equation (5) is $\lambda_o = \lambda\, V/(V-V_o) = V(V-V_s)/((f_s(V-V_o))$. As $f_o = (V-V_o)/\lambda_o$, then insert λ_o into (5) to get (6) as $f_o = f_s\,(V-V_o)^2/((V(V-V_s))$. Equation (6) is the general collinear Doppler effect. Note that in a constant wind, $V = V_{propagation} + V_{wind}$ can be inserted into (5) or (6). If both the source and observer move with the same speed, (i.e., $V_o = V_s$), then (5) reveals the transmitted wavelength is preserved (i.e., $\lambda_o = \lambda_s$). If both the source and observer are stationary (i.e., $V_o = 0 = V_s$), then $f_o = f_s$, even in the presence of a wind, which Figures 4 and 5 indicate. Equation (6) reduces to the standard Doppler equation if the observer's velocity is significantly less than the wave's total speed (i.e., $V_o << V = V_{propagation} + V_{wind}$).

A.3: Simultaneity, Chronometrology, and the Two Postulates of Relativity [28]

Replace (2) with (2) in this paper, so that $L_{BP} = Lc/(c+v)$. Also, $L_{AP} = Lc/(c-v)$, and $\Delta T_{AP} = L_{AP}/c = L/(c-v)$. Replace (4) with the updated ΔT_{BP} so that $\Delta T_{BP} = L_{BP}/c = L/(c+v)$. Then, the light speed $c_{AP} = L/\Delta T_{AP} = c-v$ in the original (5). Equation (6) is updated as $c_{BP} = L/\Delta T_{BP} = c+v$ without having to invoke $v<<c$. Replace (7) with (3) in this paper where $L_{\rightarrow} + L_{\leftarrow} = 2Lc^2/(c^2-v^2) > 2L$, because the original (4) is incorrect. The conclusion needs to be updated that the roundtrip distance of the moving rod of length L is greater than $2L$, but $2L$ in the inertial frame fixed with the uniformly moving rod. The speed of light obeys the addition of vector velocity according to (5) in this paper, which adjusts the transmission intervals in either direction to be the same.

A.4: Vector Addition of Light's Velocity Versus the Hafele-Keating Time Dilation Test [23]

Relace (4) with (2) in this paper, which would make $L_{C'A''} = Lc/(c+v)$. This will change (6) to be $\Delta T_{C'A''} = L/(c+v)$ and the roundtrip time as $\Delta T_{A'C'A''} = \Delta T_{A'C'} + \Delta T_{C'A''} = 2Tc^2/(c^2-v^2)$ with $T = L/c$ for the stationary frame, but 2T for the inertial frame fixed with the interferometer.

Replace (9) with $c_{C'A''} = L/\Delta T_{C'A''} = c+v$ without the need to use v << c. This analysis shows that the velocity of light obeys vector velocity addition. The comments concerning the Hafele report of 1971 and the Hafele-Keating report of 1972 remain unaltered.

A.5: Measuring Velocity of Moving Inertial Frames with Light Transmissions [29]

After making the needed changes in key equations, one retraction is made. The experimental setup will accomplish the one-way measurement of light's velocity, but it will produce the standard light speed, c, in all horizontal directions. The vertical direction will vary light speed as previously determined by the Pound-Rebka experiment [30] with $v \approx gL/c$ where g is the local gravity of Earth, L is the vertical length, and v is ± if L and g are parallel or antiparallel, respectively.

The one-way time span of light traversing a uniformly moving rod of length L in a stationary frame in either parallel or antiparallel direction of movement is exactly the same one-way time span in the moving inertial frame fixed with that rod. The reason is the distance between the light source and detector remains fixed during the test. Replace (2) with (2) in this paper so that $L_{BA} = Lc/(c+v)$. This change will revise (4) to be $\Delta T_{BA} = Tc/(c+v)$ where $T = L/c$. Also, (6) is updated with $c_{BA} = L/\Delta T_{BA} = c-v$ without requiring $v<<c$. Both (5) and (6) verify that light's velocity obeys vector velocity addition. However, one cannot use either (3) or the updated (4) to measure a different time interval for light to traverse the horizontal length L in parallel or antiparallel directions, because $\Delta T_{BA} = \Delta T_{AB}$ for the external observer as shown by (5) in this paper. The author had not considered $c_{\rightarrow} = c + v$ and $c_{\leftarrow} = c - v$ in a generalized version of (3) and (4), which would be $\Delta T_{AB} = L_{AB}/c_{\rightarrow} = Lc_{\rightarrow}/[c_{\rightarrow}(c_{\rightarrow}-v)] = L/c$ and $\Delta T_{BA} = L_{BA}/c_{\leftarrow} = Lc_{\leftarrow}/[c_{\leftarrow}(c_{\leftarrow}+v)] = L/c$. This shows that a one-way light speed will be the standard value when distance is fixed between the light source and detector even though the apparatus moves inertially in outer space, because light velocity obeys vector addition of velocity.

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