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Article

The Physical and Logical Necessity to Modify The Definition of The SI Standard of Length, The Metre

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Abstract: The SI unit of length, the Metre, is presently defined by taking the fixed numerical value of the fundamental constant 'c', the invariant speed of light in vacuum. This definition has the same physical basis as the previous definition, as the length of the path travelled by light in vacuum during a time interval of $1/299\,792\,458$ of a second. With the atomic standard second defined in terms of the ground state hyperfine transition in Caesium-133, this definition is supposed to provide a universally reproducible standard of length. However, this relies on Einstein's singular postulate that the relative velocity of light in vacuum is an invariant constant that is independent of any inertial motion of the reference laboratory. I argue that the basis of the definition of the standard metre should be changed to the specific form, "the length of the path equal to the *two-way propagation of light* in vacuum during a time interval of $1/299\,792\,458$ of a second", to be compatible and consistent with the fact that it is only the two-way relative velocity that is consistent with being an invariant. The null result in the Michelson-Morley two-way experiment, and in all such experiments to date, is consistent with a Galilean one-way propagation of light (relative velocity $c' = c \pm v$) as well as an invariant relative velocity of light. All practical methods and protocols related to the implementation of length standard involve also a two-way propagation, not conforming to the present definition. Besides, this redefinition is absolutely necessary because the relative velocity of light in one-way propagation is indeed Galilean, and not an invariant, as proved here in multiple ways including a direct experiment.

Keywords: the SI metre; metrology; Einstein's light hypothesis; two-way relative velocity; galilean propagation; GNSS

1. Introduction

The modern SI system of metrology standards and units is based on our confidence in determining and understanding several fundamental constants of nature, coupled with universally reproducible physical standards based on quantum phenomena at the atomic scale. The standard of Time based on a narrow atomic transition holds a primary role due to the precision, reproducibility, and reliability with which it can be determined and maintained. The older 'atomic' definition of the standard Metre was as a fixed multiple of the vacuum wavelength of an electronic transition in krypton-86 atom. This was revised in 1983; the standard of length, the metre, was defined as the length of the path travelled by light in vacuum during a time interval of $1/299\,792\,458$ of a second [1,2]. In 2019, a further refinement of the definition in terms of the fixed and invariant value of 'c' as a fundamental constant was adopted, with full continuity to the previous definition. The exact definition now reads: "Metre, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum c to be $299\,792\,458$ when expressed in the unit ms^{-1} , where the second is defined in terms of the caesium frequency $\Delta\nu_{\text{Cs}}$." This is based on the century old fundamental hypothesis of Einstein's Special Theory of Relativity that the relative velocity of light is an invariant constant, independent of any inertial motion of a reference laboratory [3,4]. Based on this, and on several decades of precision measurements, the velocity of light is now fixed as the exact numerical value $299\,792\,458$ m/s. However, very few people are aware that the assertion of the invariance of the relative velocity of light, Einstein's 'light hypothesis', is only a postulate that is generally believed to be consistent, and not an experimentally verified fact. That is, there is no experiment to date that

prove that *the relative velocity c' of light in unidirectional propagation*, relative to an inertial frame moving at the velocity v , is an invariant constant ($c' = c$), and not Galilean ($\vec{c}' = \vec{c} - \vec{v}$).

What is experimentally verified amply is that *the relative velocity of light in a situation of two-way propagation is an invariant constant*. The Michelson-Morley experiment and all its variations are of this type, where light propagates in both directions – parallel and antiparallel – relative to the direction of motion of a laboratory. The null results of such two-way experiments are fully consistent with both a Galilean one-way relative velocity of light ($c' = c \pm v$) and a propagation with an invariant relative velocity of light (this is proved in the next section). All experiments relying on electromagnetic cavities are also of this type. The method of realising the SI metre in terms of a fixed number of wavelengths in a cavity, of an atomic radiation of accurately determined frequency, also rely on the invariance of the two-way relative velocity of light. Hence all modern measurements of the velocity of light and methods to realise the SI metre are based on a two-way propagation of light. In fact, *there is no physical way of determining the relative velocity of light in one-way propagation over a fixed linear path in a manner that is independent of a specific theory of relativity* because of the need to synchronize two independent clocks at the end points of the reference length [5,6]. Such a synchronisation is dependent on a *chosen convention and assumption about the nature of propagation of light*. There is no physical or logical justification in extrapolating from the empirically supported invariance of a two-way velocity to the postulated invariance of the one-way relative velocity, because first order effects that depend on the velocity v of the reference laboratory (proportional to v/c) cancel out in a two-way propagation. In fact, the practice of determining the length standard is always done employing physical situations involving a two-way propagation of light.

Given this situation, *and entirely independent of any other fact or experiment regarding the propagation of light*, the only reliable and reasonable definition of the standard meter should be based on the two-way relative velocity of light, fixed as 299 792 458 m/s; that is light takes 2 standard seconds to travel a path length of 299 792 458 m both ways, parallel and antiparallel, independent of any inertial motion of a laboratory. Thus, the definition with sufficient logical and empirical rigour should be that “the standard metre is the length of the path equal to the *two-way propagation of light* in vacuum during a time interval of $1/299\,792\,458$ of a second.” Besides, *this modified definition is absolutely necessary and physically imperative because the genuine one-way relative velocity turns out to be Galilean to first order in v/c , and not an invariant constant, as I will prove later with reliable and impeccable evidence*.

If the one-way propagation of light is indeed Galilean to first order in v/c with its velocity relative to a frame moving in the same direction or opposite being $c' = c \pm v$, as I will show, then the notional error in the SI standard of metre made by the current definition is large, $(c \pm v)/c \approx 1 \pm v/c$. The grave nature of the error implied in the current definition is striking when we realise that even for the modest velocity of 10 m/s for a slowly moving terrestrial platform, the correction implied is as large as $\pm 3 \times 10^{-8}$. Taking the more significant time varying velocity of the terrestrial laboratory as 30 km/s (ignoring the much larger cosmic velocity of 370 km/s), we see that the error in the definition is as much as 1 part in 10,000, which is totally unacceptable for the international standard of length. It is no consolation to think that the factual protocols of standard comparison, employing interferometry techniques, are all based on a two-way propagation due to practical reasons, and therefore remain insensitive to this error. The cancellation of the large first order error in the only feasible two-way methods is not a valid justification to continue with the current ambiguous definition that relies on a restricted postulate on the one-way propagation.

2. Facts that Necessitate the Redefinition

I will now present several facts that are relevant for my call for the urgent redefinition of the SI length standard. First, I will prove that the Michelson-Morley experiment [7], and all such two-way experiments and variations, are consistent with both a Galilean propagation of light, at the relative velocity $c' = c \pm v$, as well as with Einstein's postulate, of a propagation at an invariant relative velocity (Einstein's light hypothesis). Hence such experiments do not address, let alone establish, the invariance

of the relative velocity of light. This proof is of cardinal importance because of the widespread unawareness and misunderstanding of this crucial fact. Then I will prove that the postulate of a constant invariant relative velocity of light for one-way propagation is indeed inconsistent in a world in which there are Galilean waves like sound! This impeccable proof that relocates the foundations of relativity and dynamics will reinforce the urgent need for the redefinition of the SI standard of length. Though these two robust proofs are sufficient to support my assertion, I will also describe two pieces of reliable experimental evidence, one from protocols of location finding in GNSS facilities like the GPS, and another, in a brief appendix, from a direct experiment to determine the nature of the one-way propagation of light.

2.1. Two-Way Experiments and the Relative Velocity of Light

Consider the two-way propagation of light along a length L . The reference frame is moving at the velocity v relative to some arbitrary reference (one may take it as an 'absolute frame' or the frame in which the Cosmic Microwave Background Radiation (CMBR) is isotropic, for concreteness). We assume explicitly that the propagation of light is Galilean, i.e., that its relative velocity is $c' = c \pm v$, and then prove that any evidence for this is unobservable in a two-way experiment. This result is in fact the empirical basis of the Principle of Relativity.

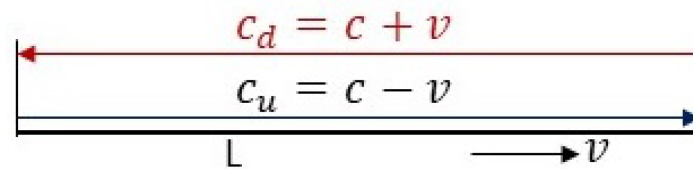


Figure 1. An experiment involving a two-way propagation of light over a length L , in a reference frame moving at the uniform velocity v . If the relative velocity of light is indeed $c' = c + v$, the total time of propagation is $T_u + T_d = (L/c - v) + (L/c + c) = 2L/c(1 - v^2/c^2)$. However, the small second order term is masked by the dual relativistic effects of length contraction and time dilation, rendering the total time as $T = 2L/c$.

The time taken for the propagation parallel to the velocity v in the absence of any other physical phenomenon is

$$T_1 = \frac{L}{c - v} \quad (1)$$

The duration taken for the return propagation is

$$T_2 = \frac{L}{c + v} \quad (2)$$

Therefore, the total duration is

$$T' = \frac{L}{c - v} + \frac{L}{c + v} = \frac{2L}{c} \frac{1}{(1 - v^2/c^2)} \quad (3)$$

However, including the (post-1895) "new" phenomena of length contraction and time dilation, the total duration is

$$T = \sqrt{1 - v^2/c^2} T' = \sqrt{1 - v^2/c^2} \frac{2L\sqrt{1 - v^2/c^2}}{c} \frac{1}{(1 - v^2/c^2)} = \frac{2L}{c} \quad (4)$$

The Galilean nature of light, manifest only to second order in v/c in two-way propagation, is entirely masked by the two second order relativistic effects [6,9]. Thus any experiment that relies on a two-way propagation of light is entirely consistent with a Galilean relative velocity, $c' = c \pm v$. If the two-way propagation is perpendicular to the velocity of the frame, then only one factor of $\sqrt{1 - v^2/c^2}$ for

the time dilation is relevant, which cancels the second order factor in the propagation delay of $2L/c(\sqrt{1-v^2/c^2})$. Thus, the phase shifts in the two arms of a Michelson Interferometer are separately and independently consistent with a Galilean propagation. Of course, the two-way experiment is also consistent with an invariant relative velocity of light. In other words, such experiments cannot address the nature of propagation of light, contrary to the prevalent misplaced belief.

2.2. A Proof that Invalidates Einstein's Light Hypothesis

Now I present a crucial proof that falsifies the postulate of an invariant relative speed of propagation of light. A serious internal inconsistency, arising if the relative speed of light is postulated to be an invariant constant, is easily demonstrated, given our knowledge that the propagation of familiar waves like sound waves is Galilean, with a relative velocity linearly varying with the velocity of the reference frame [6].

Consider an experiment in which a sharp pulse of sound and a pulse of light are emitted simultaneously at a point in space by a dual source in a reference frame that is moving at the uniform velocity v . We take the time of emission as $t' = 0$, at the point $x' = 0$ (observer/detector O') in the moving frame. The coordinates in a stationary laboratory frame O are $t = 0$ and $x = 0$. The pulses move forward, and go around in a looped path of total length L (Figure 2). Of course, in the duration the pulse of sound goes around once, the pulse of light will go around about a million times. Both the moving observer and the stationary observer in the laboratory are counting the number of passes (intersections) of the pulse of light with the moving observer O' . Since this is a countable pure number N , of coincidences in space and time, it is the same number for all observers. The velocity v is arranged such that both pulses are detected simultaneously in the moving frame at $t' = T'$, $x' = 0$, after exactly one round trip of the pulse of sound. At this point, the count of the intersections with light is N , which can be calculated in both frames O and O' , knowing the relative velocities. Since both the emission and the detection are (separate) simultaneous events ($\Delta t' = 0, \Delta x' = 0$), they are simultaneous events for all observers, moving or stationary. Now we will write down the expressions relating the number count N and the relative velocities of sound and light.

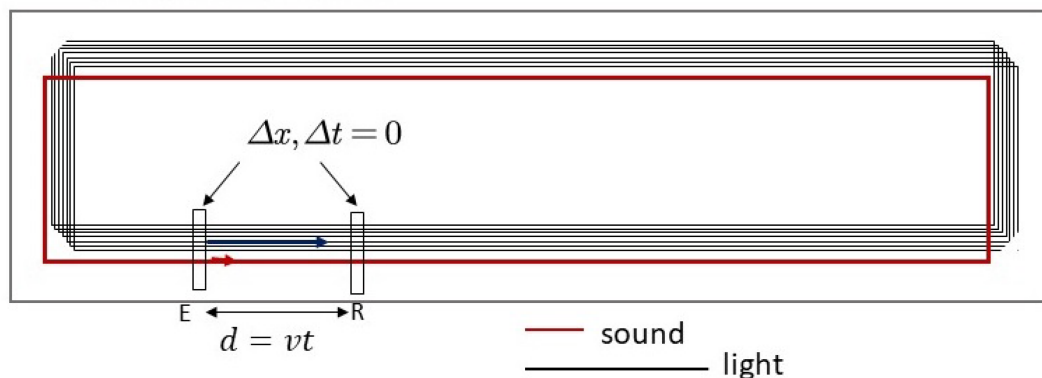


Figure 2. The simple proof of a fatal inconsistency in the postulate of an invariant relative velocity of light in a world in which there are Galilean waves. Pulses of light and sound are simultaneously emitted at the point E from a uniformly moving reference frame, and detected simultaneously at the point R after 1 round trip of sound and N round trips and coincidences of light with the moving frame O' . The number N should be an invariant, the same for all observers, from the requirement of simultaneity at E and R. However, the expressions for the round trip coincidences are different, if Einstein's light hypothesis is assumed, for the moving frame and a stationary laboratory frame O , relative to which the velocity v of O' is specified. See also Figure 3.

For the stationary observer, the relative velocity of sound is s and that of light is c . By the time sound goes around once, taking a duration T , light goes around and crosses O' N times. Since the

observer O' is moving relative to O , the distance travelled by O' and the detector between emission and detector is $\delta x = vT$. Therefore, the total duration from emission to detection obeys

$$T = \frac{NL}{c} + \frac{vT}{c} \implies cT(1 - v/c) = NL \quad (5)$$

A similar relation applies to the pulse of sound as well, with $N = 1$,

$$T = \frac{NL}{s} + \frac{vT}{s} \implies sT(1 - v/s) = L \quad (6)$$

The length L and duration T are eliminated in the ratio, giving an expression for N ,

$$N = \frac{c - v}{s - v} \quad (7)$$

We see that this is equal to the ratio of the total distances travelled by light and sound around the loop minus the distance travelled by the moving reference frame O' , relative to the stationary frame O . cT is the total distance travelled by light (and sT by sound) in the loop, and vT is the distance travelled by O' in the same duration. Hence, $N = (cT - vT)/(sT - vT) = (c - v)/(s - v)$.

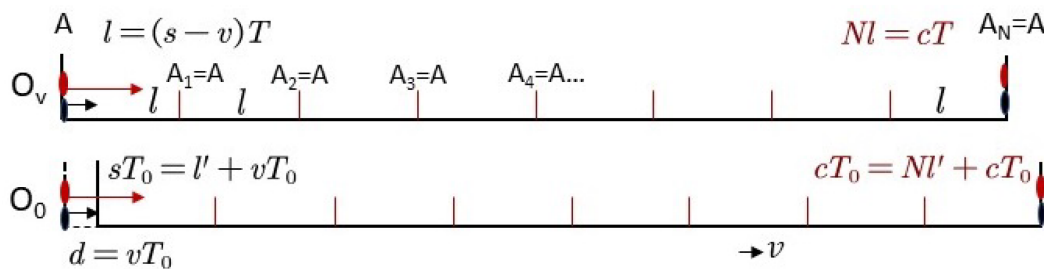


Figure 3. The analysis of the experiment depicted in Figure 2. Pulses of light and sound are simultaneously emitted at A, and detected simultaneously again, after N round trips of light and 1 round trip of sound. The number of times the light pulse crosses (N of simultaneity) the observer O_v , while the sound pulse completes one round, should be the same invariant for all observers. When the closed loop of the propagation is 'opened up', it is evident that this number cannot be the same N for a stationary observer and a moving observer, *unless the relative velocity of light is strictly Galilean*, $c' = c - v$. Each segment (A_i to A_{i+1}) is of length l (the loop length) and there are N such. The frame moves the distance $d = vT_0$ in the duration from the emission to detection.

Relative to the observer O' , the frame O' is the rest frame and the detector is at $x' = 0$ at all times. If t'_0 is the duration for one passage of the light pulse, and T' is the total duration from emission to detection, $Nt'_0 = T'$. The relative distance is the relative velocity multiplied by the duration T' . The number of crossings N is the ratio of the relative distances travelled by light and sound (see Figure 3 for a straightforward proof),

$$N = \frac{cT'}{(s - v)T'} = \frac{c}{s - v} \quad (8)$$

Surprisingly and rather shockingly, the two observers do not agree on the number of crossings that is required to be an observer-independent integer, *when calculated under the assumption that the relative velocity of light is an invariant constant c* . The gross inconsistency revealed in the conflict between the expressions 7 and 8, for the hypothesis of an invariant relative velocity for light, is evident and insurmountable. This inconsistency is removed only by accepting that the genuine relative velocity of light is indeed Galilean, giving $c' = c - v$ relative to frame O' .

I have proved that the postulate of an invariant relative velocity of light is inconsistent and invalid in a world in which there are Galilean waves like sound. Einstein based his light hypothesis on the postulated (but unverifiable) behaviour of moving clocks at a distance X from an observer who is moving at

a relative velocity v , by re-interpreting the first order term $-vX/c^2$ in the Lorentz transformations (Lorentz's hypothetical 'local time'). However, this term representing a clock at a distance $x = X$ is not accessible for an observer at $x = 0$ except by bringing a signal from $x = X$ to $x = 0$. Then the time at which such a signal is received depends on the exact nature of propagation of light. Obviously, any protocol of clock synchronisation under these circumstances is dependent on the choice of a postulate about the one-way propagation of light.

2.3. The Relative One-Way Velocity in GNSS

The Global Navigational Satellite Systems (GNSS) operate on the basis of converting durations for light-travel between several satellites and a receiver using a theoretical model of the one-way propagation of light [9,10]. The precise timing signals sent by several satellites at a distance of about 20000 km are received by a GNSS receiver near the Earth's surface. After corrections for larger ionospheric delays etc. there are corrections to be applied for the second order motional relativistic effects as well as for the gravitational time dilation. I am not focusing on those corrections here. Assuming that those are done to the required accuracy, one can examine the model adapted for the one-way propagation of the electromagnetic signal in GNSS. The general impression given is that the invariant relative velocity of Einstein's light is applicable for the conversion of duration Δt to the distance to the satellite. Four such distances are needed to fix the location of the receiver (one extra than what is needed in 3-dimensional space because the receiver does not have precision atomic clock). If the relative velocity of light is indeed independent of the motion of the receiver, then the equation for conversion is obviously $d_s = c\Delta t_s$. However, if the relative velocity is $c - v$, as expected for a Galilean propagation of light, then the distance is $d_s = |\vec{c}'|\Delta t = |\vec{c} - \vec{v}|\Delta t$. This is

$$d'_s = |\vec{c} - \vec{v}|\Delta t = (c^2 + v^2 - 2\vec{c} \cdot \vec{v})^{1/2}\Delta t \approx c\Delta t - \vec{c}\Delta t \cdot \vec{v}/c^2 = d_s - \vec{d}_s \cdot \vec{v}/c^2 \quad (9)$$

One may verify that this is exactly the expression used to convert durations to distances in any GNSS operation, and not the expression $d = c\Delta t$ of Einstein's relativity. This confirms that localisation algorithms in GNSS directly refutes Einstein's light hypothesis. What works in this real physical situation is the Galilean propagation of light, with its relative velocity linearly dependent on the velocity of the reference frame. There is absolutely no ambiguity about this.

I can give more proof from GNSS, scrutinising finely even the second order motional relativistic corrections in GNSS [6,9]. But they are much smaller corrections compared to the large first order Galilean correction shown in the expression 9. With $d_s \approx 2 \times 10^8$ metres, a car driving at 10 m/s needs a Galilean correction amounting to 6 meters every second, which is a very large error for a localisation system with centimetre level precision! The correction that GNSS use in the name of a 'Sagnac term' is a special case of this Galilean correction when the velocity of the frame is the tangential component of the Earth's rotational velocity at a particular latitude. The expression 9 is more generally applicable and it is critical for the guidance of high speed inertial systems. It is an undeniable fact, irrespective of how people name post-facto corrections, that the operational GNSS like the GPS and Galileo needed to incorporate the Galilean propagation of light with its relative velocity linearly varying with the velocity of the observer.

In fact, the post-facto first order (v/c) correction, to the one-way distance between two timing devices, incorporated in GNSS exposes the inappropriate nature of the current definition of the standard metre, based on the assumed invariance of the one-way relative velocity of light. In the appendix, I describe a direct experiment that compared the nature of propagation of light and the nature of propagation of sound, which we know is a Galilean wave. The results confirm with high confidence that the propagation of light is Galilean, with a relative velocity $c' = c \pm v$, similar to the propagation of sound.

2.4. The Direct Measurement of the Relative Speed of light in One-Way Propagation

The thought experiment described earlier to clearly bring out the physical inconsistency of the postulate of an invariant relative velocity of light can be implemented as a set of real experiments in the laboratory. This comparison between the propagation of light and the propagation of a Galilean wave (sound) has indeed been done in various phases and the unambiguous Galilean nature of the propagation of light was verified [6,11,12]. Since these results are reported in previous publications, I have given a short description of these experiments in an appendix. The experiments are readily done in a well equipped laboratory with facilities for optical interferometry with moving optical and opto-mechanical elements. The experimental results show clearly that the nature of propagation of sound and light is similar, with the relative velocity linearly dependent on the velocity of the observer frame.

A short comment on several experiments that were done to *determine the nature of one-way propagation of light employing spatially separated emitter and detector, amounting to two spatially separated clocks*, is in order [13,14]. The fact that such experiments are ineffective to discriminate between a Galilean propagation and a propagation with an invariant relative velocity was shown in reference [15]. The null results seen in such experiments is fully consistent with a Galilean one-way propagation of light, combined with the effect of relativistic time dilation of the spatially separated clocks. The impossibility of synchronising two spatially separated clocks, independent of a chosen theoretical convention, is behind the inefficacy of such experiments to determine the nature of propagation of light. This is fully explained in reference [12].

It is obvious that the postulate of an invariant relative velocity of light cannot be maintained at all after seeing the results from the direct experiments (appendix), the clear evidence in the GNSS localisation algorithms (section 2.3), and the insurmountable logical proof of a fatal internal inconsistency in Einstein's light postulate (section 2.2). This should be more than sufficient reason for an immediate redefinition of the SI standard of length, freeing it from the presumed but invalid invariance of the relative one-way velocity of light. What is invariant is only the duration for the two-way propagation over a fixed length L ; this quantity is absolutely independent of the motion of the reference frame and provides the physical basis for a reproducible length standard.

3. Concluding Remarks

I have presented multiple evidence to establish that the relative velocity $c(v)$ of light in one-way propagation relative to an inertially moving frame is Galilean, $\vec{c}(v) = \vec{c} - \vec{v}$, and not an invariant constant as postulated and generally believed. This necessitates the urgent redefinition of the SI unit of length because the typical first order (v/c) notional correction to the measure of SI Metre that is implied by this situation is several orders larger than the precision desired in an international standard of length. I have clarified that it is only the relative velocity in a strict two-way propagation of light that remains an invariant constant, independent of any theoretical bias. It is solely the two-way velocity of light that can be physically fixed as the constant 299 792 458 m/s, both empirically and with theoretical consistency. There is a serious logical and physical incompatibility between the current definition and the factual implementation of length metrology. The current definition is based on a falsified postulate on the one-way propagation of light, whereas the practical length comparisons and measurements rely on the two-way propagation. Therefore, it is imperative that the current definition is changed to a formal equivalent of the statement, "the SI Metre is the length of the path equal to the two-way propagation of light in vacuum during a time interval of $1/299\,792\,458$ of a second".

Appendix: The Direct Measurement of the Relative Speed of Light in One-Way Propagation

The relative velocity of light is a hybrid (ratio) physical quantity, *requiring the measurement of relative distance and relative duration*. The distance in the moving reference frame can be fixed at a particular value L . Any motional relativistic correction of distance is then second order in v/c , and will

not affect a first order (v/c) signal characterising a Galilean propagation. Then, what is to be measured is the duration T taken by a pulse of light (or a particular wavefront of light) to travel the distance L' between the emitter and detector as the reference frame is moving at an inertial velocity v .

The conceptual difficulty in measuring the relative velocity in one-way propagation is the impossibility to synchronise two spatially separated clocks in a manner that is independent of an assumed theory of relativity and the nature of propagation of light. However, since one is interested in checking whether the relative speed of one-way propagation is an invariant constant or not, all one has to monitor is the relative duration light takes to traverse a path of fixed relative distance irrespective of the shape of the path, while ensuring the observer (detector) maintains inertial motion, at constant velocity along a straight line. It is obvious that the durations taken by light for one-way propagation are identical for a straight path of distance L and a piecewise linear polygonal path of total length L (except for negligible frame-independent fixed corrections). Therefore, one can arrange a rectangular stadium-like closed path for light while ensuring that the source-detector assembly and its single clock are in linear inertial motion. The situation is exactly equivalent to identifying the two end points of a one-way propagation experiment (akin to a one-path in a linear train made to loop around in a closed path). Essentially, one is managing to bring together the two clocks required at the end points in spatial proximity without sacrificing the fact that light still has to travel a distance L between the two clocks! Clearly, the distance from the source to the detector remains fixed L relative to frame O' , to first order in v/c , because there is no relative motion between the source and the detector. This arrangement eliminates any possibility of first order Doppler shift as well.

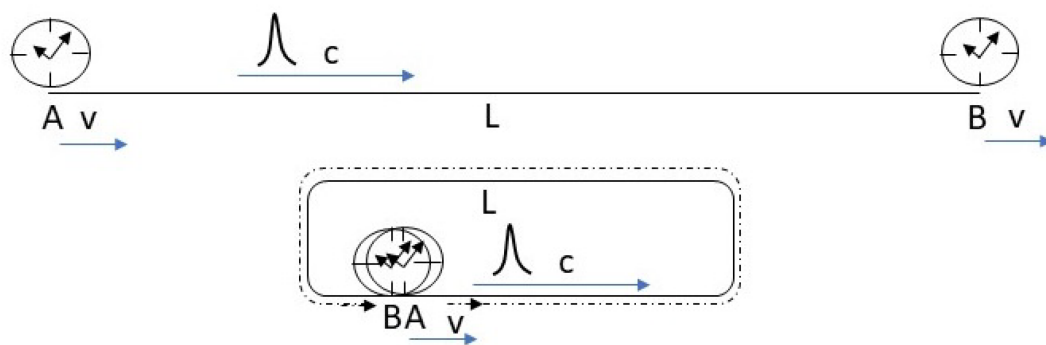


Figure 4. The design concept of the experiment to monitor the genuine one-way propagation and the relative speed of light, relative to an inertially moving frame. The upper panel shows the task with two end points and identically moving clocks A and B with distance L between them. But, the spatially separated clocks cannot be synchronised independent of the theoretical assumption about the propagation of light. The lower panel depicts the correct solution. The time taken by light to cover a distance L is independent of the shape of the one-way trajectory in vacuum. If the path is looped around, then the clocks at A and B can be synchronised and moved together inertially. The distance from A to B remains fixed as L' in the moving frame. Then, the relative velocity is obtained by measuring the relative duration T' for the round trip.

The duration taken by light relative to the moving frame O' can now be measured as a function of the linear velocity of O' that is essentially chasing a pulse of light throughout its propagation in the closed path. When done with a path of laboratory scale, sufficient precision can be achieved only by resorting to interferometry, by arranging both a clockwise path and an anti-clockwise path in the loop and then interfering the two beams. Assuming a Galilean propagation of light and that the local direction of the velocity of the frame O' coincides with the clockwise directed path, we can derive the

velocity-dependent relative durations light takes to traverse the closed paths (accurate to first order v/c , because v^2/c^2 is less than 10^{-8} of the v/c signal):

$$T_{cw} = \frac{L}{c - v} \quad (10)$$

$$T_{ccw} = \frac{L}{c + v} \quad (11)$$

Then the difference signal that can be measured as a shift of the interference phase between the two beams is:

$$\Delta T = T_{cw} - T_{ccw} = \frac{2L}{c} \frac{v}{c} \quad (12)$$

If this signal that is proportional to the velocity of the moving frame is observed in an experiment, then it is a clear proof of the Galilean nature of the propagation of the light waves. On the other hand, if the relative speed of light is an invariant constant, one does not expect any signal that depends on the motion of the reference frame to first order in v/c .

For a path length of $L \approx 3$ m, and for a frame-velocity of 10 cm/s, the extra duration ΔT light takes in its Galilean propagation is only about 3×10^{-18} s, which cannot be measured directly. Hence, a spatial interferometric technique is necessary. Resolving an interference fringe in the visible region with a precision of 1/1000 corresponds to a duration of about 10^{-18} seconds. Hence, interferometry with moderate precision is adequate to test the Galilean nature of propagation of light. If done on a scale of 100 metres or so, a direct measurement of the velocity-dependent Galilean signal is possible using pulses from a femtosecond laser, though refractive index fluctuations in the light path can restrict the precision. A determination of the average centroid of 100 fs pulses with a practical precision of 0.1 fs is required for such an experiment. Here again, taking a difference signal (not interferometry) after splitting the pulse into two oppositely directed looped paths is required for a reliable measurement.

To be absolutely certain that the experimental strategy is based on rigorous logic and established physical principles, one can perform the experiment with a known Galilean wave like sound in the experimental configuration of a closed piece-wise linear path and an inertially moving reference frame. This has been done, making the exercise a direct comparison between the familiar Galilean waves of sound and the waves of light. For the experiment with sound, a rectangular closed path of 8.3 m was created with 50 mm diameter PVC pipes. A piezo buzzer operating at few kHz was the source and miniature microphones served as the detector, all assembled together on a movable 'reference frame'. Sound takes about 25 ms to traverse the path. If the reference frame moves at the moderate velocity of 10 cm/s, the Galilean signal (additional velocity dependent duration taken by sound due to a reduced relative velocity) is approximately 7.6 microseconds. Since a short pulse of sound at the emission and detection after a round trip can be located in time using an oscilloscope directly with sufficient precision, the experiment can be conducted without much technical difficulty. The results are shown in Figure 5, clearly confirming the known Galilean nature of the propagation of sound.

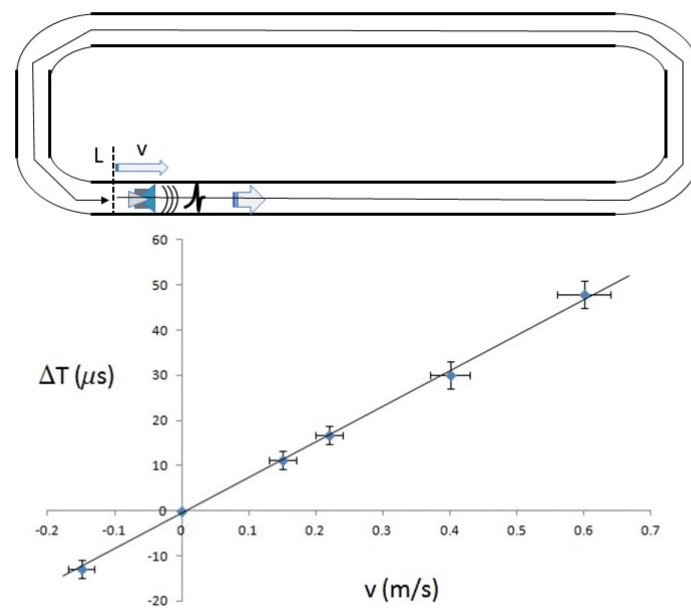


Figure 5. The experiment with sound confirms its known Galilean nature of propagation, showing the characteristic linear variation of the propagation delay with the relative velocity of the reference frame. The upper frame shows the scheme of the experiment where a reference frame at a uniform velocity v is inertially following a pulse of sound with the intrinsic speed s (in stationary air). The pulse is detected in the moving frame after one round trip. If and only if the relative speed is $s - v$, the duration for the round trip (relative to the frame) will linearly increase with the velocity v , as observed. This result is identical to the result obtained when the looped path is opened up into a linear section.

The experiment with light was conducted in two phases, one with a He-Ne laser and another using a fibre-coupled 780 nm ECDL laser source. The schematic diagram is shown in Figure 6. The beam is split with cube beam splitter and directed in oppositely directed paths. After a round trip, the beams are recombined to get an interference pattern. The light intensity is detected with a Si photodetector with an adjustable aperture. The inevitable vibrations in the linear translation stage limited the velocity of the reference frame to values less than 20 cm/s. Even with the constraints mentioned, the results of the duration of propagation duration that is linearly increasing with the velocity of the reference frame unambiguously establish the Galilean nature of the propagation of light. The relative speed of light in vacuum is not an invariant constant; Einstein's light hypothesis is falsified beyond doubt in a direct laboratory experiment.

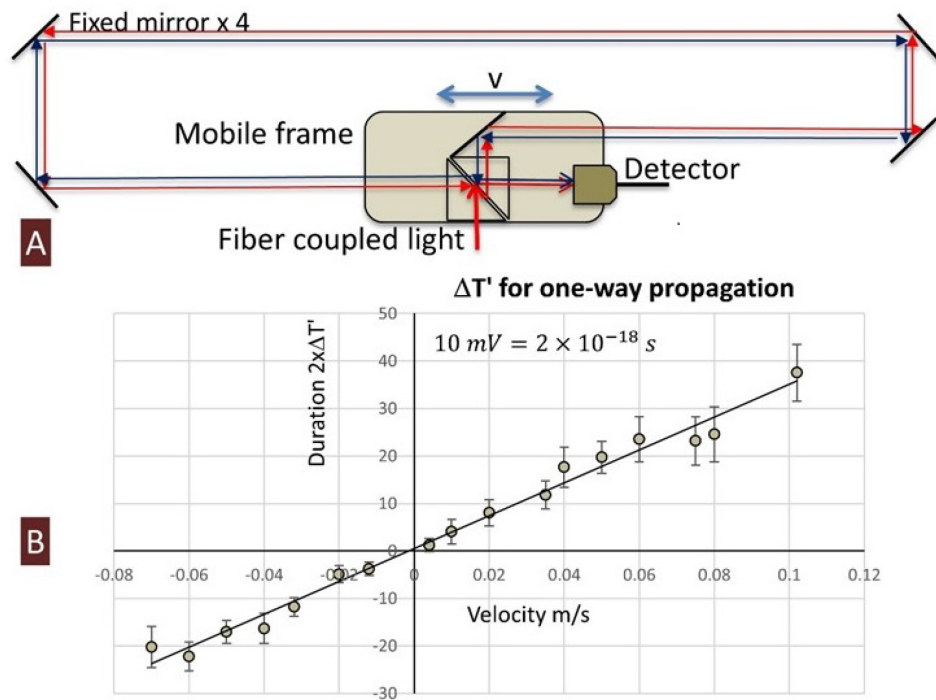


Figure 6. The determination of the relative one-way velocity of light, relative to a reference frame that moves at the uniform velocity v . The results establish the Galilean nature propagation with a relative velocity $c' = c \pm v$, and refute the postulate of an invariant constant relative velocity of light in vacuum.

In Section 2.2, I presented a proof that Einstein's light hypothesis is inconsistent, and false, in a world in which there are Galilean waves like sound. That simple proof involved the simultaneous emission and detection of a pulse of light and a pulse of sound, both propagating in a looped path relative to an inertially moving reference frame. This is of course not possible to realise practically in a real experiment due to technical challenges. However, a comparison of the nature of propagation of light with that of sound in two separate experiments is readily feasible, as I described here. The results confirm unambiguously that the relative speed of light in free space is Galilean, and not an invariant constant.

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