A Scheme for Measuring Anisotropy of One-Way Light Speed. (Part I)

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Abstract

Einstein's special relativity theory asserts or implies that one-way light speed is isotropic in every frame of reference for which the laws of mechanics hold good. Measurement of one-way light speed anisotropy would refute that notion. Qualitative refutation has already been achieved. A scheme for earth-bound measurement of one-way light speed anisotropy that does not require clock synchronization is described. The accomplishment of such a measurement could establish a preferred frame of reference, an "absolute rest frame."

Introduction

The relativity theory of Albert Einstein[1] has been lauded as a great scientific achievement. Although it is said to have been consistently confirmed, not all aspects of the theory have been; the isotropy of one-way light speed has not been confirmed.

Although often presented as an explanation of the apparent null result the Michelson-Morley experiment,[2] special relativity theory was not created as such. Einstein declared his motivation was his firm belief that there was no reality corresponding to the notion of absolute rest and that in 1905 he had only second-hand knowledge of the Michelson Morley experiment, (probably from mention by Wein in 1899.)[3] Einstein imagined timing a light signal between two clocks and considered the effect of relative motion between observer and observed; whereas, the experiment of Michelson and Morley involved no clock and no relative velocity between observer and observed phenomena.

The essence of the Michelson-Morley null result is that interferometric measurement of length of a solid object holds true with changes of the orientation and velocity of the measurement. The null result is well explained by George Francis FitzGerald's conjecture[4] that Abraham Michelson's anticipated lengthening of light's round trip time is offset by contraction of the interferometer arms, because molecular bonds, (hence all solids including the interferometer arms,) contract to maintain constant interferometric length. Standards organizations, (NIST, BIPM, OIML, ILAC and ISO,) now rely on that fact by using interferometric calibration of solid length standards. Length contraction vitiates the Michelson-Morley experiment as a measurement of velocity relative to the luminiferous ether. Assigning the round-trip average speed of light in vacuo the defined constant value c makes the length measure of a solid object with respect to its proper frame of reference an invariant, *length* = ½ c × *time-round-trip*.

FitzGerald did not address the influence of time dilation. Length contraction of solids is necessarily implied by the Michelson Morley null result, but the contraction factors would be influenced by time dilation. Length measure in terms of wave count can be maintained by the combination of longer light path with proportionately longer wavelength. The "contraction" could even be lengthening.

Einstein presented special relativity as a deduction based on two postulates. He presented two versions of those postulates in his special relativity paper.

The Postulates of Special Relativity

(version one)

I. The same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.

II. Light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body.

(version two)

I. The laws by which the states of physical systems undergo change are not affected, whether these changes be referred to the one or the other of two systems in uniform translatory motion.

II. Any ray of light moves in the "stationary system" of co-ordinates with the determined velocity c, whether the ray be emitted by a stationary or by a moving body.

Together his two postulates imply that the speed of light is isotropic in any inertial frame of reference arbitrarily designated as the "stationary system," thus denying a basis in reality for the notion of absolute rest, consistent with his motivation for creating the theory. Yet, the empirical confirmation of the isotropy of light speed has been limited to round-trip average speed of light, (now a defined constant,) not one-way speed. When one assumes *time-forward* = *time-back*, as special relativity theory requires for synchronization of clocks using light signals, it vitiates timing the one-way speed of light between the synchronized clocks. One-way speed of light, has never been measured. However, with a bit of finesse, as will be shown, today's atomic clocks make one-way light speed measurable without the clocks being synchronized.

Einstein's belief that there is no reality corresponding to the notion of absolute rest is open to challenge. There is reason believe that when relativity's claim of one-way light speed isotropy is tested, it will prove false. The Sagnac effect[5] suggests there is anisotropy of one-way light speed. Astronomical observations also support the expectation that the frame of reference in which one-way speed of light is isotropic is unique.[6][7][8] Such a unique frame of reference is worthy of being deemed the absolute rest frame; it is the luminiferous ether as a frame of reference, not as a medium.

If there were no basis in reality for the notion of absolute rest, the one-way speed of light would be the same for any evacuated light path independent of orientation for every frame of reference, and Einstein's theory would be again confirmed. On the other hand, dependence on orientation demonstrates a real basis for the notion of absolute rest. This essay presents not only a test to detect which hypothesis pertaining to isotropy of one-way light speed is tenable, but also a way to measure our velocity relative to the absolute rest frame.

Herein, the term "inertial frame" shall be used as equivalent to "frame of reference for which the equations of mechanics hold good" and to "system in uniform translatory motion," and "dilation" and "contraction" can be positive or negative.

In this essay (Part I) a Euclidean rest frame in which one-way light speed is isotropic is assumed. As in FitzGerald's conjecture, material lengths and proper spatial coordinates of moving inertial frames are contracted relative to the rest frame. The possibility that gravity affects the speed of light or that departures from Euclidean geometry are somehow forced upon us is to be addressed in part two.[11]

A Realizable Test of the Isotropy of Light Speed

Assumptions.

Taking care throughout that we do not assume our conclusion, we shall provisionally adopt the conjecture of FitzGerald in this discussion. Accordingly, we assume strictly true that, absent thermal changes or deforming forces, all solids maintain constant interferometric length measure. Length measure is based on the interval of local time required for light to complete a round-trip. The proper length of molecular bonds is fixed; so light's round-trip between bond ends is of constant duration relative to the local frame. The proper length of a moving molecular bond, however, may differ from its length relative to the rest frame.

The fraction of light speed of an inertial frame's velocity relative to the conjectured absolute rest frame is designated beta, $\boldsymbol{\beta}$. Using time and length measure of the rest frame, the contraction expected in FitzGerald's theory would be by a factor $(1-\beta^2)$ parallel to the motion and by $(1-\beta^2)^{½}$ perpendicular to the motion. For convenience, we define gamma, $\gamma = 1/(1-\beta^2)^{½}$. These FitzGerald contraction factors are derived below, and were also derived by Michelson and Morley, and by Einstein in his special relativity paper before an abracadabra in the name of "substituting for x' its value," after which he uses Lorentz transformations. If solid bodies do contract, spaces between unconnected solid bodies would appear greater relative to the moving local frame than they do to the rest frame.

We shall also consider the possible impact of time dilation, which was not addressed by FitzGerald. If there is time dilation, slowing of local time and inversely proportionate lengthening of wavelength and of the moving object might occur. Time dilation may alter the contraction factors, but time dilation would affect all directions by the same factor, so the ratio of perpendicular to parallel contraction factors must remain $\gamma = 1/(1-\beta^2)^{½}$.

Experimental Setup.

Consider an experimental inertial frame with a non-zero velocity $\boldsymbol{\beta}\cdot c$ with respect to the conjectured rest frame. The experimental frame's absolute velocity is to be determined. Suppose we fix two atomic clocks sufficiently far apart for timing light travel and eliminate refraction by evacuating the direct light path between the clocks. Let a light signal be sent forward from the first clock to the second clock where it is reflected back to the first, with times of these events noted according to the respective clocks. Several trials are executed with differing orientation of the line between the clocks. In the example below the change of path orientation is effected by Earth rotation. The clocks need not be synchronized, but are assumed to measure time at the same rate throughout all trials; if not, rate differences must be known and compensated for.

We shall be interested in:

1. ***beta***, $\boldsymbol{\beta} = \boldsymbol{v}/c$, velocity of the experimental frame ÷ speed of light,
   alternatively expressed as its vector coordinates, (β, α, δ), where *alpha* and *delta* are, respectively, right ascension and declination in the celestial coordinate system.
2. *time-forward*, the time taken by light to travel from the first clock to the second clock, possibly including a synchronization error.
3. *time-back*, the time taken by light to travel from being reflected at the second clock back to the first clock, possibly including the opposite synchronization error.
4. *time-difference* = *time-forward* − *time-back*, possibly including a double synchronization error.
5. *sigma*, σ = *time-sum* = *time-forward* + *time-back*, (*time-round-trip*, no synchronization error.)
6. *rho*, ρ = *time-difference* ÷ *time-sum*, (a ratio strictly between one and minus one if, relative to any frame of reference, the clocks

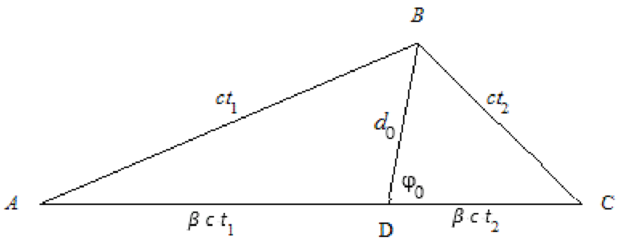
are synchronized.)

7. *phi*, φ, the angle between the velocity, $\boldsymbol{\beta}$, of the experimental frame and the line determined by the two clocks.

[Note: Boldface is used for the vector value, if not boldfaced, the scalar magnitude is meant.]

The measure of the angle φ is frame of reference dependant. Accordingly, subscript zero φ_0 will denote rest frame value, and subscript beta φ_β will denote experimental frame value. These will be equal at angles, 0, $\frac{1}{2}\cdot\pi$, and π.

Figure 1



The rest frame vector difference $\boldsymbol{c} - \boldsymbol{\beta}\cdot\boldsymbol{c}$ of the velocity of the light signal and the velocity of the experimental frame will have the magnitude $c\cdot(1-\beta\cdot\cos\varphi_0)$, the same for any evacuated light path the same angle φ_0 from $\boldsymbol{\beta}$. If the clocks be absolutely synchronized, i.e. synchronized with respect to the rest frame, then perpendicular to $\boldsymbol{\beta}$ the ratio ρ = *time-difference* ÷ *time-sum* must be zero, because *time-difference* must be zero. However, for light path orientations at other angles φ from $\boldsymbol{\beta}$ non-zero ratios ρ are expected, and parallel to $\boldsymbol{\beta}$ the maximum ρ is expected. In contrast, if the special relativity postulates were compatible and absolute rest were meaningless, $\rho = 0$ always.

Figure 1 idealizes a trial of the experiment in rest frame scale. The two clocks, synchronized in the rest frame, move to the right at speed $\beta\cdot c$, the points A, B, and C are the fixed rest frame locations where three events occur: at A, the first clock emits a light signal at *time_1* as it passes through point A; at B, the second clock reflects the light signal at *time_2*; at C, the light signal and the first clock arrive together at *time_3*. The point D is the location of the first clock at *time_2*. So we have time intervals t_1 = *time_2* − *time_1* and t_2 = *time_3* − *time_2*. The angle between the line determined by the two clocks and the velocity $v = \boldsymbol{\beta}\cdot c$ of the experimental frame is labeled φ_0.

Time dilation influences act as a scaling factor independent of direction and would have no effect on the ratio ρ or the angle φ.

Derivations.

Let us now derive equations for our variables of interest and the generalized transformations for any value of φ. Then, we will see the very factors derived by Michelson and Morley for $\varphi = 0$ and $\varphi = \frac{1}{2}\pi$.

The cosine law and quadratic formula yield solutions for t_1 and t_2 in the triangles ***ADB*** and ***CDB*** respectively. First, t_1 from triangle ***ADB*** in equations (1.1) through (1.3):

$$(ct_1)^2 = (\beta c t_1)^2 + d_0^2 + 2\beta c t_1 d_0 \cos\varphi_0$$

(1.1) cosine law for ΔADB

$$(1-\beta^2)c^2\ t_1^2 - 2\beta c d_0 \cos\varphi_0\ t_1 - d_0^2 = 0$$

(1.2) eq 1.1 in standard quadratic form

$$t_1 = \frac{d_0\left(\beta\cos\varphi_0 + \sqrt{1-\beta^2\sin^2\varphi_0}\right)}{c(1-\beta^2)}$$

(1.3) quadratic formula solution

Then, t_2 from triangle ***CDB*** in equations (1.4) through (1.6):

$$(ct_2)^2 = (\beta c t_2)^2 + d_0^2 - 2\beta c t_2 d_0 \cos\varphi_0$$

(1.4) cosine law for ΔCDB

$$(1-\beta^2)c^2\ t_2^2 + 2\beta c d_0 \cos\varphi_0\ t_2 - d_0^2 = 0$$

(1.5) eq 1.4 in standard quadratic form

$$t_2 = \frac{d_0\left(-\beta\cos\varphi_0 + \sqrt{1-\beta^2\sin^2\varphi_0}\right)}{c(1-\beta^2)}$$

(1.6) quadratic formula solution

Now we see the time-difference, the time-sum, and the ratio ρ.

$$t_1 - t_2 = \frac{2d_0\beta\cos\varphi_0}{c(1-\beta^2)}$$

(1.7) time-difference

$$t_2 + t_1 = \frac{2d_0\sqrt{1-\beta^2\sin^2\varphi_0}}{c(1-\beta^2)}$$ (1.8) time-sum

$$\rho = \frac{\beta\cos\varphi_0}{\sqrt{1-\beta^2\sin^2\varphi_0}}$$ (1.9) ratio

The experimental frame observer judges length by round-trip time of light, so $d_\beta = ½c(t_1 + t_2)$. The equations for tranformation of lengths between moving and ether frames are:

$$d_\beta = \gamma^2 d_0\sqrt{1-\beta^2\sin^2\phi_0}$$ (1.10) length transformation, [recall: $\gamma = 1/(1-\beta^2)^{½}$.]

$$d_\beta = \gamma^2 d_0$$ (1.11) parallel, sin 0 = 0

$$d_\beta = \gamma d_0$$ (1.12) perpendicular, sin ½π = 1

The spatial distance appears greater in the moving frame because the local measuring sticks are contracted.

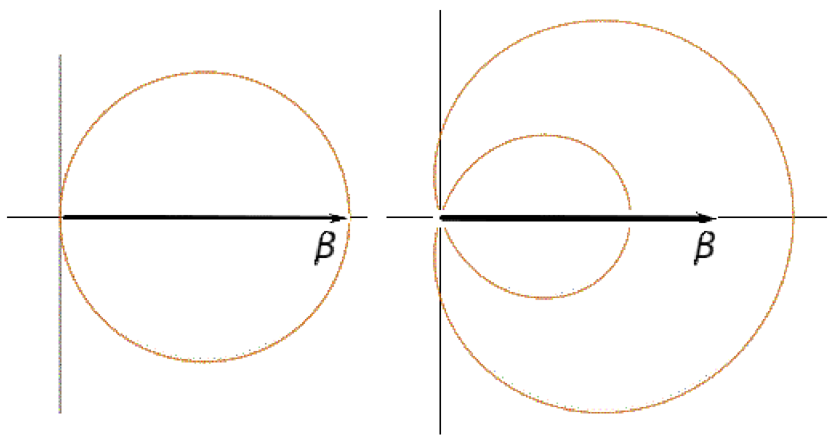
Applying length transformations to the cosine function, $\cos\varphi_\beta = \cos\varphi_0(1-\beta^2\sin^2\varphi_0)^{-½}$, it turns out that ρ is a quite simple function of φ_β independent of time dilation:

$$\rho = \beta\cos\varphi_\beta$$ (1.13) $\rho(\varphi_\beta)$

The influence of unknown time dilation must be isotropic, so it will enter these equations as a factor tau, τ; for example, $d_\beta = \tau\,\gamma^2 d_0\,(1-\beta^2\sin^2\varphi_0)^{½}$.

Expectations and Analysis.

Figure 2



Absolutely Synchronized With Synchronization Error

Polar coordinate plots of ρ as a function of φ_β for constant β appear in figure 2.

For clocks absolutely synchronized, the two dimensional plot is a circle that intersects the origin at $\varphi = ½\cdot\pi$, and the diameter from the origin will equal $\boldsymbol{\beta}$. The plot for $\varphi \in [0, ½\cdot\pi]$ coincides with the plot for $\varphi \in [½\cdot\pi, \pi]$.

A synchronization error would produce a $|\rho_{error}|$ less than β if for some φ the clocks had been locally synchronized rather than being absolutely synchronized. In that case, the plot will separate into two loops; the 2D plot is a limaçon. The magnitude of the error $|\rho_{error}|$ is half the distance between the two absolutely maximal intersections with the symmetry axis, and $\boldsymbol{\beta}$ will be the midpoint between the same two points. Rotation about the symmetry axis yields a three-dimensional plot.

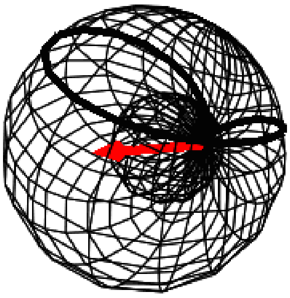
Shown below in figures 3 and 4 are surface plots of ρ in the celestial coordinate system. The surfaces have symmetry axes through the origin parallel to $\boldsymbol{\beta}$. In the absence of synchronization error, $\boldsymbol{\beta}$ is the point (ρ, α, δ) of the sphere farthest from the origin, possibly deduced from a minimum of four independent data points. A constant synchronization error would add a fixed ρ_{error}, positive for clock two lagging, to each data point, presenting an expanded spheroidal surface for $\rho_{raw} = \beta\cdot\cos\varphi_\beta + \rho_{error}$ of one sign and a contracted surface for ρ_{raw} of the other sign. There would remain an intersection at the origin $\rho_{raw} = 0$. The two unknowns, $\boldsymbol{\beta}$ and synchronization error, ρ_{error}, can both be determined from the full surface plot. The point midway between the surface's two absolutely maximal points is $\boldsymbol{\beta}$. The value of ρ_{raw} for $\varphi = ½\cdot\pi$ will be ρ_{error}, which is also half the distance between the maximal points. The full plot can be reproduced from as few as five data points.

As Earth turns, an earth-bound horizontal light path of fixed length not parallel to the earth's rotational axis will present a cone of orientations of like declination δ that includes (1) a path of maximal ρ_{raw} at φ_{min}, (2) a path of minimal ρ_{raw} at φ_{max}, and (3) equal φ pairs with equal ρ_{raw}. This is a pattern of bilateral symmetry about a plane parallel to both $\boldsymbol{\beta}$ and the earth axis. A lack of synchronization does not alter the orientation of the symmetry plane provided the synchronization error is constant. Figures 3 and 4 show a dark trace for such a conical sample with declination $\delta = 45°$ and $\rho_{\text{error}} = 0.0003$ on a surface representing all possible orientations; in figure 3 $\boldsymbol{\beta} = (0.001, \alpha, 32.7°)$, and in figure 4 with $\boldsymbol{\beta} = (0.001, \alpha, -24.6°)$.

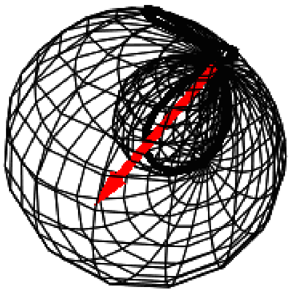
How accurate must clocks be to make a decisive test? Let us suppose a test site situated at the Bonneville Salt Flats (Lat. 40.736556, Long. -113.411537) with path ninety kilometer long and forward direction about 19° east of true north to give a constant 45° declination. The relative velocity of the endpoints of the path would be less than 5 meter per second. The value of σ is 0.6 millisecond. Further, suppose $\boldsymbol{\beta} = (\beta, \alpha, \delta) = (0.001, 10°, -34°)$. The expected 0.00117 range of ρ, from $0.001 \cdot \cos(169°) = -0.00098$ to $0.001 \cdot \cos(79°) = 0.00019$, implies a one-way timing range of 0.35µs. Nanosecond timing accuracy would resolve this range into 350 parts, enough for a decisive test. An alternative site, for providing the desired long horizontal light path, might be in still water under the ice of a frozen lake. For highest precision, an extraterrestial site would surely be best but would require more complex control and analysis.

$$\rho_{\text{raw}} = \rho_{\text{true}} + \rho_{\text{error}} \quad (1.13)$$

$$\text{error of second clock time relative to first clock} = \tfrac{1}{2} \cdot \sigma \cdot \rho_{\text{error}} \quad (1.14)$$



(figure 3)
$\boldsymbol{\beta} = (0.001, \alpha, 32.7°)$



(figure 4)
$\boldsymbol{\beta} = (0.001, \alpha, -24.6°)$

Discussion.

The purpose of this essay has been to show the feasibility of measuring one-way light speed anisotropy. The analysis was idealized for the sake of clarity and simplicity. Due to Earth's motions, an earth-bound experiment site has inconstant $\boldsymbol{\beta}$, so the determination of $\boldsymbol{\beta}$ must be referred to a specific time and place. The exposition above neglected the variations of experimental site velocity due to Earth motion and held relative differences in clock velocity and gravitation to negligible levels. By choosing a light path of virtually constant gravity any such effect would be minimized, but open questions remain about gravitational effects. It certainly does appear that atomic spectra are affected by gravity, and that may affect bond length. In a more complete analysis, data must be adjusted for these deviations from the ideal. However, the evidence of anisotropy cannot be obliterated by isotropic time dilation or its secondary effects.

Ultimately, considering the much longer light paths achievable with a space-based test, an earth bound test may be deemed uninteresting. A space based test would be computationally more complex because it would involve variable gravity and variable path lengths. The effect of gravity will need further elucidation, but ρ is independent of path length.

Unfortunately, a demonstration of one-way light speed anisotropy does not guarantee the determination of an ideal absolute rest frame. The possibility remains that light speed, length and time may vary by locality in any given reference frame. If gravity affects time dilation and length contraction, for example, the local frame metric might be location dependent. It would be difficult to specify a consistent Euclidean coordinate system for a particular frame of reference.

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