

The c-equivalence principle and its implications for physics

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Abstract: The c-equivalence principle, commonly accepted as true by most physicists, is the unstated assumption that $1/\sqrt{\epsilon_o\mu_o}$ equals the kinematic speed of light. Should someone prove the principle false, it would render the composition of two Lorentz transformations meaningless. The second hypothesis of the Special Theory of Relativity in its strong form would also be invalidated. This paper examined some of the consequences for physics, should this principle be proven false and outline some experiments to determine light speed, which could falsify the principle and provide evidence for the ether.

Keywords: c-equivalence principle, Maxwell's constant, Lorentz transformation, light speed experiments, Special relativity theory, Sagnac Effect, Michelson-Morley, Kennedy-Thorndike, Ives-Stilwell, Ether

1. Introduction

When James Clerk Maxwell formulated the equations of electromagnetism that now bears his name, he based them upon an ether/medium model characterized by three measurable quantities $\epsilon_o, \mu_o,$ and σ_o . Today we called these quantities respectively the electric permittivity, magnetic permeability, and electric conductivity of the vacuum. Usually, the quantity σ_o is set to zero and so terms having it as a factor disappear. These σ_o -terms model the resistivity or dampening aspect of the medium to electromagnetic waves. Thus, in setting σ_o to zero, we are modeling electromagnetic waves that are isolated from matter and can propagate without losing energy. Without these damping terms, the speed of electromagnetic waves in Maxwell's theory, denoted by c_o , is defined in terms of the other two quantities by $c_o = 1/\sqrt{\epsilon_o\mu_o}$. The quantity c_o is really the ratio between the electrostatic and electromagnetic units and is called Maxwell's constant. As to why we usually take it to be the velocity of electromagnetic waves, we are just continuing the practice of Maxwell. His words on the matter may provide some insight:

It is manifest that the velocity of light and the ratio of the units are quantities of the same order of magnitude. Neither of them can be said to be determined as yet with such degree of accuracy as to enable us to assert that the one is greater than the other. It is to be hoped that, by further experiment, the relation between the magnitudes of the two quantities may be more accurately determined. In the mean time our theory, which asserts that these two quantities are equal, and assigns a physical reason for this equality, are not contradicted by the comparison of these results such as they are. [p 436, Volume II].

Yet according to the widely accepted Einsteinian special theory of relativity (STR), the medium "does not exist" [1] and so can not have properties like $\epsilon_o, \mu_o, \sigma_o$. Thus, STR can only define the speed of electromagnetic waves like light kinematically by $c = \text{path length/duration of travel}$. Prof. Einstein and most researchers tacitly assumed that $c = c_o$, but there is no obvious reason or evidence that the two definitions should agree. [4, 7] The assumption that $c = c_o$ is called the c-equivalence principle by Jose Heras, in the

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same vein as inertial mass and gravitational mass are taken to be equivalent.[4] Before Heras named it, Roberto Monti analyze this assumption in his insightful article.[10] Even Herbert Ives, of the Ives-Stillwell experiment, did not believe that the speed of light has the same value in all inertial frames. He assumed length contraction and time dilation to get an elaborate formula for light speed as measured by moving detectors in his paper "Light Signals on Moving Bodies as Measured by Transported Rods and clocks." [31]

We will examine this principle and some consequences for physics should it be false, especially what it means to the Lorentz transformation. In the first section, we look at the connection between the Lorentz transformation and the c-equivalence assumption. We then examine an ether model of light propagation and contrast it with STR and other theories in the third section. We briefly related three famous experiments used to support STR to the c-equivalent hypothesis in the fourth section. Lastly, we examine some experiments that could prove the c-equivalent proposition false.

2. The Lorentz transformation and the c-equivalence principle

Since the Lorentz transformation is the heart of the special theory of relativity, there are many derivations of it since the days of Lorentz and Einstein. In particular, Jean-Marc Levy-Leblond showed that the Lorentz transformation follows from five commonly accepted hypotheses.[6] These being (1) the principle of relativity by which is meant the covariancy of equations modeling physical phenomena, (2) the homogeneity of spacetime and linearity of inertial transformations, (3) the isotropy of space, (4) the requirement that the transformations form a mathematical group and (5) causality. Yet in his derivation, the value of the velocity constant is unclear. Requiring the covariancy of Maxwell's equations in the form derived by Heras will yield the value of this constant for electromagnetism. In vacuum, Maxwell's equations, with a partial time derivative and not assuming the c-equivalence principle, have the forms: [4]

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}, \quad \nabla \cdot B = 0, \quad \nabla \times E = -\frac{c_o^2}{c^2} \frac{\partial B}{\partial t}, \quad \nabla \times B = \mu_0 J + \frac{1}{c_o^2} \frac{\partial E}{\partial t}. \quad (1)$$

Using the standard method to derive the wave equations from Maxwell's equations on (1) yields the same undamped wave equation in free space:

$$\nabla^2 E - \frac{1}{c^2} \frac{\partial^2 E}{\partial t^2} = 0, \quad \nabla^2 B - \frac{1}{c^2} \frac{\partial^2 B}{\partial t^2} = 0, \quad (2)$$

indicating that c is the speed of the EM wave. The Lorentz transformation (LT) with the undetermined velocity parameter U in the standard situation of two inertial frames moving with relative speed v along their common x-axis is given by:

$$x' = \gamma(x - vt), \quad y' = y, \quad z' = z, \quad t' = \gamma(t - vx/U^2), \quad \gamma = (1 - v^2/U^2)^{-1/2}. \quad (3)$$

By using the inverse Lorentz transformation and standard relations among differentials we get the following relations among the derivative operators:

$$\partial_{x'} = \gamma \left(\partial_x + \frac{v}{U^2} \partial_t \right), \quad \partial_{y'} = \partial_y, \quad \partial_{z'} = \partial_z, \quad \partial_{t'} = \gamma (\partial_t + v \partial_x). \quad (4)$$

The most important equations to get the value of the LT velocity parameter are (1) when the sources are zero. In fact, only one pair of equations from those equations involving the partials derivative with respect to x and x' are needed:

$$\partial_x E_y - \partial_y E_x = -\frac{c_o^2}{c^2} \partial_t B_z \quad \partial_z B_x - \partial_x B_z = \frac{1}{c_o^2} \partial_t E_y, \quad (5)$$

The corresponding equations for the moving frame are:

$$\partial_{x'} E_{y'} - \partial_{y'} E_{x'} = -\frac{c_o^2}{c^2} \partial_{t'} B_{z'} \quad \partial_{z'} B_{x'} - \partial_{x'} B_{z'} = \frac{1}{c_o^2} \partial_{t'} E_{y'}. \quad (6)$$

Using (4) in (6) and rearranging the equations yield:

$$\partial_x (\gamma E_{y'} + \gamma \frac{vc_o^2}{c^2} B_{z'}) - \partial_y E_{x'} = -\frac{c_o^2}{c^2} \partial_t (\gamma \frac{vc_o^2}{U^2 c_o^2} E_{y'} + \gamma B_{z'}), \quad (7)$$

and

$$\partial_z B_{x'} - \partial_x (\gamma \frac{v}{c_o^2} E_{y'} + \gamma B_{z'}) = \frac{1}{c_o^2} \partial_{t'} (\gamma E_{y'} + \gamma \frac{vc_o^2}{U^2} B_{z'}). \quad (8)$$

The covariancy requirement of the equations forces (7) and (8) to have the same forms as (5). This makes the quantity within the first parentheses on the left-hand side of (7) equal to the quantity within the parentheses on the right-hand side of (8). Consequently, the coefficients of the $B_{z'}$ terms must be equal:

$$\frac{\gamma vc_o^2}{c^2} = \frac{\gamma vc_o^2}{U^2}, \quad (9)$$

so that $U = c$. This process, if carried out in full using all the equations would yield the transformations for the components of the E and B fields. Of course, if the c-equivalence principle is accepted, everything agrees.

One reason not to accept the c-equivalence principle is revealed in the analysis of time-of-flight experiments to determine light speed.

3. Measuring Light Speed

To provide context for what follows, we give a description of the various theories of light before the wide acceptance of the special theory of relativity. In the 19th century, the leading theory is that light is a wave requiring an all-pervading medium, the so-called "luminiferous ether." There were two main versions of the ether theory: (1A) one in which the Earth and all other bodies move through the ether with little interaction and (1B) the entrained ether, in which the Earth and other material bodies dragged the ether in their motions. Movement through the ether as in (1A) would generate winds which would affect the speed of light depending upon the direction of the wind/movement. Variant (1B) can be further broken down to partial or total entrainment, with the version in which the ether is completely entrained often attributed to George Stokes in 1845. The totally entrained ether theories are often called local ether theories. In a local ether theory, there is no relative motion of the Earth and the ether near the Earth's surface where we live and conduct most of our experiments, hence no ether wind to detect. A few scientists supported an alternative to the wave theory of light, namely the particle/ballistic theory which requires no medium or ether.

Assuming the existence of the ether, we now give a brief derivation of an equation relating the two speed parameters for an ideal setup to measure the speed of light by the time-of-flight method. Let S be a reference frame in which the electromagnetic speed of light c_o equals the kinematic speed of light c . This frame is at rest relative to the ether. In essence, the ether is defined to be the frame where $c = c_o = 1/\sqrt{\epsilon_o\mu_o}$. Let S_m be a frame moving with a constant nonzero velocity v relative to S . At rest in S_m is a transceiver and reflector separated by a distance L . In actual experiments, this frame has historically been the lab frame near the Earth's surface. We assumed the quantity c_o to be invariant and unaffected by motion, since it is a property of the ether. This assumption is akin to the constancy of light speed hypothesis in Einstein's version of the special theory of relativity.

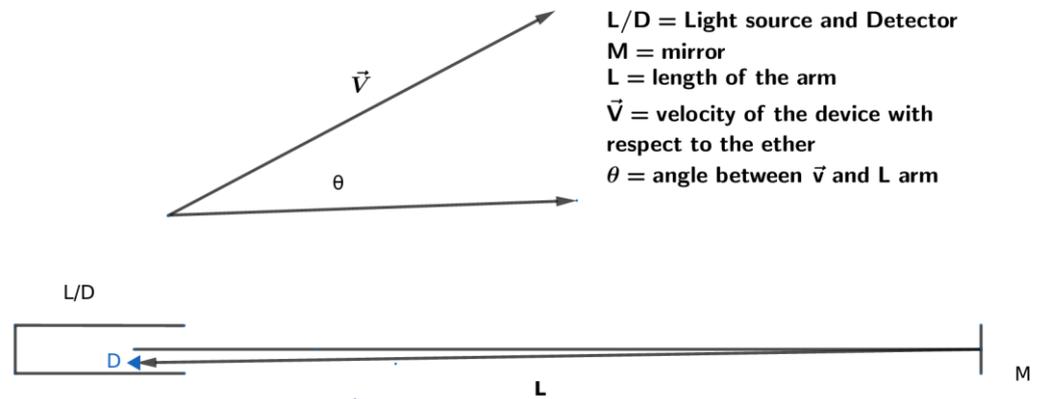


Figure 1. A schematic drawing of a setup to measure the speed of light using time-of-flight methods. In actual devices, the light path may be more complicated.

We need to find c in the moving frame as the quotient of distance traveled and the duration of travel. Referring to Figure 2, by solving the equation for the duration of travel in the forward direction of L we get the forward travel duration to be

$$\Delta t_f = \frac{L}{c_o(1-\beta_o^2)} [(1-\beta_o^2 \sin^2 \theta)^{1/2} + \beta_o \cos \theta], \quad \beta_o = v/c_o, \quad (10)$$

and for the return trip, the duration is

$$\Delta t_r = \frac{L}{c_o(1-\beta_o^2)} [(1-\beta_o^2 \sin^2 \theta)^{1/2} - \beta_o \cos \theta]. \quad (11)$$

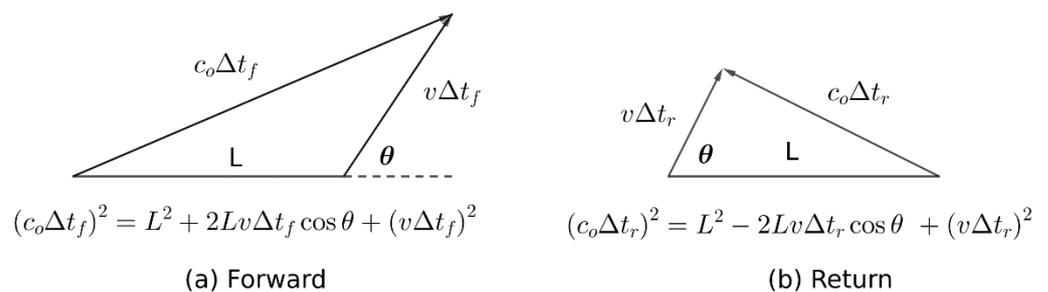


Figure 2. Calculation of the optical paths for the forward and back directions of the light ray along the distance L using the standard vector addition law. For $\theta = 0, \pi$, many would consider this situation as the addition of two velocities, but it is really just the calculation of the actually travel distance in the medium frame.

Note that $\Delta t_f > \Delta t_r$, implying that the one-way speed of light relative to the moving detector and its rest frame is different in the forward and return paths even though the speed of light has the same value with respect to the medium in either direction. The difference in the two durations can be understood as follows. In the forward path, the reflector is pulling away from the approaching light ray thus increasing the separation distance the ray must travel in the medium's frame. While on the return trip, the detector is approaching the ray as the ray is approaching it, thus decreasing the separation distance between the ray and the detector in the medium's frame. If the forward and return rays are superimposed upon each other, fringe shifts due to a phase difference can be detected. This phase difference between the two rays has been called the generalize Sagnac effect and was confirmed in the experiments of Wang and collaborators. [16, 17]

But many researchers consider measuring one-way speed light to be impossible, since synchronization of clocks are required. The two-way speed of light is easier to do, since it only requires one clock at the transceiver and no synchronization. Toward the expression for the two-way speed, the total duration of the back-and-forth travel along L is

$$\Delta t_{fr} = \Delta t_f + \Delta t_r = \frac{2L}{c_o(1-\beta_o^2)} [(1-\beta_o^2 \sin^2 \theta)^{1/2}]. \quad (12)$$

Thus, the two-way kinematic speed of light along L in the rest frame of the transceiver is

$$c = \frac{2L}{\Delta t_{fr}} = \frac{c_o(1-\beta_o^2)}{(1-\beta_o^2 \sin^2 \theta)^{1/2}}. \quad (13)$$

For the rest frame of the ether $v = 0$, the above equation forces $c = c_o$. For frames moving with respect to the ether frame, (13) implies that $c_o > c$, falsifying the c-equivalence principle. Consequently, (1) and (2) are the equations of the EM fields and waves in these frames.

If we accept the c-equivalence principle as true and the above model approximates reality, then (13) forces $v = 0$, contradicting our working assumption of nonzero v . Many people today accept the c-equivalence principle and reject the above classical Newtonian framework used in the analysis. Yet even if length contraction and time dilation are assumed, the contradiction does not disappear as a quick calculation will reveal. The two remaining possibilities are the entrained ether model that the velocity of the measuring device is zero relative to the local ether near the Earth's surface, or that light travels like particles and is unaffected by the ether.

Unknown to most, there is a form of the entrained ether hidden within Einstein's general relativity theory, as the following summary of his works will reveal. In 1905, Albert Einstein put forth the hypothesis that the speed of light is constant in his special theory of relativity to derive the Lorentz transformation. Once Professor Einstein developed the general theory of relativity, he made some interesting statements concerning the domain of validity of the constancy of light speed, a selection of which follows and can be found in his collected papers [3]:

1911: If c_o denotes the velocity of light at the coordinate origin, then the velocity of light c at a point with a gravitation potential ϕ will be given by the relation

$c = c_o(1 + \phi/c^2)$. The principle of the constancy of the velocity of light does not hold in this theory in the formulation in which it is normally used as the basis of the ordinary theory of relativity. [V3, D23, p 385]

1913: I have shown in previous papers that the equivalence hypotheses leads to the consequence that in a static gravitational field the velocity of light c depends on the gravitational potential. This led me to the view that the special theory of relativity provides only an approximation to reality; it should apply only in the limit case where differences in the gravitational potential in the space-time region under consideration are not too great. [V4, D13, p 153]

1916: In the second place our result shows that, according to the general theory of relativity, the law of the constancy of the velocity of light in vacuo, which constitutes one of the two fundamental assumptions in the special theory of relativity and to which we have already frequently referred, cannot claim any unlimited validity. [V6, D24, p 328]

More recently, Irwin Shapiro talked about the variable speed of light in his 1964 paper on what is now called the Shapiro delay.[12]

All these statements imply that light speed is not constant but is only approximately so for regions within a nearly uniform gravitational potential. These statements also suggest that the medium for light transmission is related to the dominant gravitational potential in the region of space under observation. If we accept that light speed is determined by gravity, we are in essence accepting a form of Stokes' totally entrained ether, since all material bodies carry their gravitational potential along with them in their orbital motion.

There is some evidence to support this in the experiment of Wolf and Petit that was designed to measure directional dependence of light speed using the satellites of the Global Positioning System (GPS).[19] For those who are unfamiliar with the GPS, this system use satellites about 20,000 km above the Earth's surface, equipped with synchronized atomic clocks, and transmitters and receivers to broadcast signals carrying information of both times and positions. It or systems like it used an Earth-Centered Inertial (ECI) frame to calculate the positions and times of moving transmitters or receivers to high accuracy.[5] The ECI frame is an approximate inertial frame so does not partake in the Earth's rotation. This frame, within the altitude of the GPS satellites, is dominated by Earth's gravity and is where most GPS experiments are conducted, including those of Wolf and Petit. Their experiment gave an upper limit to light speed anisotropy of $\delta c/c < 5 \times 10^{-9}$, and thereby showed that light speed is constant and independent of direction to a very high degree for receivers at rest in this frame.[19]

Returning to our principal theme, the same argument used to derive (10), (11), and (13) can be applied to an emitter and detector pair moving relative to the ECI frame with velocity u . Here c would play the role of c_o , and the two-way speed of light as measured by the moving detector, c_m , would be related to c by:

$$c_m = \frac{c(1 - \beta^2)}{(1 - \beta^2 \sin^2 \phi)^{1/2}}, \quad \beta = \frac{u}{c}, \quad (14)$$

with ϕ the angle between u and the direction of the light path. Some researchers has proposed experiments to test the formulas corresponding to (10) and (11) where $\phi = 0$ or $\phi = \pi$, with modern technologies and the global positioning system. [15, 18] Among them is Ronald Hatch, a GPS expert who held various patents on GPS technologies as either inventor or co-inventor and who served numerous roles within the Institute of Navigation (ION).[15] These experiments would disprove the second hypothesis of STR--interpreted in its strong form that the speed of light is the same in all inertial frames. They would also disprove the c-equivalence principle, and would indicate that the logic behind the formulas (13) and (14) is sound.

Now if the c -equivalence principle is disproved, the two-way kinematic speed of light, its wavefront or group speed, would depend on the velocity of the moving detector with respect to the ether or stationary frame. Thus light speed is not the same constant in every inertial frame, contradicting the strong form of the second postulate of relativity. With the speed of light not being the same in every inertial frame, the composition of two Lorentz transformations would not yield a Lorentz transformation, as an elementary computation will reveal. The relativistic velocity addition law would not hold and some derivations of the Lorentz transformation would also be invalidated.

Since the Earth also rotates, in real earth-based experiments conducted over several days v is not constant from hour to hour, and so c would have small daily variations. Such daily speed of light variations could appear in interferometry experiments like the ones of Michelson and Morley and the ones of Kennedy and Thorndike. In fact, the analysis of these experiments would have to be redone if the c -equivalence principle is false.

4. Three experiments often cited to support the LT

We briefly examine the three type of experiments often cited in support of the Lorentz Transformation, the heart of special relativity, should the c -equivalence principle be false. These experiments are the Michelson-Morley ether wind experiments, the Kennedy-Thorndike experiments, and the Ives-Stilwell transverse doppler effect experiments. In fact, using the result of these three, the Lorentz transformation can be derived as was done by Thompson. [23] We will examine the conclusions drawn from these three experiments and see if their results can support other theories.

4.1. Michelson-Morley and Kennedy-Thorndike Type of Experiments

In 1887, Albert Michelson and Edward Morley conducted their first ether wind detection experiment at the Physics Department of Case School of Applied Science (today Case Western Reserve University) and obtained a null result or one that were much smaller than expected.

Michelson was a firm believer in the ether theory, and designed his 1887 experiment to detect the relative motion of the Earth through the ether. In order to implement his plan, Michelson created a device now called an interferometer. This device split the beam from a single source of light with a half-silvered mirror and send the two beams traveling at right angles to one another. After leaving the splitter, the beams traveled out to the ends of arms of equal lengths where they were reflected back to the middle by small mirrors. They then recombined on the far side of the splitter producing a pattern of constructive and destructive interference based on the lengths of the two arms. Any slight change in the duration of travel of the beams due to a change in speed of light would then be observed as a shift in the positions of the interference fringes. The details of their experiment can be found in the references. The actual light path in their experimental setup up is more complicated than what is described above, as can be seen in [Figure 3](#).

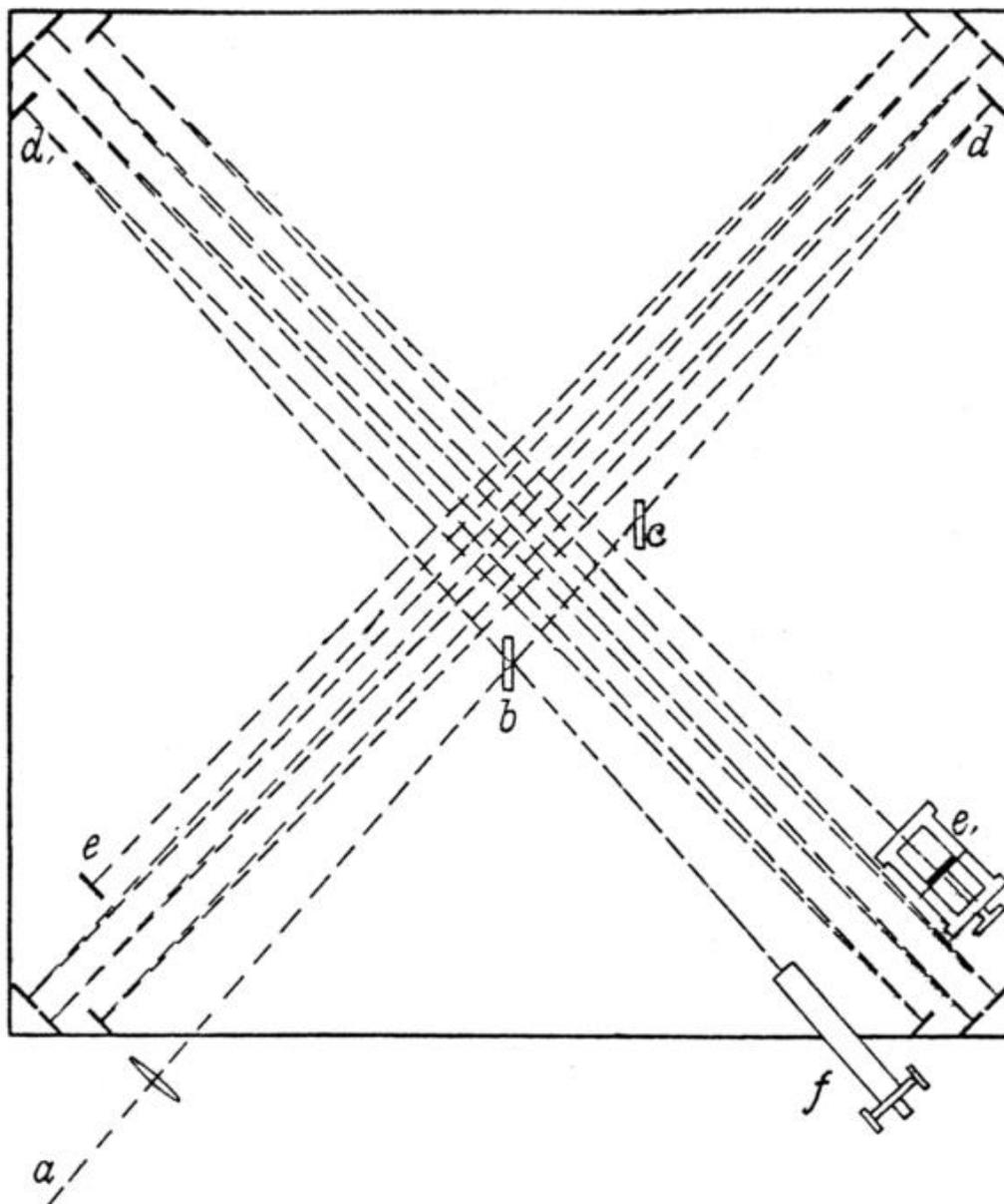


Figure 3. The actual paths for the forward and back directions of the light ray in the two arms of the M-M and Miller experiments

Let us focus on the logical ramification of the M-M experiment's null result. The null result only eliminate version (1A) of the ether theory, that the Earth moved through the ether without dragging it, and not that the ether is nonexistent as it often claimed. The entrained ether was not eliminated by this experiment. Instead of trying to determine which of the alternatives theories best explained the M-M null result or even repeating the M-M experiment, some notable scientists by the name of Lamor and Lorentz put forth the length contraction hypothesis in which the length of the arm parallel to the motion is contracted by a certain amount, enough to explain the null result. Thus it is often claimed that the M-M null experimental results provide evidence for length contraction due to motion. This is a clear example of circular reasoning and the only way to break the circle is to have some independent evidence of length contraction. In any case, experiments of the M-M type when done near the Earth's surface only revealed that the Earth's speed relative to

the ether is zero, but does not eliminated other theories. Yet, there is some experimental evidence to indicate that the shift is not zero when done at a high enough altitude. See for examples the works of Dayton Miller, which we briefly summarized below.

Miller was President of the American Physical Society and Acoustical Society of America, Chairman of the Division of Physical Sciences of the National Research Council, Chairman of the Physics Department of Case School of Applied Science, and a member of the US National Academy of Sciences well known for his work in acoustics. With his credentials, Miller interferometry work had to be taken seriously when he was alive. Miller initially borrowed the interferometer from the M-M experiment and made it more sensitive by significantly increasing the lengths of the arms. Not to mention additional refinements he made throughout the years he ran his experiments. In his 1933 paper, Miller comprehensively summarize his interferometry work including the large quantity of data which supported his conclusions. Miller's experimental setup made a total of over 200,000 individual readings, over 12,000 individual turns of the interferometer undertaken at different months of the year and at different altitudes, starting in 1902 at the Case School and ending in 1926 with his Mt. Wilson experiments. This paper excluded many data obtained from control experiments undertaken at the Case School between 1922 and 1924. More than half of Miller's included readings were made at Mt. Wilson using the most sophisticated and controlled procedures, with the most conclusive set of experiments between 1925 and 1926. In contrast, the original Michelson-Morley experiment of 1887 involved only six hours of data collection over four days, July 8, 9, 11 and 12 of that year, with a total of only 36 turns of their interferometer. Yet, in our current times the M-M experiment is celebrated and Miller's work is largely ignored.

In brief, Miller concluded that the Earth was drifting at a speed of 208 km/sec towards a point in the Southern Celestial Hemisphere, towards Dorado the swordfish in the middle of the Great Magellanic Cloud.[25, p 234] This conclusion is based upon a measured displacement of around 10 km/sec at the interferometer, and assumed the Earth was moving through a stationary Earth-entrained ether in that particular direction. This assumed motion lowered the velocity of the ether from around 200 to 10 km/sec at the Earth's surface. When his data were plotted against sidereal time, he remarked "...a very striking consistency of their principal characteristics...azimuth and magnitude... as though they were related to a common cause... The observed effect is dependent upon sidereal time and is independent of diurnal and seasonal changes of temperature and other terrestrial causes, and...is a cosmical phenomenon." [25, p 231]

There is some controversy with his results. After Miller's death when he could not answer his critics, his former student Shankland and several other people, in consultation with Einstein, reanalyses some of Miller's experimental data and concluded the shift was due to a temperature gradient.[26] In their analysis, they lumped some of Miller's original data from different years together and carefully selected a portion of it to claim that small natural ambient temperature gradients in Miller's Mt. Wilson observation might produce fringe shifts in the insulated interferometer. This effect is what Miller himself previously observed in his control experiments with strong radiant heaters and even remarked upon in his summary article of 1933. The Shankland paper argued there must have been "thermal effect" in Miller's Mt. Wilson measurements, but provides no direct evidence of this. They did present a statistical analysis of a portion of Miller's published 1925-1926 Mt. Wilson data, concluding that his observations "...cannot be attributed entirely to random effects, but that systematic effects are present to an appreciable degree" and that "the periodic effects observed by Miller cannot be accounted for entirely by random statistical fluctuations in the basic data." [26, p 170] More telling, the Shankland team admitted they "...did not embark on a statistically sound recomputation of the cosmic solution, but rather [searched for]...local disturbances such as may be caused by mechanical effects or by nonuniform temperature distributions in the observational hut." [26, p 172]

In summary, Shankland and his corroborators admitted that no systematic measurement error nor mechanical flaws in the interferometer apparatus gave rise to the periodic patterns in Miller's data--while admitting a disinterest in extracting any potentially validating ether-drift axis from his data. These are important admissions, since they suggested that Miller had really measured an Earth-entrained ether drift. An interesting fact to give some perspective on the Shankland's team conclusion is that the four members listed as authors of the paper did not do the statistical analysis of Miller's data! For his Master's Thesis, a Case physics student, Robert L. Stearns, did the actual analysis. [27] For such work he only received credit in a footnote of the paper. More importantly, Shankland and et al never presented evident a temperature gradient had contributed to the periodic sidereal fringe shifts observed by Miller in his published data, even though this was their stated conclusion. They did not explained exactly how an external temperature gradient could affect the interferometer readings to yield the observed systematic sidereal effect. And they never addressed the larger issue of periodic effects in the data, expressed in nearly identical cosmic sidereal coordinates at different seasons and hours of the day.

Fortunately Miller's experimental data from the Mt Wilson was published and the rest archived at Case Western University, so a more rigorous and systematic reanalyze is possible for those who want to analyze the data for themselves.

Even if we reject this form of the entrained ether, we must explained why the particle theory of light is ruled out before we can claim that the null result of the M-M experiments is due to length contraction. Now if we accept that light beams are composed of streams of photons, massless particles, with wave like behaviors emerging from large ensembles, we are accepting a form of the ballistic theory of light. In either of the above cases, there is no need for the length contraction hypothesis to explain the null results of experiments of the M-M type.

The length contraction hypothesis is modelled using the gamma factor in the LT, and without that gamma factor the LT is just the transposition of subrelativity found in O'Rahilly book.[34] More importantly, without length contraction, experiments of the Kennedy-Thorndike (K-T) type is also inconclusive at best, since K-T type experiments assumed length contraction to prove so-call time dilation. In their own words:

The theory of the this experiment requires the following two assumptions: (a) There exists at least one coordinate system in which Huyghen's principle is valid and the velocity of light is the same in all directions. This assumption is unobjectionable from the standpoint either of relativity or of any plausible hypothesis involving an ether; for relativity, it is true for all uniformly moving systems, and in the latter case for any system at rest in the ether. (b) The Michelson-Moreley experiment indicates that a system moving with uniform velocity v with respect to such a system has dimensions in the direction of motion contracted in the ratio $[1 - v^2 / c^2]^{1/2}$ as compared to dimensions in the fixed system, while dimensions in the direction of and perpendicular to the motion are unchanged. This is in part assumption, for although there can be little doubt that the experimental yields a strictly null result, nevertheless it actually shows only that dimension in the direction of and perpendicular to the motion are in the ratio mentioned; either of these dimensions might be any function of the velocity so long as that ratio is preserved. [28]

The Kennedy-Thorndike experiment is very similar to the M-M experiment in many aspects. The biggest different being an interferometer with arms of unequal lengths.[28] Because of the unequal arms' lengths their experimental apparatus acted like a gyroscope and could detect the rotation of the Earth, as Monti pointed out.

Both of these expirments give null results or result smaller than expected near the Earth's surface, so they can be used to support all sort of many theories, as was pointed out by many people including Herbert Ives. In fact, Ives pointed out that the M-M experiment's null result can be explained by theories in which the length contraction in the direction of motion is in the ratio

$$[1 - v^2 / c^2]^{(n+1)/2} : 1, \quad (15)$$

and in the perpendicular direction to the motion by

$$[1 - v^2 / c^2]^{n/2} : 1. \quad (16)$$

The results of the K-T experiment are then explained if the time scale at the origin is altered in the ratio

$$[1 - v^2 / c^2]^{(1-n)/2} : 1. \quad (17)$$

Ives also noted that n can not be determined from these type of experiment and that the Ives-Stilwell type experiments could determined $n = 1$.

4.2. Ives-Stilwell Experiments

Herbert Ives was a firm believer in the Lorentz-Larmor relativity theory and did not accepted the constancy of light speed hypothesis when he conducted his famous experiments with Stilwell.

Kantor did a carefully analysis of their experiment and those of Otting and concluded that they were inconclusive at best. [35] If the result of Ives-Stilwell is accepted, its actually falsified the c-equivalence principle. According to them they showed the following equations to hold: [29]

$$\lambda = \lambda_o (1 - v^2 / c^2)^{1/2}, \quad (18)$$

$$v = v_o (1 - v^2 / c^2)^{1/2}, \quad (19)$$

which when multiplied together gives

$$c = \lambda_o v_o (1 - v^2 / c^2)^{1/2}, \quad (20)$$

with $c_o = \lambda_o v_o$, and thus if $c = c_o$ and is finite, we must have $v = 0$. Thereby contradicting the motion of the ions in their experiment.

5. Proposed Experiments

To falsify the c-equivalence principle, someone would need to conduct an experiment that shows $c \neq c_o$ beyond all doubts. This requires measuring c_o and c independently, then comparing them. There are some experimental indications that $c \neq c_o$ from the Shapiro's delay but also from the speed of radar signals that were bounced off of Venus. When such data were publicly available, Bryan Wallace observed that the data seem to show that c is not constant and that the classical velocity addition law holds for light.[14] An independent scientist from Russia, Tolchel'nikova confirmed Wallace's observations and even presented them at an international conference.[13] The first step to determine the truth of the c -equivalence principle could be the reanalysis of these interplanetary data by independent researchers.

Currently, there are several methods to determine light speed, such as using cavity resonance and interferometry. The most relevant to us is measuring the electromagnetic

constants ϵ_0 and μ_0 , and time-of-flight methods. The vacuum permittivity ϵ_0 is determined from measuring the capacitance and dimensions of a capacitor, while the value of the vacuum permeability is fixed at exactly $\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$ through the definition of the ampere. Rosa and Dorsey, the last recorded researchers to use EM measurements, used it in 1907 to get their result. To determine if (13) hold, experimentalists would need to update the measure of ϵ_0 with modern technology and perform it again along with modernized time-of-flight measurements.

The last recorded time-of-flight measurement was the experiment designed by Albert Michelson, of the famous Michelson and Morley experiment, and carried out by Pease and Pearson at the Irvine Ranch close to Santa Ana, California, between September 1929 and March 1933. In this experiment, a system of mirrors folded the path length of 12.8 to 16 km to fit within a 1.6 km long pipe, evacuated to pressures between 66 and 734 pascals. During its lifetime, 2885.5 determinations of light speed were made, giving the simple mean of $c = 299,774 \text{ km/sec}$ with an average deviation of 11 km/sec.[9] Since they did this experiment during different times of the day and year, variations due to the direction and speed of the Earth relative to the ether may exist within their experimental data. A reanalysis of their experimental data is worth doing to see if the variations can be accounted for. Methods that use interferometry to measure wavelength and independent ways to measure frequency yielding c as their product could be a replacement for the time-of-flight method if they do not use standing waves.

Modern kinematic measures of c can be done using the satellites of a global navigation satellite system like GPS, or a modernized version of the Michelson, Pease, and Pearson experiment. If a modern equivalent to the setup of Michelson, Pease, and Pearson is used, we suggest having at least two identical devices far from urban centers and seismically active areas, enclosed in a climate control housing at a constant temperature. This would minimize error sources like temperature fluctuations and ground vibrations. One such experimental setup should be at sea level and one at a higher altitude, perhaps at the top of a mountain. The experimental apparatus would automatically send the raw daily data to independent labs for analysis. This has to be done considering the CGPM (1983) definition of the meter in terms of the speed of light as pointed out by Mare and collaborators.[7]

6. Closing remarks

What are the consequences of falsifying the c-equivalence principle? As we mentioned previously, showing that $c \neq c_0$ would also invalidate the second postulate of the Special Theory of Relativity in its strong form interpretation that light speed has the same value in all inertial frames.

If (13) is shown to hold then the ether exists! And a way to determine the speed relative to the ether is found, although it may need to be done far enough away from the dominant gravity field. This would also imply that the forward time of travel is greater than the return time $\Delta t_f > \Delta t_r$, so that the kinematic speed of light is no longer isotropic with respect to the moving detector. Also, the transformations to preserve covariancy from one frame to another for the various electromagnetic fields will need to be modified. Lastly, since the Lorentz transformations of different frames depend on different c values, the composition of two Lorentz transformations and the relativistic velocity addition law are rendered meaningless.

It would also invalidate any conclusion based upon the assumption that the two way velocity of light is the same in all directions and in all inertial systems, such as the Selleri transform. [37, p 326]

What is this ether? Many think it is the frame of the fixed stars or the frame wherein the cosmic microwave background radiation is uniform in all directions. Others think it is the quantum vacuum.

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