The Continuing Relevance of Lorentz Ether Theory in the Age of Relativity

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With the advent of relativity the Lorentz Ether theory has been relegated to not much more than a historical footnote. What is less well known is that virtually all optical experiments to date to test the validity of special relativity cannot distinguish between the predicted outcomes of the two theories. We review the historical development of the Lorentz theory as it evolved to address the results of key optical observations of the 19th century. We then examine how modern optical experiments attempting to detect the relative inertial motion of an observer with respect to a preferred reference frame for light remain consistent with Lorentz's predictions.

1. Introduction

One of the first theoretical explanations for the failure to discover an ether drift in Michelson and Morley's famous experiment was developed by Lorentz in his theorem of corresponding states. The theory was in a sufficiently complete form by 1904 that it has been considered by some to be only another way of describing relativity theory which came shortly after, only differing in its acceptance of the simultaneity of events for two reference systems in a state of relative motion. A. A. Tyapkin once commented:

> "It is important to clear out that Lorentz's approach not only should be acceptable for explaining Michelson's experiment, but also should be a consistent system for describing relativity effects for any possible experiments. Many scientists have stated quite justifiably the absence of an "experimentum crusis" for Lorentz theory and special relativity." [1]

It is a common misconception that the ether theory of the late 19th and early 20th century was decisively disproved by the Michelson Morley experiment and one need not question the validity of its greatest rival and successor, Einstein's special and general relativity. Herein we wish to review some of the critical optical experiments which led to the development of the Lorentz ether theory, and show how it has remained consistent with the results of a wide array of optical tests up to the present day.

2. Early Wave Theory and Stellar Aberration

After Young's double slit experiment of 1801 served as vindication of Huygens' wave theory of light and overturned the previous corpuscular theory of Newton, it was necessary to develop a new understanding of optical phenomenon consistent with the idea of a medium of space. One of the most important phenomena to explain was stellar aberration, discovered in the previous century by Bradley and originally explained in terms of the corpuscular theory. One explanation of light aberration using wave theory relies on Huygens' principle and assumes an immobile ether, as was described by Lorentz [2]. Following this principle, any point on the wave front can be considered the origin of a new spherical wave front. Due to the motion of the earth through a preferred frame for light, plane waves approaching the earth from a perpendicular direction will come through a line bent by the aberration angle as has been explained in detail by Janssen [3]. Such models readily explained Stellar aberration in the context of a stationary ether and were subsequently included in the wave theory paradigm.

3. Experiments of Arago, Fizeau, and Hoek

A problem arose when it came to explaining the aberration expected in telescopes or light paths with a refractive index other than 1. Arago found that there was no change in the aberration angle when the light from a star was passed through a glass prism [4]. The issue was addressed by Fresnel, who found that the aberration angle would be expected to be different in a glass filled telescope as compared to an empty telescope [5]. The only way to explain the difference was to assume that the refracting material in the telescope changed the speed of the light in the glass by the fraction: $f = 1 - 1/n^2$. This factor became known as the Fresnel coefficient, and was successful in explaining the null result of the Arago experiment. It implied that the medium for light was stationary ether that is partially dragged by matter depending on its refractive index. In Fizeau's experiment of 1851, he succeeded in demonstrating directly the Fresnel coefficient in a moving dielectric (water), by showing that the beam of light is dragged by the velocity of the moving water (a positive result) [6]. In earlier experiments such as Arago's, the coefficient had always been used to compensate some other effect of ether drift that one would expect to observe but that proved to be undetectable (i.e. a null result). Dragged ether models such as Stokes model had the advantage of explaining the lack of ether drift in various experiments, but the positive result of the Fizeau experiment confirmed that the Fresnel drag coefficient must be taken into account.

Hoek's experiment of 1868 addressed the issue of ether drag in a dielectric medium, but differed from Fresnel's experiment in that the dielectric was co-moving with the interferometer through space. Hoek's arrangement was a simple square closed path interferometer, where light counter-propagates in opposite directions along the paths to interfere at a detector close to the original source of the light [7]. The only difference in this case being that one of the four beams passed through water, having an RI of 1.333. Using simple Galilean addition of velocities, one might expect to find a fringe shift due to an ether drag with respect to the moving earth, due to the difference in the counter-propagating velocities of light in the water as compared to the other paths. This is in fact not so, and the null result served to underscore that in optical experiments involving dielectric media with a refractive index > 1, simple Galilean addition of velocities will not yield the correct result. The result can be explained in terms of ether theory, but only if one assumes the validity of Fresnel's drag coefficient.

4. Lorentz Theorem of Corresponding States

A partial ether drag as implied by the Fresnel coefficient presented a problem for the theory – most notably requiring the relative velocity of ether and matter to be different for various colors, which is evidently not the case. In 1892 Lorentz wrote an extensive treatise on the electrodynamics of moving bodies, and was able to show that for a wave propagating along the direction of motion of a frame moving with velocity v must have a velocity

$$\frac{c}{n}-\frac{v}{n^2}$$

in that frame (to order v/c) [8]. Hence, the wave velocity with respect to the ether in accordance with the Fresnel coefficient would be

$$\frac{c}{n}-\frac{v}{n^2}+v=\frac{c}{n}+v\left(1-\frac{1}{n^2}\right)$$

This new view of Lorentz suggested that it is the waves that are partially dragged and not the ether. The electric field of the wave displaces the electrons in the refractive medium creating a common motion. The moving electrons are then subjected to an additional Lorentz force from the magnetic field of the wave. Both of these effects reduce the velocity of the wave by v/n^2 from the value of c/n when the medium is at rest in the ether [3]. This new treatment readily explained the first order optical test results of Arago, Fizeau, and Hoek, under the umbrella of a single ether theory since the Fresnel coefficient could be seen to result from a modification of the propagation of light waves, and is not due to ether entrainment. Lorentz completed this theorem to counter Lienard's proposed experiment with an interferometer with an arm with a refractive index greater than 1. Lorentz's exact theorem of corresponding states also explicitly notes (1899) that the frequency of oscillating electrons generating the light waves is lower in systems in motion than in those at rest by [2]:

$$\gamma T=\frac{T}{\sqrt{1-v^2/c^2}} \tag{1}$$

This idea was also presented by Larmor in more detail in 1900, and is sometimes referred to as Larmor time dilation [9]. Consequently, the idea of time dilation pre-dates the work of Einstein – differing only in interpretation - time dilation for Lorentz/Larmor is a mechanical effect on the rate of a moving clock due to the velocity of light with respect to the preferred frame, and does not imply that real time actually changes with velocity. This aspect is particularly important in light of the interpretation of many experiments which have been held out as an "experimentum crucis" in favour of relativity and against Lorentz Ether theory. In these cases the frequency shift predicted by the Lorentz theory of the laser and/or the receiver, due to its motion with respect to the ether of:

$$f=\frac{f_0}{\gamma}=f_0\sqrt{1-\frac{v^2}{c^2}} \tag{2}$$

is often excluded, leading to the suggestion that the Lorentz theory will predict a positive result when in fact it predicts a null.

5. Michelson-Morley Experiment

By the time of Michelson, it was already understood that in many optical experiments attempting to detect ones translation through space, first order differences in the speed of light will perfectly cancel in the return paths inside an interferometer, yielding a zero fringe shift. However, Michelson sought instead to look for a second order fringe shift due to the motion of his interferometer with respect to the ether, and fully expected to find one based on the understanding of the day [10]. The null result of this experiment was at first a major puzzle for the Maxwellians, until Fitzgerald proposed the idea of matter contracting in the direction of motion [11]. Lorentz added this idea into his final theory (1904) covering all first and second order effects in interferometers, in what came to be known as the "Lorentz contraction" hypothesis [3]. This hypothesis was later adopted, with a slightly different meaning, into the theory of special relativity. The fully formed Lorentz ether theory of 1904 had an uncanny resemblance to the special relativity theory of Einstein of 1905. Both theories required that sources or observers in motion would experience time dilation, but for Lorentz/Larmor the effect was not meant to imply that real time has been altered, in contrast to Einstein. For Lorentz the apparent constancy of the speed of light in inertial frames has an explanation in the form of our motion with respect to an undetectable ether. Einstein instead assigned to all inertial frames a constant velocity of light, without proposing a mechanism, with the Lorentz contraction and real time dilation following as consequences. The genius of Einstein's proposition was not just its attractiveness in preserving the physical laws in all inertial frames, but even more than that, it benefited from the fact that every optical experiment to distinguish these two competing ideas would affirm relativity theory, even if Lorentz was right!

To show how this is so, we will now proceed to examine the results of more modern optical experiments to see how they fare on the judgement of Lorentz ether theory. These experiments can generally be categorized into the following groups, all of which have been cited as experimental evidence validating the theory of relativity:

- First and second order closed path optical tests
- One way speed of light experiments (first order)
- Tests for Lorentz violations

All of these experiments have had null outcomes (with the exception of Fizeau's experiment) for detecting the velocity of the experiment with respect to space. As will be shown below, this is the same outcome that would be anticipated by Lorentz ether theory even if the ether is present.

6. 1st and 2nd Order Closed Path Optical Tests

The first order experiments include Arago, Fizeau, and Hoek type experiments, all of which are adequately explained within Lorentz's theorem of corresponding states as discussed earlier. An analysis of these experiments performed by the late H.E. Wilhelm using a Galilei covariant electrodynamic model arrives at equations which are identical to those used in Lorentz ether theory [38]. A more modern experiment along these lines was the Trimmer experiment (1973) which is simply a triangular form of the Hoek interferometer and which gives a null result for identical reasons [12]. The Fizeau coefficient has recently been used by Valil'ev to better predict the velocity aberration and the entrainment of light in prism retro-reflectors aboard spacecraft [13].

Using Lorentz's theorem of corresponding states for dealing with first order effects, combined with the Lorentz contraction hypothesis for second order effects, is sufficient to explain the inability to detect an ether drift in all Michelson type interferometer experiments, including Morley, Miller, Illingworth, and Joos [14]. The time delay on the forward or return optical path of each arm can be calculated at least to second order using the equation:

$$\frac{L}{\gamma\left(\frac{c}{n}\pm\frac{v}{n^2}\right)} \tag{3}$$

where L is the arm length, γ is the Lorentz contraction based on the angle of the arm with respect to the motion, v is the velocity of the ether wind, and n is the refractive index of the arm path. Similar considerations can also be applied to the Kennedy and Thorndike experiment, which will be discussed in greater detail shortly. This highlights the inapplicability of closed path single source optical interferometers in addressing this question. Included are interferometers with differing arm lengths, with arms with differing refractive indices, or even other interferometer types (Mach-Zehnder configuration, etc.). One example is Shamir and Fox (1969) who used a Michelson Interferometer with one arm in Perspex (RI = 1.49) [15]. Applying the above time delay in each arm into a spreadsheet, it is immediately clear to second order that the addition of the Perspex arm makes no difference in the anticipated result, which is effectively zero fringe shift. A similar opinion was put forward by Mansouri and Sexl [16] that the purported distinguishing between relativity and ether theory in the Shamir and Fox experiment is "impossible in principle."

7. One Way Speed of Light Experiments

One-way tests of the speed of light have been addressed in detail by Tyapkin [1], who criticized the proposed experiments of Moller [17] (two way counter-propagating maser beams) for misinterpreting the outcome of the experiment as a means of distinguishing between the theories of Einstein and Lorentz. He pointed out that Moller had failed to take into account that Lorentz's fully developed theory of 1904 had anticipated all of the equivalent relativistic second order effects including time dilation, Doppler effects and even mass increment in describing physical phenomena with respect to the unique system he had identified with the ether. This argument also applies to the irrelevance of the null results of the Mossbauer experiments of Ruderfer [18], Turner and Hill [19], and Champeney et.al. [20], since they do not take into consideration all the time dilation effects acting on the rotating source and detector predicted by Lorentz, as has been pointed out by Ron Hatch [24]. Ruderfer, one year after claiming his Mossbauer experiment had disproven Lorentz's theory, issued an errata to his paper [25], in which he explained that after reconsidering the variation of frequency with motion ω through the ether predicted by Lorentz, the rotating source in his Mossbauer experiment would be recalculated as having a frequency of:

$$f=\frac{f_0}{\gamma}=f_0\sqrt{1-\frac{v^2}{c^2}} \tag{4}$$

where $v=\omega s$ for a radiator at the center of a turntable. For the rotating absorber, $v_a=\left|\vec{\mathbf{v}}+\vec{\boldsymbol{\omega}}s\right|$, resulting in absorber frequency:

$$f_a=f_o\sqrt{1-\frac{\omega^2s^2+v^2-2\omega sv\cdot\sin\theta}{c^2}}\,. \tag{5}$$

The relative frequency shift due to clock motion is, to first order:

$$\frac{\Delta f}{f_{Cl}}=\frac{f_a-f}{f}=\frac{\omega sv\cdot\sin\theta}{c^2}\,. \tag{6}$$

This frequency shift exactly cancels any positive result anticipated from the net velocity with respect to a preferred frame for light. This would occur even if the radiator was not at the center of the turntable. This prompted Ruderfer to make the surprising admission that "the proper interpretation of the predicted null result is that detection of an ether is precluded as required by the special theory of relativity and that existence of an ether is permitted as required by the (Lorentz) contraction theory." This assessment is affirmed in the thesis of Preikschat (1968) on the Mossbauer effect [21].

The Cialdea experiment [22] which purported to test for a one-way ether drift using the interference of two separate HeNe lasers, is in fact wrong on multiple levels. This experiment was replicated in our own laboratory [37], where it was demonstrated that the interference output is completely insensitive to wavelength changes when reliable positive controls are used. It also fails on theoretical grounds, as pointed out by Tyapkin [1], who noted that even if the experiment worked as designed, the motion of the laser source in being rotated by 180 degrees would cause a time delay in the laser output that would exactly cancel the anticipated fringe shift. This is after taking into consideration all second order effects anticipated from the theory of Lorentz.

Similarly, the Gagnon Microwave Experiment [23] was described by its authors as a one-way speed of light test, but the closed path Mach-Zehnder configuration cannot be treated any differently that a Michelson interferometer in terms of the expected null result from the Lorentz theory, even with two waveguide arms having refractive indices < 1. The authors also appear to use a classical velocity addition formula in determining their predicted results. The foregoing considerations of time dilation effects on the source should also apply to other one-way velocity of light experiments such as Ragulsky [26], and Krisher et.al. [27], the latter limited in scope by being fixed to the earth.

8. Tests for Lorentz Violations

Mansouri and Sexl's test theory provides a basis for analysis of interferometer experiments examining local Lorentz invariance [28]. Assuming the existence of a preferred frame (e.g., one at rest with respect to the cosmic microwave background radiation), in which the speed of light is isotropic, then in a laboratory moving with velocity v relative to this frame, the two-way speed of light propagating at angle θ from v is given by [29]:

$$\frac{c(\theta)}{c} = 1 + \left(\frac{1}{2} - \beta + \delta\right)\frac{v^2}{c^2}\sin^2\theta + (\beta - \alpha - 1)\frac{v^2}{c^2} \qquad (7)$$

For relativity theory, the time dilation factor $\alpha = -1/2$, the Lorentz contraction factor $\beta = +1/2$, and the contraction perpendicular (normal) to v factor $\delta = 0$. In the context of their test theory, first order tests are equivalent to measurements of the time dilation factor. They state explicitly that first order tests cannot be used to distinguish between special relativity and ether theory, since the two classes of theories can be transformed into one another by a change of conventions about clock synchronization. Experiments designed to test for the Lorentz contraction factor are of the Michelson-Morley (M&M) type, where $1/2 - \beta + \delta = 0$, Kennedy-Thorndike type, where $\beta - \alpha - 1 = 0$, and Ives-Stillwell experiment types where the first order Doppler effects are eliminated revealing the second-order time dilation effect. As is well known, Ives was an advocate of the Lorentz ether theory and performed his experiment to validate it. M&M type experiments determine only $\beta + \delta$; Mansouri and Sexl felt that the direct optical observation of the Lorentz contraction is impossible. They also point out that a light ray going both ways in one of the arms of a Michelson interferometer can be considered as a clock, and thus the two arms can be considered a comparison of the frequency of two clocks – which is similar to the experiment of Essen [16] which actually compared the frequency of two clocks in rotation. The lack of change of clocks or propagation times in etalons or both in rotation can be considered a validation of either relativity or Lorentz ether theory. Numerous experiments have now been performed to test for Lorentz violations and to establish $\beta + \delta$ to ever increasing degrees of certitude. Examples include Javan and Townes [30] using HeNe microwave lasers, Brillet and Hall [31] using Etalons and CH4 stabilized HeNe lasers, Hils and Hall [32], Mueller [33] using non-rotating cryogenic resonators, Schiller et.al [34] and Antonini et.al [35] using rotating cryogenic resonators. The Space time Asymmetry research (STAR) [36] mission (2010) seeks to extend these observations using satellites to 10^{-12} for the M&M coefficient, 7×10^{-10} for the Kennedy-Thorndike coefficient, and to measure the absolute anisotropy in the speed of light to 10^{-18}.

9. Conclusion

The key to understanding the persisting relevance of ether theory is in understanding how in virtually every optical experiment conceivable, the potentially measurable effects due to the inertial motion of an optical system through a preferred frame for light always exactly cancel out, making such a preferred frame undetectable. Lorentz's success in deriving Fresnel's coefficient directly from his theory, by re-interpreting it as an interaction between ether and matter, allowed for the removal of the concept of ether drag completely. Without the need for ether drag, Einstein was perfectly positioned to take the next predictable step - the un-detectability of the ether became an emotionally powerful justification for the central idea of relativity theory that what cannot be measured does not exist. However, this need not be so – the optical evidence to date, as has been shown herein, continues to support the alternative hypothesis that the ether of Lorentz does exist, and this is particularly desirable for those who seek a more rational and consistent description of the physical world.

References

[1] A. A. Tyapkin, *Lett. Nuovo Cimento* **7** (15): 760-764, (1973).
[2] H. Lorentz, **Lectures on Theoretical Physics**, V.1 pp. 14-19 (1927).
[3] M. Janssen, J. Stahl, *Max Planck Inst. His. Sci.*, Pre-print 265 (2004).
[4] A. Arago, *Comptes Rendus* **36**: 38-49 (1853).
[5] A. Fresnel, *Annales de chimie et de physique* **9**: 57-66 (1818).
[6] H. Fizeau, *Comptes Rendus* **33**: 349-355 (1851).
[7] M. Hoek, *Arch. Neerlandaises exactes Nat.* **3**: 180–185 (1868).
[8] H.Lorentz, *Arch. Néerlandaises exactes Nat.* **25**: 363–552 (1892).
[9] J. Larmor, **Aether and Matter** (Cambridge University Press, 1900).
[10] A. A. Michelson, E. Morley, *Am. J. Sci* **34** (203): 333-345 (1887).
[11] G. FitzGerald, *Science* **13** (328): 390 (1889).
[12] W. S. N. Trimmer, et al, *Phys. Rev. D* **8** (10): 3321-3326 (1973).
[13] V. Vasil'ev, et al, *Pis'ma Zh. Eksp. Teor. Fiz.* **55** (6): 317-320 (1992).
[14] L. Swenson, **The Ethereal Aether** (Univ. Texas, 1972).
[15] J. Shamir, R. Fox, *Phys. Rev.* **184**: 1303-1304 (1969).
[16] R. Mansouri, R. Sexl, *Gen. Rel. Grav.* **8** (10): 809-814 (1977).
[17] C. Moller, *Suppl. Nuovo Cimento* **6**: 381 (1957).
[18] M. Ruderfer, *Phys. Rev. Lett.* **5** (5): 191-192 (1960).
[19] K. Turner, H. Hill, *Bull Am. Phys. Soc.* **8**: 28 (1963).
[20] D. Champeney, et al, *Phys. Lett.* **7** (4): 241-243 (1963).
[21] E. Preikschat, "The Mossbauer Effect and Tests of Relativity", Thesis, Chapter 4-10 (U. of Birmingham, 1968).
[22] R. Cialdea, *Lettere Al Nuovo Cimento* **4** (16): 821 (1972).
[23] D. R. Gagnon, et al, *Phys. Rev. A* **38** (4): 1767 (1988).
[24] R. Hatch, *Proc. 58th Ann. Meeting Inst. Nav.*, pp. 70-81. (2002).
[25] M. Ruderfer, *Phys. Rev. Lett.* **7** (9): 361 (1961).
[26] V. V. Ragulsky, *Phys. Lett. A* **235**: 125 (1997).
[27] T. Krisher, et al, *Phys. Rev. D* **42**: 731-734 (1990).
[28] R. Mansouri, R. Sexl, *Gen. Rel. Grav.* **8** (7): 497-513 (1976).
[29] N. Ashby, "Science Goals of the Primary Atomic Reference Clock in Space Experiment", http://tf.nist.gov/general/pdf/2004.pdf.
[30] C. Townes, et al, *Phys. Rev.* **133**: A1221 (1964).
[31] A. Brillet, J. L. Hall, *Phys. Rev. Lett.* **42** (9): 549-552 (1979).
[32] D. Hils, J. L. Hall, *Phys. Rev. Lett.* **64** (15): 1697-1700 (1990).
[33] H. Mueller, et al, *Phys. Rev. Lett.* **91** (2): 020401 (2003).
[34] S. Schiller, et al, http://arxiv.org/abs/physics/0510169v1.
[35] P. Antonini, et al, http://arxiv.org/abs/gr-qc/0504109v1.
[36] R. Byer, J. L. Hall et al, "Space Time Asymmetry Research (STAR)", http://docs.google.com.
[37] D. Marett, "A Replication of the Cialdea One-Way Speed of Light Experiment" (2010), http://www.conspiracyoflight.com.
[38] H. E. Wilhelm, *Apeiron* **15**: 1-6, (1993).
[39] E. W. Silvertooth, *Spec. Sci. Tech.* **10** (1): 3-7 (1986).

Comparison of Select Experiments to Date:

Experiment	Supports Einstein's Relativity	Supports Lorentz Ether Theory (LET)	Supports isotropic ECI frame*	Reference
Bradley Stellar Aberration (1725)	✓	✓	✓	[2],[3]
Arago Experiment (1810)	✓	✓	✓	[2],[3],[4],[13]
Fizeau Experiment (1851)	✓	✓	✓	[2],[3],[4],[38]
Hoek Experiment (1868)	✓	✓	✓	[2],[3],[4],[38]
Michelson Morley Experiment (1887)	✓	✓	✓	[16],[28]
Kennedy Thorndike Exp. (1932)	✓	✓	✓	[16],[28]
Ives Stillwell Experiment (1939, 1942)	✓	✓	✓	[16],[28]
Ruderfer Experiment (1960)	✓	✓	✓	[16],[18],[21],[28]
Champeney Experiment (1963)	✓	✓	✓	[16],[18],[21],[28]
Townes Experiment (1964)	✓	✓	✓	[16],[18],[28],[29]
Shamir and Fox Experiment (1969)	✓	✓	✓	[15],[16]
Cialdea Experiment (1972)	n/a	n/a	n/a	[1],[22],[37]
Trimmer Experiment (1973)	✓	✓	✓	[12],[38]
Brillet and Hall Experiment (1979)	✓	✓	✓	[16],[18],[28],[29],[31]
Silvertooth Experiment (1986)	☒	✓	☒	[39] ** See note below.
Gagnon Experiment (1988)	✓	✓	✓	[16],[23],[28],[38]
Krisher Experiment (1990)	✓	✓	✓	[16],[28]
Ragulsky Experiment (1997)	✓	✓	✓	[16],[28]
Mueller Experiment (2003)	✓	✓	✓	[16],[18],[28],[29],[33]
Schiller, Antonini Exp. (2005)	✓	✓	✓	[16],[28],[29],[34],[35]

* A common model of the ether that assumes that the earth carries the ether with it in translation but not in rotation. The Earth Centered Inertial (ECI) frame is the coordinate frame used in GPS calculation. This is distinct from the Earth Centered Earth Fixed (ECEF) frame which is a coordinate frame that remains fixed with the surface of the earth. A Hertz ether or Stokes ether would be stationary with respect to the ECEF frame.

** The Silvertooth experiment reported a one way wavelength of light consistent with our motion with respect to the Cosmic Microwave Background (CMB). Since the Silvertooth experiment measures the wavelength difference between a one way beam and a reference, and does not rotate the interferometer to see the measurement difference, the laser is not subjected to a counter-acting time dilation effect as in many other experiments cited above. A null result in an experiment like this would support relativity, Stokes ether or Hertz ether. The reported result contradicts relativity or the idea that the Earth Centered Inertial (ECI) frame is isotropic for the speed of light.