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EXPERIMENTAL ANALYSIS OF ABSOLUTE SPACE-TIME LORENTZ THEORIES

by

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ABSTRACT

Experiments designed to test Special Relativity are reviewed and their capabilities of distinguishing Special Relativity from Absolute Space-Time theories is analysed. Of two specific forms of Absolute theories proposed in recent years, we show that one is refuted by past experiments while the other is still in contention.

Key-words: Absolute space-time; Ether theories; Special relativity.

1. INTRODUCTION

In a recent paper$^{(1)}$, hereafter referred to as I, we have discussed Lorentz Absolute Space Time Theories (LET for short) as possible contenders for Special Relativity (SR). In connection with the rotation-translation of rigid bodies, two specific forms of LET, extended LET$^{(2,3)}$ (E-LET) and strict LET$^{(3)}$ (S-LET) were defined and theoretical predictions of experimentally measurable quantities were derived. The present work is a followup of I. Now we review past experiments designed to test the validity of SR focusing on their potential capabilities of distinguishing LET from SR.

In section 2 we argue that E-LET can be considered eliminated by already longstanding experimental results, in fact by experiments that are older than the theory itself in its specific version$^{(2,3)}$. This material was first presented by one of the present authors (JT) in the 1985 Marcel Grossmann Meeting$^{(4)}$.

In section 3 we concentrate on S-LET and shall see that only a few of the experiments in search of violations of SR carried out to date are potentially sensitive to the S-LET predictions of such violations as derived in I. This is so because, provided Einstein coordinates$^{(1)}$ are used, most of Physics remains Lorentz invariant even if S-LET is to replace SR, and therefore most experimental confirmations of SR in the past may also be interpreted as confirmations of S-LET. The absence of an "Ether Wind" for example is a common feature of both theories.

It will be shown that those experiments which potentially could detect S-LET manifestations of non-relativistic nature were mounted with different purposes in mind (usually Ether Wind detection) and therefore either the geometry of the apparatus was such as to induce a cancellation of the S-LET effects, or the treatment of the results was unsuitable for a S-LET minded analysis.

More suitable geometries and analysis of both old and more recent important experiments are proposed which could either discard one of the competing theories or reveal other instances of violations of SR. A summary of the material contained in this section has appeared previously in the form of a Letter(5)

Sections 2 and 3 have been written in a completely independent format so that either can be skipped without compromising the other.

2. EXPERIMENTAL REFUTE OF E-LET

A detailed description of the basic postulates and assumptions upon which E-LET is built is found in I. A fundamental principle is that the free rotation of a rigid body is uniform when observed in the Absolute Reference Frame S_o and described by the absolute coordinates (t_o, x_o). Thus, in S_o, the angular motion of a general point $\vec{R}_o(t_o) = (R(\phi_o), \phi_o(t_o))$ in free rotation is given by

$$\phi_o(t_o) = \phi_o(0) + \Omega_o t_o \qquad (1)$$

where Ω_o is a constant, and this has been called the t_o-synchronization in I. Equation (1) can be converted to the commonly used Einstein coordinates (t,x) in the laboratory frame S,

$$x = \gamma(x_o - Vt_o) \; ; \; t = \gamma(t_o - Vx_o)$$

and becomes$^{(1)}$,

$$\phi(t) = \phi(0) + \gamma\Omega_o t + V\Omega_o R \cos(\phi(0) + \Omega_o t)$$

$$- (V^2/4)\sin 2(\phi(0) + \Omega_o t). \qquad (2)$$

In section 4 of I we introduced the possibility that rotation might affect the Lorentz-Fitzgerald contraction along $\vec{V}$. A parameter $\beta(\Omega) < 1$ has been introduced, satisfying $\lim\beta(\Omega \to 0) = 0$, such that an effective boost factor

$$\tilde{\gamma} = (1 - (1 - \beta)V^2)^{-1/2}$$

substitutes the orthodox γ. Thus, some point solidary to a rotating body, a distance R away from the rotation axis (measured before rotation takes place) has its position vector, when under rotation, given by$^{(1)}$,

$$\vec{R}(t) = R(1 + \beta V^2/2) \cos\phi(t)\hat{x} + R \sin\phi(t)\hat{y} \qquad (3)$$

As seen from eqs. 2 and 3, E-LET implies non-rigidity in Einstein coordinates for the rotating solid body. Such departures from a rigid like motion could in principle be detected by optical devices, given the Lorentz invariant character of the Maxwell equations in vacuum in Einstein coordinates. For that purpose we have calculated$^{(1)}$ the time dependence in vacuum of the optical distance $L(t) \equiv L_o + \delta L(t)$ between any two fixed points in a rotating disc, which in the particular case of endpoints that are equidistant to the centre of rotation becomes

$$\begin{aligned}\delta L(t)/L_o &= v\cos(\phi_o/2) - v\,V\cos(\phi_o/2)\sin(\phi_o/2 + \Omega t)\\ &+ (\beta V^2/2)\sin^2(\phi_o/2 + \Omega t)\\ &- (V^2/2)\cos^2(\phi_o/2)\cos(\phi_o + 2\Omega t) \qquad (4)\end{aligned}$$

Here L_o and ϕ_o are the lenght and central angle of the optical path as measured at rest (no rotation) and $v = \Omega_o R$ is the average tangential velocity of its endpoints.

The first term in (4) is related to the Sagnac effect$^{(6)}$ and is common to both SR and LET. The others are all SR violating (V-dependent) and, as mentioned in I, a theoretically undesirable feature of E-LET as a physical theory is manifest in the last term of (4) which does not vanish as $\Omega \to 0$, thereby not leading to pure Lorentz contraction as a no-rotation limit. This constitutes a strong theoretical argument against E-LET.

In the remainder of this section we show that two past experiments constitute sufficient proof against this theory. To consider the orders of magnitude involved in (4), we associate V to the Earth's translation velocity$^{(7)}$ in the isotropy frame of the Universe's background microwave radiation, $V \sim 10^{-3}$.

E-LET predictions have been inside the experimental detection limits for many decades now, but most experimental settings were such as to have optical paths along the diameters of a rotating base (say, a turntable), running through the centre of rotation with the consequent vanishing of all terms in (4) ($\cos(\phi_0/2) = 0$) except for the β-term. This is of course a handicap towards the manifestation of possible E-LET effects, but on the other hand it is fortunate that the β-term, which originates from a supposedly damped Lorentz contraction due to rotation, can be studied in isolation.

Past experiments indeed set very low upper limits for $\beta(\Omega)$ in the low Ω domain. Michelson-Morley type optical length measurements via the analysis of interference fringes culminate with the Jena experiment of Joos$^{(8)}$ in 1930. This is a null result of the form

$$\delta L/L_0 \lesssim 10^{-11} \cos 2\Omega t$$

setting a limit $\beta(\Omega) \lesssim 10^{-5}$ for the low values of $\Omega \sim 1\,s^{-1}$ typical of such experiments. Under the same conditions of optical lengths that run through the centre of rotation we also find experiments with high Ω. These are the more recent Doppler Shift measurements of frequency fluctuations $\delta\nu/\nu_0$ between source and absorber mounted on a fast ($\Omega \sim 10^3 s^{-1}$) rotor$^{(9,10)}$. Unfortunately only the "Ether-Wind" like first harmonic

($\vec{v}.\vec{V} \sim \cos\Omega t$) dependence of $\delta\nu/\nu_o$ was analysed in such experiments whereas the "β-effect" predictions for $\delta\nu/\nu_o$ are of second harmonic nature(1). It might be instructive, if still possible, to retrieve those measurements and investigate a $\cos 2\Omega t$ - like dependence.

Going back to eq. (4) , its last (v-independent) term, against which we have objected on theoretical grounds, predicts a large ($\sim 10^{-6}$) second harmonic effect which could have been detected, if existent, as early as 1881 when Michelson was experimenting with a non-rotating interferometer with a $\delta L/L_o \sim 10^{-7}$ sensitivity. The rotating base can then be thought of as being the Earth itself. Most "Ether Wind" experiments, both in the length shift and Döppler shift categories, were run with optical arms passing through the centre of rotation, thus masking the predictions of eq. (4). Two experiments however escape this handicap.

Jaseja et al.(11) measured relative frequency shifts between two maser cavities placed on a turntable. By measuring highly monochromatic frequency shifts (for each cavity, $\delta\nu/\nu_o = - \delta L/L_o$) this experiment is a significant technological improvement over the Michelson-Morley version which relies on optical interferometry. Jaseja et al. mounted both identical cavities along two perpendicular diameters of a rotating table that oscilates between two extreme positions at angles θ and $\theta + \pi/2$ at which it is instantly at rest with respect to the Earth. At these two extreme positions the apparatus is in rotation only around the Earth's axis and, from eq. (4), assuming θ to be along the East-West direction, we should expect (we drop here the β-term)

$$\delta L/L_o \overset{\sim}{\sim} 10^{-6}\alpha \cos 2\Omega_E t + 10^{-9}\alpha \sin \Omega_E t \qquad (5)$$

where Ω_E is the Earth's angular frequency and an overall factor α has been introduced ($0 < \alpha < 1$) because the table is at its rest positions instantly, not permanently. We therefore do not know to what extent the apparatus can be thought of as solidary (firmly anchored) to the Earth ($\alpha = 1$) or insensitive to the Earth's rotation ($\alpha = 0$).

The result of the Jaseja et al. experiment is

$$\delta L/L_o \lesssim 10^{-11} \sin 2\Omega_E t \quad . \qquad (6)$$

A first harmonic analysis of their measurements is not explicitely given, but from their published data, Tiomno$^{(12)}$ shows that it should be consistent with

$$\delta L/L_o \lesssim 10^{-10} \sin \Omega_E t \quad . \qquad (7)$$

Equations 5,6 and 7 disprove E-LET, suggesting values of α of the order 10^{-5} for the second harmonic analysis and 10^{-1} for the first harmonic.

A further sensitivity improvement is the Brillet-Hall$^{(13)}$ readout of a stable etalon of length achieved with laser frequency locking techniques. In this experiment the length etalon rotates non diametrally with angular frequency $\omega \overset{\sim}{\sim} 6$ rpm and the result is

$$\delta L/L_o = (1.5 \pm 2.5) \times 10^{-15} \cos 2\omega t \quad .$$

It disproves E-LET's second harmonic effect prediction by nine orders of magnitude despite its rather suitable geometry for the manifestation of that effect.

Closing this section we feel we have presented enough evidence, both theoretical and experimental, against E-LET.

3. THE DETECTION OF S-LET

A detailed description of the basic postulates and assumptions upon which S-LET is built is found in I. A fundamental principle is that the free rotation of a rigid body as observed in a co-moving inertial frame S is uniform when described by the Fitzgerald-Lorentz coordinates (T,X) which relate to the usual Einstein (t,x) coordinates, and to the absolute (t_o, x_o) coordinates by $(c = 1)$,

$$\begin{aligned} X &= x = \gamma(x_o - Vt_o) \\ T &= \gamma^{-1} t_o = t + Vx(t) \end{aligned} \tag{8}$$

These coordinates were called "Ives-Marinov" in ref. [3].

Thus, in S, the angular motion of a general point $\vec{R}(T) = (R\ ,\ \phi(T))$ in free rotation is given by

$$\phi(T) = \phi(0) + \Omega T \quad , \tag{9}$$

where R and Ω are constants, and this has been called the T synchronization in I. Equation (9) can be re-written in the more intuitive and useful Einstein coordinates

$$\phi(t) = \phi(0) + \Omega(t + \vec{V}.\vec{R}(t))$$

which together with(14)

$$\vec{R}(t) = R\cos\phi(t)\hat{x} + R\sin\phi(t)\hat{y}$$

yield

$$\phi(t) = \phi(0) + \Omega t + \Omega RV\cos(\phi(0) + \Omega t). \tag{10}$$

As seen in equation (10), S-LET implies non-rigidity in Einstein coordinates for the rotating solid body. Such departures from a rigid like motion could in principle be detected by optical devices, given the Lorentz invariant character of Electromagnetism in Einstein coordinates. For that purpose we have calculated(1) the time dependence of the optical distance $L(t) = L_o + \delta L(t)$ between any two fixed points in a rotating disc.

In the particular case of endpoints that are equidistant to the centre of rotation we find

$$\delta L(t)/L_o = v\cos(\phi_o/2) - vV\cos(\phi_o/2)\sin(\phi_o/2 + \Omega t) \tag{11}$$

Here L_o and ϕ_o are the length and central angle of the optical path as measured at rest (no rotation) and $v = \Omega R$ is the average tangential velocity of its endpoints.

The first term in (11) is related to the Sagnac effect(6) and is common to both SR and LET. The second is a manifest violation of SR whose experimental detection is discussed next.

For order of magnitude estimation we associate V to the Earth's translation velocity(7) in the isotropy frame of the Universe's background microwave radiation, $V \sim 10^{-3}$.

Let us consider first optical interferometry experiments of the Michelson and Morley type, of which the most notable and precise was carried out by Joos(8) in 1930. His apparatus is sensitive to relative length variations (or equivalently variations in the photon transit time) between the ends of two perpendicular and identically built optical paths. Experiments of this type were carried with spectrometers placed in a turntable in nearly free rotation, the optical arms lying along rotation diameters. Under such circumstances, the S-LET predicted $\delta L/L_o$ is not observable due to the vanishing of $\cos(\phi_o/2)$ in eq. (11) with $\phi_o = \pi$.

Now suppose the same interferometer firmly anchored to the ground. Then its rotation movement is that of the Earth, with a tangential velocity $v \sim 10^{-6}$ if far from the poles. Supposing one of the optical arms fixed along the East-West direction, its length L, according to (11), will vary as

$$\delta L/L_o = vV \sin\Omega t \stackrel{\sim}{\sim} 10^{-9} \sin\Omega t \qquad , \qquad (12)$$

Ω being the Earth's angular velocity and the North-South arm serving as a standard of unchanging lenth.

Joos' measurements were analysed for a second harmonic (Ether-Wind like) dependence on the table's rotation angle ωt, and yielded a null result of

$$\delta L/L_0 \lesssim 10^{-11} \cos 2\omega t \quad ,$$

consistent with both SR and S-LET. This is however an indication that his apparatus, as early as 1930, if mounted in the conditions of the preceeding paragraph, might be sufficiently sensitive to detect the S-LET effect of eq. (12).

The later experiments of Jaseja et al.$^{(11)}$ and Brillet-Hall$^{(12)}$ are also measurements of $\delta L/L_0$, now with the sensitivity advantages of highly monochromatic laser frequency metrology rather than optical interferometry. Jaseja et al. searched for relative length shifts δL in the optical paths between the reflecting ends of two masers mounted perpendicularly on a rotating platform. Relative frequency shifts are measured and related to length shifts by $\delta\nu/\nu_0 = -\,\delta L/L_0$. The platform oscillates horizontally between two extreme positions at angles θ_0 and $\theta_0 + \pi/2$ at which it is instantly at rest relative to the Earth. From eq. (11), assuming θ_0 to be along the East-West direction, the S-LET prediction for measurements at the two extreme (rest) positions is as in eq. (12).

Jaseja et al. analysed the twelve hour period (Ether drift like, $\sim \sin 2\Omega t$) dependence of their data and present a null result

$$\delta L/L_o \lesssim 10^{-11} \sin 2\Omega t \quad .$$

However, one of the present authors (J.T.) has shown(12) that their published experimental points (Jaseja et al. fig. 3) for a six hours'run can comfortably accomodate a first harmonic dependence

$$\delta L/L_o \approx 10^{-10} \sin\Omega t \quad .$$

Such result can be made compatible with the S-LET prediction if we remember that two factors are possibly missing in eq. (12). First, the apparatus is mounted on a turntable and not permanently at rest. S-LET effects due to the Earth's rotation may therefore only be partial. Second, if the θ_o direction is not along the East-West, a further factor of $\cos(2\theta_o')$ is needed in (12), where θ_o' measures how much θ_o departs from the East-West. Note that if the two masers are at equal angles (45^0) with the East-West, no S-LET effect connected with the Earth's rotation should show up, since any length variations in both cavities will be identical and the apparatus is sensitive to relative length changes. It is clear that these two facts may easily account for a factor of 10^{-1} in (12), and this leaves S-LET very much in contention.

A very significant sensitivity improvement is the Brillet and Hall(14) readout of a stable etalon of length achieved with laser frequency locking techniques. The entire electro-optical apparatus was mounted onto a motor-driven continuously rotating turntable at $\omega = 0.1$ cps. Analysing the Ether -

drift like second harmonic laser frequency beat, they find a null result of $\delta L/L_0 = (1.5 \pm 2.5) \times 10^{-15} \sin 2\omega t$, a four order of magnitude improvement over previous results.

The exact geometry of the experimental mounting is not given in their paper. Nevertheless we may arrive at an estimate of the S-LET predicted sine wave effects knowing the dimensions (90 x 40 cm.) and angular speed of the turntable, the length (30 cm.) of the interferometer and its approximate position relative to the centre of rotation (Brillet-Hall Fig. 1). It seems that this mounting is indeed appropriate to the detection of S-LET, having a geometry that resembles the most favourable configuration for that purpose, according to eq. (11) in paper I. Such configuration is that in which the interferometer has its mirror ends equidistant from the rotation axis and determining a central angle of $\pi/2$. Under these conditions ($R_1 \approx R_2 \approx 20$ cm, $v \approx 10^{-9}$), eq. I-(11) reads

$$\delta L/L_0 \approx 10^{-12} \sin\omega t \quad . \tag{13}$$

It is intriguing that Brillet and Hall report a spurious sine wave signal, allegedly due to gravitational stretching of the interferometer, which exactly matches eq. (13).

Another method of SR violation detection we consider is the Döppler shift measurement of radiation between absorber and source that are the endpoints of a rotating optical path. In I we obtained an expression for the Döppler frequency fluctuations $\delta\nu/\nu_0$ expected in LET, where ν_0 is the natural frequency of the emitter at rest. In the case of S-LET, with ab sorber and source equidistant to the centre of rotation and defining a central angle ϕ_o,

$$\delta\nu/\nu_o = v^2 V \sin\phi_o \cos(\phi_o/2 + \Omega t) \tag{14}$$

Döppler type experiments in a rotating frame generally exhibited absorber and source in diametral opposition ($\phi_o = \pi$) or in conjunction ($\phi_o = 0$) at different radii. Notable examples of each kind are respectively references 9 and 10.

Again, such geometries, suitable for an Ether-Wind search, are inadequate for the detection of S-LET non-rigidity effects which are of angular (and not radial) origin.

Supposing absorber and source in quadrature ($\phi_o = \pi/2$) and taking typical values for $v(\sim 10^{-6})$ in Döppler experiments(9,10), eq. (14) predicts

$$\delta\nu/\nu_o \approx 10^{-15} \cos\Omega t \quad ,$$

an effect still (but only just) outside the sensitivity of references 9 and 10.

4. CONCLUSIONS

We have shown that the theory we called S-LET(3,4) still stands as a contender to Special Relativity. Of course, this is probably so because no experiments to this date were performed with S-LET in mind, and most were run in rather unfavourable conditions for the detection of $\delta L/L_0$ (eq. 11) or $\delta\nu/\nu_0$ (eq. 14). However, a few modifications in the geometry and running of the original experiments, might render then quite effective in discarding one of the competing theories.

In the length measurement domain, we suggest that experiments such as those of Joos$^{(8)}$ and Jaseja et al.$^{(11)}$ be repeated with one of the optical arms aligned with the East West direction, the whole apparatus solidary to the Earth's-rotation. Hourly data could be recorded for several days and analysed for a 24 hour period (first harmonic) dependence, with possible repetitions in different times of the year.

As to the Brillet and Hall$^{(13)}$experiment, we think it should be repeated in search of a better understanding of theiri sine wave signal. If of S-LET origin, then in anchored conditions with interferometer along the East-West, it should show up some 10^3 times larger (since v is now 10^{-6} instead of the original 10^{-9}) with a 24 hour period. Also, in a turntable with tunable angular speed w, a S-LET predicted linear dependence of the amplitude of $\delta L/L_0$ with w might be detectable.

Finally, given that the sensitivity of present Döppler shift analysers has improved since the experiments of references 9 and 10, the Döppler technology might be quite effective in the detection of the S-LET predicted longitudinal motion between absorber and source under rotation in eq. (14) Transverse contributions to the Döppler shift are not present in (14) because, being damped by another factor of v^2, are far beyond detectability. This explains why the most suitable geometry is that of absorber and source in quadrature.

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