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EXPERIMENTAL EVIDENCE AGAINST A LORENTZ AETHER THEORY (LAT)+

by

Jayme Tiomno

Centro Brasileiro de Pesquisas Físicas - CNPq/CBPF
Rua Dr. Xavier Sigaud, 150
22290 - Rio de Janeiro, RJ - Brasil

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ABSTRACT

Computation in Relativity violating theories is made using Einstein's co-moving coordinates. Results of Mansouri and Sexl are confirmed and extended. Application of the method to a form of LAT usually explicitly adopted lead to predictions shown to be up to 10^9 times larger then the experimental results already known.

Key-words: Lorentz aether theory (LAT); Relativity violating theories; Tests of special relativity; Disproof of ELAT.

1. INTRODUCTION*

This paper is not well within the scope of this meeting. It is not about experimental tests of General Relativity (GR) but of Special Relativity (SR) - which is, however, the basis of GR. Proposals of alternative theories to SR are older then SR itself. The trouble with most proposals is that they are in general, neither precisely defined, nor free of computational mistakes. One of such examples is the Lorentz Aether Theory (LAT). Recently Mansouri and Sexl[1] called the attention to the fact that to test SR to a high degree of accuracy one must beforehand express this high degree by the smallness of specific parameters. For this a class of well defined rival theories has to be defined with parameters indicating deviation from SR, to be compared with it.

I shall make this comparison of SR with LAT, for experiments done in vacuum, and show that of the two forms of LAT considered by myself and Rodrigues[2] one (ELAT) which was first examined by Kolen and Torr[3] is eliminated by already existing experimental results; the other (SLAT) considered in ref. (2) has already been shown by myself and Maciel[4] not to be contradicted by present experimental results to the same degree of accuracy that SR is not contradicted. In order to make clear the method used I shall first consider the cases analysed in ref. (1) using, instead, Einstein co-moving coordinates[4].

1.1. Test of SR *and* LAT for experiments (in vacuum) done in frames moving with uniform constant velocity V_0 and not involving accelerated objects.

As in Newton-Fresnel Aether theory I assume that there exists at least one *absolute frame* in which light propagates uniformly and isotropically with a velocity independent of the velocity of the source (take c = 1). In SR this is any inertial frame. In LAT this is possibly a unique frame, as in pre-relativistic Aether theories. Both SR and LAT impose the *exact* Fitzgerald-Lorentz contraction of lengths of bodies in uniform motion and the exact Lorentz time dilation. Departures of this behaviour involving small parameters,

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* References when not given explicitly are contained in references (1,2).

will be considered as in ref. (1).

The distinction of LAT and SR lays in synchronization of distant clocks: while SR assures that *all* synchronization procedures lead to the same result in the co-moving frame as say, the Einstein synchronization by light signals; LAT assures, that, besides Einstein's synchronization, which always exists, an absolute synchronization exists which can be performed internally as a consequence of some violation of SR and by which these violations may be detected. In general we might have any number of synchronization procedures leading to several "definitions" of time. Here I shall assume that whenever a departure of LAT and of SR (which is an special case of LAT) exists it is unique.

For this study it is convenient to consider a few types of co-moving coordinates, and to indicate the relation among them and the absolute coordinates ($\vec{X}$, T): Galilean coordinates ($\vec{x}_G$, t_G); Einstein coordinates ($\vec{x}_E$, t_E); Fitzgerald-Lorentz coordinates ($\vec{x}_F$, t_L); Material coordinates ($\vec{x}_0$, t_0). The last ones are given by marks in the moving frame (S') and indications of real clocks attached to the frame. I take the x-axis in the direction of the constant velocity $\vec{V}$ of the frame ($\hat{X} = \hat{V}$). Table I gives the connections among them:

TABLE I - Co-moving coordinates

t_G	=	T	=	$\gamma(t_E + Vx_E)$	=	γt_L	=	$A\,\gamma(t_0 + EV\,x_0)$
x_G	=	$X(T) - V\,T$	=	$\gamma^{-1}\,x_E$	=	$\gamma^{-1}\,x_F$	=	$B\gamma^{-1}\,x_0$
y_G	=	$Y(T)$	=	y_E	=	y_F	=	$D\,y_0$
z_G	=	$Z(T)$	=	z_E	=	z_F	=	$D\,z_0$

where A,B and D are constants and $\gamma = (1-\vec{V}^2)^{-1/2}$. E is an arbitrary constant. E = 1 for Einstein's and E = 0 for absolute synchronization. For LAT and SR A = B = D = 1. Experiments which do not compare times at different points (no determination of one-way velocity of light) cannot distinguish LAT from SR. A = 1, D = B ≠ 1 includes also a uniform 3-space dilation. In Table I the connection of absolute coordinates to Einstein's is given by the Lorentz transformation, while the connection to Fitzgerald-Lorentz (F-L) coordinates is given by the corresponding length contraction and time dilation. We call F-L transformations:

$$t_L = \gamma^{-1}\, T; \; x_F = \gamma(X - VT).$$

I shall follow here neither the more popular method of working in absolute space-time coordinates[3], as computations become very cumbersome and errors are easily introduced, nor the co-moving "material" coordinates used by Mansouri and Sexl[1]. Instead, I use Einstein's coordinates obtained from the absolute coordinates by a Lorentz transformation[4] as done in references (2). Then the Lorentz invariant phenomena, such as light propagation, have the same properties in S' as in S. Only the explicitly introduced possibly non-Lorentz invariant phenomena shall have descriptions in the co-moving coordinates, different from that in absolute coordinates. For instance, if lengths of solids and clock indications differ from those in Einstein coordinates the law of such departure must be explicitly given as in Table I (last column) for coordinates x_0, t_0. In this sense they are more physical then the other co-moving ones.

We parametrise A, B, D as:

$$A = 1 - \alpha V^2 + O\,(V^4); \quad B = 1 - \beta V^2 + O\,(V^4); \; D = 1 - V^2\delta + O\,(V^4),$$

and assume $V \sim 10^{-3}$ which corresponds to the idea that the absolute frame is that in which the background radiation is isotropic[5]. It should be mentioned that as our α and β differ by $+\frac{1}{2}$ and $-\frac{1}{2}$, respectively, of the α and β of ref.(1), our α, β and δ are expected, to be small quantities.

2. THE CLASSICAL EXPERIMENTAL TESTS OF SR (AND OF LAT!)

I shall consider several types of experiments where light propagates in direction $\vec{k}$ in the Laboratory ($\vec{k}^2 = 1$) and $\vec{V} = \vec{V}_0 + \vec{v}\,(t')$ where $\vec{v}$ is slowly varying in time. Then along an arm $\vec{L}' = L'\,\vec{k}$.

$$L' = L[1 - \bar{\beta}\,(\vec{V}.\vec{k})^2 - V^2\delta] \simeq L\ [1 - \bar{\beta}(\vec{V}.\vec{k})^2]\ (1 - V^2\delta);$$
$$\nu' = \nu\ (1 + \alpha V^2) \simeq \nu(1 + \bar{\alpha}V^2)\ (1 + V^2\delta)$$

where primed quantities are given in Einstein co-moving coordinates (in S') and unprimed are the corresponding quantities when the experiment is made at rest in S. Also: $\bar{\alpha} = \alpha - \delta$; $\bar{\beta} = \beta - \delta$.

2.1. Phase variation experiments (interferometry).

For one arm we find (two ways experiment): $\theta = 2\,\nu_0'\,L_0' =$

$$\simeq 2\,\nu_0 L_0\ (1 + \bar{\alpha}\ V_0{}^2)\ [1 - \bar{\beta}(\vec{V}_0.\vec{k})^2 + 2\,\bar{\alpha}\,\vec{v}.\vec{V}_0 - 2\,\bar{\beta}\,\vec{V}_0.\vec{k}\,\vec{v}.\vec{k}]$$

The factors in the first parenthesis give only a new normalization of ν_0. $(\vec{V}_0.\ \vec{k})^2$ gives a second harmonic in the angle of rotation of the arm and $\vec{v}.\vec{V}_0$ a first harmonic in the angle of $\vec{v}$ with $\vec{V}_0$ if $\vec{v}$ rotates in time, which can be detected.

The Michelson-Morley experiment[1], improved by Miller, found $\bar{\beta}\ V^2 \sim 10^{-9}$ and Joos[1] found $\bar{\beta}\ V^2 \simeq 10^{-11}$. Thus they found respectively, $|\bar{\beta}| \lesssim 10^{-3}$ (M.M) and $|\bar{\beta}| \lesssim 10^{-5}$ (Joos).

As the terms $(\bar{\alpha}\ \vec{v}.\vec{V}_0 - \bar{\beta}\ \vec{k}.\vec{v}\ \vec{k}.\vec{V}_0)$ are difficult to detect in the equal arms interferometer Kennedy and Thorndyke used an interferometer of unequal arms obtaining $|\bar{\alpha}| \sim |\bar{\alpha}-\bar{\beta}| \lesssim 2.10^{-2}$. This was a verification of Lorentz time dilation: $|\alpha| \lesssim 2.10^{-2}$ if there is no Yves dilation ($\delta = 0$, or $\bar{\beta} = \beta$). Thus Ives-Stillwell[1] determined α by the transversal Doppler effect, finding $|\alpha| \lesssim 10^{-2}$, from

$$\Delta\nu/\nu = 1 - [1 + \alpha(\vec{V}_0 + \vec{v})^2]\ [1 - \alpha V_0^2] \qquad (1)$$

This is an instance of the

2.2. Clock (frequency) one way experiments.

They are based on equ. (1), which, both for $V_0 << v$ and $v << V_0$ take the form $\Delta\nu/\nu = 2\alpha\ \vec{V}_0.\vec{v}$. Thus experiments by Turner and Hill[6], Champeney et al[7] (both with Mössbauer effect in turntable) and, recently, Kaivola et al[8] (with atomic beams tuned to a laser) led to $\alpha \cong \pm\ 10^{-5}$ (Isaak claims to have found $\alpha \simeq 10^{-7}$). This with the above results indicate that $|\alpha| \lesssim 10^{-5}$, $|\beta| \lesssim 10^{-2}$. We may express these results in a better way: *i)* Lorentz time dilation is confirmed to 10^{-5} (or 10^{-7}). *ii)* Except for an additional uniform 3-space dilatation ($|\delta| \lesssim 10^{-2}$) a Lorentz contraction (in the direction of $\vec{V}$) is confirmed to 10^{-5}.

2.3. Lenght variation experiments.

They imply measurement of $\delta L/L = -\delta\nu/\nu$ by the frequency variation of a laser radiation (locked to a Fabry-Perot interferometer in the Brillet-Hall experiment). We find

$$- \delta L/L = \bar{\beta}\,(\vec{V}_0.\vec{k})^2 + 2\vec{V}_0.\vec{v}\;\delta + 2\,\bar{\beta}\,\vec{V}_0.\vec{k}\;\vec{v}.\vec{k} + (V_0{}^2+v^2)\delta + \vec{\beta}(\vec{v}.\vec{k})^2$$

In Jaseja et al[9] experiment $\vec{v}$ is due to Earth rotation ($v \sim 10^{-6}$)

We find with M-S[1] $|\bar{\beta}| \lesssim 10^{-5}$. In the Brillet-Hall[10] experiment where $\vec{v}$ is provided by the rotation of a table ($v \sim 10^{-9}$) we find $|\bar{\beta}| \lesssim 10^{-7}$. However these very sensitive experiments do not improve the upper limit of δ and thus of β. It is only when we impose that either $|\beta| << |\delta|$ or $|\delta| << |\beta|$ that we may conclude $|\beta|$ and $|\delta| < 10^{-7}$. The possibility $|\beta| = |\delta| \simeq 10^{-2}$ is not excluded to this date as mentioned by M-S[1]. As this is most unprobable I shall impose the alternative LAT or SR which imply $\alpha = \beta = \delta = 0$

3. LAT VÈRSUS SR. ELAT AND SLAT

For simplicity I assume here that most of Physics is invariant under L.T (Maxwell and Dirac equations, Point particle dynamics, etc) and include as the only specific violation of SR the properties of "rigid" freely rototranslating bodies. The question is in which coordinate system they are "rigid" and have constant angular velocity ($\vec{\omega} = \vec{\omega}_0$)? SR imposes it to be in Einstein coordinates. Thus we are now completely outside the scope of Mansouri-Sexl paper!

We consider two possibilities for LAT, distinct of SR, for which Born rigidity occurs, either: *i)* in absolute frame (coordinates X, T) where $\Omega = d\phi/dT = \omega_0$. Thus $\omega_E = \omega\,(\psi_E, t_E)$. Here Lorentz contraction in the direction of $\vec{V}_0$ and local time dilation are maintained. This form of LAT was proposed by Kolen and Torr[3] (K-T) and called ELAT by Rodrigues and Tiomno[2]; or *ii)* in Fitzgerald-Lorentz co-moving coordinates where $\omega_{FL} = d\psi/dt_L = \omega_0$ and thus we have $\omega_E = \omega(\psi_E, t_E)$. This form of LAT was proposed by myself and Rodrigues[2] who called it SLAT. Maciel and myself[4] have already proved that it cannot be distinguished from SR by existing experiments and proposed new experiments to test SR against SLAT[11].

Thus I shall concentrate in ELAT, restricting to light propagation in vacuum and I shall prove that it disagrees with already made experiments. I shall not be concerned with situations involving light propagation in dispersive or anysotropic media as of anysotropic propagation of sound, etc.

For simplicity I shall use from now on $(t, \vec{r}, \omega)$ instead of $(t_E, \vec{r}_E, \omega_E)$. Thus in the co-moving (but not co-rotating) inertial frames, we have in Einstein coordinates for the points in the turntable (or the Earth itself):

$$\vec{v}\ (\vec{r},\ t) = \vec{\omega}(t)\ \times \vec{r}(t).$$

Following Maciel and Tiomno[11] I find

$$\omega(t) = d\psi/dt = d\psi/d\phi \quad d\phi/dT\ dT/dt = \omega_0\ d\psi/d\phi\ dT/dt \text{ and}$$

$\omega(t) \cong \omega_0 + \omega_0(\vec{V}_0 .\ \hat{v}(t))^2 + O(vV_0,\ V^2)$ with $\hat{v} = \vec{v}/v$

which, after integration gives

$\psi(t) = \psi^0 + \gamma\omega_0 t + \frac{1}{2}\ V_0^2\ (\hat{v}.\hat{V}_0)\ \cos\ (\omega_0 t + \psi^0)$, where

$\hat{v}.\ \hat{V}_0 = -\sin\ (\omega_0 t + \psi^0)$. Finally, for the distance $L(t)$ of two points $(R,\ \psi_1(t))$ and $(R,\ \psi_2(t))$ *in the turntable* it is found[11]

$$\delta L/L_0 = L(t)/L_0 - 1 \cong -\frac{1}{2}\ V_0^2\ \cos^2\phi_0\ \cos\ 2\ (\omega_0 t + \phi_0)$$

Here $\vec{V}_0$ is the projection of the translation velocity in the plane of the turntable, L_0 is the distance of the points for the turntable at rest and I took $\psi_1{}^0 = 0$, $\psi_2{}^0 = 2\ \phi_0$. Also it must be noticed that for a rotating source $\nu_0' = \nu_0 + 0\ (v^2)$ or $\nu_0' = \nu_0$ to the order of approximation considered. Therefore we obtain for the rotating, M.M. experiment $\delta(\nu\ L(t))/\nu_0 L_0 = -\ V_0^2\ \cos^2\ (\omega_0 t + \phi_0)\ \cos^2\ \phi_0 \cong 10^{-6}$ which is of the form of phase shifts detected by M.M. and Miller (10^{-9}) and also by Joos (10^{-11}). This is not, however, a disproof of ELAT since in these experiments the arms were disposed along diameters and, thus $\phi_0 = \pi/2$ or $\cos\ \phi_0 = 0$!

One should however notice a very unsatisfactory feature of this theory (if not unacceptable!), say that δL does not vanish in the limit of very small values of v!

Again, by a very simple treatment, the frequency shift in a Mössbauer rotor Doppler shift experiment is found to be[11]

$$\Delta\nu/\nu_0 \cong -\ 2V_0^2\ v\ \text{sen}\ \phi_0\ \cos^2\ \phi_0\ \text{sen}\ 2(\omega_0 t + \phi_0)$$

which for the experiments of the refs. (6) and (7) should be of the order 10^{-12} while they found $\Delta\nu/\nu_0 \lesssim 10^{-14}$. Again these experiments do not disprove ELAT as $\cos\phi_0 = 0$ in ref. (7). For the Turner-Hill experiment $\Delta\nu = 0$ for other reasons.

4. EXPERIMENTAL DISPROOF OF ELAT

As I have just shown most of the sophisticated experiments of the M.M. type and others could not be used to disprove ELAT due to the geometrical arrangement and the "free" rotation of the equipment relative to the Earth. Thus, as the mirrors at the extreme of one arm had a central angle $2\phi_0$ viewed from the axis of rotation with $\phi_0 = \pi/2$, the factor $\cos\phi_0$ in the expression of $\delta(\nu L)/\nu_0 L_0$ made it vanish. A modification of the experiment with $\cos^2\phi_0 \cong 1$ was not made in turntable experiments as it was not necessary for the purpose of the experiments at the time they were done.

It is interesting to mention however that the only such experiment was done by Michelson in 1881 using a non rotating spectrograph — thus the free rotation involved was that of the Earth and $\phi_0 \cong 0$ for one of the arms in the West-East direction. Michelson obtained $\delta(\nu L)/\nu_0 L_0 \cong 10^{-7}\cos 2\omega t$ which was taken at the time as an indication that cV_0 could be of the order of 100 km/s or $V_0^2 \sim 10^{-7}$. We know that improvements of this experiment with rotating interferometers favoured SR (and LAT!) as examined in sec. 2 and that *all* known experiments with roto-translating bodies are also in agreement with SLAT. However if we compare Michelson's experimental result with the prediction of ELAT ($\delta L/L_0 \sim 10^{-6}\cos 2\omega t$ if $V_0 \sim 10^{-3}$) we see that it already disproves this theory.

A better result is obtained from the Jaseja et. al.[9] experiment which compares the optical lengths of two maser cavities at 90^0 with each other. Thus $\Delta L/L_0 = (\delta L_2 - \delta L_1)/L_0 = V_0^2 \cos 2\theta_0 \cos 2\omega t$ valid also for the relative variation of the two arms of the Michelson spectrometer. Here ω is the Earth's angular velocity and θ_0 is the angle of the arm in position 1 with the West-East direction. In obtaining this result the expression given above for $\delta L/L_0$ was used for the projection of the arm in the W-E direction, using $\delta L = 0$ for directions orthogonal to that one. Thus both the

Michelson and the Jaseja et. al. experiments should give a second harmonic effect: $\Delta L/L_0 \cong 10^{-6} \cos 2\theta_0 \cos 2\omega t$. Both experiments disagree, however, with this prediction respectively by factors $10^{-1}/\cos 2\theta_0$ and $10^{-5}/\cos 2\theta_0'$. So in both cases ELAT is disproved (unless the very unprobable coincidence $\theta_0 = \theta_0' = 45^0$ occurred!).

Finally I consider the Brillet et Hall experiment[10] which determined the time dependence $\delta L(t)/L_0$ of the optical lenght of a rotating Fabry-Perot spectrometer using as in ref. (9) the time variation of the frequency of a laser beam stabilized by frequency locking. Then a variation δ L or L_0 induces a variation $\delta\nu$ of ν_0 (the characteristic frequency). Precise measurement of $\delta\nu$ leads to precise determination of δL^0: $\delta L/L_0 = - \delta\nu/\nu_0$. Here ELAT predicts, again for the turntable experiment (with angular velocity ω): $\delta L(t)/L_0 = - (V_0^2/2) \cos^2\theta_0 \cos 2(\omega t + \theta_0) \cong 2\times10^{-7} \cos 2(\omega t + \theta_0)$ as $\cos^2 \theta_0 \sim 0.5$. However Brillet-Hall obtained a second harmonic effect of the order 10^{-15}, thus disproving ELAT by a factor 10^{-8}, leaving no place for any fortuitous cancellation as in the previous cases. This experimental result has no consequences for SLAT which predicts[4,11,12] (as SR) no second harmonic effect.

Concluding I like to point out that I have assumed that in ELAT a rotating disk remains circular in the co-moving Einstein coordinates. However ELAT continues to disagree with experiment even when we permit the disk to become elliptical in that frame[11]. Also the measurements made in experiments here considered are independent of the coordinate system used (Einstein's). Indeed in the Michelson experiments it is not the lenght variation but the invariant phase variation which is measured; in the laser experiments again it is not length variations but time delays of the beat frequency ν_0 with $\nu_0 + \delta\nu$ in units of ν_0^{-1} that are measured. Therefore if the computations were made in absolute coordinates they would be much more complicated but would lead to the same results.

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