ISSN 0029 - 3865

CBPF-NF-046/86

ANALYSIS OF ABSOLUTE SPACE-TIME LORENTZ THEORIES

by

A.K.A. Maciel and J. Tiomno

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

ABSTRACT

Two particular forms of absolute space time theories are examined. There follows a derivation of their predictions for measurements that are within present day detection limits.

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

1 INTRODUCTION

The problem of a clear experimental evidence in favour of Special Relativity (SR) versus absolute space-time theories is as old as SR itself and seems to have eluded physicists to this date[1]. Claims[2] of experimental evidence against SR have motivated its confrontation[3,4] with versions of a rival theory generally called the Lorentz Ether Theory (LET), which should be better called Lorentz Absolute (space-time) theory.

It has been shown[4] that, to distinguish LET from SR, experiments must involve the direct comparison of time measurements by SR violating timekeeping effects with SR abiding ones. To our knowledge, the only performed experiments supposedly satisfying the above requisites are those by Marinov[2], the conclusions of which are said to favour LET over SR. His two rotating disks, driven by an axle rigidly attached to them, are reported to favour a synchronization in the time

$$T = t + \vec{V}.\vec{x}(t)/c^2$$

where $\vec{V}$ is the laboratory velocity with respect to an absolute reference frame S_0 and t is Einstein's time. Here and throughout we use Einstein $(t,\vec{x})$ coordinates,

$$x = \gamma(x_0 - V\,t_0) \quad ; \quad y = y_0 \quad ; \quad z = z_0$$
$$t = \gamma(t_0 - V\,x_0) \quad ; \quad \gamma = (1-V^2)^{-1/2} \quad ; \quad c = 1 \tag{1}$$

even in contexts lying outside the scope of SR.

We do not consider Marinov's published results conclusive and leave for a future paper the analysis of his experiments which we think should be independently repeated.

More recently there have been claims[14,15] that there are three other experimental results which exclude LET and confirm SR.

One of these[14] refers to the Arago experiment on refraction of light by a prism. The paper concludes that, to first order in V/c, ether theories of the Stokes-Planck type only, account for Arago's results. Although Lorentz proposed his absolute ether theory in presence of dispersive media, we are presently restricting ourselves exclusively to vacuum propagation for the sake of simplicity, and we shall not discuss here the results of ref. (14).

The analysis[15] of the other two experiments are wrong. The first is a comparison of two distant atomic clocks by the one way velocity of light, and by slow moving clocks. As correctly proved by Mansouri and Sexl[5], both processes equivalently lead to the Einstein synchronization, even if LET is in operation, and cannot therefore distinguish LET from SR.

The second analysis in ref. (15) is based in a rotor Doppler experiment. Such experiments are unable to distinguish LET from SR[1] if emitter and absorber are placed in opposition along the same diameter in the rotor, as can readily be seen in our eq.(17) with $\phi_0=\pi$ for the equal radii case. Similarly, a null result is found if either emitter or absorber are placed at the center of rotation. Besides, there is no "Moller" term in ωRV ($=v\,V$) that leads to eq. (18) in ref. (15) as proved here in our last section.

In a preliminary analysis[1] of past experiments designed to test the validity of SR, we concluded that SR and one specific form of LET, called strict LET (S-LET)[3], can be experimentally distinguished with presently existing technology but no experiment performed to date has had the necessary characteristics to unquestionably favour one of these competing theories. One of us (JT) showed that another form of LET, extended LET (E-LET)[3] is, however, ruled out by already existing experimental results[4].

The present paper serves the purpose of organizing preliminary theoretical information that is scattered through references (1, 3,4) presenting it in a complete and generalized form.

Sections 2,3 and 4 are devoted respectively to the presentation of LET and of two forms of LET, strict LET and extended LET, and to the derivation of their equations of angular motion for the free rotation of a solid body in Einstein's coordinates.

In Section 5 quantitative predictions of measurable quantities that would evidence departures from SR are derived in both models. Some results have already appeared in approximated forms and adapted to specific cases in previous publications[1,3,4].

In Section 6, comments and conclusions on the theoretical aspects of the problem are presented.

2 ABSOLUTE SPACE-TIME THEORIES AND LET

A common feature of most absolute space-time theories is the existence of a preferred (absolute) frame of reference S_0 experimentally distinguishable from all other inertial frames S, those in uniform translation with respect to S_0. Absolute theories have been proposed with various characteristics. Here we state the basic features of the theory we shall refer to as LET, in the form of three postulates:

(i) The round trip vacuum propagation of light is isotropic in S_0 (with speed c=1) and independent of the velocity of the source.

(ii) Lengths contract and time rates dilate in the usual SR abiding way for *uniformly* translating systems in S_0.

Postulates (i) and (ii) are entirely consistent with SR, where S_0 is any inertial frame. It is the problem of synchronizing distant clocks (postulate iii) that renders LET and SR distinguishable.

Before we proceed to the third postulate, we introduce a classification of synchronization procedures that is due to Mansouri and Sexl[5] and which consists of two classes:

(a) *System external* synchronization methods are those in which clocks in all inertial systems are synchronized by direct or indirect comparison with standard clocks in S_0. Therefore, synchronizing clocks in any frame S by an external method presuposes previous knowledge of the preferred frame or of the absolute velocity $\vec{V}$ of S with respect to S_0.

(b) *System internal* synchronization methods are those which rely ex clusively on information locally obtainable in the reference system where synchronization is being carried out.

Three examples in this class are the light signal, slow transport, and shaft methods. As mentioned earlier, the first two have been shown to equivalently lead to Einstein's t-synchronization *both* in SR or LET, or in fact in any theory satisfying postulates (i) and (ii).

It is well known that in SR any internal synchronization procedure, by different methods or parametrizations, is necessarily *equivalent* to the light signal method. So we come to the third postulate which finally renders LET and SR distinguishable:

(iii) LET may admit *internal* synchronization methods that are *inequivalent* to Einstein's light signal method.

For later use we now introduce a particular synchronization in which positions and times measured in S and S_0 will relate by the Lorentz-Ives-Marinov[2]-Tangherlini [13] transformations

$$X = \gamma(x_0 - V t_0) \quad ; \quad Y = y_0 \quad ; \quad Z = z_0$$
$$T = \gamma^{-1} t_0 \quad ; \quad T = t + \vec{V}.\vec{x}(t) \quad . \tag{2}$$

Equations (2) define what we shall refer to as "Fitzgerald-Lorentz coordinates" (X,T), called "Ives coordinates" in ref. (1), and the absolute T-synchronization.

The T-synchronization can be implemented within the context of SR by *external* methods, as described in Mansouri and Sexl's[5] recipe of section 3.

The Lorentz-Fitzgerald coordinates can be used in SR just as well as the Einstein coordinates are used here in LET. Coordinates are only labels, and cannot specify a theory.

However, the T-synchronization cannot be implemented within the context of SR by *internal* methods, since this would necessarily imply the existence of an SR violating process to be used as time-keeping, and from which a measurement of the laboratory's absolute velocity would also be made possible. This can only occur in an exclusively LET regime, as established by postulate (iii). Furthermore, should this T-synchronization be made possible by some experiment in S involving SR violations, then the absolute t_o synchronization of S_o would be determined directly in S, since $\vec{V}$ is necessarily a by-product of that experiment.

Our next concern is to discuss possibilities whereby specific types of absolute synchronizations could effectively be installed in a reference frame via an *internal* method, that is, without previous (external) information of an absolute frame. This can only be done after we have tentatively decided in what domain of physics SR can be violated in such a way that the absolute time manifests itself.

Inspired by past experiments we have decided to examine the rotation-translation of rigid bodies as a possible source of SR violations. Our program shall consist of formulating hypothetical models which contain explicit assumptions of absoluteness, and of extracting from them observables with different SR and LET predictions that can be submitted to experimental verification. This is the object of the next section where we consider two such models within LET.

Our is a complementary approach to that of Mansouri and Sexl[5] who studied only consequences of possible deviations of the contraction and dilation factors from the Lorentz value, thus concluding that LET and SR are indistinguishable.

It should from now on be remembered that whenever a synchronization is mentioned, an *internal* process is to be associated with it, since we do not consider external methods in this paper.

3 STRICT AND EXTENDED LET

We now consider the kinematics of rotating rigid bodies, a traditional testing ground for manifestations of absoluteness. We do so by addressing ourselves to the question of the uniformity of the angular velocity in a rotating rigid disk. Two specific kinematical hypothesis are examined, leading to the so-called S-LET (for strict LET) and E-LET (for extended LET) models[3], which are presented in direct comparison with SR.

It will be assumed for simplicity that the laboratory's absolute velocity $\vec{V}$ is perpendicular to the rotation axis $\hat{z}$ of the disk. In general, $\vec{V}$ should be replaced by its component in the plane of rotation, which defines the direction $\hat{x}$,

$$\hat{z} \wedge \vec{V} \wedge \hat{z} = \vec{V}.\hat{x}\,\hat{x} \;.$$

In future formulae $\hat{x}$ has been chosen as the angle measurement origin.

It should also be stated that in our future discussions we shall always assume that the absolute system S_0 is that in which the Universe's 2.7^0K background radiation is isotropic, for which the Earth's velocity is of order 10^{-3}.

Consider now a freely rotating rigid disk with axis at rest in the (laboratory) reference frame S which is in uniform translation $\vec{V} = V\,\hat{x}$ with respect to S_0.

Rigidity in SR is such that all points in the disk have, in S and in Einstein coordinates $(\vec{r},t)$, the same constant angular velocity ω. Such uniform rotation is described by

$$\phi(t) = \phi(0) + \tilde{\omega} t \ . \tag{3-a}$$

Under the same conditions, but in direct contrast with SR, we introduce S-LET and E-LET in the form of two kinematical hypothesis. At this early stage we certainly want to sidestep any dynamical explanations, say at particle level, as to how the rotation of solid bodies should depart from SR, especially since this has never been consistently observed.

In this section we work under the further assumption that whatever the dynamics of the Lorentz contraction due to rotation is, it is such as to preserve radial lengths and symmetries in S, in Einstein coordinates.

It is important to make here an observation which was implicit in references (1,3,4). In all cases (SR or LET), the rotating disk when observed in S_0 (absolute coordinates, t_0 constant) assumes an elliptical form. Its description in S, Einstein coordinates, restores the circular form because measurements are made with Lorentz contracted rods.

3.1 Strict LET

The physics of free rotation according to S-LET is such as to satisfy hypothesis 1:

(hyp. 1) 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.

Thus, if a general point solidary to this body is described in

S by the polar vector $\vec{R}(T) = (R, \Phi(T))$ with R constant, its angular motion is given by (Ω is a constant)

$$\Phi(T) = \Phi(0) + \Omega T \qquad (3\text{-b})$$

Equations (3-a) and (3-b) (and the yet to come, 3-c) represent each a different physical law for the free rotation of a rigid body, and the true one (if any) is to be determined experimentally, for example by the methods discussed in section 5. In case Nature has "chosen" eq. (3-b), then the free rotation of a solid as observed with Einstein abiding instruments (rods, atomic clocks light signal synchronized, optical instruments in general) will nolonger appear as a rigid motion.

To see this quantitatively, we want to express equation (3-b) in Einstein coordinates where $\vec{r}(t) = (R, \phi(t))$ and both $\vec{r}(t)$ and $\vec{R}(T)$ have a common origin at the center of rotation. From equations (1) and (2), spatial coordinates are identical in both systems:

$$\vec{R}(T) = \vec{r}(t) \; ; \; \Phi(T) = \phi(t) \; ; \; T = t + \vec{V}.\vec{r}(t) \; .$$

Equation (3-b) can therefore be re-written as

$$\phi(t) = \phi_o + \Omega(t + \vec{V}.\vec{r}(t)) \qquad (4)$$

where ϕ_o is some arbitrary constant.

For future use we develop eq. (4) further. Substitution of

$$\vec{r}(t) = R\cos\phi(t)\hat{x} + R\sin\phi(t)\hat{y} \qquad (5)$$

into equation (4), with $v \equiv \Omega R$ gives

$$\phi(t) = \phi_0 + \Omega t + Vv \cos(\phi_0 + \Omega t) + O(v^2V^2) \tag{6}$$

Thus, according to S-LET, the free rotation of a disk as seen in S(Einstein coordinates) is such that the angular velocity of its points will be oscillating harmonically around an average value Ω, each with a position dependent phase of its own. Time varying phase differences between different points will imply departures from a rigid like motion as we know it in Einstein coordinates. More specifically, rigidity in S-LET means $|\vec{R}_1(T)-\vec{R}_2(T)|$ = constant for all T for any two points 1 and 2, instead of the usual SR constancy of $|\vec{r}_1(t)-\vec{r}_2(t)|$. This is precisely the effect that we suggest[1,3,4] should be looked for in an experiment designed to test S-LET against SR in the dynamics of rotating bodies.

A physical manifestation of this effect is the length oscillation (with time t) of the chord of an arch in a rotating disk. The relative movement between its ends can be detected with optical path length measurement devices, or by Doppler means. The relevant observables in such experiments are calculated in section 5.

Yet another manifestation of this non rigidity is the deformation of a radial straight line $\phi = \phi_0$ marked in a rotor disk when at rest (Ω=0). Under rotation, it is seen instantly in the Einstein frame as a parabola, departing from a straight line by the tangential amount ($0 < r < R$)

$$\eta \equiv (\phi(t) - \phi_0 - \Omega t)r = r^2 V\Omega \cos(\phi_0 + \Omega t) \; .$$

The angle by which it departs from the radial direction at some ra dial distance R,

$$\delta\alpha = d\eta/dr = 2vV \cos(\phi_o + \Omega t)$$

could in principle be measured by the reflection of light on a mirror conveniently placed at the disk.

3.2 Extended LET

The work of Kolen and Torr(7) has led Rodrigues and Tiomno(3) to consider one other model of LET, namely E-LET. In parallel with S-LET, the physics of free rotation according to E-LET is presented as a second hypothesis :

(hyp. 2) The free rotation of a rigid body is uniform when observed in S_o and described by the absolute coordinates.

Thus, if a general point solidary to this body is described in S_o by the polar vector $\vec{R}_o(t_o) = (R_o(\Phi_o), \Phi_o(t_o))$, its angular motion is given by

$$\Phi_o(t_o) = \Phi_o(0) + \Omega_o t_o \ . \tag{3-c}$$

We must translate this equation into Einstein coordinates in the laboratory frame S. Remembering that angles in both frames differ by a Lorentz boost,

$$\tan \Phi_o(t_o) = \gamma \tan \phi(t)$$

and using the transformation $t_o = \gamma(t + \vec{V}.\vec{r}(t))$ we find

$$\phi(t) = \phi_o + \gamma\Omega_o t + Vv_o \cos(\phi_o + \Omega_o t)$$

$$- (V^2/4) \sin 2(\phi_o + \Omega_o t) + O(V^4, v_o V^3, v_o^2 V^2) \quad , \qquad (7)$$

where ϕ_o is an arbitrary constant and $v_o = \Omega_o R$.

It is clear that S-LET and E-LET differ radically. Departures from SR in E-LET originate from the fact that the oblongue (Lorentz contracted) object seen in S_o has constant angular velocity.

In order to render future derivations and discussions more practical, we merge equations (6) (S-LET) and (7) (E-LET) into one single equation (8) of free rotational motion by means of the binary parameter λ defined such that $\lambda = 0(1)$ whenever S-LET (E-LET) is in operation. We also drop the indices (o) in E-LET constants since λ will unambiguously indicate which model is being considered and therefore which constants should be used. Thus,

$$\phi(t) = \phi_o + (1+\lambda V^2/2)\Omega t + Vv \cos(\phi_o+\Omega t)$$

$$- (\lambda V^2/4) \sin 2(\phi_o+\Omega t) + O(V^4, vV^3, v^2V^2) \qquad (8)$$

3.3 Disk synchronization

Freely rotating disks may be thought of as clocks themselves, in which angle measurements are time measurements, or can be used to synchronize distant clocks.

For example, the S-LET rotating disk seen as a clock is such that at its center t=T (i.e. the Einstein and Fitzgerald - Lorentz times coincide), whereas away from the center, where T≠t, T may be defined as

$$T = (\Phi(T) - \Phi(0))/\Omega \quad ,$$

Ω being the angular velocity measured at the center, the same for SR and S-LET.

Disk synchronization is yet another example of an internal method, and can be implemented as follows.

Suppose two non-rotating clocks, at rest in the laboratory, one atop the axle of a freely rotating disk, the other sitting close to the disk's rim. The radial line joining these two clocks defines ϕ_o. Two previously marked points, one in the neighbourhood of the centre, the other at the border, both along some arbitrarily chosen radial line of the disk, may then be used to start the clocks as they cross ϕ_o.

It is in this sense that we may speak of equations (3-a,b,c) as respectively implying the Einstein t-, Fitzgerald-Lorentz T-, absolute t_o - synchronizations.

4 PARTIAL FITZGERALD-LORENTZ CONTRACTION EFFECTS

We investigate next the consequences of yet another tentative mechanism of Lorentz invariance breaking which, being presumed independent in origin from S-LET and E-LET, might occur simultaneously with either.

In the S_o description of a freely rotating body, supposedly at rest in S, we allow for the possibility that the Fitzgerald-Lorentz contraction along $\vec{V}$ may be slightly altered due to the rotation. For that purpose we introduce a modified boost parameter $\tilde{\gamma}=\gamma(\Omega_o)$

satisfying.

$$\lim_{\Omega_0 \to 0} \tilde{\gamma} = \gamma = (1-V^2)^{-1/2}$$

such that a full contraction is restored in the case of no rotation.

As a model we take

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

where $\beta = \beta(\Omega_0)$ is a positively or negatively increasing function of Ω_0 from $\beta(0) = 0$ to any limit lower or equal to 1 in modulus at high Ω_0.

If such is the case, consider a solidly built non rotating circular disk in S of radius R. Under rotation, a peripheral point will have in S_0 a position (polar) vector

$$\vec{R}_0(t_0) = (R/\tilde{\gamma}) \cos \phi_0(t_0)\hat{x} + R \sin \phi_0(t_0)\hat{y}$$

and, in S, its equation of motion in Einstein coordinates will be recovered from S_0 by a full Lorentz transformation, giving

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

or, in powers of V^2,

$$\vec{r}(t) = R(1+\beta V^2/2) \cos\phi(t)\hat{x} + R \sin\phi(t)\hat{y} + O(V^4) \quad . \tag{9}$$

Equation (9) should hereafter replace eq. (5) and has an extra β-term responsible for a dilation ($\beta > 0$) or contraction ($\beta < 0$) of the Einstein coordinate x-components in case the modified Fitzgerald Lorentz contraction between S and S_0 takes place. This is however of no concern to the equations of angular motion of either S-LET or E-LET up to the orders of magnitude considered here. In fact, the added term in $\vec{r}$ (t) will contribute to $\phi(t)$ in eqs. (6) and (7) only at the neglected vV^3 scale.

Its consequences will unfold clearly in the next section which is devoted to the derivation of experimentally detectable consequences of LET.

We like to mention the work of Atkins[8] who considers inertial effects on the rotating body that prevent it from attaining its instantaneous (Lorentz contracted) equilibrium configuration. The consequences are of a similar nature to those originated from our "ad hoc" introduction of the parameter β.

Assuming that Electromagnetism is Lorentz invariant if written in Einstein coordinates, we shall consider only experiments involving electromagnetic signal and detection devices. Thus our concern in writing the equations of motion in Einstein coordinates throughout, so we are assured that the only differences in future confrontations between theory and experiment come from explicit SR violations such as those contained in eq. (8).

5 CONSEQUENCES OF LET

We concentrate on two different methods of search for SR violations in the dynamics of rotating bodies.

5.1 Length measurements

The first one deals with the detection of length (or time) variations $\delta L(t)$ in the optical path between two points, say, two reflecting mirrors, solidary to a rotating system. The optical distance between points 1 and 2

$$L(t) = |\vec{r}_2(t+\delta t) - \vec{r}_1(t)| \tag{10}$$

where $\delta t(t) = L(t)$ is the light transit time from 1 to 2. Use of eqs. (8) and (9) here supposes $\vec{r}_1, \vec{r}_2$ and $\vec{V}$ coplanar, a view we adopt for simplicity. Should any of these lie outside the rotation plane, its modulus in the remaining formulae must be multiplied by the cosine of its latitude. All following calculations remain true to the order considered. From eqs. (9) and (10),

$$L^2(t) = R_1^2 + R_2^2 - 2R_1R_2\cos[\phi_2(t+\delta t) - \phi_1(t)]$$

$$+ \beta V^2 [R_1 \cos\phi_1(t) - R_2 \cos\phi_2(t+\delta t)] + O(V^4)$$

This equation is to be iterated with (8) up to terms of order V^2, ΩR and ΩRV. With the convention that

$$\phi_{01} = 0 \quad \text{and} \quad \phi_{02} = \phi_0$$

the LET result for $L(t)$ can be written as

$$L(t) = L_0 + \delta L(t) = L_0 \Big\{ 1 + q\,\Omega L_0 \sin\phi_0 - q\,V\Omega X(t) \sin\phi_0$$

$$- (\lambda V^2/2) q \sin^2\phi_0 \cos(\phi_0 + 2\Omega t)$$

$$+ \beta V^2 X^2(t)/(2L_0^2) + O(vV^2) \Big\} \qquad (11)$$

where

$$q = R_1 R_2 / L_0^2 \quad , \quad X(t) = R_1 \cos\Omega t - R_2 \cos(\phi_0 + \Omega t)$$

and

$$L_0 = (R_1^2 + R_2^2 - 2R_1R_2\cos\phi_0)^{1/2}$$

The term in ΩL_0 contributes to the Sagnac effect[9] and does not evolve with time. Our conventions imply that in the optical measurement of $L(t)$ or $\delta L(t)$ the light path starts off at site (1) being detected at (2). ϕ_0 is the angular separation $(\phi_{02}-\phi_{01})$ at rest (no rotation) between points (1) and (2) as measured in S_0 (E-LET) or in S (S-LET). As most experimental situations involve optical paths whose ends are equidistant from the center of rotation, we re-write eq. (11) for the special case $R_1 = R_2 = R$:

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

$$- (\lambda V^2/2) \cos^2(\phi_o/2) \cos(\phi_o + 2\Omega t)$$

$$+ (\beta V^2/2) \sin^2(\phi_o/2 + \Omega t) + O(vV^2) \qquad (12)$$

5.2 Doppler shift measurements

The second method of SR violation detection we discuss is based on Doppler shift technology with an emitter and an absorber as endpoints of the rotating optical path. Let us consider three inertial frames of reference S, S' and S" which are, respectively, co-moving with the laboratory (S) and instantaneously co-moving with emitter (S') and absorber (S"), all of them using Einstein coordinates. Then, according to either SR or LET in Einstein Coordinates, phase invariance of the Electromagnetic radiation allows us to write

$$\omega(t - \vec{k}.\vec{r}) = \omega'(t' - \vec{k}'.\vec{r}') = \omega''(t'' - \vec{k}''.\vec{r}'')$$

$$\vec{k}^2 = (\vec{k}')^2 = (\vec{k}'')^2 = 1$$

In particular, for the emitter (e) at any instant we have

$$\omega(t - \vec{k}.\vec{r}_e(t)) = \omega'(t' - \vec{k}'.\vec{r}'_e(t')).$$

Differentiation with respect to t gives

$$\omega(1-\vec{k}.\vec{v}_e(t)) = \omega' dt'/dt$$

where $\vec{v}_e(t) = \dot{\vec{r}}_e(t)$, and since

$$t' = \gamma_e(t-\vec{v}_e(t).\vec{r}_e(t))$$

$$dt'/dt = \gamma_e(1-v_e^2(t)) = \gamma_e^{-1} \quad ,$$

we find

$$\omega' = \omega\gamma_e(1-\vec{k}.\vec{v}_e(t)) \tag{13-a}$$

where $\vec{k}$ is the unit vector in the direction of propagation as observed in S (Einstein Coordinates). Analogously, for the absorber (a) we may write

$$\omega'' = \omega\gamma_a(1-\vec{k}.\vec{v}_a(t)) \quad . \tag{13-b}$$

Now let ν, ν_0 and ν_a be the emitted light frequency (Einstein time) as measured respectively in S, S' and S". Then, from eqs. (13) in either SR or LET we have

$$\nu = \nu_0\left[\gamma_e(1-\vec{k}.\vec{v}_e(t))\right]^{-1} = \nu_a\left[\gamma_a(1-\vec{k}.\vec{v}_a(t+\delta t))\right]^{-1} \quad . \tag{14}$$

Contrary to a common belief, equation (14) does not necessarily imply relativity. It is a consequence only of postulate

(i) (in section 2) and of the use of Einstein Coordinates, being also valid for any absolute Space-time theory. It is only when expressions (8) and (9) are used with $V \neq 0$ $(V = 0)$ that LET (SR) will be imposed.

In rotor Doppler type experiments the observed quantity is the frequency shift

$$\delta\nu/\nu_o = (\nu_a - \nu_o)/\nu_o \quad , \tag{15}$$

obtainable from equation (14). We restrict ourselves to the equal radii case (emitter and absorber equidistant from center of rotation), where $\gamma_e/\gamma_a = 1 + O(v^3)$, and find ($v$ and ϕ_o are as previously defined)

$$\delta\nu/\nu_o = \vec{k}.(\vec{v}_e(t) - \vec{v}_a(t + \delta t)) + (\vec{k}.\vec{v}_e(t))^2 + O(v^3)$$

$$= -\dot{L}(t) + v^2\cos^2\phi_o/2 + O(v^3) \tag{16}$$

where $\vec{L}(t) = \vec{r}_a(t + \delta t) - \vec{r}_e(t) = \delta t\,\vec{k}$.

Time differentiation of $L(t)$ in equation (11) with $R_1 = R_2 = R$ gives the LET prediction

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

$$- \lambda v V^2 \sin\phi_o \cos(\phi_o/2)\sin(\phi_o + 2\Omega t)$$

$$- \beta v V^2 \sin(\phi_o/2)\sin(\phi_o + 2\Omega t) + O(v^3, v^2V^2) \tag{17}$$

The reader is reminded that $\lambda = 0$ or 1 for S-LET or E-LET respectively, and β parametrizes hypothetical departures from an exact Lorentz contraction (where $\beta = 0$) between S_o and S, as discussed in section 4.

From equation (16) it is clear that the origin of the time dependent Doppler shifts (according to LET, in the equal radii case and to the orders of approximation considered) is the relative longitudinal motion between emitter and absorber, either approaching or receding from each other. Notice that if these are in opposition ($\phi_o = \pi$), LET effects are masked to this order since there is only relative transverse motion, accounted for in higher orders.

6 COMMENTS AND CONCLUSIONS

Analysing the then current status of experimental verifications of Special Relativity, Mansouri and Sexl[5] argue that, contrary to the general feeling of a high degree of accuracy between predictions and measurements, there is still room left for speculation on possible competing theories[1,3,4]. Indeed it is difficult to express this accuracy in specific numbers, unless rival theories are defined and compared with SR. This has been the subject of our previous sections where LET has been compared with and differentiated from SR for experiments involving the rotation of rigid bodies.

LET has been the object of previous studies and many disputes in the literature (see, for example, references 12 and 5 vs 10, 11 and 3 vs 7). One of the reasons for these confrontations is the imprecise definition of the specific LET in question. For instance, Moller's work[12] of 1957 on the experimental distinction between SR and the pre-relativistic (no length contraction and time dilation) Newton-Fresnel ether theory is frequently analysed in connection with LET, many wrong conclusions ensuing. Besides the pre-relativistic longitudinal Doppler effect which leads to the lowest order $\delta\nu/\nu_o = 2\vec{v}.\vec{V}$ of references (12), time dilation in LET contributes a transverse Doppler effect which, for emitter and absorber equidistant from rotation center, exactly cancels the above leading order term. This is a known result, commented in references 3,7 and 10, whose (yet unpublished, to our knowledge) proof, valid for any angular separation between emitter and absorber, is briefly indicated here for completeness.

Consider the general expression for $\delta\nu/\nu_o$ (LET or SR) taken from equation (14) and valid in Einstein coordinates in any inertial frame. In particular, in the absolute frame S_o it reads.

$$1 + \delta\nu/\nu_o = \left[\frac{1 - u_e^2(t)}{1-u_a^2(t+\delta t)}\right]^{1/2}\left[\frac{1 - \vec{k}_o.\vec{u}_a(t+\delta t)}{1 - \vec{k}_o.\vec{u}_e(t)}\right]$$

where u's are Einstein velocities in S_o and $\vec{k}_o$ the unit vector of light propagation. The two factors on the right are respectively the transverse δ_T and longitudinal δ_L contributions. To obtain them in lowest order and in terms of laboratory (S) velocities ($v \lesssim 10^{-6}$) and the S to S_o relative velocity V $\sim 10^{-3}$, we use $\vec{u} \approx \vec{v} + \vec{V}$ and the fact that $(\vec{v}_a+\vec{v}_e)$ and $(\vec{v}_a-\vec{v}_e)$ are orthogonal. Then it is straightforward that

$$\delta_T = 1 + \vec{V}.(\vec{v}_a - \vec{v}_e) + \ldots$$

For δ_L we have

$$\delta_L = 1 - \vec{k}_o.(\vec{u}_a(t + \delta t) - \vec{u}_e(t))$$

where

$$\vec{k}_o = (\vec{r}_{oa}(t + \delta t) - \vec{r}_{oe}(t))/\delta t = \delta\vec{r}_o/\delta t + \vec{u}_a(t)$$

and in terms of quantities measured in S,

$$\delta_L = 1 - (\delta\vec{r}/\delta t + \vec{v}_a + \vec{V}).(\vec{v}_a - \vec{v}_e + \delta t\dot{\vec{v}}_a) + \ldots$$

whose piece

$$\delta_L = 1 - \vec{V}.(\vec{v}_a - \vec{v}_e) + \ldots$$

exactly cancels its analogous one in δ_T above, to lowest order in the product $\delta_L\delta_T$. Thus, the Galilean[12] $\delta\nu/\nu_o = \vec{V}.(\vec{v}_a - \vec{v}_e)$ (or $2\vec{v}.\vec{V}$ for emitter and absorber in opposition) is no longer valid when time dilation is taken into account.

In conclusion, we hope to have cleared out the long-standing controversy on the equivalence between LET and SR. They are certainly inequivalent, provided absolute theories are properly defined. We stress further that mere coordinate changes, such as the transformations of equation (2) alone do not yield an absolute theory. Specific violations of SR have to be introduced, as for example we do in sections 3.1 and 3.2 with the models S-and E-LET. These will lead to physically observable SR violating manifestations, other than an ether drift which is absent in both SR or LET.

Equation (11) is the central result from which experimentally measurable quantities of interest can be obtained[1]. Examples are $\delta L/L_0$ (eq. 12) and $\delta\nu/\nu_0$ (eq. 17). The experimental detection of these quantities is examined in a following paper.

Prior to any experimental analysis, a serious objection to E-LET may be placed here on theoretical grounds. The V-independent term in eq. (11) for δL is such that

$$\lim_{V\to 0} \delta L/L_0 \neq \delta L/L_0\Big]_{V=0} = 0 \quad .$$

This discontinuous character is highly undesirable of a physical theory, and constitutes strong theoretical evidence against E-LET in our view.

REFERENCES

(1) A.K.A. Maciel and J. Tiomno, Phys. Rev. Lett. 55, 143, (1985)

(2) S. Marinov, Czech J. Phys. 24, 965 (1974), Gen. Rel. Grav. 12, 57 (1980), and Found. Phys. 9, 445 (1979).

(3) W.A. Rodrigues and J. Tiomno, Found. Phys. 15, 945 (1985)

(4) J. Tiomno, Proc. 4th Marcel Grossman Meeting on Gen. Rel., R. Ruffini (ed.), Elsevier Sci. Pub. (1986) . Note that in this reference a misprint in the second member of Eq. (1) omitted a term $- v^2/2$ which was actually detected by Ives and Stilwell

(5) R. Mansouri and R. Sexl, Gen. Rel. Grav. 8, 497 (1977).

(6) R. Mansouri and R. Sexl, Gen. Rel. Grav. 8, 515 (1977)

(7) D.G. Torr and P. Kolen, Found. Phys. 12, 265 (1982) and Found. Phys. 12, 401 (1982).

(8) K.R. Atkins, Phys. Lett. 80A, 243 (1980). See also F. Winterberg, Z. Naturforsch 42A, 1374 (1987).

(9) G. Sagnac, C.R. Acad. Sci. Paris, 157, 1410 (1913)

(10) A.A. Tyapkin, Lett. Nuovo Cim. 7, 760, (1973)

(11) S.J. Prokhovnik, Found. Phys. 10, 197 (1980)

(12) C. Moller, Suppl. Nuovo Cim. 6, 381 (1957). This is also analysed in section 3 of reference (6), and in chapter 11 of J.D. Jackson's "Classical Electrodyhamics", 2nd ed., Wiley and Sons (1975).

(13) F.R. Tangherlini, Suppl. Nuovo Cimento 20, 1 (1961).

(14) G. Spavieri, G. Contreras, Nuovo Cimento 91B, 143 (1986).

(15) G. Spavieri, Phys. Rev. A 34, 1708 (1986).

(16) G.F. Smoot, M.V. Gorenstein, R.A. Muller, Phys. Rev. Lett. 39, 898 (1977).