CBPF-NF-38/82

ON EXPERIMENTS TO DETECT POSSIBLE FAILURES OF RELATIVITY THEORY

by

W. A. Rodrigues[1] and J. Tiomno

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

[1]Instituto de Matemática
IMECC - UNICAMP
Caixa Postal 6155
13100 - Campinas, SP. - BRASIL

ABSTRACT:

We analyse in this paper conditions under which we may expect failure of Einstein's Relativity. We also give a complete analysis of a recently proposed experiment by Kolen—Torr showing that it must give a negative result.

1. INTRODUCTION

A number of experiments have been proposed or reported which supposedly would detect the motion of the laboratory relative to a preferential frame S_o (the ether), thus provinding an experimental distinction between the so called "Lorentz" Ether Theory[1] and Einstein Theory of Relativity.

Much of the confusion on the subject, as correctly identified by Tyapkin(2) (where references until 1973 can be found) is possibly due to Møller(3) who in 1957 started a discussion of a seemingly new possibility to test experimentally relativity. He suggested comparing the Doppler shift of two-maser beams whose atoms move in opposite directions. His calculation of the Doppler shift on the basis of pre-relativistic physics, gave rise to the appearance of a term linearly dependent upon the velocity $\vec{v}$ of the laboratory sytem moving with respect to the ether.

The experiment was made in 1958(4) and yielded a negative result. This has been interpreted by Moller(5) as proving Einstein Theory of Relativity and disproving "Lorentz" Ether Theory. This,

---

1. "Lorentz" Ether Theory is called by Erlichson(1) the Rod Contraction - Clock Retardation Ether Theory (RC-CR ether Theory). Erlichson's paper presents a very interesting history of the RC-CR ether theory, showing that it never existed in a coherent formulation before 1905. After discussion of several experiments and/or proposals to distinguish both theories he concludes: "... as of this date there do not seem to have been any experimental proposals offered which would clearly distinguish between the STR (Special Theory of Relativity) and the RC - CR ether theory. On the other hand, we have also not been able to find any theoretical proof showing the impossibility of such a conclusion".

however, is quite unjustified since the Doppler effect calculated in Lorentz Ether Theory leads to no effect linear in $\vec{v}$. This result was proved by Lee and Ma in 1962 and independently rediscovered recently[6]. This observation seems relevant here since text books[7] continue to present Moller's wrong analysis.

More recently new experiments have again been proposed or reported[8,11]. The experiments of references (8,9) are a variant of Møller's proposal and obviously must give a null result in view of the result quoted above. A detailed analysis of the experiment of ref(8) can be found in ref(12).

In general the proposed experiments have been shown not to survive a careful analysis, leading necessarily to a negative result. Exceptions are Marinov's experiment[11] (which compares directly two synchronization procedures, the rotating shaft mechanism and Einstein's radiation method and, perhaps, some other proposals which we mention in §4.

In this paper we analyse the Kolen-Torr[10] proposed experiment and show that it leads necessarilly to a null result if we accept solely

(i) the isotropic propagation of light with velocity c, independent of the motion of the source, *in* S_o

(ii) time dilation of moving clocks (time T) relative to time t *in* S_o (where all clocks are synchronized by light signals or slow transportation of test clocks[2]) given by

---

2. Eqs(3) and (10) prove that indeed both methods are equivalent if the result expressed by eq(1) is true.

$$T(t) - T(0) = \gamma^{-1} t \qquad (1)$$

$$\gamma^{-1} = \sqrt{1 - v^2} \qquad (c = 1)$$

where $\vec{v}$ is the velocity of the clock measured by S_o .

(iii) The Lorentz-FitzGerald contraction of the lenght of a moving rigid body as compared to the lenght at rest in S_o

$$\delta X = \gamma \delta x; \qquad (\delta t = 0). \qquad (2)$$

$$\delta Y = \delta y; \quad \delta Z = \delta z \qquad (\vec{v} = v\hat{e}_x)$$

Observe that Einstein's Relativity includes besides (i), (ii), (iii) the phase differences of Einstein's clocks at different positions as seen by S_o observers:

$$T(\vec{x}_1, t) - T(\vec{x}_2, t) = - \gamma \vec{v} \cdot (\vec{x}_2 - \vec{x}_1) \qquad (3)$$

which is obtained from the usual procedure of synchronization with electromagnetic radiation (Einstein's method) in the moving *frame* S. In sec. 2, we assume no a priori synchronization of distant clocks.

2. THE KOLEN-TORR EXPERIMENT

In the Kolen-Torr experiment two rubidium-frequency standards of the same known period are placed a distance D apart (as measured in the laboratory (S)), the whole system moving with velocity $\vec{v}$ relative to S_o . This is shown in Fig. 1, where A and B represent the two clocks at $t = 0$ (position (1)) in a table moving with velocity $\vec{v}$, which may rotate showly so to bring the clocks to the situation B'A' at $t = t_o$ (position (2)).

Actually, as $D \simeq 300$ m, the moving table is not introduced in their proposal[10], the rotation being provided by the earth's rotation.

No attempt is made by them to synchronize the clocks when they are apart. However they assume that the frequency of the cloks is perfectly stable, so that there is no drift in their relative phase, i.e., that the phase difference ΔT of the clocks *remains constant* when they move from position (1) to (2).

We shall show that the last assumption is wrong and when the correct computation is made (no Einsteinian Relativity implied !) a cancellation of the time delay obtained in ref(10) occurs. To understand this point let us first obtain the corrected results.

In the experimental arrangement shown in Fig. 1 a signal from clock A is used to trigger the start imput at $T = \tilde{T}_A$ (clock A time) of an interval counter located at clock A itself. A signal from clock B conveniently prepared is fed to the stop imput of the counter at $T = \bar{T}_A$. The counter registers the time interval $\Delta T_{A_1} = \bar{T}_{A_1} - \tilde{T}_{A_1}$ (see Fig. 2) in the situation 1 .

Assuming that $\vec{v} = (dx/dt)\hat{e}_x = v\hat{e}_x$, is in the plane of the table we have

$$\vec{r}_{AB} \cdot \hat{e}_x = d \cos \theta,$$

where

$$\vec{r}_{AB} = \vec{r}_B(t) - \vec{r}_A(t),$$

is the radius vector from A to B, all quantities being referred to S_o.

If we take $t_B = 0$ at the time the clock B sends its signal

(Fig. 2) them the transit time for light to reach A is $t_{\bar{A}} - t_B = t$, which is given, from $t^2 = d^2 + v^2t^2 - 2dvt\cos\theta$, by

$$t = \gamma^2 d(\sqrt{1 - v^2\sin^2\theta} - v\cos\theta) \qquad (3)$$

Thus from (1) and (3)

$$\Delta T_{A_1} = \Delta T + \gamma^{-1}t$$

$$= \Delta T + \gamma d(\sqrt{1 - v^2\sin^2\theta} - v\cos\theta) \qquad (4)$$

If the table is rotated by 180^o, or, as in the Kolen -Torr proposed experiment, twelve hours rotation is made by the earth, the clocks positions are interchanged (situation 2 in Fig. 1). Thus if the experiment is repeated again the time interval recorded by the counter (located at A') will be

$$\Delta T_{A_2} = \Delta T + \gamma d(\sqrt{1 - v^2\sin^2\theta} + v\cos\theta) \qquad (5)$$

Thus we find

$$\delta T = \Delta T_{A_1} - \Delta T_{A_2} = -2\gamma vd\cos\theta \qquad (6)$$

which for $\theta = 0$ gives, using eq(2)

$$\delta t(\theta = 0) = -2vd \qquad (7)$$

which coincides with eq (9) of Kolen and Torr[10], although their reasoning is misleading. Here the initial phase difference (ΔT) cancelled due to their hypothesis.

In order to show that the phase difference does not remain constant, consider the clocks A and B, in such a way that for

$t = 0$ (in S_o) they have radius vectors $\vec{r}_A(0)$ and $\vec{r}_B(0)$ (in S_o)

During the rotation of the table (or the earth) the clocks A and B are moving with a variable velocity.

We have

$$\vec{v}(t) = \frac{d\vec{r}}{dt} = \frac{d\vec{r}_o}{dt} + \frac{d\delta\vec{r}}{dt}$$

$\vec{r}_o$ being the radius vector of the center of the table, or

$$\vec{v}_A(t) = \vec{v} + \delta\vec{v}_A(t); \quad \vec{v}_B(t) = \vec{v} + \delta\vec{v}_B(t) \tag{8}$$

Notice that $\delta\vec{v}$ is measured in the frame S_o, *not* in S.

The times registred by the clocks A and B and the time t in S_o are related by

$$T_{\substack{A\\B}}(t) = T_{\substack{A\\B}}(0) + \int_o^t dt\{1 - (\vec{v} + \delta\vec{v}_{\substack{A\\B}}(t))^2\}^{1/2}$$

$$= T_{\substack{A\\B}}(0) + t(1-v^2)^{1/2} - (1-v^2)^{-1/2}\vec{v}\cdot\int_o^t \delta\vec{v}_{\substack{A\\B}}(t)dt + 0(\delta\vec{v}^2_{\substack{A\\B}}) \tag{9}$$

Thus for very slow (clock) motions $(\delta\vec{v}_{\substack{A\\B}} \to 0)$

$$T_B - T_A = \Delta T - (1 - v^2)^{-1/2}\vec{v}\cdot\int_o^t [\delta\vec{v}_B(t) - \delta\vec{v}_A(t)]\,dt$$

Now

$$\vec{r}_{AB}(t) = \int_o^t (\delta\vec{v}_B - \delta\vec{v}_A)dt$$

and we have

$$T_B - T_A = \Delta T - (1 - v^2)^{-1/2} \vec{v} \cdot \vec{r}_{AB}(t) \tag{10}$$

which for $\Delta T = 0$ is identical[1] to eq(6).

Eq(10) shows that the relative phase of the clocks is not constant, contrary to the Kolen and Torr assumption. As the clocks A and B move to a new position they will be out of phase not by ΔT but by

$$\Delta T' = \Delta T - (1 - v^2)^{-1/2} d(t) \cos\theta(t) \tag{11}$$

Thus, even if they were synchronized at $t = 0$, with $\Delta T = 0$, they would be out of phase as the table (earth) rotates, according to S_o.

It is clear that

$$\vec{r}_{AB}(\theta) = -\vec{r}_{AB}(\theta + \pi) \tag{12}$$

where θ is the angle of rotation of the table. In the case of the Kolen-Torr proposal θ corresponds to situation (1), in Fig. 1, at $t = 0$, and $\theta + \pi$ corresponds to situation (2) in Fig. 1, at $t = t_o$.

---

1. The time phase shift for a clock moving with velocity $\vec{w}$ in the direction of $\vec{v}$ was first obtained by Ives (pages 5 - 15, in the second of Refs. 13). Although his computation is incorret (he took T instead of t in his eq(1)) the result $\vec{w} \to 0$ is corret.

We conclude that the right equations for the intervals of times registred by the interval counter are

$$\Delta T'_{A_1} = \Delta T + \gamma v d \cos\theta + \gamma d\,(\sqrt{1 - v^2 \sin^2\theta} - v\cos\theta)$$
$$\Delta T'_{A_2} = \Delta T - \gamma v d \cos\theta + \gamma d\,(\sqrt{1 - v^2 \sin^2\theta} + v\cos\theta) \qquad (13)$$

Then the difference of total time registrations of the counter is

$$\delta T' = \Delta T'_{A_1} - \Delta T'_{A_2} = 0 \qquad (14)$$

a null result.

3. GENERAL PROOF OF THIS AND SIMILAR RESULTS

We shall present here a general proof of this and similar results. For this we define two coordinates systems for moving frames (I) Ives - Marinov[13,14] coordinate system or I - M transformations

$$X = \gamma(x - vt); \quad Y = y; \quad Z = z$$
$$T = \gamma^{-1} t \qquad (15)$$

(II) Einstein - Lorentz coordinate system of E - L tranformations

$$x' = \gamma(x - vt); \quad y' = y; \quad z' = z$$
$$t' = \gamma(t - vx) \qquad (16)$$

We call eqs (15), the Ives - Marinov transformations since they are the natural ones from postulates (i), (ii), (iii) given in §1, which, as first recognized by Ives[13], were enough to explain all relativistic experiments proposed in his time[1]. These transformations have been recently introduced by Marinov[14].

The E-L transformations, were discovered by Einstein[15] and Lorentz[16][2]. It is important to quote here that Larmor[17] also arrived at the complete transformation in 1900[3]. But Lorentz, Larmor and also Poincaré[19] used the transformations as a mathematical tool without a clear understanding of its physical meaning.

These transformations (eqs(16)) result from assumptions (i) - (iv) in §1. Even if (iv) is found not to be valid for *any* internal synchronization procedure, as assumed by Einstein, the E - L transformations will remain as canonical transformations which retain the form of Maxwell equations, Einstein particle dynamics and Minkowski ds^2, being useful (at least) for analysis in the rest frame of experiments not involving coupled clocks(i.e., clocks which has been synchronized with a non-Lorentz invariant phenomenon. See §4).

It is essily seen that although $(x',y',z') = (X,Y,Z)$, it is t' and not T which gives the time of identical clocks synchronized at the origin and slowly (infinitesimally) displaced to the positions $\vec{r}$. This is the result expressed by eq(10) which also shows that slow transport of clocks and Einstein's method

---

1. The assumption $M = \gamma M_o$ is also needed. See pages 112-123 in the second of Refs.(13).

2. Lorentz obtained first the transformations valid in first order in v (see, first of the references (16)) and in 1904 obtained the transformation that is exact to all orders of the small quantity v (see, second of the references (16)).

3. See in this connection the interesting paper by C. Kittel[18].

(eq(4)) using electromagnetic radiation yield the same synchronization.

Therefore if the laws of Physics for a given phenomenon being investigated are invariant under E-L transformations (as is the case for experiments involving only electromagnetic phenomena) the analysis using E-L transformations will involve no effect of $\vec{v}$ relative to the preferential frame - in the sense of Einstein's Principle of Relativity[15].

If we use the Ives-Marinov transformations, which are not canonical, to study physical phenomena that are E-L invariant, new "ficticious" or coordinate effects (aberration, etc.) should be taken into account to correctly calculate the results in the moving frame - in the sense of the Poincaré's Principle of Relativity[19] - but we should be led again to negative results.

As long as the space-time, i.e., the collection of all possible events, is supposed to be a four-dimensional manifold, we can in principle use whatever coordinate transformations (belonging to the Manifold Mapping Group) we want. All that is necessary to bear in mind is that in general these non-canonical coordinates need not be directly related to the readings of standard rulers and clocks.

4. CONCLUSIONS

If in some domain of Physics the laws are not E-L invariant we might prepare an internal clock synchronization procedure (involving some of these phenomena) which may lead to experiments appropriate to detect absolute motion or failure of the Einstein Theory of Relativity. However, this theory should remain valid when no such phenomenon is involved, as seem to be the case with the field theories and particle dynamics with present-day energies.

Let us speculate briefly about one such experiment described recently by Marinov[11]. If his results are correct, he has proved that the laws involved in the Physics of rotating 'rigid' bodies (as metals) are not E-L invariant. This cannot come from electromagnetic interaction (as presently understood). Thus it should come from non-E-L invariance of many-body interactions and quantum effects. We do not know of any suggestion of an alternative coherent formulation of quantum theory with these properties.

We would like also to mention, a number of suggested experiments (and models) that might detect a possible violation of Einstein causality. They are related to the Einstein - Podolsky-Rosen problem[20] as the recent discovery by Aspect et al[21] of space - like correlations, the colapse of the wave function problem[22], as well as the problem of a minimum lenght[23] and time-interval[24], as in Blokhintsev proposed experiment[25] [see also in this connection references (26) and (27)]. Finally we mention the problems associated with finite space-time lattices[28].

ACKNOWLEDGEMENTS

We thank Prof. H. Brown for useful comments, and are also grateful to CNPq (Brasil) for a research grant.

REFERENCES

1. H. ERLICHSON, Am. J. Phys. 41, 1068(1973).

2. A. A. TYAPKIN, Lett. Nuovo Cimento, 7, 760(1973).

3. C. MOLLER, Suppl. Nuovo Cimento, 6, 381(1957).

4. J. P. CEDARHOLM, G. F. BLAND, B. L. HAVENS and C. H. TOWNES, Phys, Rev. Letters, 1, 342(1958).

5. C. MØLLER, Proc. Roy. Soc., A 270, 306(1966).

6. E. T. P. LEE and S. T. MA, Proc. Phys. Soc., 79, 446 (1962); L. Janossy, The Theory of Relativity Based on Physical Reality, Akademiai Kiado, Budapest (1971); V. Buonomano and J. E. Moore, Am. J. Phys, 42, 1021(1974); S. J. Prokhovnik, Found. of Phys., 10, 197(1980).

7. M. A. TONNELAT, Histoire du Principe de Relativité, Flammarion, Ed., Paris, (1971); J. D. Jackson, Classical Electrodynamics, J. Wiley, N. York (1975).

8. A. N. DOS SANTOS, Nuovo Cimento, 32 B, 519(1976).

9. D. G. TORR and P. KOLEN, Found. of Phys., 12, 265(1982).

10. P. KOLEN and D. G. TORR, Found. of Phys., 12, 401(1982).

11. S. MARINOV, Czech. J. Phys., B 24, 965(1974); Gen. Rel. Grav. 12, 57(1980).

12. W. A. RODRIGUES Jr. and V. BUONOMANO, Nuovo Cimento, 34 B, 240(1976).

13. H. E. IVES, J. O. S. A., 27, 263(1937); R. Hazellet and D. Turner (editors) "The Einstein Myth and the Ives Papers", The Devin-Adair Company Publ., Old Greenwhich, Connecticut (1970).

14. S. MARINOV, Int. Journ. Theor. Phys. 13, 189(1975).

15. A. EINSTEIN, Ann. der Physik, 17, (1905).

16. H. A. LORENTZ, Proc. Amst. Acad. (English edn), i, 427(1899); Proc. Amst. Acad. (English edn.) vi, 809(1904).

17. J. LARMOR, Aether and Matter, Cambridge Univ. Press, Cambridge (1900).

18. C. KITTEL, Am. J. Phys, 42, 726(1974).

19. H. POINCARÈ, Eletricité et Optique, edited by E. Néculcéa, Paris, Carré et Naud (1901); Rapports presèntés au Congrèss International de Physique réuni à Paris en 1900 (Paris, Gauthiers - Villars, 1900), Tome I, p. 1, at p. 21 - 22; Bull. des Sc. Math. (2) XXVIII (1904).

20. A. EINSTEIN, B. PODOLSKY, and N. ROSEN, Phys. Rev. 47, 777 (1935).

21. A. ASPECT, J. DALIBARD, G. ROGER, preprint Inst. d'Optique Théorique et Appliqué, B.P. 43, F 91406 Orsay-Cedex-France, July 82 - to appear in Phys. Rev. Lett.

22. T. TATI, Nuovo Cimento, 33B, 461(1976).

23. G. WATAGHIN, Zs. Phys. 88, 92(1934).

24. G. I. POKROWSKI, Zs. Phys. 51, 730(1928); 51, 737(1928).

25. D. I. BLOKHINTSEV, Phys. Lett, 12, 272(1964).

26. R. L. INGRAHAN, Renormalization Theory of Quantum Field Theory with a Cut - off, Gordan and Breach (1967).

27. W. A. RODRIGUES, Jr., Proc. of the 3rd Brasilian Nat.Conference on the Physics of Fields and Particles, p. 175 - 200, edited by Soc. Brasil. Física (1981).

28. A. ZEE, Phys. Rev. D25, 1864(1982).

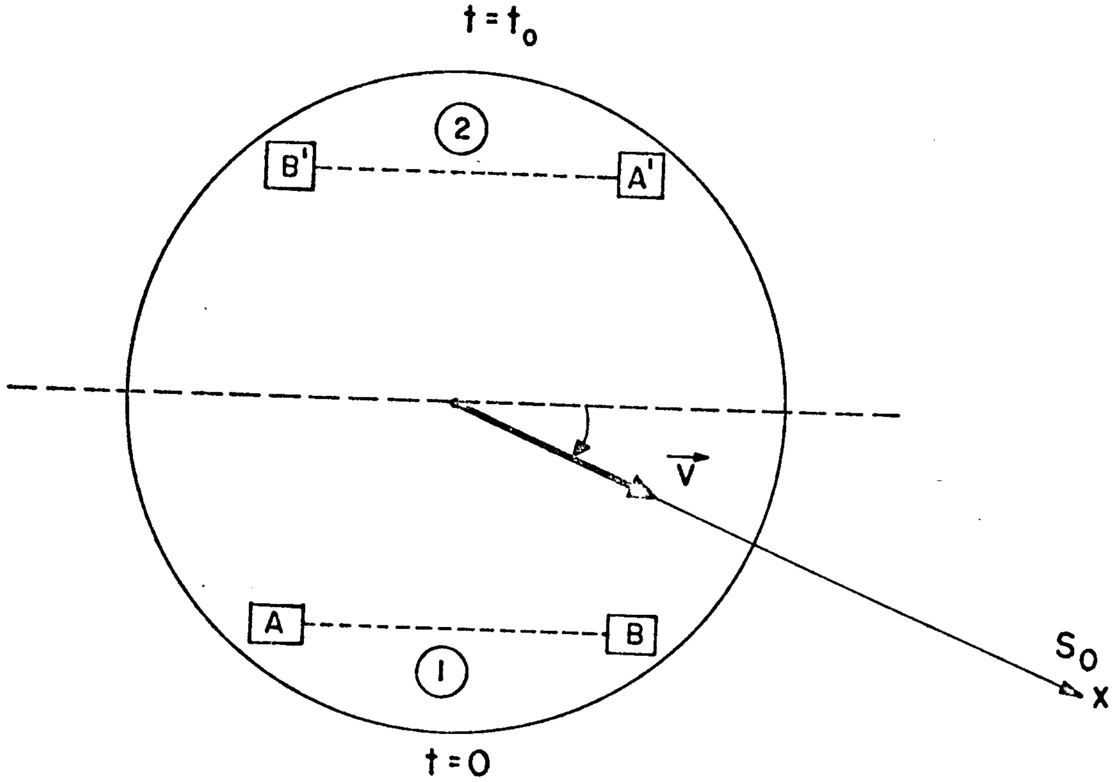

Fig. 1 Schematic View of the Experiment.

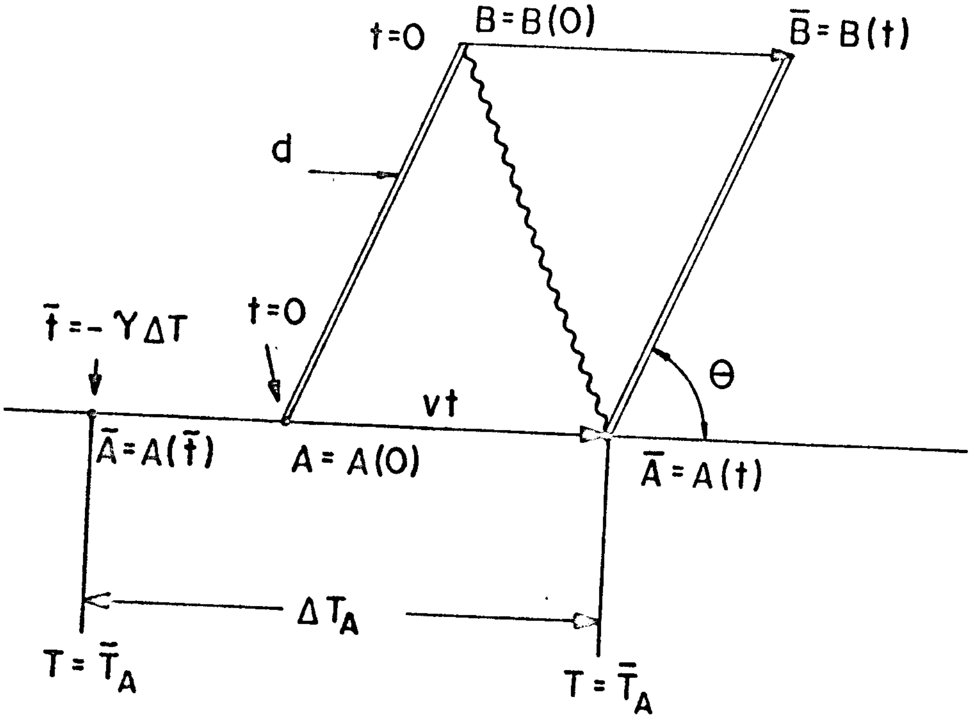

Fig. 2 Motion of the clocks relative to S_0