A New Experimental Test of Special Relativity.

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Summary. — Although the special theory of relativity is almost generally accepted as a verified theory, existing experiments cannot distinguish it from a number of other rival theories that assume the existence of a preferred frame of reference (ether), and physical Lorentz contractions. It is shown that the Michelson-Morley experiment, performed in a solid transparent medium, is capable of such a distinction. The negative result of this experiment enhances the experimental basis of special relativity.

1. – Introduction.

It is almost generally accepted that the special theory of relativity (STR) is fully verified experimentally. There are however a number of rival theories, based on the existence of a preferred frame of reference often called the « ether », that are also in agreement with existing experimental results. The present reason for singling out STR is, therefore, its elegance and relative simplicity, rather than its better agreement with experiment. One of these rival theories is the well-known Lorentz theory of the electron (1) (1904). IVES (2-4) (1937, 1945) also obtained the Lorentz transformation based on the existence of an ether. JÁNOSSY (5-7) (1962, 1963, 1966) on the other hand

(1) H. A. LORENTZ: *Procedings of the Academy of Sciences of Amsterdam*, vol. **6** (1904).
(2) H. E. IVES: *J.O.S.A.*, **27**, 263 (1937).
(3) H. E. IVES: *J.O.S.A.*, **27**, 310 (1937).
(4) H. E. IVES: *Phil. Mag.*, **36**, 392 (1945).
(5) L. JÁNOSSY: *Filozofiai Szemle*, **6**, 153 (1962).
(6) L. JÁNOSSY: *Acta Phys. Hung*, **17**, 421 (1963).
(7) L. JÁNOSSY: *Acta Phys. Hung*, **21**, 1 (1966).

constructs a theory where the absolute frame of reference is produced by gravitational fields and again obtains the Lorentz transformation. Recently, (1962) GORDON [8] also obtained the Lorentz transformation from a theory based on a preferred frame.

The discovery of the cosmic-microwave background radiation [9] makes the existence of a preferred reference frame even more of a possibility. In principle this radiation can serve as a reference frame since it should be possible to detect motion through it [10]. An observer moving through the black-body radiation in space will see different temperatures in different directions. We can define a preferred frame of reference as the frame in which the 3 °K black-body radiation is isotropic.

Because the cosmic background radiation brings new meaning to the notion of a preferred reference frame, experiments that might help to distinguish between STR and the rival theories mentioned above become imperative. We are interested in experiments that assume the Lorentz contraction as a physical process and are sensitive to the motion with respect to a possible « ether ». One such experiment was performed in (1937) by WOOD, TOMLINSON, and ESSEN [11]. The vibration period of a quartz rod was determined very accurately while it was being rotated in a horizontal plane. The constancy of the vibrating frequency indicated that a physical Lorentz contraction is unlikely, although not excluded.

We performed a second experiment that distinguishes between STR and the rival theories, based directly on the propagation of light, which is reported here.

The Michelson-Morley experiment (MME) did not yield a strictly zero result [12]. The nonzero result might have been real and due to the fact that the experiment was performed in air and not in vacuum. The effect of the lengthened optical path due to the presence of air, in contrast to vacuum, would not be cancelled by a physical Lorentz contraction. The MME would then yield a zero result only if performed in vacuum. We performed the MME in a solid transparent medium which would enhance the possible effect of the refractive index.

In Sect. **2** we analyse the MME when performed in a solid transparent medium. In Sect. **3**, we describe the experiment while the measurements, results and conclusions are presented in Sect. **4**.

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(8) C. N. GORDON: *Proc. Phys. Soc.*, **80**, 569 (1962).

(9) R. B. PARTRIDGE and D. T. WILKINSON: *Phys. Rev. Lett.*, **18**, 557 (1967); and references there.

(10) C. V. HEER: *Phys. Rev.*, **144**, 1611 (1968).

(11) A. B. WOOD, G. A. TOMLINSON and L. ESSEN: *Proc. Roy. Soc.*, **158**, 606 (1937).

(12) A. A. MICHELSON: *Studies in Optics* (Chicago, 1927).

2. – Analysis of the experiment.

We make three assumptions here which are included in most of the rival theories to STR:

a) There exists a preferred frame of reference (« ether ») with respect to which we can (in principle, at least) measure velocities and accelerations.

b) The Lorentz contraction of length is a real physical process.

c) The Fresnel drag coefficient is given exactly by

$$b = 1 - \frac{1}{n^2}, \tag{1}$$

where n is the refractive index of a transparent material.

Assumptions a) and b) are always needed in order to ensure a negative result of the MME. Assumption c) is usually dealt with only for the special case when light travels parallel to the direction of motion of the transparent medium. Assumption c) is known very accurately by experiment [13]. The result of assumption c) is that if a light ray travels through a transparent moving medium, in any direction, it is dragged along in the direction of the motion with a velocity

$$\Delta \boldsymbol{v} = \boldsymbol{v} b, \tag{2}$$

where $\boldsymbol{v}$ is the velocity of the transparent medium through the ether.

We analyse the MME performed in a transparent medium on the basis of these three assumptions, describing the experiment as seen by an observer stationary with respect to the ether. An observer moving with the system (laboratory frame) observes the same final measured effect which is a permanent record of the fringe shift.

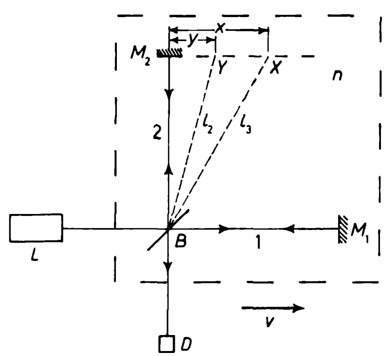

Fig. 1. – Diagram of experiment. L, laser; B, beam splitter; M_1 and M_2, mirrors; D, detecting system.

Figure 1 describes the experiment. An observer stationary with respect to the ether sees a Michelson interferometer immersed in a transparent medium of index n moving to the right with a velocity v. Assume the interferometer arms are each of length l, as measured when stationary with respect to the

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([13]) W. M. Macek, J. R. Schneider and R. M. Solomon: *Journ. Appl. Phys.*, **35**, 2556 (1964).

ether. We wish to calculate the transit times of a light ray in each arm in the moving system. The length of arm 1 in Fig. 1 is contracted by the Lorentz contraction:

$$l_1 = l(1-\beta^2)^{\frac{1}{2}}\,, \qquad (\beta = v/c)\,, \tag{3}$$

where c is the vacuum velocity of light. The velocity of light in this arm is

$$u_\pm = \frac{c}{n} \pm vb\,. \tag{4}$$

Here we used eq. (2); the (+) sign referring to the velocity parallel to v while (—) to the velocity antiparallel to v.

During the light transit, mirror M_1 and beam splitter B move to the right, so that the light travels distances

$$l_\pm = l_1 \pm vt_\pm\,, \tag{5}$$

where $t_\pm$ refers to the respective transit times in the two directions. Multiplication of eq. (4) by $t_\pm$ yields the distance $l_\pm$. We thus obtain

$$\left(\frac{c}{n} \pm vb\right) t_\pm = l_1 \pm vt_\pm\,, \tag{6}$$

or using eq. (1)

$$t_\pm = l\,\frac{(1-\beta^2)^{\frac{1}{2}}}{c/n \mp v/n^2}\,. \tag{7}$$

The overall transit time through arm 1 is given by

$$t_1 = t_+ + t_- = \frac{2ln}{c}\,\frac{(1-\beta^2)^{\frac{1}{2}}}{1-\beta^2/n^2}\,. \tag{8}$$

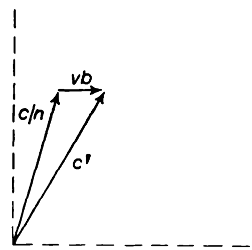

Fig. 2. – Demonstration of the dragging effect.

The length of arm 2, l, is not Lorentz-contracted due to the motion. However, during the time of the light transit, mirror M_2 moves to the point X, where

$$X = vt \tag{9}$$

(t is the transit time of the light from B to M_2).

The light ray striking M_2 at X, has thus travelled a distance l_3. From Fig. 2, we see that the velocity along l_3 has two components. One is the drag velocity directed to the right with magnitude vb; the second has a magnitude c/n. Then we have

$$\mathbf{c}' = \mathbf{c}/n + \mathbf{v}b\,. \tag{10}$$

Multiplying this equation by t we obtain the relation between the distances l_2, l_3 and $(x-y)$ that appear in Fig. 1:

$$l_3 = l_2 + (x-y)\,. \tag{11}$$

Using eq. (1), we can express y by

$$y = vt - vbt = \frac{v}{n^2}\,t\,. \tag{12}$$

Again, from Fig. 1

$$l_2^2 = l^2 + y^2\,,$$

or

$$\left(\frac{c}{n}\,t\right)^2 = l^2 + \left(\frac{v}{n^2}\,t\right)^2. \tag{13}$$

We obtain then that the overall transit time through arm 2 is

$$t_2 = 2t = \frac{2ln}{c(1-\beta^2/n^2)^{\frac{1}{2}}}\,. \tag{14}$$

The difference in transit times between the two arms is given by

$$\Delta t = t_2 - t_1 = \frac{2ln}{c}\left(\frac{1}{(1-\beta^2/n^2)^{\frac{1}{2}}} - \frac{(1-\beta^2)^{\frac{1}{2}}}{1-\beta^2/n^2}\right). \tag{15}$$

Expanding and retaining only terms of second order in β we have

$$\Delta t \approx \frac{ln\beta^2}{c}\left(1-\frac{1}{n^2}\right) = \frac{lnb}{c}\,\beta^2\,. \tag{16}$$

If the frequency of light is ν and its wave length in vacuum λ, the phase difference of the two beams will be

$$\delta = \nu\,\Delta t = \frac{l}{\lambda}\,nb\beta^2\,. \tag{17}$$

A rotation of 90° will interchange arms 1 and 2, but will not affect the frequency ν of the light source [a laser] due to our assumption that the MME gives a negative result in vacuum. We thus have for the total observed fringe shift for a 90° rotation of the system,

$$\varDelta = 2\delta = 2\,\frac{l}{\lambda}\,nb\beta^2\,. \tag{18}$$

3. – The experimental system.

The Michelson-interferometer arms consisted of perspex rods, and the light source was a He-Ne laser. For sensitive detection of fringe shifts, the fringes were projected onto a pair of photoresistors that consisted of two arms of a Wheatstone bridge. Such a set-up is capable of measuring fringe shifts with a sensitivity up to 10^{-5} fringe ([14]). The whole system rested on a heavy turntable (about 3.5 t), which floated on mercury.

The output of the fringe-sensing system was connected to the y-input of an xy recorder, the x input being a voltage proportional to the sine of the angle of rotation of the table.

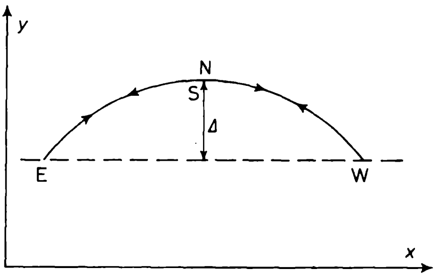

Fig. 3. – Idealized recorder trace.

A positive result would have appear ed on the xy recorder as shown in Fig. 3. The Figure represents the trace going from East, North, West, South and back again to East, the total fringe shift being Δ. The effect is a second-order one (there should be no difference between East and West, nor between North and South), thus the line EW should be horizontal and the lines ENW and WSE should coincide.

4. – Measurements, results and conclusions.

In our measurements, the line EW was not exactly horizontal, indicating a drift during the measurement. This shift was isolated as thermal. It was small and not bothersome since we measured directly with respect to the line EW. The more bothersome difficulty was the first-order effect of the lines ENW and WSE not exactly coinciding (S and N lay on different sides of the EW line). After much investigation this effect could only be attributed to strains induced in the table by the earth's magnetic field. The effect decreased when a magnetic shield was used.

The magnetic field effect was the limiting factor in the accuracy attainable by the system. The fringe-sensing system operated at a sensitivity of 3000 mm/fringe. The final experimental result was a Δ (see Fig. 3) measured to be less than one mm.

Thus,

$$\Delta < \frac{1}{3000}\,\text{fringe}\,. \tag{19}$$

From this we can place an upper limit to the velocity of the earth through the ether. Using eq. (18), we obtain

$$\beta^2 = \frac{\Delta\lambda}{2ln(1-1/n^2)}\,. \tag{20}$$

([14]) J. Shamir, R. Fox and S. G. Lipson: *Appl. Opt.*, **8**, 103 (1969).

Substituting the values of Δ, λ, l and n in this experiment

$$\Delta = \frac{1}{3000}\,, \quad \lambda = 6330\ \text{Å}\,, \qquad l = 26\ \text{cm}\,, \qquad n = 1.49\,,$$

we obtain

$$\beta^2 \leqslant 4.95 \cdot 10^{-10}\,, \tag{21}$$

or

$$v \leqslant 6.64\ \text{km/s}\,. \tag{22}$$

The upper limit to the velocity of the earth through the ether (6.64 km/s) that was obtained in this experiment is much less than the orbital velocity of the earth around the sun (about 30 km/s). The experimental basis of special relativity is thus enhanced by this negative result.

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We wish to thank N. ROSEN for several helpful comments, and M. ALBAHARI for fruitful discussions which helped to initiate the present experiment.

RIASSUNTO (*)

Sebbene la teoria della relatività ristretta sia quasi generalmente accettata come una teoria verificata, gli esperimenti esistenti non possono distinguerla da un certo numero di altre teorie rivali che suppongono l'esistenza di un sistema di riferimento privilegiato (etere), e le contrazioni fisiche di Lorentz. Si dimostra che l'esperimento di Michelson e Morley, realizzato in un mezzo solido trasparente, rende possibile una tale distinzione. Il risultato negativo di questo esperimento migliora la base sperimentale della relatività ristretta.

(*) *Traduzione a cura della Redazione.*

Новая экспериментальная проверка специальной теории относительности.

Резюме (*). — Хотя специальная теория относительности является почти общепринятой, как проверенная теория, существующие эксперименты не могут различить ее от ряда других альтернативных теорий, которые предполагают существование выделенной системы отсчета (эфир) и физических сокращений Лорентца. Показывается, что эксперимент Михельсона-Морлеи, выполненный в твердой прозрачной среде дает возможность для такого различия. Отрицательный результат этого эксперимента усиливает экспериментальную основу специальной теории относительности.

(*) *Переведено редакцией.*

IL NUOVO CIMENTO

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SOMMARIO
DI QUESTO FASCICOLO