On the Trail of Fresnel's Search for an Ether Wind

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A recollection is presented of the experiment in which Fizeau, back in 1851, proved how the velocity of light propagation in moving water varies. In this experiment he has also verified that such variation is in accordance with the equation proposed by Fresnel in 1818. Reference is made to how since then numerous experimental verifications have given to that equation the extraordinary importance that it has still today. The work in which Fresnel presents his ether partial-dragging hypothesis is recalled. His equation is based on this hypothesis. The relativistic interpretation of that equation is summarised.

An alternative model of the refraction mechanism is proposed based on the scattering concept of light radiation by atoms. The effect of the body movement aberration on that scattering model is also presented. The model is applied to Fizeau and Michelson experiments, which made it possible to conclude that the precision of the latter was not enough to detect the ether wind. Reference is made to the Shamir and Fox experiment (1969) in which a 6.64 km/s velocity was detected, *i.e.*, about 22% of the orbital velocity of earth (30 km/s). Nevertheless, the very authors and other relativity theory specialists have considered such result as negative.

Therefore, two experiments are suggested, which are likely to contribute to enlighten the problem: the first is similar to Shamir and Fox's. In this experiment, the optical fiber reels replace the apparatus arms. The second is an attempt to detect the ether wind by means of the variation of the refraction index, provided that the measurement of that index is likely to be done with a 10-4 precision.

"L'importance du postulat de la constance de la vitesse de la lumière dans le vide, quel que soit le systeme de reference inertial choisi, est telle que toute vérification directe est toujours hautement souhaitable." (Tonnelat, 1971)

1 – Introduction

In 1851, Fizeau (1) performed his crucial experiment aiming at verifying the main hypotheses that were at the time proposed as regards the ether behaviour, which was assumed to exist inside moving bodies. Such hypotheses could be summarised as follows:

- Whether the ether adheres to the body molecules and shares therefore all movements induced to the bodies;
- Or the ether is free and independent and the body does not drag it;
- Or, lastly, the Fresnel's hypothesis, in which a part of the ether is free and only the other part adheres to the body molecules, being dragged with it in its movement (1).

The predictions based on Fresnel's hypothesis have been confirmed by the experiment referred to previously. Nevertheless, this hypothesis seemed so extraordinary and hard to admit to Fizeau that

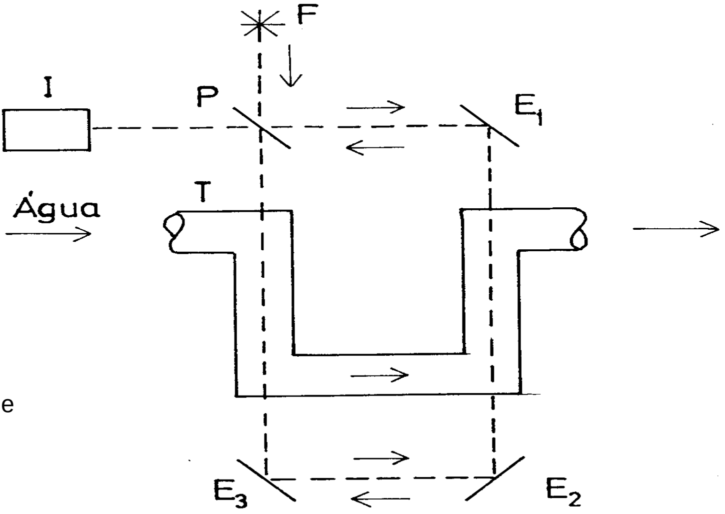

Fig. 2.1 – Fizeau's experiment scheme

he considered that other tests and a thorough examination should be carried out before adopting it as an effective expression of the reality of things (1).

Many subsequent experiments have been performed, which have proved the Fizeau experiment and which have therefore confirmed the Fresnel's equation. Nevertheless, the hypothesis on which it is based is still nowadays regarded with scepticism (2).

With the advent of the theory of relativity, at the beginning of this century, the interpretation of such experiments became possible to achieve without the partial ether-dragging hypothesis, disregarding even the ether concept. This has been however accomplished based on postulates involving fundamental concepts of space and time that were mistrusted by some of his illustrious contemporaries, such as Poincaré and Lorentz (2) and which remain still today as a source of paradox (3 and 4);

Thus, it seems legitimate to ask: has the non-relativistic interpretation of the experiences referred to previously been exhausted? In other words: has the problem been sufficiently studied as Fizeau had appealed a century and half ago?

Considering that the problem is not a closed subject, a contribution to its study is presented below.

2 – Fizeau's Experiment

Fig. 2.1 shows a schematic presentation of Fizeau's experiment. The interference of two luminous beams crossing equal paths but in different senses through moving water is observed using an interferometer (I).

Light emitted by source F is divided in two beams by a semitransparent plate P: one, reflected by mirrors E1, E2 and E3, crosses pipe T with water returning to plate P; the other is transmitted in a reverse sense (E3, E2, E1) and returns also to plate P (1).

The luminous beams go through water in two situations: with immobile water and with it moving at a velocity of 7.069 m/s. From the displacement of the interference fringes, Fizeau observed that there was an alteration of the velocity of light according to Fresnel hypothesis.

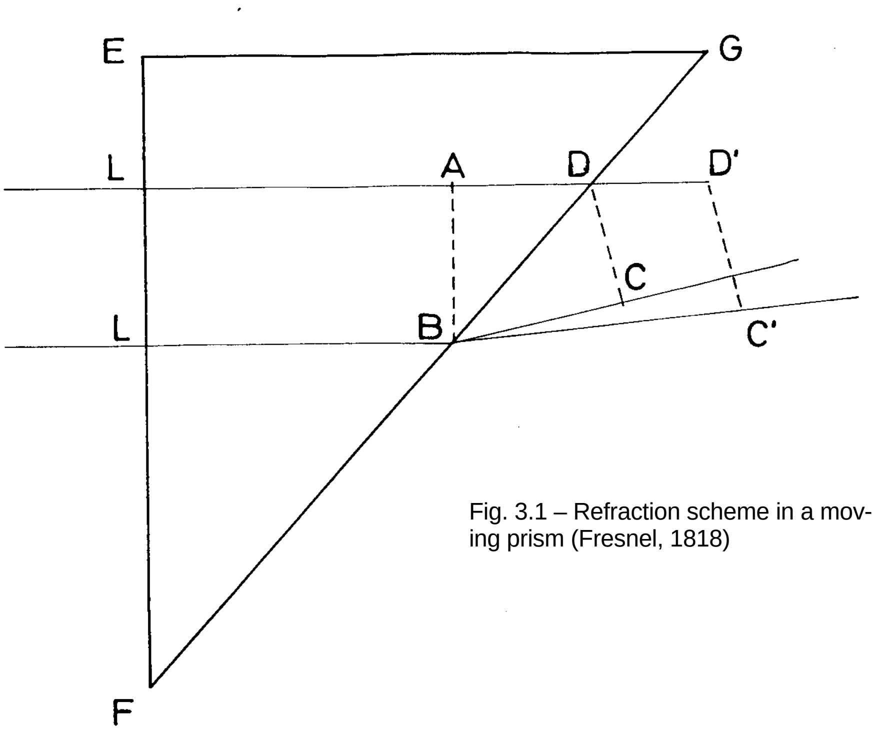

Fig. 3.1 – Refraction scheme in a moving prism (Fresnel, 1818)

3 – Fresnel's Partial Ether Drag

In his letter addressed to Arago (5), Fresnel explained how he deduced his equation:

EFG (Fig.3.1) being a prism whose face EF is assumed as normal to the ecliptic and to striking beams, which are thus in the direction of the earth movement and if it is possible to influence their refraction, this will be the case in which such influence is to be more significant. Light is then assumed to propagate in the same direction as the prism.

The beams being normal to the entrance face, they are not submitted to any refraction this side of the prism. Therefore, only the effect on the second face is to be considered. LD and LB being two of those beams that find the exit face in points D and B; BC being the path followed by the LB beam when leaving the prism, on the condition that it is immobile and if a perpendicular line is drawn from point D down to the emergent beam; and if from point B, BA is normally drawn to the incident beams, then, light should go through AD and BC at the same time. This is thus the law that dictates the direction of the refracted wave DC.

But if the prism is dragged by the earth movement while light goes through the interval AD, then the point B moves. Thus, when the difference in the paths followed in the glass by the two beams CD and LB is increased, a variation in the refraction angle is expected to occur.

By considering that FG represents the position of the emerging face and that D' is the point in which the beam AD strikes that face when the striking wave reaches AB; considering that BC' is the new direction of the refracted beams, then the normal D'C' is to represent the emerging wave that should satisfy the general condition that AD' should be crossed at the same time as BC'. In order to determine the length relations between these two intervals it is necessary to estimate the variation that the prism movement determines in the velocity of the light waves that go through it.

If the prism drags with it all the ether it contains, the whole medium that acts as a vehicle for the waves would share therefore the earth movement. Consequently, the velocity of the light waves should be the one they were expected to have in an immobile medium, plus the earth movement. Nevertheless, the present case is more complicate: just a part of that medium is dragged by earth, which is precisely the one consisting of the part exceeding its density over the envelope ether.

The analogy indicates that, since it is only a part that moves, only the velocity of the gravity centre of the system should be added to the velocity of wave propagation.

Thus, by considering that the light delay through the prism, when immobile, results only from a higher density, then, it is possible to determine the relation of the density of the two media, because it is known that it should be the inverse of the squares of the velocity of wave propagation. By considering that d and d' are the wavelengths of the light in the ether medium and in the prism, and that Δ and Δ' are the densities of those two media, it is possible to obtain the proportion $d^2{:}d'^2 = \Delta'{:}\Delta$, thus $\Delta' = \Delta(d^2/d'^2)$ and therefore $\Delta' - \Delta = \Delta(d^2 - d'^2)/d'2$. This is the density of the mobile part of the prismatic medium. By considering that t represents the space travelled by earth during a light oscillation, either the displacement of the gravity centre of this medium during the same interval, which is assumed as the unit, or the velocity of that gravity centre will be $t(d^2 - d'^2)/d^2$. Consequently, the wavelength d' in the prism dragged by earth will be equal to $d' + t(d^2 - d'^2)/d^2$.

By calculating with the help of that expression the space AD', travelled by the beam AD, before leaving the prism, then, the direction of the refracted beam BC' can be easily determined. By comparing it with the beam BC, in the case of the immobile prism, and, disregarding all the terms multiplied by their squares and higher powers due to the insignificance of t, one can find the following expression for the sine of CBC'

$$\frac{t}{d}\cdot \sin i \cos i - \frac{t}{dd'}\sin i\sqrt{d'^2 - d^2 \sin^2 i}$$

in which i represents the incidence angle ABD (5).

Thus, Fresnel deduced his famous equation:

$$w' = w + v\left(1 - \frac{1}{n^2}\right) \qquad 3.1$$

where w is the velocity of the light propagation in the immobile body, w' the same, in a body moving with velocity v, n the body's refraction index ($n = c/w$), c is the velocity of light in vacuum.

4 – Relativistic Interpretation

According to Relativity Theory, the Lorentz transformation should be used in the composition of velocity v and w instead of Galileo's (6). Galileo's transformation referring to a referential (O'X'Y'Z') that moves at a uniform velocity v in relation to another (OXYZ) is given by

$$x' = x - vt, \quad y' = y, \quad z' = z, \quad t' = t \qquad 4.1$$

From which, as $x' = wt'$; $x = w't$; $t = t'$ we deduce

$$w' = w + v \qquad 4.2$$

The Lorentz transformations are:

$$x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}}\,, y' \text{-}\, y,\, z' - z,\; t' = \frac{t - \frac{v}{c^2}x}{\sqrt{1 - \frac{v^2}{c^2}}}\,, \qquad 4.3$$

From which is deduced

$$x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{t - \frac{v}{c^2}x}{\sqrt{1 - \frac{v}{c^2}}}$$

And, as $x = w't$, one has

$$w' - v = w\left(1 - \frac{v}{c^2}w'\right)$$

From which

$$w' = \frac{w + v}{1 + \frac{vw}{c^2}} \qquad 4.4$$

According to Einstein (6), since $\frac{vw}{c^2} << 1$, Eq. 4.4 may be replaced by

$$w' = (w + v)\left(1 - \frac{vw}{c^2}\right)$$

From which

$$w' = w + v - \frac{v^2 w}{c^2} - \frac{vw^2}{c^2}$$

and as $\frac{v^2 w}{c^2} \cong o$,

$$w^{'} = w + v - \frac{vw^2}{c^2} = w + v\left(1 - \frac{1}{n^2}\right)$$

which is Eq. 3.1. This equality of results, to minus terms higher than v^2/c^2 obtained from Fresnel equation and from Lorentz Transformation has been also demonstrated by Abreu Faro (1992), directly from the two Einstein's postulates: in any inertial referential, natural phenomena occur in identical ways (1st.); the velocity of propagation of light in the vacuum is constant (2nd.).

5 – An Alternative Model for the Refraction Mechanism

It is still considered as feasible to deduce the Fresnel equation from the Wave Theory. This is to be achieved by resorting not to the ether partial dragging theory, but rather to a model of the refraction mechanism that consists basically in assuming, as a first approach, the hypothesis that light follows a zigzag trajectory inside refracting bodies, as Fig. 5.1 shows.

As is generally assumed, such model does not contradict Huygens' principle (1690). According to this principle each ether point reached by the light excitement may be considered as the centre of a new spherical wave (6). Nevertheless, mention should be made of the fact that inside the refracting bodies light goes around their composition atoms as if these atoms were points reached by the light excitement, but with the particularity of only emitting light through a solid angle 2α, α being = arc

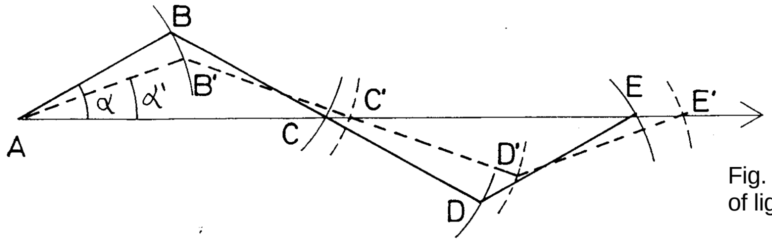

Fig. 5.1 – Zigzag trajectory of light.

cos 1/*n*. It also seems that this model is well adjusted to the light radiation scattering phenomena by means of the atoms (or molecules) of the bodies (7).

Let us assume (Fig. 5.1) that as a result of the scattering effect, light follows a zigzag trajectory ABCDE, characterised by the scattering angle α formed by the sides of that trajectory with the propagation direction. The velocity of propagation of light along each zigzag side is constant and equal to the velocity c of light in the vacuum. If *t* is the time spent by light to travel through one of these sides AB with a length *ct* (Fig. 5.2), the velocity *w* according to the propagation direction will be such that

$$\frac{w}{c} = \cos\alpha = \frac{1}{n} \tag{5.1}$$

If the body is animated with velocity *v*, the scattering angle, by an aberration effect, goes from α to α'. For the light that continues travelling with the velocity *c*, everything happens as if it was another material, with a different refraction index *n'* given by

$$\frac{w'}{c} = \cos\alpha' = \frac{1}{n'} \tag{5.2}$$

the new scattering angle being given by

$$tg\alpha' = \frac{c sen\alpha}{c\cos\alpha + v} \tag{5.3}$$

The new zigzag trajectory will then be AB'C'D'E' (Fig. 5.1).

The difference of velocities will be given by

$$w' - w = c(\cos\alpha' - \cos\alpha) \tag{5.4}$$

and as Fig. 5.3 shows, this value is almost the same as in Fresnel equation (Eq. 3.1).

In fact, for low values of *v/c*, BB' = BQ can be considered. Thus, by taking *t* = 1, the following

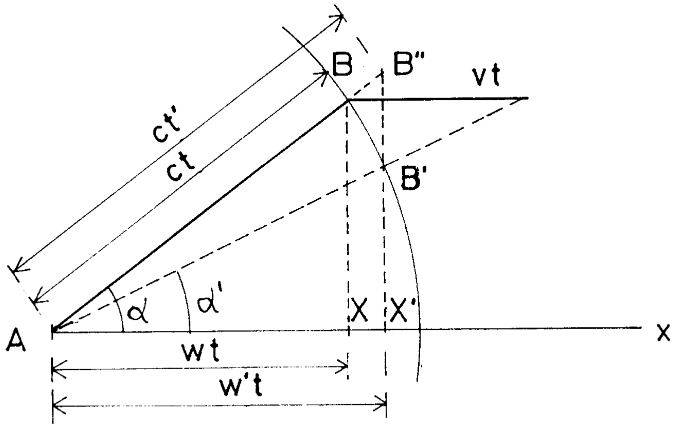

Fig. 5.2 – By the aberration effect due to velocity *v*, the scattering angle changes from α to α'.

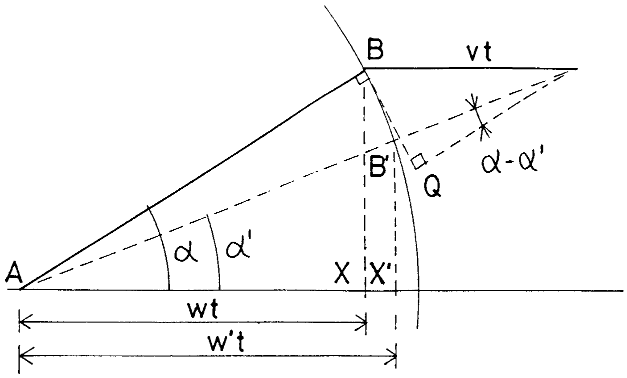

Fig. 5.3 – For very small *v/c*, BQ = BB'. Therefore, *w'* – *w* given by Fresnel equation is almost the same as the one given by Eq. 5.4.

equation will be obtained

$$w'-w = xx' = BQsen\alpha = vsen^2\alpha = v\left(1-\frac{1}{n^2}\right)$$

As Fig. 5.2 shows, the same result is also obtained if the effect of the velocity *v*, instead of changing the scattering angle from α to α', it changes the time of *t* into *t'*. Therefore, the length AB", higher than AB, would be travelled with the same velocity *c*.

It can be deduced from that figure that

$$\frac{t'}{t}=\frac{w'}{w}=\frac{\cos\alpha'}{\cos\alpha}$$

By putting cos α' in function of tg α' and by taking into consideration that $t_g\alpha' = \frac{csen\alpha}{w+v}$, it can be deduced

$$w' = \frac{w+v}{\sqrt{1+2\frac{wv}{c^2}+\frac{v^2}{c^2}}}$$

On the other hand, Eq. 4.4 of the Relativity Theory can be written as

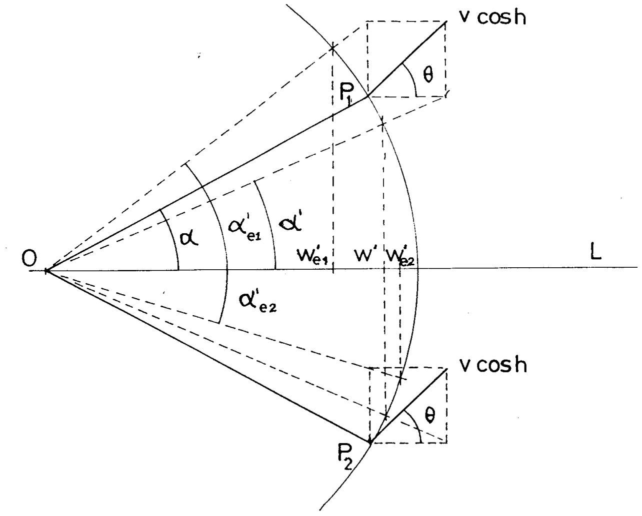

Fig. 5.4 – General case of the velocity *v* of the body that is not parallel to the direction OL of light propagation

$$w'_E = \frac{w+v}{1+2\frac{wv}{c^2}+\frac{1}{n^2}\frac{v^2}{c^2}}$$

As can be seen, for n close to the unity, it will be $w'E = w'$.

Fig. 5.4 shows an overview of the problem referring to the case of velocity v of the body that is not parallel to the direction OL of light propagation. The angular co-ordinates θ and h formed by v with a reference plan defined in the figure by OL and by a given beam OP_1 of the scattering cone should then be considered. In this case, in which there is birefringence, the problem for the ordinary beam is reduced to the previous case by replacing v in Eq. 5.3 by the component $v.\cos h.\cos \theta$. It is thus obtained

$$tg\alpha' = \frac{c sen\alpha}{c\cos\alpha + \upsilon\cdot\cosh\cdot\cos\theta} \qquad 5.5$$

The other two components $v.\cos h.\sin \theta$, at the same plane and $v.\sin h$, normal to that plan, both being orthogonal to OL light propagation, correspond to extraordinary beams. Fig. 5.4 indicates the angles α'_{e1} and α'_{e2} as well as the velocities w'_{e1} and w'_{e2} corresponding to the first of the orthogonal components referred to previously.

Mention should be made of the fact that only the ordinary beam follows the refraction laws.

6 – Application of the Model to the Fizeau Experiment

The refraction index of the water being $n = 1.333$, Eq. 5.1 gives as light velocity in water, when immobile, $w = 225{,}056{,}3$ km/s. Nevertheless, according to Eq. 5.2 and 5.3, in the case of water animated with velocity $v = 7.069$ m/s, as in Fizeau experiment (1), that velocity increases $w'F - w = 3.091$ m/s.

In accordance with Fresnel Eq. 3.1 there can be also obtained $w'F - w = 3.091$ m/s. According to Einstein's Eq. 4.4 that increase is slightly lower: $w'F - w = 3.090$ m/s.

7 – Application of the Model to the Michelson Experiment

With the purpose of detecting ether wind, Michelson and Morley (1887) performed the experiment schematised in Fig. 7.1.

Light emitted by a source F is divided into two beams by means of a semitransparent plate P. One of the beams follows the path FPE_1P, of a length double than l, the other follows the path FPE_2P, of the same length. Subsequently, both of them continue towards the interferometers I, in which, by means of the displacement of the interference fringes, it is possible to measure the difference between the corresponding optical paths (8).

By assuming that the ether is immobile; that the velocity c of light is equal in all the directions; and, that due to the effect of orbital velocity v of earth, both velocities c and v are composed according to Galileo's transformation, then the difference $\Delta t = t_1 - t_2$ between the time travels of the two light beams can be calculated.

By orienting one of the device arms in parallel to the orbital velocity of the earth, the following equation can be deduced (8)

$$\Delta t = \frac{l}{c}\frac{v^2}{c^2} \qquad 7.1$$

Thus, c being = 300.000 km/s, v = 30 km/s and l = 30m, one obtains $\Delta t = 10^{-15}$s.

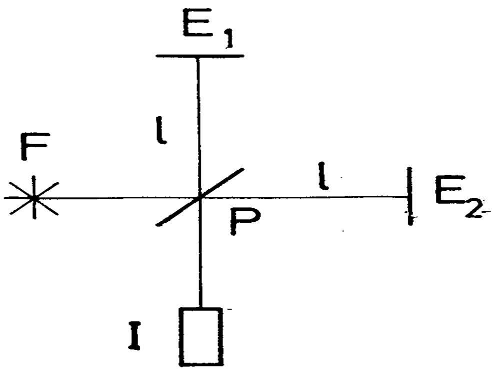

Fig. 7.1 – Scheme of the device used in Michelson experiment

The yellow light used in the experiment ($\lambda = 6.10^{-5}$ cm) had a period of 2.10^{-15}s (8). Even though it was considered that with such a device, time differences of 10^{-15} could be detected, the result of the experiment was negative.

According to the model proposed, by assuming that the arm PE_1 forms an angle θ with the orbital velocity, then, the propagation time of that arm would be in a first approach,

$$t_1 = l\left(\frac{1}{w'_\theta} + \frac{1}{w'_{\theta+180}}\right) \qquad 7.2$$

and in arm PE_2

$$t_2 = l\left(\frac{1}{w'_{\theta+90}} + \frac{1}{w'_{\theta+270}}\right)$$

The refraction index of the air being $n = 1.0003$, and 1 = 30m, the difference Δt was calculated. Fig. 7.2 shows its variation with θ. As can be seen, when one of the arms is parallel to the orbital velocity, as in Michelson's experiment, a difference of time travel of $\Delta t = 2.10^{-18}$s would occur. This difference was so small that it was not detected in the experiment. Fig. 7.2 shows that if the arms are 45° oriented in relation to orbital velocity, the difference Δt will be null.

8 – Shamir and Fox Experiment

Shamir and Fox (9) performed in 1969 an experiment similar to that of Michelson but with a very significant difference: light propagation in the device arms was not accomplished through the air, it was instead accomplished through perspex rods with a refraction index $n = 1.49$. By using 0.26 m arms and a wavelength light of $\lambda = 6330$ A, the following time travel difference between

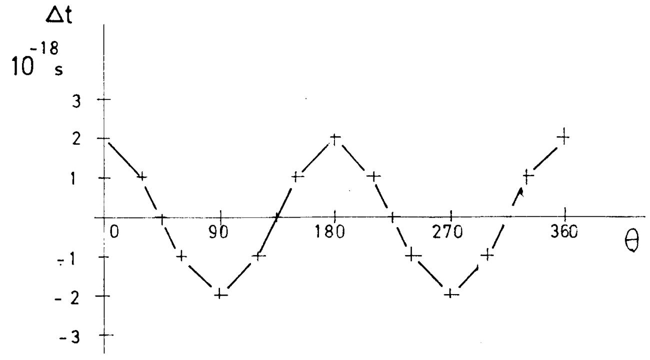

Fig. 7.2 – Time travel difference Δ t in relation to the device θ orientation.

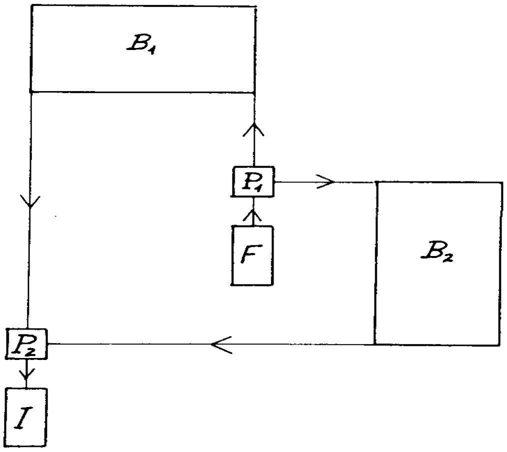

Fig. 9.1 – Experiment similar to Shamir and Fox's, in which the arms are replaced by optical fiber reels.

arms 2 and 1 was detected:

$$\Delta t = t_2 - t_1 = \frac{1}{3000} \times \frac{\lambda}{2c} = 3{,}5 \times 10^{-19}\,\mathrm{s} \qquad 8.1$$

According to the very authors this difference corresponded to a velocity of 6.64 km/s through the ether, *i.e.*, about 22% of the orbital velocity of the earth (30km/s). The authors of the experiment have nevertheless considered that this result is "much less than the orbital velocity of the earth around the sun…," they concluded that "the experimental basis of special relativity is thus enhanced by this negative result. " Besides, this is also the conclusion obtained by Möhler (10) from that experiment.

9 – Two Experiments to Detect Ether Wind

Since it has been considered that more experimentation is required for enlightening the problem, two experiments are suggested below. The first is similar to the Shamir and Fox experiment. Fig. 9.1 shows a schematic presentation of this experiment, which consists of the following:

The light beam emitted by source F is conducted by means of an optical fiber to the semitransparent plate P_1 where it is divided in two: one of them continues until the optical fiber reel B_1, the other proceeds to the optical fiber reel B_2. The beams after exiting these reels are collected in a semitransparent plate P_2; subsequently they leave that plate and move towards the interferometer I.

The diameter d of the reels multiplied by the number N of the spires corresponds to length l of the arms of the previous experiments:

$$l = N \cdot d \qquad 9.1$$

For instance, with an optical fiber having a refraction index N=1,45, in reels with a diameter $d = 1$ m with one hundred spires ($N = 100$), differences of time travel of approximately 10-14 would be obtained according to the model. This is completely within the precision range of the interferometer.

The second experiment is based on the measurement of the refraction index. For regions with a latitude around 40ºN, in September, approximately at the Autumn Equinox, the azimuth θ and the height h above the horizon of orbital velocity v are those indicated in Fig. 8.1.

At sunrise, the orbital velocity v is parallel to the local meridian ($\theta = 0$) and forms with direction N, indicated by the straight line ON_1, the angle

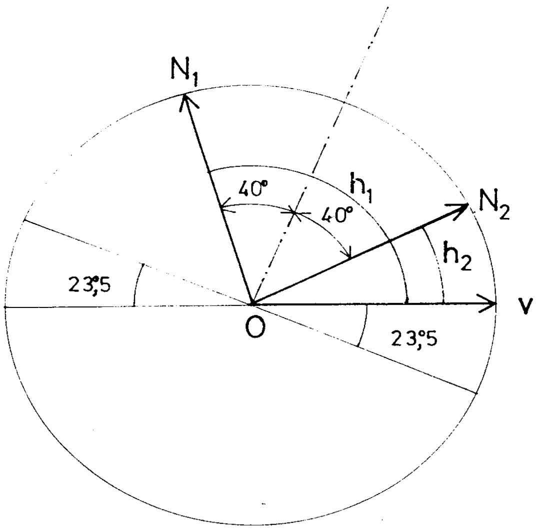

Fig. 8.1 – Height above the horizon of orbital velocity *v*, in a region with a latitude of 40ºN, in September, at sunrise (h_1) and at sunset (h_2).

$$h_1 = 2 \times 40^o + 26^o.5 = 106^o.5$$

At sunset, *v* becomes again parallel to the local meridian ($\theta = 180^o$), forming with N indicated by straight line ON2, the angle

$$h_2 = -(90 - 40) - 23^o.5 = -26^o.5$$

On the basis of these co-ordinates, a calculation was carried out of the variation due to orbital velocity, of the refraction indices of glass and diamond in relation to their index at rest. This variation was 1.5 and 2.417, respectively. It was assumed that the refraction index is measured in a prism with a vertical E-W oriented entrance face and it was also considered that the light enters that face addressing north.

The following results were obtained for the difference $n' - n$:

	Sun rising	**Sun setting**
	θ=0 h=106.5	θ=180 h=-26.5
Glass (n=1.5)	0.000036	0.000112
Diamont (n=2.417)	0.000138	0.000433

As can be seen, according to this model, it seems possible to detect the ether wind due to the orbital movement of the earth, if the methods of determination of the refraction index have a 10^{-4} precision.

Both experiments must be quarterly repeated for a year, in order to detect not only the orbital movement of earth, but also, other possible movements.

10 – Conclusions

The influence of the movement of the refringent bodies on the velocity of propagation of light that crosses them, Fresnel's well-known "ether partial dragging," seems also possible to be modelled by adding to the refraction mechanism the scattering concept, as well as the aberration effect caused by the movement in that scattering angle.

According to that model, the Michelson experiment presented a negative result, because the precision of the experimental mechanism was insufficient to detect the time differences to be measured.

Even though the Shamir and Fox experiment has detected a 22% ether wind of the orbital velocity of earth, the very authors and other relativity theory specialists consider such result as negative.

By considering that further experimentation is required to enlighten the problem, two experiments are suggested: the first is similar to the Shamir and Fox's, except for the fact that the arms of the device are replaced by optical fibre reels. In the second, an attempt is made to detect the ether wind by means of the variation of the refraction index, provided that the measurement of that index is likely to be made with a 10^{-4} precision.

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