Absolute Motion Determined from Michelson-Type Experiments in Optical Media

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Z. Naturforsch. **66a,** 228 – 230 (2011); received March 10, 2010 / revised June 19, 2010

The symmetry of vacuum is characterized by the Lorentz group with the parameter c. Physical space inside the homogeneous optical medium should be described by the Lorentz group with the parameter c/n, where n is the refractive index of the medium. Violation of a one-parameter phenomenological symmetry in the discrete medium, such as gas, creates the opportunity for the experimental detecting of the motion of the optical medium relative to luminiferous aether.

Key words: Michelson Experiment; Dielectric Media; Drag of Light; Aether Wind.
PACS numbers: 42.25.Bs, 42.25.Hz, 42.79.Fm, 42.87.Bg, 78.20.-e

1. Introduction

Vacuum is isotropic in any inertial reference frame. This holds due to the fact that d'Alembert's equation, governing the propagation of light, is Lorentz-invariant with the parameter c, and inertial frames are related by the Lorentz transformation with the same parameter c.

The situation may change if we will introduce an optical medium with the refractive index $n > 1$. The anisotropy of the speed of light propagating in the otherwise isotropic medium arises when the medium moves in the laboratory reference frame, since the moving medium drags the light so that the speed of light in the direction of motion acquires a new value $\tilde{c} \gtrless c/n$. The law of dragging may be such that the system retains its anisotropy, at least partially, in the reference frame of the moving medium, i. e. again the new value $\tilde{c}'$ of the light speed differs from c/n.

If a theoretical model for the dependence of $\tilde{c}$ on n and on velocity $\mathbf{v}$ of the motion of the medium is available, then, measuring $\tilde{c}$ as a function of n, the velocity v of the absolute motion of the medium can be determined.

2. Conditions for Anisotropy of Wave Speed in a Moving Medium

We will consider a general situation when the system is characterized by the Lorentz group with the parameter w, and the wave propagates in it with the speed u. Transforming u to the reference frame moving with the velocity v yields

$$u' = \frac{u - v}{1 - uv/w^2}. \tag{1}$$

Reversing (1) and renaming $u \to \tilde{u}$ and $u' \to u$, the velocity

$$\tilde{u} = \frac{u + v}{1 + uv/w^2} \tag{2}$$

may be interpreted as the result of the drag of the wave by a moving with the velocity v medium. Passing by (1) to reference frame of the moving medium, we will obviously obtain $\tilde{u'} = u$, i. e. the speed of the wave becomes isotropic again. In other words, the drag (2) does not lead to the anisotropy in the reference frame of the moving medium.

Expanding (2) over $v \ll w$,

$$\tilde{u} = u + v(1 - u^2/w^2) - uv^2/w^2(1 - u^2/w^2) + \ldots, \tag{3}$$

and then dropping in (3) higher orders gives the model

$$\tilde{u}_\mathrm{F} = u + v(1 - u^2/w^2) \tag{4}$$

referred to as the Fresnel drag. The form (4) can be considered independently on the group transformation (2) used to motivate it [1]. Substituting (4) for u in the right-hand part of (1) gives the anisotropy of the wave's speed as observed in the moving together with the medium reference frame:

$$\tilde{u}'_\mathrm{F} \approx u\left[1 + \frac{v^2}{w^2}\left(1 - \frac{u^2}{w^2}\right)\right], \tag{5}$$

i. e. the wave's speed in the direction collinear to **v** will be (5) while in the perpendicular direction u as before. Still, this anisotropy is of the same order as the terms dropped out in (3).

We may specify (5) in terms of the speed c of light in vacuum and refractive index n of a dielectric medium. Take notice in (5) that $\tilde{u}'_F = u$ when $u = w$, i. e. when the wave speed u coincides with the symmetry parameter w of the system. This may be realized in two physically distinct situations. There is no anisotropy in vacuum, when $w = c$ and $u = c$. Another case is $n > 1$, $w = c/n$, and $u = c/n$, i. e. when the dielectric medium shapes the physical space. Such may be inside a homogeneous optical continuum (cf. [2]).

The most interesting situation is $w = c$ whereas $u = c/n$. Then $\tilde{u}'_F \neq u$, and the anisotropy of light speed is evaluated from (5) as the difference between the two orthogonal directions:

$$\frac{\delta u}{u} = \frac{\tilde{c}' - c/n}{c/n} \approx \frac{v^2}{c^2}\frac{n^2-1}{n^2}. \tag{6}$$

Supposedly, this configuration is realized in discrete medium, such as rarified gas ($n \sim 1$). Therefore, the anisotropy of light propagation in the moving together with the medium reference frame may arise provided that this 'medium' represents a small or point-like perturbation of vacuum.

3. Michelson Interferometer in Dielectric Media

Now we may calculate with $w = c$, $u = c/n$ the difference of light round-trip times in the collinear and transverse to **v** orientations of the Michelson interferometer. The collinear path time can be immediately found from (5) as $t'_\parallel = 2l/\tilde{u}'_F$, where l is the arm's length of the interferometer. However, $t'_\perp \neq 2l/u$, since in the transverse direction, because of the inclination of the wave's trajectory, there should also be taken into account the drag of the wave by the medium. So, it is convenient to perform calculations in the absolute reference frame (see Appendix A). Thus we obtain for $v \ll c$

$$\Delta t' \approx \frac{v^2}{c^2}\frac{l}{cn}(n^2-1)(2-n^2) \tag{7}$$

(here we have taken $\Delta t' \approx \Delta t$ since by the dilation of time $\Delta t' = \Delta t\sqrt{1 - v^2/c^2}$). By the initial supposition, (7) is valid only for $n \gtrsim 1$. Nevertheless, formula (7) is capable to describe, at least in general features, the dependence of $\Delta t'$ on the refractive index of optically denser media.

In agreement with the conditions above stated, experiments on gas-mode Michelson interferometer ($n_{\text{air}} \approx 1.0003$) indicate the anisotropy of light speed, estimating by means of (7) the velocity v of the Earth in aether as several hundreds kilometers in a second [3, 4]. While experiments in the solid optical monolith ($n = 1.5 \div 1.75$) show negligible interference fringe shift [5 – 7] or may be an equivalent [8], i. e. $\Delta t'_{\text{solid}} = 0$. This agrees with $w = c/n$, $u = c/n$ case. We may expect that for moderate optical densities an intermediate between $w = c$, $u = c/n$ and $w = c/n$, $u = c/n$ phenomenology takes place. So that $\Delta t'$ first grows with the increase of n, and further declines to null. This corresponds to the behaviour of the function (7) in the range $1 < n^2 \leq 2$.

Still, Demjanov [3] claims that the experimental curve measured by him changes the sign and goes to negative in accord with (7) at $n^2 \geq 2$. He criticizes [9, 10] the accuracy of solid body experiments [5, 6] with their close to null results, suspecting that the experimenters actually measured in the air and at short distances. So that v, recalculated from their data by means of the formula (7) yet with different values of n and l, appears just several hundreds km/s.

4. Conclusion

The crucial point in detecting the anisotropy of light propagation in the moving together with the medium laboratory is the validity of the Fresnel drag (4) in the absolute reference frame, i. e. in aether. In this event, it is important that the Fresnel drag of light, obtained above from kinematical relation (2), can be derived independently in optics of moving media [1]. One way or another, the accuracy of the derivation ought to be higher than v^2/c^2.

Appendix A: Round-Trip Times in a Moving Medium with Fresnel Drag of Light

We consider a Michelson interferometer whose working chamber is filled with the dielectric medium that is at rest in the device. Supposedly, the interferometer moves (along with the Earth) uniformly with a velocity $v > 0$ in the absolute reference frame, where $v \ll c$.

To account for the drag of light by the moving medium, the Fresnel formula with the appropriate sign

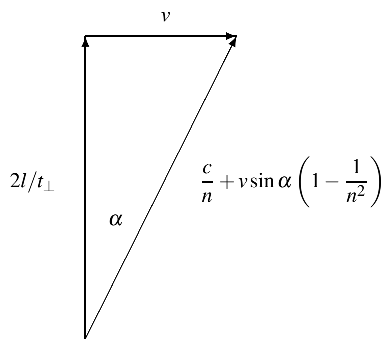

Fig. 1. Velocity triangle in the transverse arm of the medium-filled Michelson interferometer.

before v can be used:

$$\tilde{c}_\pm \approx \frac{c}{n} \pm v\left(1-\frac{1}{n^2}\right). \tag{A1}$$

In order to compute the light round-trip time $t_\parallel$ collinear to the $\mathbf{v}$ orientation, we will use the classical addition $\tilde{c}_\pm \mp v$ with subsequent account of the Lorentz contraction [5]. This gives in the absolute reference frame

$$\begin{aligned} t_\parallel &= \frac{l_\parallel}{\tilde{c}_+ - v} + \frac{l_\parallel}{\tilde{c}_- + v} \\ &= l\sqrt{1-\frac{v^2}{c^2}}\left(\frac{1}{\frac{c}{n}-\frac{v}{n^2}} + \frac{1}{\frac{c}{n}+\frac{v}{n^2}}\right) \\ &\approx \frac{2l}{c}n\left[1+\frac{v^2}{c^2}\left(\frac{1}{n^2}-\frac{1}{2}\right)\right], \end{aligned} \tag{A2}$$

where the longitudinal arm of the interferometer is $l_\parallel = l\sqrt{1-v^2/c^2}$, and terms of the order higher than v^2/c^2 were neglected.

Accounting for tangential incline of light in the transverse arm, we will consider the velocity triangle (Fig. 1). Here the light is dragged due to the projection of $\mathbf{v}$ on $\mathbf{c}/n$. Insofar as the inclination angle α is small, it can be approximated by

$$\sin\alpha = \frac{v}{c/n + v\sin\alpha(1-1/n^2)} \approx \frac{vn}{c}. \tag{A3}$$

Then we have from Figure 1 with the account of (A3)

$$l^2 + \left(\frac{vt_\perp}{2}\right)^2 \approx \left[\frac{c}{n} + \frac{v^2 n}{c}\left(1-\frac{1}{n^2}\right)\right]^2 \left(\frac{t_\perp}{2}\right)^2. \tag{A4}$$

Relation (A4) gives for the transverse round-trip time $t_\perp$ in the reference frame of aether

$$\begin{aligned} t_\perp &\approx \frac{2l}{\sqrt{\left[\frac{c}{n} + \frac{v^2 n}{c}\left(1-\frac{1}{n^2}\right)\right]^2 - v^2}} \\ &\approx \frac{2ln}{c}\left[1-\frac{v^2}{c^2}\left(\frac{n^2}{2}-1\right)\right], \end{aligned} \tag{A5}$$

where terms of order higher than v^2/c^2 were neglected. Formula (A5) differs drastically from that obtained for $t_\perp$ in [5].

Subtracting (A2) from (A5), we obtain

$$\begin{aligned} \Delta t &= t_\perp - t_\parallel \\ &\approx \frac{v^2}{c^2}\frac{l}{cn}(n^2-1)(2-n^2) = \frac{v^2}{c^2}\frac{l}{c\sqrt{\varepsilon}}\Delta\varepsilon(1-\Delta\varepsilon), \end{aligned} \tag{A6}$$

where $\Delta\varepsilon = n^2 - 1$ accounts for the contribution of the particles of matter into the dielectric permittivity $\varepsilon = n^2$ of the luminiferous medium, aether plus the dielectric substance. Formula (A6) has been first proposed by Demjanov in order to describe the run of the experimental curve obtained by him from measurements on a Michelson interferometer in various optical media and at different wavelengths [3].

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