Why over 30 years aether wind was not detected in Michelson-type experiments with resonators

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We show that measured by S.Herrmann et al., Phys.Rev.D 80, 105011 (2009) the relatively small variation $\delta\nu$ of the resonance frequency of a chosen mode of an evacuated optical resonator, when changing its orientation in space, can not serve as an indication of the absence of a preferred direction related with the motion of the setup in aether. In order to detect the absolute motion and determine the value and direction of its velocity, the volume of the resonator should be regarded, at any degree of evacuation, as being an optical medium, with its refractive index $n > 1$ to be necessarily taken into account, irrespective of the extent of the medium's tenuity.

If the working body is a gas then $\delta\nu$ is proportional to $n^2 - 1$ and to the square of the velocity υ that the resonator moves with in aether. At sufficiently large values of optical density, $\delta\nu$ is proportional to $(n^2-1)(2-n^2)$, and at $n > 1.5$ it may possess such a great value that there even becomes possible a hopping of the automatic laser frequency trimmer from the chosen mode of the reference resonator to its adjacent modes. Taking into account the effect of the medium permeability in experiments with resonators performed by the scheme of the Michelson experiment enabled us to estimate the absolute speed of the Earth as several hundreds kilometers per second.

1. Introduction

The resonance frequency ν of the $\text{TEM}_{\text{oo}m}$-wave in a linear sample, constrained at the ends by reflecting mirrors, is determined by the integer number m of half-waves fit in the sample's length l

$$\nu = \frac{cm}{nl} \tag{1}$$

where n is the refractive index, and c/n the light speed in the stationary medium. Comparing ν for various orientations of the resonator in space, the authors [1] have found a very small maximal relative shift $\delta\nu/\nu = 10^{-17}$ of the resonance frequency. Substituting the latter into the variation of (1) under constancy of the experiment's parameters

$$\frac{\delta\nu}{\nu} = \frac{\delta c}{c} \tag{2}$$

gives $\delta c/c \approx 10^{-17}$, that by [1] allegedly corresponds to the absence of light speed anisotropy.

I will show below that the adequate interpretation of the experiments with the proper accounting of n leads not to the demonstration of the isotropy of the light speed in optical media, as the authors [1, 2] think, but on the contrary, it reveals the regular anisotropy of the light speed related with the motion of the medium in aether, and velocity υ of this motion has the order of several hundreds km/s.

It is vacuum ($n = 1$) that is isotropic, and any moving in aether isotropic medium ($n \neq 1$), which an experimenter deals with, is, in general case, anisotropic for propagation of light. As will be shown, this anisotropy can be observed in the reference frame moving together with the medium. This means that in experiments of Earth's laboratories one should not identify laboratory vacuum, which always has $n > 1$, with the true vacuum, which has $n = 1$ and where solely the searched for by the authors [1, 2] Lorentz-invariance is realized. The tendency of experimenters to evacuate the working space, aiming at the rise of their resolution power, leads, as a rule, to decrease of the observed effect (here $\delta\nu/\nu$) in such number of times as the resolution power of the observed effect increases due to the reduction of the contribution of the source of the effect (in this case, the concentration of particles represented in terms of $n^2 - 1$). As a result, the quantity conveying the physics of the process, in this case υ, which is calculated as the ratio of $\delta\nu/\nu$ (observed effect) to $n^2 - 1$ (cause of the effect), remains unchanged.

2. Analyzing measurements [1] at evacuated resonators

We will adopt the Fresnel model of the drag of light by the moving optical medium. This model takes into account explicitly the refractive index $n>1$ of the medium and velocity υ of its motion in aether:

$$\tilde{c}=\frac{c}{n}+\upsilon\left(1-\frac{1}{n^2}\right). \tag{3}$$

Passing by the Lorentz group transformation of the velocity $\tilde{c}$ to the moving with the velocity υ reference frame we obtain from (3)

$$\tilde{c}'=\frac{\tilde{c}-\upsilon}{1-\tilde{c}\upsilon/c^2}\approx\frac{c}{n}\left[1+\frac{\upsilon^2}{c^2}\left(1-\frac{1}{n^2}\right)\right]. \tag{4}$$

By (4) the relative variation of the light speed in the Earth's reference frame can be found:

$$\left(\frac{\delta c}{c}\right)_{\text{mov.med.}}=\frac{\tilde{c}'-c/n}{c/n}=\frac{\upsilon^2}{c^2}\frac{n^2-1}{n^2}\quad , \tag{5}$$

where $\tilde{c}'$ is the light speed in the direction collinear to $\mathbf{v}$, and c/n – in the perpendicular direction (the same value c/n as in the resonator stationary in aether). Clearly, we obtained a different in principle result, than that in [1, 2]. As we see from (5), $\delta c/c$ is proportional to υ^2/c^2 and explicitly depends on n, for gases with $(n^2-1)<<1$ it is proportional to n^2-1. Insofar as the observed in the experiment value is $\delta\nu/\nu$, substituting (2) in (5), we obtain

$$\left(\frac{\delta\nu}{\nu}\right)_{\text{mov.med.}}=\frac{\upsilon^2}{c^2}\frac{n^2-1}{n^2}. \tag{6}$$

First, we will interpret results of the work [1], where various orientations of resonance cavities, evacuated to the pressure $<10^{-8}$ bar, were compared. After pumping out, the authors assumed that the space inside the cavities can be treated as an absolute vacuum ($n=1$). In fact, there left in the cavity a rarified gas accounting for whose permeability is essential for the interpretation of $\delta c/c$ in the sense of (5). The permeability of the gas with the pressure 10^{-8} is evaluated as $n^2=1+6\cdot10^{-12}$ [3]. The maximal relative shift of resonance frequencies registered in this experiment is $\delta\nu/\nu=10^{-17}$. Substituting latter quantities to (6), we obtain for velocity of the absolute motion of evacuated resonators

$$\upsilon=c\sqrt{\frac{n^2}{n^2-1}\left(\frac{\delta\nu}{\nu}\right)_{\text{mov.med.}}}=c\sqrt{\frac{10^{-17}}{\le 6\cdot10^{-12}}}\ge 400\ \text{km/s}. \tag{7}$$

It is clear from (7), that the degree of evacuation of the gas in the volume of resonator should be measured more accurately than it was done in [1, 2], since the extent of evacuation determines n^2-1 and the anisotropy of the light speed, by (6) and (2), stated in these experiments. The value of υ thus found agrees well with those measured by me [4, 5] and [6, 7] in the classical Michelson experiment in gases and other optical media.

3. Analyzing measurements [2] at sapphire resonator

In order to calculate υ at $n^2-1>0.5$, we must take into account more subtle effects, which are stipulated by the drag of light by the medium in the transverse orientation of the resonator. Then we obtain a more general formula suitable for any value of n:

$$\left(\frac{\delta c}{c}\right)_{\text{mov.med.}}=\frac{\upsilon^2}{c^2}\frac{(n^2-1)(2-n^2)}{n^2}\quad . \tag{8}$$

As already was mentioned, the observed in the experiments [1-2] value is $\delta\nu/\nu$. After substituting (2) in the left part of (8), we obtain

$$\left(\frac{\delta\nu}{\nu}\right)_{\text{mov.med.}} = \frac{\upsilon^2}{c^2}\frac{(n^2-1)(2-n^2)}{n^2} \quad . \tag{9}$$

In the measurements at the sapphire resonator with $m = 10000$ the authors [2] encountered with some difficulties in the observation of the difference frequency $\delta\nu_{\text{saph}} = \left|\nu_{\text{saph.}} - \nu_{\text{evac.}}\right|$ which they attributed to "small deformations of the breadboard carrying the optics" and other laboratory effects. In my view, the experimenters faced with an unexpected by them large shift $\delta\nu_{\text{saph}} \sim 10^9\,\text{Hz}$ of the resonance frequency of the sapphire while the frequency of vacuumed resonators remained here almost invariable ($\delta\nu_{\text{evac.}} \sim 0.001 \div 1$ Hz). The shift of the resonance frequency of the sapphire resonator appeared to be 10^{12} times greater than that of vacuumed ones, i.e. much greater than was expected in [2]. The shift $\delta\nu_{\text{saph.}}$ may even exceed the distance $\Delta\nu$ between adjacent modes of the reference cavity resonator, that we will estimate from (1) with $m = 380000 \pm 1$ as

$$\left(\frac{\Delta\nu}{\nu}\right)_{\text{evac.}} \approx \frac{1}{m} = \frac{1}{380000} \approx 3\cdot 10^{-6} . \tag{10}$$

Clearly, in this event $\left(\Delta\nu/\nu\right)_{\text{saph.resonator}} = 1/10000 \gg \left(\Delta\nu/\nu\right)_{\text{evac.resonator}}$. Here and further on $\Delta\nu$ designates the difference between frequencies of adjacent modes, while $\delta\nu$ – the shift of the resonance frequency under turning the resonator. Part of the reason why the experimenters have not noticed an abnormally high frequency shift could be the use of low-frequency spectrum analyzer from work [1], designed for beat note in the interval $10^{-3} \div 1$ Hz, that is suitable only for monitoring the frequency shift of $10^{-17} < \delta\nu/\nu < 10^{-14}$ in a pair of evacuated cavities. If my supposition concerning the occurrence of the unnoticed by the experimenters skip in the electronics of trimming the laser frequency (because of the skip in the automatic laser frequency trimmer at 380000±1 mode) is true, then estimating υ by (6) we must use the unaccounted in [2] skip (10), corresponding to 380000±1 mode, in the capacity of the shift, but not the artifact value $\left(\delta\nu/\nu\right)_{\text{saph.}} = 4\cdot 10^{-15}$ measured in [2]. Thus, we assume for the experiment with the sapphire resonator

$$\left(\frac{\delta\nu}{\nu}\right)_{\text{mov.med.}} \approx \left(\frac{\Delta\nu}{\nu}\right)_{\text{evac.}} . \tag{11}$$

Using (11) in (9) gives

$$\left(\frac{\Delta\nu}{\nu}\right)_{\text{evac.}} = \frac{\upsilon^2}{c^2}\frac{(n^2-1)(2-n^2)}{n^2} \quad . \tag{12}$$

Substituting (10) in the left side of (12) and using $n \simeq 1.75$ in the right side, we obtain for velocity of the absolute motion of the sapphire resonator

$$\upsilon = c\sqrt{\left|\left(\frac{\Delta\nu}{\nu}\right)_{\text{evac.}} \frac{n^2}{(n^2-1)(2-n^2)}\right|} \approx \sqrt{\frac{1.5}{380000}} \approx 600 \;\text{ km/s} , \tag{13}$$

that coincides in the order of value with υ computed by the same model of the dynamic anisotropy for the frequency variation in evacuated resonators.

4. Discussion

So, we used the Fresnel model (3) of drag of light by the moving medium regarding the medium's velocity υ to be its velocity in the absolute frame of reference. This model has prompted us to take into account the medium where the light propagates. Introducing all the characteristics and result of the experiment [1] in the calculation of formula (6) or (9) derived from the Fresnel model we obtained $\upsilon \neq 0$. This indicates that measurements [1] were performed not in vacuum ($n=1$) but in the medium having the refractive index $n>1$.

With υ thus found the prognosis $\delta\nu/\nu = (\upsilon^2/c^2)(n^2-1)$ of the relative difference between resonance frequencies of orthogonal resonators can be made for media having various optical densities n. As we see from Fig.1 the remolded in terms of $\delta\nu$ results of [10, 12] fall at the extrapolation of the straight line, thus constructed from [1], to larger densities.

The authors [1] may quickly check the validity of this prediction with their experimental setup. The general recommendation is that measurements should be made first for moderate values of the gas pressure, starting from $p=10^{-8}$ bar and then pass to higher densities making sure that the frequency shift does not exceed the operation limit of measuring instruments.

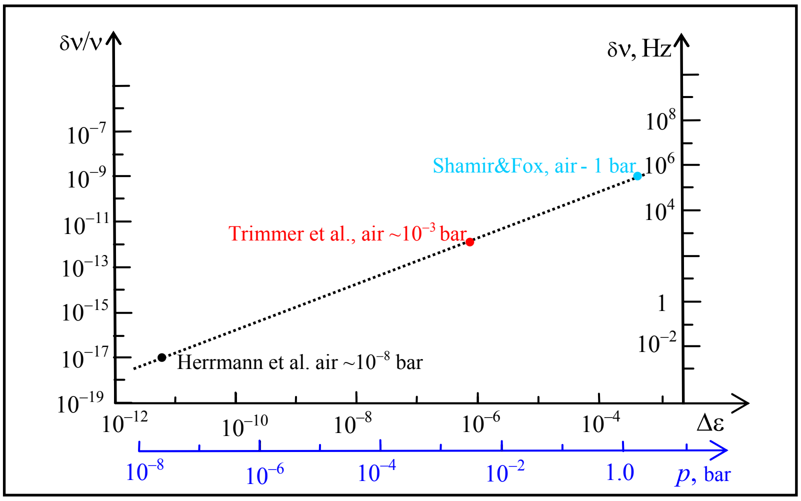

Fig.1. The dependence of the relative difference $\delta\nu/\nu$ between resonance frequencies of orthogonal gas-filled resonators on the pressure of the gas, or on the contribution $\Delta\varepsilon = n^2 - 1$ of particles into its dielectric permittivity.

If the relation of the kind (6) continues to be valid in the solid optical medium, as in the case of (8), when in order to measure the probable large shift of the frequency there should be employed a beat note extraction electronics and spectrum-analyzer operating in a more wide range of frequencies, up to 10^9 Hz (i.e. it is necessary to replace the spectrum-analyzer in the range $10^{-3} \div 1$ Hz [2] by that in the range $1 \div 10^9$ Hz). In this case, gradually turning the resonator, one would observe a smooth frequency shift $\delta\nu_{\text{saph.}} = |\nu_{\text{saph.}} - \nu_{\text{evac.}}|$ which is much larger than $\delta\nu_{\text{evac.}} = |\nu_{\text{evac.}\perp} - \nu_{\text{evac.}||}| = 10^{-3} \div 1$ Hz. The frequency shift lasts up to the instant when $\delta\nu_{\text{saph.}} = \Delta\nu_{\text{evac.}} = \nu/m \approx 3\cdot 10^{14}/380000 = 0.79\cdot 10^9$ Hz by (10), where $\nu = 3\cdot 10^{14}$ Hz is the resonance frequency of the resonators. At this instant the electronics of trimming the laser frequency fails at 380000 mode. The failure happens because of the mode hopping in this device from m = 380000 to the mode with m = 380000 ± 1.

In order to increase the sapphire ratio signal/noise in frequency converter output there would be useful to decrease the amplitude of the input laser signal under 20 mW, without fear of reducing the signal power at the output of the converter below 20 nW, since its noise of reduced nonlinearity may fall down in more times.

To avoid possible disruption of the resonance state and for more stable operation of the resonators at the chosen frequency ν in the regime of the automatic frequency trimming of signal-delivering lasers, one can take the cavity with a smaller linear size l. Then by (1) m

will become smaller and hence by (10) the distance between adjacent modes will increase up to the value which is not overlapped by $\delta\nu_{\text{saph.}} = |\nu_{\text{saph.}} - \nu_{\text{evac.}}|$.

Disregarding the influence of the medium remaining in the cavity, or incorrect accounting of it, is typical in the history of experiments of the Michelson-Morley type. The table below presents data of experiments of various authors and my re-calculation performed using the model of light's entrainment by the medium as well as fixing marked flaws of experiments over last ~130 years.

Table 1. Published over the past 130 years by various authors the results of measurements of the dynamic anisotropy of the speed of light (aether wind speed υ), and removing mistakes in measurements or in interpretation that gives the true value $\upsilon \approx 500$ km / sec.

№	Authors	Velocity of aether wind (anisotropy of light speed)	Refined by me speed of aether wind after correcting errors or artifacts of experiment	Removing mistakes in experiment or its interpretation
1	Michelson	$0 \le \upsilon \le 6$ km/s	$\upsilon \le 240$ km/s	Noise reduced, enhanced resolution of fringe shift from ~$^1/_{40}$ [6, 7, 8, 9] up to $^1/_{120}$, fixed 40-fold underestimation of results [4]
2	Michelson&Morley	$2 \le \upsilon \le 6$ km/s	$\upsilon \le 240$ km/s	
3	D.C.Miller	$3 \le \upsilon \le 12$ km/s	$120 \le \upsilon \le 480$ km/s	
4	Demjanov	$140 \le \upsilon \le 480$ km/s	–	Correct formula for processing measurements derived [4, 5]
5	Shamir&Fox [10]	$\upsilon \le 6.6$ km/s	υ ~400 km/s	Reflection of beams from straight ends of plexiglas rods taken into account [11]
6	Trimmer et al. [12]	$\upsilon \le 3.8$ cm/s	υ ~400 km/s	Reflection of beams from straight ends of glass rods taken into account [13]
7	Herrmann et al. [1]	$\delta c = 30$ angstrom/s	υ ~500 km/s	Permeability of laboratory vacuum inside resonators taken into account, see (6-7).
8	Nagel et al. [2]	$\delta c = 0.3$ micron/s	υ ~600 km/s	Fixed omission of skip in electronics of stabilization of laser frequency from 380000 to 380000±1 modes of reference cavity resonator, see (9-13).

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