Schematic diagrams of classic interferometers
(study)

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Abstract

All possible schematic diagrams of classical interferometers for measuring the velocity of the Earth relative to the ether are investigated. With one of the schemes the experiment is set and the exact calculation is carried out which has confirmed absence of displacements of interference bands. The analysis of Michelson's works on experiments with another of schemes is carried out, the errors in calculations which led Lorentz to the erroneous hypothesis and derivation of wrong coordinate transformations are shown.

Introduction

Let us call as classic interferometer schematic diagrams all known diagrams of the XIX – XXI centuries used to measure the relative velocity of bodies or the orbital velocity of the Earth. Let us consider and analyze their possible variants who could have implemented such measurements. Let us find out the special features of light propagation in moving bodies, which are interferometers. The main task of the interferometer was to combine two or more beams that came from one light source in different ways to the screen on which the interference pattern is established. The discovery of the effect by Doppler made it possible to measure velocity of bodies through the difference of travel paths of the light by analogy with sound waves. A simple solution was to direct the paths of light on the sides of the quadrangle. Variants of beam path in quadrangles are shown in Fig.1. The beam of light from the light source S is split at the apex A into two beams of close intensity, which on the sides of the quadrilateral come to any of its vertices and, united, interfere on the screen.

Interference is not influenced in principle by beam paths running on the sides of quadrangles with opposite sides in pairs unequal or in pairs equal not at right angles. Therefore, the sides of rectangles should be considered optimal beam paths.

We place the beam splitting plate P_1 at the vertex of a rectangle A, and the mirrors $S_{1\text{-}3}$ at other vertices. It is assumed that the interferometer always has some translational velocity V, and the task of experience is to detect its projection onto a plane that is parallel to the propagating rays of light. In each of the proposed below variants of schemes, we will change the vertex of the beam collection going to the screen, and by rotating the interferometer in a plane parallel to the light beams evaluate the possibility of changing the interference pattern on the screen.

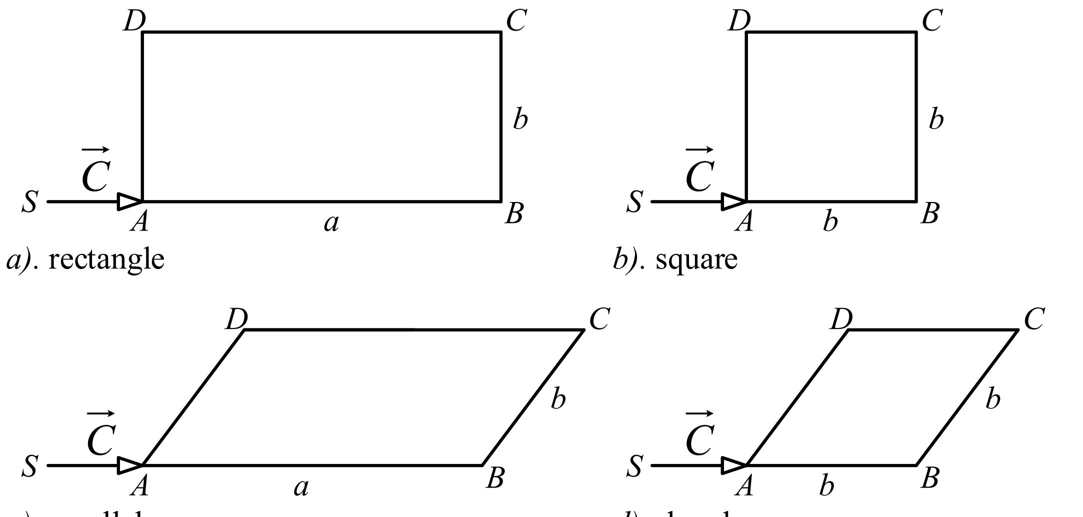

Fig.1.

1. Variant 1. Ray Collection Point – vertex *A*

In the first variant, Fig.2, each ray of the beam split by the beam splitting plate P_1 at point *A* runs on the perimeter of the rectangle towards each other and at the starting point is split again into two beams, which in pairs go to the screen and the light source *S*, where they interfere.

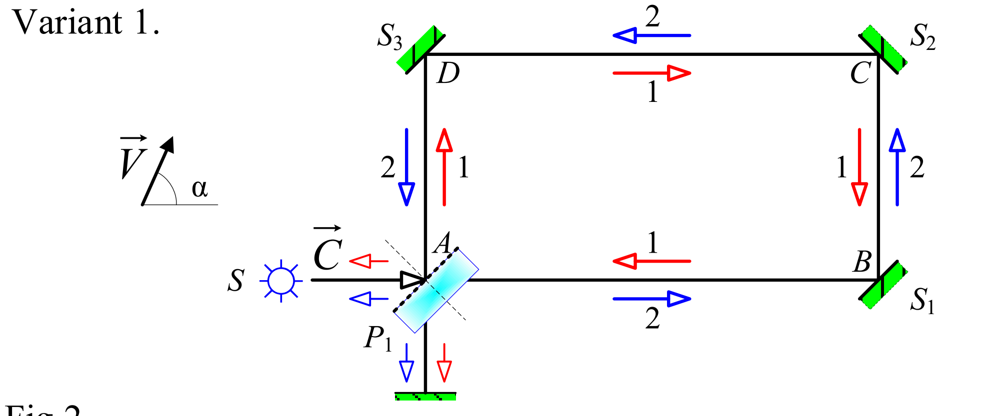

Fig.2.

It can be seen from the diagram that the paths of different rays coincide in direction on the parallel sides of the rectangle. Formally, it can be considered that their lengths are the same, although in reality it is not so, what will be shown below by an exact calculation. That said, the difference in paths traveled by the rays on the perimeter, obtained during adjustment, will remain and will not change when the interferometer is rotated by an arbitrary angle α. We can say that on the sides of the rectangle, the path length of each beam changes so that the sum of their paths to the screen will be constant.

Experiments of 19th century conducted with such a scheme gave a negative result – no displacements of interference bands has been detected by rotation of the interferometer. For this variant, it is also possible to perform an accurate calculation similar to variant 2, at the same time there are no changes in the difference in light paths when the interferometer rotates.

2. Fresnel dragging how it is

In variant 1, Fig.3, let us place transparent plane-parallel plate on one side of the rectangle. A similar experiment was conducted in 1868 by M. Heck [1]. The negative result of the experiment was explained by the presence of a Fresnel dragging coefficient compensating effect, which could be caused by the movement of the Earth in first-order experiments.

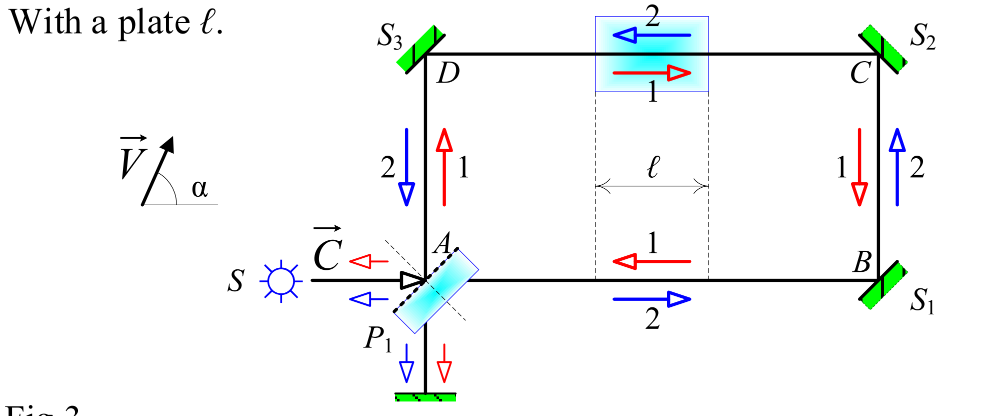

Fig.3.

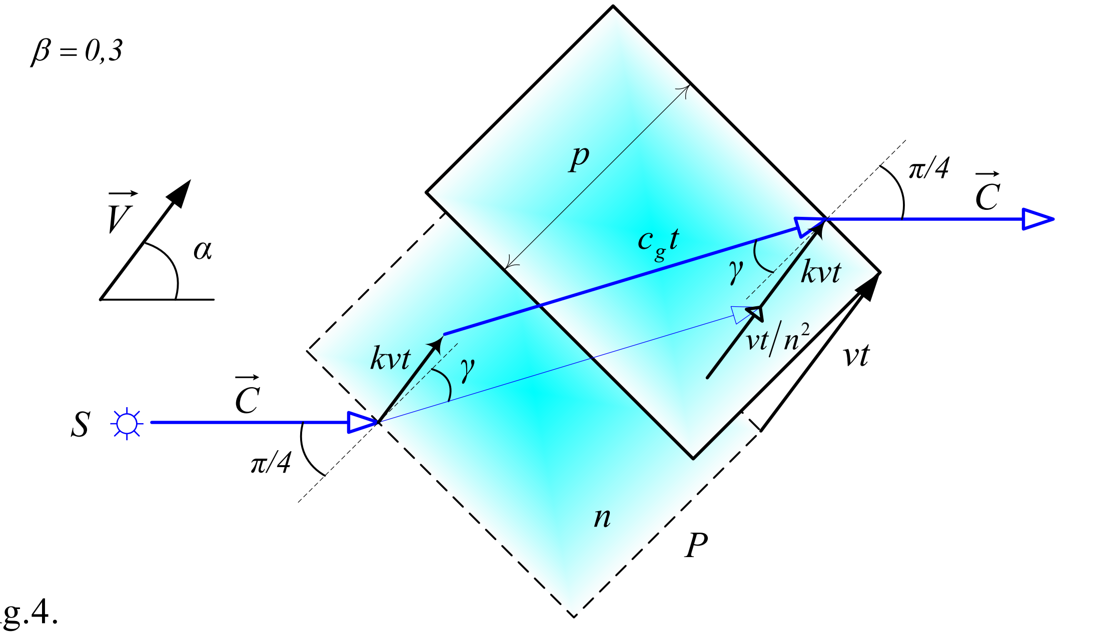

Fig.4.

To understand the process of light propagation in optically dense media and why O.J. Fresnel [2] called the coefficient "draggings", we will decompose the path of light in the plate into components, Fig.4.

The beam of light entered at the angle of refraction γ into the plane-parallel plate P, is heading to the opposite face, while passing a path vt/n^2, where: n – is the optical density of the plate glass. Further, the beam of light is transferred by the plate parallel to its movement by a distance kvt, where: k – is a dragging coefficient of light by the plate equal to $k = 1 - 1/n^2$, before the beam leaves its plane at an angle of incidence γ. As a result, the beam incident on the plate is parallel to the beam that came out of it. The length of the path of light in the plate can be calculated through its thickness p or a projection onto the beam incident on the plate, as will be shown below for the diagram of the variant 2.

Coming back to Fig.3, let us consider the reasonability of Fresnel dragging to explain the negative result of Heck's experience, but in a different method. Let us find the path traveled by light in the air on the segment ℓ and compare to the similar path traveled by it in the plate for its velocity vector v at an angle α= 0°. For beam 2, the path of light will be: $ct_2' = \ell + vt_2'$ and for beam 1 – $ct_1' = \ell - vt_1'$. Then the travel time and the same way will be:

$t_2' = \dfrac{\ell}{c - v}$ and $t_1' = \dfrac{\ell}{c + v}$ or $ct_2' = \dfrac{\ell}{1 - \beta}$ and $ct_1' = \dfrac{\ell}{1 + \beta}$, were: $\beta = \dfrac{v}{c}$, c – speed of light, and a path difference will be:

$$c\Delta t' = ct_2' - ct_1' = \ell \cdot \left(\frac{1}{1-\beta} - \frac{1}{1+\beta} \right) \Rightarrow c\Delta t' = 2\ell \cdot \frac{\beta}{1-\beta^2}.$$

With a small value β^2, we get $c\Delta t' \cong 2\ell\beta$.

Let us write in order the versions of plate passage with rays. In the plate, the speed of light is less by its refractive index n and equal to $c_g = c/n$.

Variant 1. $c_g t_1'' = \ell + vt_1''$ and $c_g t_2'' = \ell - vt_2''$. Then we find the path difference similarly:

$$c\Delta t'' = ct_1'' - ct_2'' = \ell n \cdot \left(\frac{1}{1-n\beta} - \frac{1}{1+n\beta} \right) \Rightarrow c\Delta t'' = 2\ell \cdot \frac{n^2\beta}{1-n^2\beta^2} \Rightarrow c\Delta t'' \cong 2\ell n^2 \beta.$$

And the difference between the two paths is not zero $c\Delta t'' - c\Delta t' \neq 0$, therefore, this option does not support experiment.

Variant 2. $c_g t_1'' = \ell + vt_1''/n$ and $c_g t_2'' = \ell - vt_2''/n$. Let us find similarly the difference in the path back and forth:

$$c\Delta t'' = ct_1'' - ct_2'' = \ell n \cdot \left(\frac{1}{1-\beta} - \frac{1}{1+\beta} \right) \Rightarrow c\Delta t'' = 2\ell \cdot \frac{n\beta}{1-\beta^2} \Rightarrow c\Delta t'' \cong 2\ell n \beta.$$

The difference between two paths is not zero in this variant too $c\Delta t'' - c\Delta t' \neq 0$.

Variant 3. $c_g t_1'' = \ell + vt_1''/n^2$ and $c_g t_1'' = \ell - vt_1''/n^2$. Let us find similarly the difference in the path back and forth:

$$c\Delta t'' = ct_1'' - ct_2'' = \ell n^2 \cdot \left(\frac{1}{n-\beta} - \frac{1}{n+\beta} \right) \Rightarrow c\Delta t'' = 2\ell \cdot \frac{n^2\beta}{n^2-\beta^2} \Rightarrow c\Delta t'' \cong 2\ell \beta.$$

In this variant, the difference between the two paths is zero $c\Delta t'' - c\Delta t' = 0$, therefore this version satisfies the negative result of the experiment. Yet the plate passes the path vt and then the light pass the remaining part of the path $kvt = vt - vt/n^2$ with a velocity of the plate or is dragged by the plate with a coefficient equal to $k = 1 - 1/n^2$.

As a result, similar sections of different optical density of media give to light the same path difference when they passing in mutually opposite directions.

3. Variant 2. Ray Collection Point – Vertex *B*
3.1. Physical formula – formal calculation method

In this variant, Fig.5 both beams converge and are re-split into two beams by plate P_2 at point *B* and go in pairs to the screens, where they interfere.

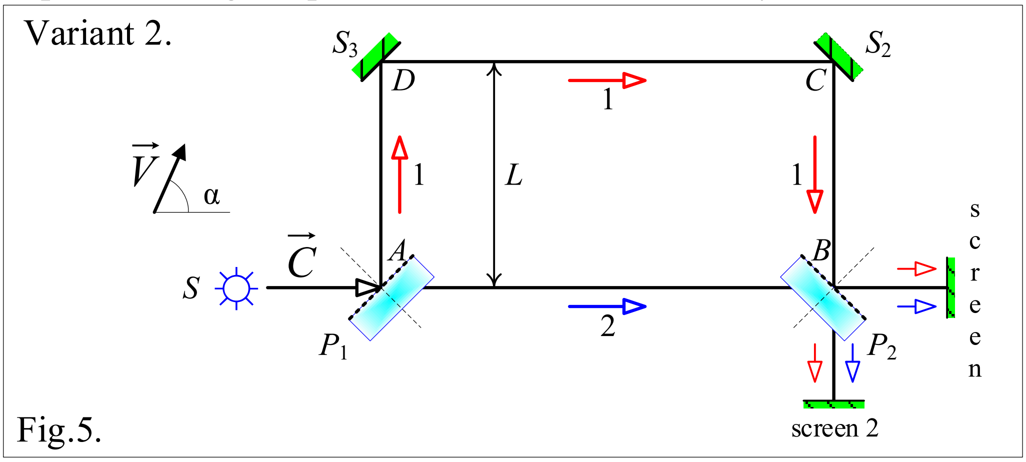

Fig.5.

The diagram shows that on the two parallel sides of the rectangle, the paths of the different rays coincide in the direction, and on the other two, one beam makes the path back and forth. Therefore, one beam 1 will produce a light path difference when the interferometer rotates. We apply the formal method of calculation according to the so-called physical formula of the mathematical form. We write the difference in the path of light with indication of the directions of light propagation and the angles *α* of rotation of the interferometer.

$$(c\uparrow+\downarrow-0)-(c\overset{\rightarrow}{\underset{\leftarrow}{+}}-0)=(c\uparrow+\downarrow-c\overset{\rightarrow}{\underset{\leftarrow}{+}})$$

α = 0º α=90º α = 0º → 90º

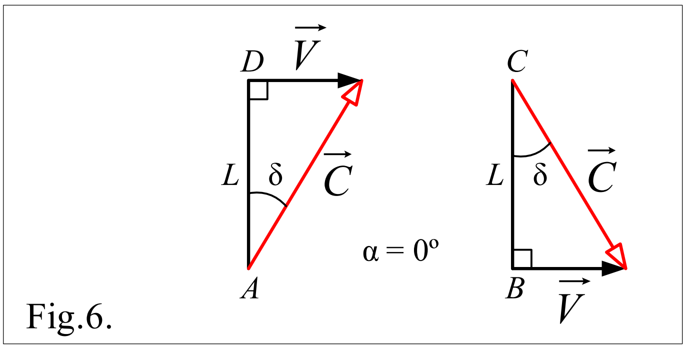

Fig.6.

Let us convert the physical formula into a mathematical for the calculation of the light propagation in the transverse direction to the Earth's motion, Fig.6:

$(ct_1')^2 = L^2 + (vt_1')^2$ and $(ct_1'')^2 = L^2 + (vt_1'')^2$ or $t_1' \cdot \sqrt{c^2 - v^2} = L$ and $t_1'' \cdot \sqrt{c^2 - v^2} = L$.

Then the sum of the two ways will be:

$$c\Delta t_{0^\circ} = ct_1' + ct_1'' = L\cdot\left(\frac{1}{\sqrt{1-\beta^2}} + \frac{1}{\sqrt{1-\beta^2}}\right) \Rightarrow \; c\Delta t_{0^\circ} = \frac{2L}{\sqrt{1-\beta^2}}.$$

When you turn the interferometer 90° in the same directions, the paths will be:
$ct_1' = L + vt_1'$ and $ct_1'' = L - vt_1''$, or $t_1'\cdot(c-v) = L$ and $t_1''\cdot(c+v) = L$.

We convert similarly and obtain:

$$c\Delta t_{90^\circ} = ct_1' + ct_1'' = L\cdot\left(\frac{1}{1-\beta} + \frac{1}{1+\beta}\right) \Rightarrow \; c\Delta t_{90^\circ} = \frac{2L}{1-\beta^2}.$$

The difference of paths when turning the interferometer by 90° will be:

$$c\Delta t_{0^\circ-90^\circ} = c\Delta t_{0^\circ} - c\Delta t_{90^\circ} = 2L\cdot\left(\frac{1}{\sqrt{1-\beta^2}} - \frac{1}{1-\beta^2}\right) \text{ or } c\Delta t_{0^\circ-90^\circ} \cong L\beta^2.$$

3.2. Exact calculation method

Beam motion formulas at *V*=0

Let write dependencies of the refractive angle of the plate, Fig.7. The refracting index in the plate – n, and in the air – n_a=1,0003, the value of which can be neglected by taking it as a unit. We assign the angle of incidence 45°. Then the ratio of the sine of the refraction angle γ to the sine of incidence angle is equal to the inverse value of the refractive index n.

$$\frac{\sin\gamma}{\sin 45} = \frac{1}{n} \Rightarrow \; \sin\gamma = \frac{1}{\sqrt{2}n} \text{ and } \cos\gamma = \frac{\sqrt{2n^2-1}}{\sqrt{2}n} \Rightarrow \; \cos\gamma = \frac{r}{\sqrt{2}n}, \text{ were: } r = \sqrt{2n^2-1}.$$

The dependence of the distance covered by light in the plate at V=0.

$$c_g t = \frac{p}{\cos\gamma};\; L_1 = c_g t\cos(45-\gamma) \Rightarrow \; L_1 = \frac{p}{\sqrt{2}}\cdot\frac{\cos\gamma+\sin\gamma}{\cos\gamma} \Rightarrow \; L_1 = \frac{p}{\sqrt{2}}\cdot\frac{r+1}{r} \text{ or } p = \frac{\sqrt{2}L_1 r}{r+1},$$

and the travelled path of the light $c_g t = \dfrac{2L_1 n}{r+1}$.

Paths calculation of beam 1 in the air from plate P_1 to screen

The distance traveled by light from plate P_1 to mirror S_3, Fig.7, will be:

$$ct_1^I = \ell_1 - vt_1^I(\cos\alpha - \sin\alpha) \Rightarrow \; ct_1^I + vt_1^I(\cos\alpha-\sin\alpha) = \ell_1 \Rightarrow \; ct_1^I(1+\beta\cdot(\cos\alpha-\sin\alpha)) = \ell_1 \Rightarrow$$

$$ct_1^I = \frac{\ell_1}{1+\beta\cdot(\cos\alpha-\sin\alpha)}.$$

The distance traveled by light between mirrors S_3 and S_2, will be:

$$ct_2^I = L + vt_1^I(\cos\alpha-\sin\alpha) + (vt_1^I + vt_2^I)\cdot(\cos\alpha+\sin\alpha) \Rightarrow$$

$$ct_2^I = L + 2vt_1^I\cos\alpha + vt_2^I(\cos\alpha+\sin\alpha) \Rightarrow \; ct_2^I - vt_2^I(\cos\alpha+\sin\alpha) = L + 2vt_1^I\cos\alpha \Rightarrow$$

$$ct_2^I(1-\beta\cdot(\cos\alpha+\sin\alpha)) = L + 2ct_1^I\beta\cos\alpha \Rightarrow \; ct_2^I = \frac{L+2ct_1^I\beta\cos\alpha}{1-\beta\cdot(\cos\alpha+\sin\alpha)}.$$

The distance traveled by light from the mirror S_2 to the plate P_2, will be:

$$ct_3^I = \ell_1 - vt_3^I(\cos\alpha+\sin\alpha) \Rightarrow \; ct_3^I + vt_3^I(\cos\alpha+\sin\alpha) = \ell_1 \Rightarrow \; ct_3^I(1+\beta\cdot(\cos\alpha+\sin\alpha)) = \ell_1 \Rightarrow$$

$$ct_3^I = \frac{\ell_1}{1+\beta\cdot(\cos\alpha+\sin\alpha)}.$$

The distance traveled by the light from the plate P_2 to the screen will be:

$$ct_4{}^I = L + L_2 + \left(vt_1^I + vt_2^I + vt_3^I + vt_4^I\right)\cdot\cos\alpha - ct_2^I \Rightarrow$$

$$ct_4{}^I - vt_4^I\cos\alpha = L + L_2 - ct_2^I + \left(vt_1^I + vt_2^I + vt_3^I\right)\cdot\cos\alpha \Rightarrow$$

$$ct_4{}^I(1-\beta\cos\alpha) = L + L_2 - ct_2^I + \left(ct_1^I + ct_2^I + ct_3^I\right)\cdot\beta\cos\alpha \Rightarrow$$

$$ct_4{}^I(1-\beta\cos\alpha) = L + L_2 - ct_2^I(1-\beta\cos\alpha) + \left(ct_1^I + ct_3^I\right)\cdot\beta\cos\alpha \Rightarrow$$

$$ct_4{}^I = \frac{L + L_2 + \left(ct_1^I + ct_3^I\right)\cdot\beta\cos\alpha}{1-\beta\cos\alpha} - ct_2^I.$$

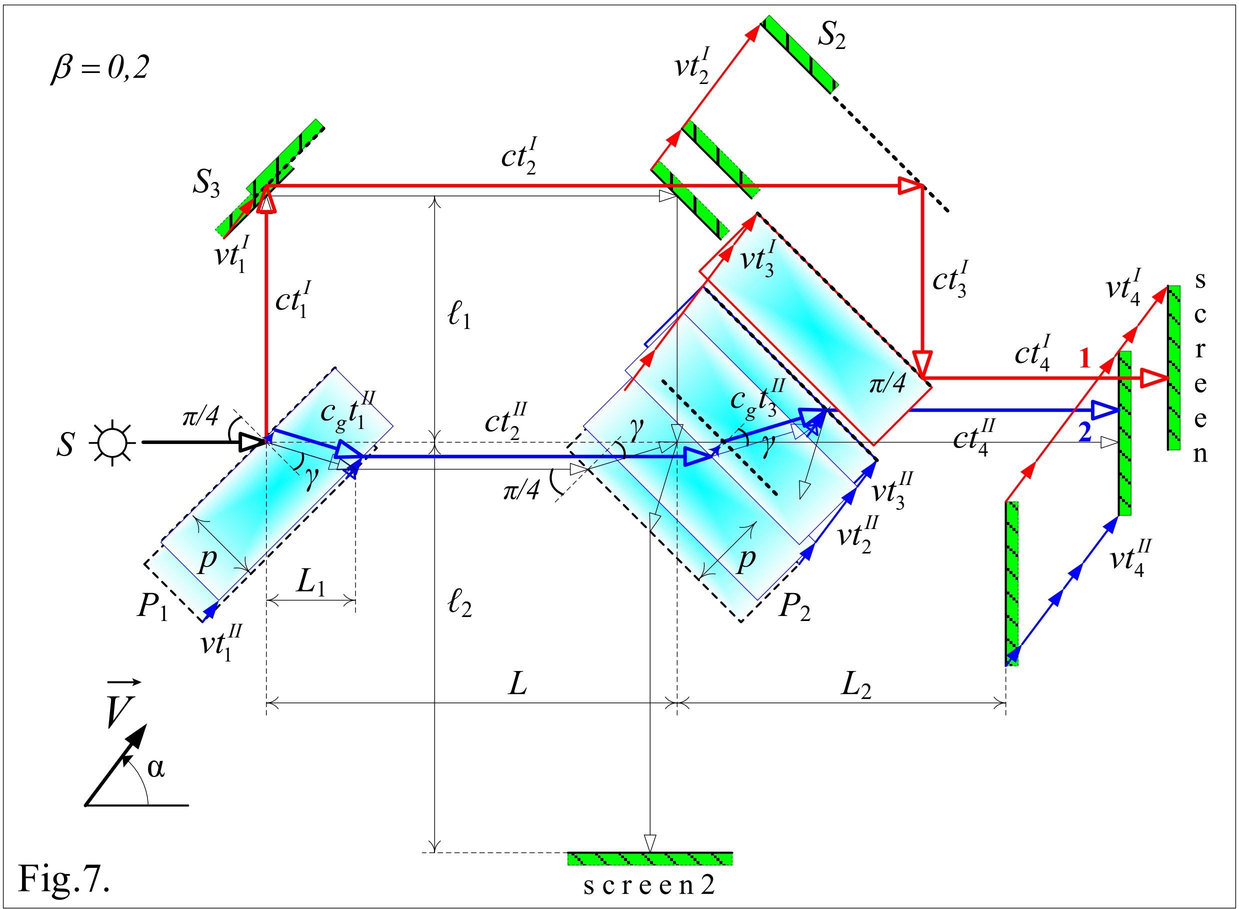

Fig.7.

Paths calculation of beam 2 in the air from plate P_1 to screen

The distance covered by the light in the plate P_1 in the forward direction will be:

$$c_g t_1{}^{II}\cos\gamma = p - \frac{vt_1{}^{II}}{n^2}\sin(\alpha-45) \Rightarrow c_g t_1{}^{II}\frac{r}{\sqrt{2}n} = p + \frac{vt_1{}^{II}}{n^2}\cdot\frac{\cos\alpha-\sin\alpha}{\sqrt{2}} \Rightarrow$$

$$ct_1{}^{II}r - vt_1{}^{II}(\cos\alpha-\sin\alpha) = \sqrt{2}n^2 p \Rightarrow c_g t_1{}^{II} = \frac{\sqrt{2}np}{r-\beta\cdot(\cos\alpha-\sin\alpha)}.$$

The distance traveled by light in the air between the plates P_1 and P_2 will be:

$$ct_2{}^{II} = L - 2L_1 - \left(c_g t_1{}^{II}\cos(45-\gamma) + kvt_1{}^{II}\cos\alpha - L_1\right) -$$

$$-\left(c_g t\sin(45-\gamma) - c_g t_1{}^{II}\sin(45-\gamma) + kvt_1{}^{II}\sin\alpha\right) + \left(vt_1{}^{II} + vt_2{}^{II}\right)\cdot(\cos\alpha+\sin\alpha) \Rightarrow$$

$$ct_2^{\,II} - vt_2^{\,II}(\cos\alpha + \sin\alpha) = L - L_1 - c_g t_1^{\,II}\frac{\cos\gamma + \sin\gamma}{\sqrt{2}} - kvt_1^{\,II}\cos\alpha -$$

$$-c_g t\frac{\cos\gamma - \sin\gamma}{\sqrt{2}} + c_g t_1^{\,II}\frac{\cos\gamma - \sin\gamma}{\sqrt{2}} - kvt_1^{\,II}\sin\alpha + vt_1^{\,II}(\cos\alpha + \sin\alpha) \Rightarrow$$

$$ct_2^{\,II}(1 - \beta\cdot(\cos\alpha + \sin\alpha)) = L - L_1 - c_g t\frac{\cos\gamma - \sin\gamma}{\sqrt{2}} - \sqrt{2}c_g t_1^{\,II}\sin\gamma -$$

$$-kvt_1^{\,II}(\cos\alpha + \sin\alpha) + vt_1^{\,II}(\cos\alpha + \sin\alpha) \Rightarrow$$

$$ct_2^{\,II}(1 - \beta\cdot(\cos\alpha + \sin\alpha)) = L - L_1 - c_g t\frac{r-1}{2n} - \sqrt{2}c_g t_1^{\,II}\sin\gamma + vt_1^{\,II}\frac{\cos\alpha + \sin\alpha}{n^2} \Rightarrow$$

$$ct_2^{\,II}(1 - \beta\cdot(\cos\alpha + \sin\alpha)) = L - L_1 - L_1\frac{r-1}{r+1} - c_g t_1^{\,II}\frac{1}{n} + c_g t_1^{\,II}\beta\frac{\cos\alpha + \sin\alpha}{n} \Rightarrow$$

$$ct_2^{\,II}(1 - \beta\cdot(\cos\alpha + \sin\alpha)) = L - 2L_1\frac{r}{r+1} - c_g t_1^{\,II}\frac{1 - \beta\cdot(\cos\alpha + \sin\alpha)}{n} \Rightarrow$$

$$ct_2^{\,II} = \frac{L - \sqrt{2}p}{1 - \beta\cdot(\cos\alpha + \sin\alpha)} - \frac{c_g t_1^{\,II}}{n}.$$

The distance traveled by the light in the plate P_2 will be:

$$c_g t_3^{\,II}\cos\gamma = p + \frac{vt_3^{\,II}}{n^2}\cos(\alpha - 45) \Rightarrow\ c_g t_3^{\,II}\frac{r}{\sqrt{2}n} = p + \frac{vt_3^{\,II}}{n^2}\cdot\frac{\cos\alpha + \sin\alpha}{\sqrt{2}} \Rightarrow$$

$$ct_3^{\,II}r - vt_3^{\,II}(\cos\alpha + \sin\alpha) = \sqrt{2}n^2 p \Rightarrow\ c_g t_3^{\,II} = \frac{\sqrt{2}np}{r - \beta\cdot(\cos\alpha + \sin\alpha)}.$$

The distance traveled by light in the air from the plate between the plate P_2 to the screen will be:

$$ct_4^{\,II} = L_2 - \left(vt_1^{\,II} + vt_2^{\,II} + vt_3^{\,II}\right)\cdot\sin\alpha + \left(c_g t_3^{\,II} - c_g t_1^{\,II}\right)\cdot\sin(45 - \gamma) + \left(vt_1^{\,II} + vt_3^{\,II}\right)\cdot k\sin\alpha + vt_4^{\,II}\cos\alpha$$

$$ct_4^{\,II} - vt_4^{\,II}\cos\alpha = L_2 - vt_2^{\,II}\sin\alpha + \left(c_g t_3^{\,II} - c_g t_1^{\,II}\right)\cdot\frac{\cos\gamma - \sin\gamma}{\sqrt{2}} - \frac{vt_1^{\,II} + vt_3^{\,II}}{n^2}\sin\alpha \Rightarrow$$

$$ct_4^{\,II}(1 - \beta\cos\alpha) = L_2 - ct_2^{\,II}\beta\sin\alpha + \left(c_g t_3^{\,II} - c_g t_1^{\,II}\right)\cdot\frac{r-1}{2n} - \left(c_g t_1^{\,II} + c_g t_3^{\,II}\right)\cdot\frac{\beta\sin\alpha}{n} \Rightarrow$$

$$ct_4^{\,II}(1 - \beta\cos\alpha) = L_2 - ct_2^{\,II}\beta\sin\alpha - c_g t_1^{\,II}\frac{r - 1 + 2\beta\sin\alpha}{2n} + c_g t_3^{\,II}\frac{r - 1 - 2\beta\sin\alpha}{2n}.$$

Then the difference of the two light paths in the directions will be:

$$c\Delta_\alpha t = \left(ct_1^{\,I} + ct_2^{\,I} + ct_3^{\,I} + ct_4^{\,I}\right) - \left(\left(c_g t_1^{\,II} + c_g t_3^{\,II}\right)\cdot n + ct_2^{\,II} + ct_4^{\,II}\right).$$

Calculation, drawing and results

The data for drawing are given in Table 1, line 1 (Fig.7), and the calculated length of the paths of light is given in Table 2, line 1, in mm also. The lengths of both the light paths and optical elements of the interferometer directed at an angle α are built with an accuracy of $\pm 1\,\mu$m. The derivation of the equations was carried out according to the laws of linear optics. Their verification was carried out by constructing the lengths of the light paths calculated according to these equations in the direction of the rays to the contact lines of the corresponding element of the interferometer, that passed its path. If the length of the light according to the drawing was equal to the length calculated according to the equation, then it was taken to be true. Obtained equations were checked with a drawing with a different angle *α* of the direction of motion of the interferometer. When the lengths of the light paths coincided with the lines of the interferometer elements, a real interferometer was calculated from these equations, data are given in the Table 1, line 2. Based on obtained equations, the calculation was carried out in *Microsoft Excel*. To rotate the interferometer by an angle *α*, the length of the light path is given in meters, Table 2, columns 4 – 14. Paths to screen 2 were not calculated.

Table 1.

№ п/п	β	n	r	p	L	L_1	L_2	ℓ_1	ℓ_2
1	0,2	1,50	1,8708	10 *мм*	50 *мм*	10,8507 *мм*	40 *мм*	30 *мм*	50 *мм*
2	0,0001	1,50	1,8708	0,001 *м*	0,100 *м*	0,0010851 *м*	0,100 *м*	0,050 *м*	0,050 *м*

Table 2.

α, °	*cosα*	*sinα*	ct_1^I	ct_2^I	ct_3^I	ct_4^I	$\Sigma ct_{1\text{-}4}^I$	$c_g t_1^{II}$	ct_2^{II}
53,1301	0,600	0,800	31,2500	79,8611	23,4375	29,8690	164,4176	11,1016	42,4015
1	2	3	4	5	6	7	8	9	10
0,0	1,000	0,000	0,0500	0,1000	0,0500	0,1000	0,300020	0,0011	0,0978
22,5	0,924	0,383	0,0500	0,1000	0,0500	0,1000	0,300018	0,0011	0,0978
45,0	0,707	0,707	0,0500	0,1000	0,0500	0,1000	0,300014	0,0011	0,0978
67,5	0,383	0,924	0,0500	0,1000	0,0500	0,1000	0,300008	0,0011	0,0978
90,0	0,000	1,000	0,0500	0,1000	0,0500	0,1000	0,300000	0,0011	0,0978
112,5	-0,383	0,924	0,0500	0,1000	0,0500	0,1000	0,299992	0,0011	0,0978
135,0	-0,707	0,707	0,0500	0,1000	0,0500	0,1000	0,299986	0,0011	0,0978
157,5	-0,924	0,383	0,0500	0,1000	0,0500	0,1000	0,299982	0,0011	0,0978
180,0	-1,000	0,000	0,0500	0,1000	0,0500	0,1000	0,299980	0,0011	0,0978
202,5	-0,924	-0,383	0,0500	0,1000	0,0500	0,1000	0,299982	0,0011	0,0978
225,0	-0,707	-0,707	0,0500	0,1000	0,0500	0,1000	0,299986	0,0011	0,0978
247,5	-0,383	-0,924	0,0500	0,1000	0,0500	0,1000	0,299992	0,0011	0,0978
270,0	0,000	-1,000	0,0500	0,1000	0,0500	0,1000	0,300000	0,0011	0,0978
292,5	0,383	-0,924	0,0500	0,1000	0,0500	0,1000	0,300008	0,0011	0,0978
315,0	0,707	-0,707	0,0500	0,1000	0,0500	0,1000	0,300014	0,0011	0,0978
337,5	0,924	-0,383	0,0500	0,1000	0,0500	0,1000	0,300018	0,0011	0,0978
360,0	1,000	0,000	0,0500	0,1000	0,0500	0,1000	0,300020	0,0011	0,0978

As can be seen at different angles of rotation of the interferometer, the difference in light paths in the directions $c\Delta_\alpha t$ varies by a value of 1×10^{-11}m, column 14, table 2. As the distance ℓ_1 increases by 10, 100 times or more, the difference in light paths remains unchanged. Increasing the speed of the interferometer (β=0,001) by 10 times increases the change in path difference by 100 times to a value of 1×10^{-9}m. The difference of light paths in width fractions of the interference band $\Delta_\alpha t/T$ was calculated by the formula:

$\frac{\Delta_\alpha t}{T} = \frac{c\Delta_\alpha t - \ell_{const.}}{\lambda} < 1{,}0$, where: λ – wavelength of light, $\ell_{const.}$ – a constant of length.

As a constant of length $\ell_{const.}$, which depends on the value of the length ℓ_1, the difference in light paths $c\Delta_\alpha t$ was denoted to an accuracy of 1 µm, that is, till the 6th sign of the fractional part of numbers, column 14, table 2. For lengths ℓ_1=0,05m; 0,5m and 5,0m constants are selected $\ell_{const.}$=0,098768m; 0,998768m and 9,998768m, respectively. For different lengths ℓ_1 and interferometer relative velocities (β=0,0001; 0,001) at the wavelength of λ=630nm, the difference of paths in fraction of the band width $\Delta_\alpha t/T$ is given in table 2, columns 15 – 18 and, as you can see, its amplitude depend on the speed v. Amplitude of path difference in bandwidth fractions (interference band displacement) $\Delta_\alpha t/T$ for β=0,0001 and different lengths ℓ_1 is: 1,6÷2,7×10^{-5}, columns 15, 17 and 18, but for β=0,001 and different lengths ℓ_1 – 161×10^{-5}, column 16. The difference in light paths is not affected by the length values L and L_2.

Table 2 (ctd).

α, °	$c_g t_3^{II}$	ct_4^{II}	Σct_{1-4}^{II}	$c\Delta_\alpha t$	$\Delta_\alpha t/T$			
					ℓ_1= 0,05м		β= 0,0001	
	13,3347	35,5198	114,5757	49,8419	β= 0,0001	β= 0,001	ℓ_1= 0,5м	ℓ_1= 5,0м
1	11	12	13	14	15	16	17	18
0,0	0,0011	0,1000	0,201252	0,09876846326	0,735330	0,893509	0,749616	0,892473
22,5	0,0011	0,1000	0,201250	0,09876846326	0,735328	0,893231	0,749613	0,892466
45,0	0,0011	0,1000	0,201246	0,09876846325	0,735322	0,892594	0,749607	0,892454
67,5	0,0011	0,1000	0,201239	0,09876846325	0,735316	0,892035	0,749601	0,892449
90,0	0,0011	0,1000	0,201232	0,09876846325	0,735314	0,891904	0,749600	0,892457
112,5	0,0011	0,1000	0,201224	0,09876846325	0,735316	0,892243	0,749603	0,892470
135,0	0,0011	0,1000	0,201217	0,09876846325	0,735322	0,892818	0,749609	0,892476
157,5	0,0011	0,1000	0,201213	0,09876846326	0,735328	0,893314	0,749614	0,892475
180,0	0,0011	0,1000	0,201212	0,09876846326	0,735330	0,893506	0,749616	0,892473
202,5	0,0011	0,1000	0,201213	0,09876846326	0,735328	0,893314	0,749614	0,892475
225,0	0,0011	0,1000	0,201217	0,09876846325	0,735322	0,892818	0,749609	0,892476
247,5	0,0011	0,1000	0,201224	0,09876846325	0,735316	0,892243	0,749603	0,892470
270,0	0,0011	0,1000	0,201232	0,09876846325	0,735314	0,891904	0,749600	0,892457
292,5	0,0011	0,1000	0,201239	0,09876846325	0,735316	0,892035	0,749601	0,892449
315,0	0,0011	0,1000	0,201246	0,09876846325	0,735322	0,892594	0,749607	0,892454
337,5	0,0011	0,1000	0,201250	0,09876846326	0,735328	0,893231	0,749613	0,892466
360,0	0,0011	0,1000	0,201252	0,09876846326	0,735330	0,893509	0,749616	0,892473
Амплитуда				1,0×10^{-11}	1,6×10^{-5}	160×10^{-5}	1,6×10^{-5}	2,7×10^{-5}

3.3. Conducted experience and result

The scheme of interferometer according the variant 2 was implemented at home, and an experience was conducted in February 2018. It included optical elements:

beam-splitting plane-parallel plates and mirrors of the *Carl Zeiss Jena* brand (Dresden, GDR), a scattering lens, and a green semiconductor laser (Finland) with a wavelength of λ=532nm ±10 as a light source. Optical elements and laser were fixed on a laminate plate 8mm thick, Fig.8. The low coefficient of thermal linear expansion of the wood fiber laminate material, comparable to invar, reduced the likelihood of thermal change in distances between optical elements.

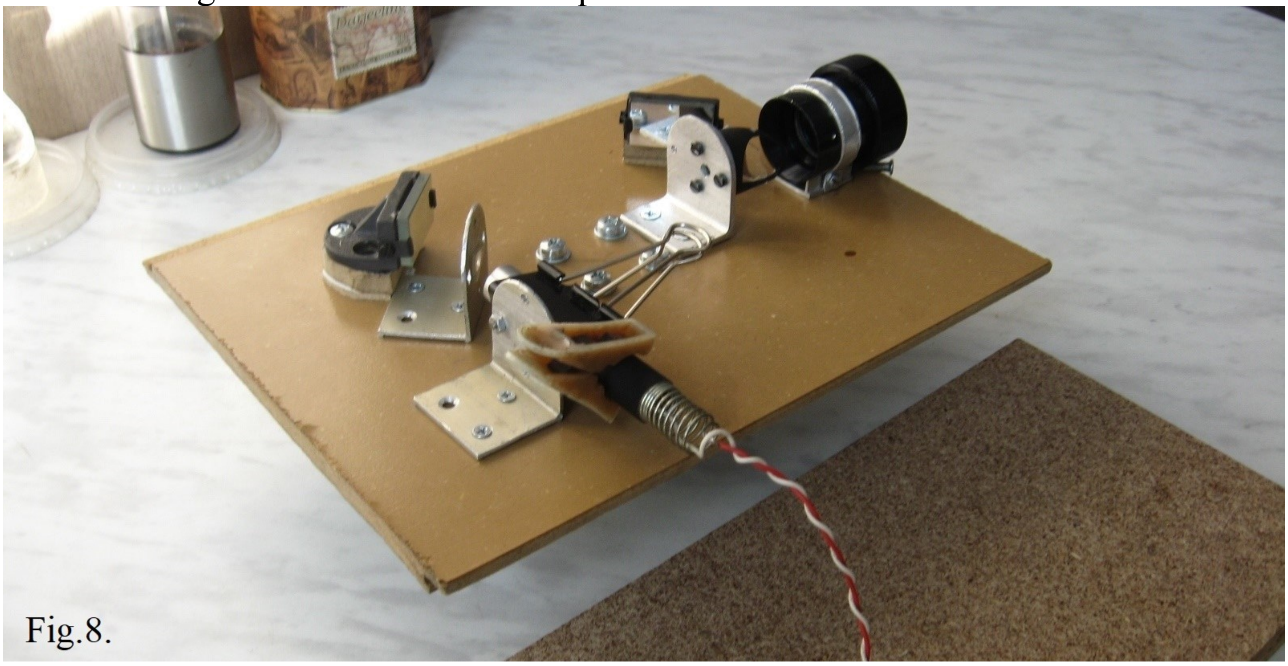

Fig.8.

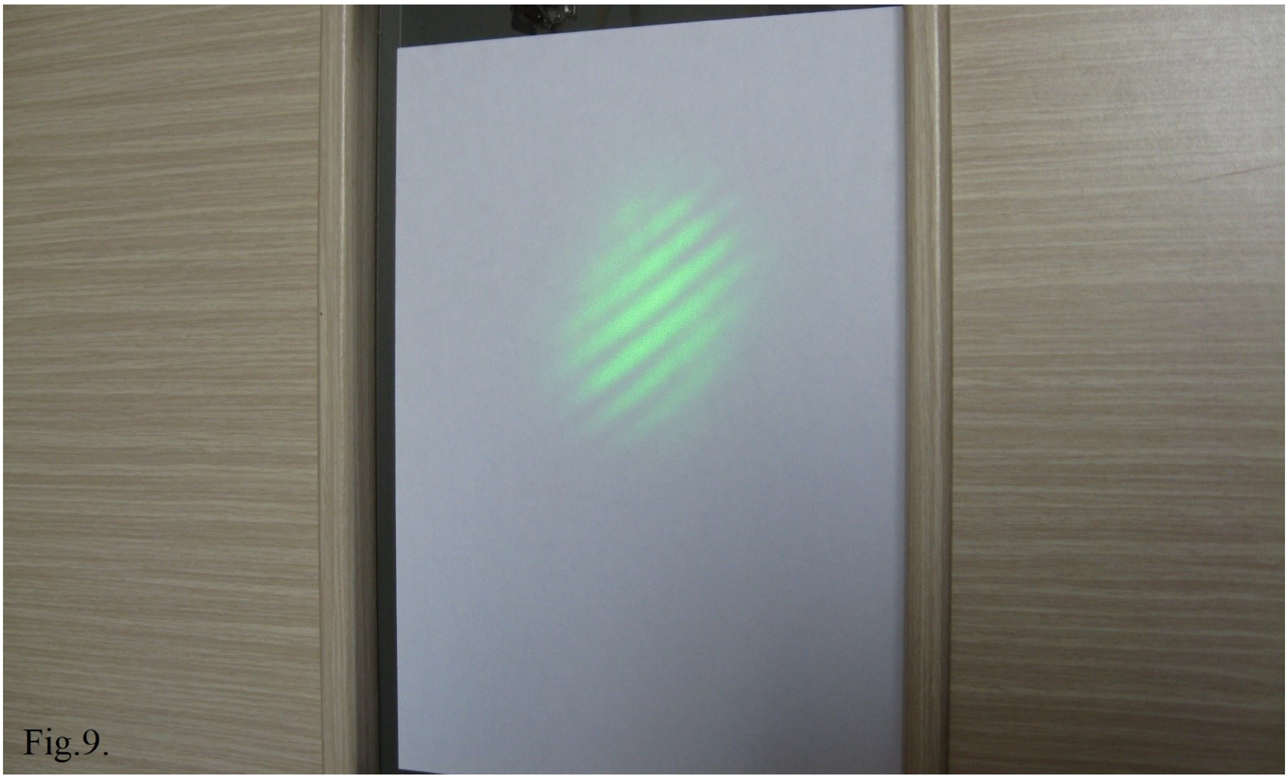

Fig.9.

The plate P_2 split again the rays of light going away in pairs at right angles. Each pair of points in the directions was reduced to one point, which ensured that the plane of rotation of the interferometer was parallel to the rays passing between the optical elements. A scattering lens was installed on the path of the rays of one direction, and an interference pattern appeared on the screen (sheet of paper), Fig.9.

Scattering lens was not installed on the path to the screen 2 of the rays of another direction, but their convergence at a point was controlled. The laminate plate had a vertical axis of rotation on the bearing, providing its smooth rotation in a horizontal plane, which excluded the effect of gravity on the mechanical structure of the interferometer and the mechanical change in distances between optical elements, as occurs when rotating in an inclined or vertical plane, parallel to which light rays propagate.

The experience showed no change in the position of the interference bands during the rotation of the interferometer. Repeating the experience at different times of the day and on different days did not give also visible shifts in the stripes. The negative result of the experiment is confirmed by exact calculation given above for wavelength λ=630nm. The physical formalism used as a method of calculation without attracting an additional hypothesis does not explain the negative result of the experience, therefore, this method is erroneous.

4. Variant 3. Ray Collection Point – Vertex *C*

In the third variant, Fig.10, each beam of the beam split by the beam splitting plate P_1 at point A goes along its semi-perimeter of the rectangle and at point C of the plate P_2, meeting, is split again into two beams and they already go in pairs to screens, where they interfere.

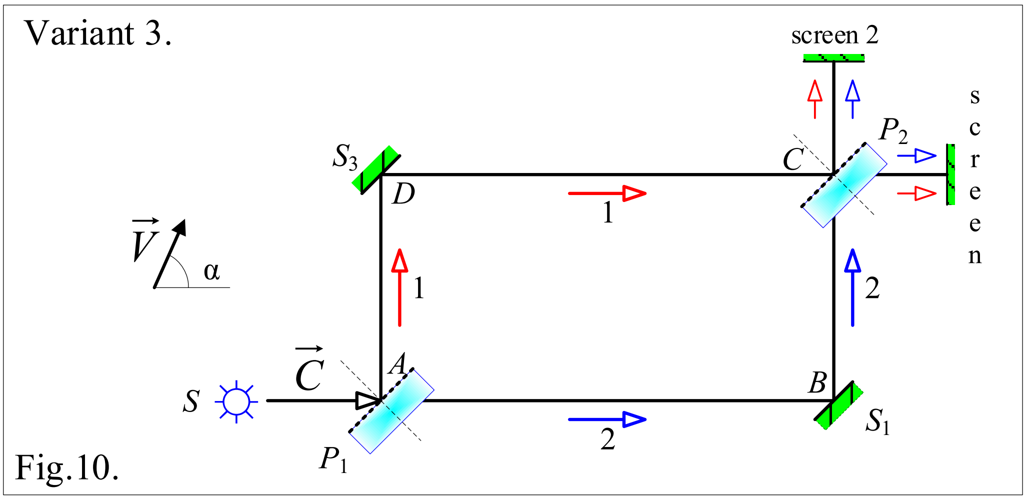

Fig.10.

The diagram shows that on the parallel sides of the rectangle the paths of different rays coincide in direction. Formally, it can be considered that their lengths are also equal, although in reality this is not the case, as it is shown by an exact calculation. Nevertheless, the difference in paths traveled by the beams on the semi-perimeters will not change when the interferometer is rotated by an angle α and will remain the same as when setting up the device. It can be said that on the sides of the rectangle, the path length of each beam changes so that the sum of their paths to the screen remains unchanged. Experiments conducted with a similar scheme in the 20th century gave a negative result – there were no displacements in the bands by rotating the interferometer.

5. Variant 4. Ray Collection Point – vertex *A*

5.1. Analogues of the diagram and calculation by the method of physical formalism

This variant is similar to variant 3, and is characterized in that the square pattern is folded on the diagonal going through vertices *B* and *D*, Fig.11. The plate P_2 coincides with the plate P_1, and the mirrors S_1 and S_3 are deployed on 45° in the direction of bent sides. As a result, each beam of the beam split by the beam splitting plate P_1 goes to its mirror and, reflecting, returns to it, splitting again into two beams going in pair to the screen and the source *S*, where they interfere.

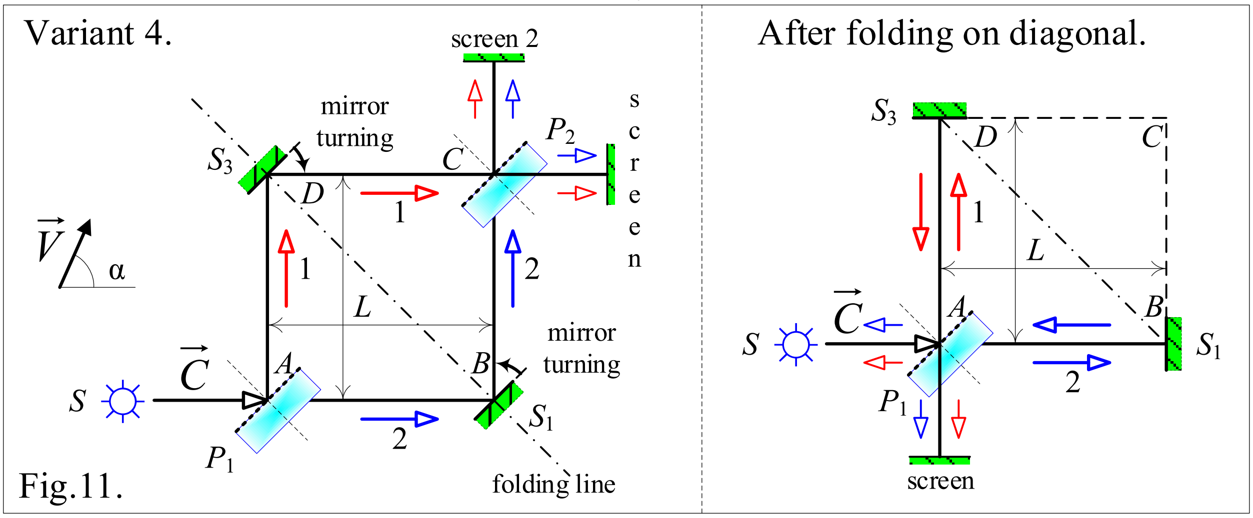

Fig.11.

If the schematic diagram of this variant is similar to the scheme of variant 3, then the calculation by the method of physical formalism coincides with the calculation for variant 2 and a physical formula would takes the following form at the corresponding angles *α* of rotation of the interferometer:

$$\underbrace{(c\,{\uparrow}{+}{\downarrow} - c\,{\rightleftarrows})}_{\alpha = 0^\circ} - \underbrace{(c\,{\rightleftarrows} - c\,{\uparrow}{+}{\downarrow})}_{\alpha = 90^\circ} = \underbrace{2\cdot(c\,{\uparrow}{+}{\downarrow} - c\,{\rightleftarrows})}_{\alpha = 0^\circ \rightarrow 90^\circ}$$

We convert the physical formula to mathematical, as shown in Fig.6. When setting the interferometer *α*=0°, the path difference will be:

$$c\Delta t_{0^\circ} = c\Delta t_1 - c\Delta t_2 = 2L\cdot\left(\frac{1}{\sqrt{1-\beta^2}} - \frac{1}{1-\beta^2}\right) \text{ or } c\Delta t_{0^\circ} \cong L\beta^2 .$$

When the interferometer is rotated by an angle *α*=90°, the *cΔt* sign will change and the total difference $c\Delta t_{0°\text{-}90°}$ will double:

$$c\Delta t_{0°-90°} = c\Delta t_{0°} - c\Delta t_{90°} = 4L \cdot \left(\frac{1}{\sqrt{1-\beta^2}} - \frac{1}{1-\beta^2} \right) \text{ or } c\Delta t_{0°-90°} \cong 2L\beta^2 .$$

As a result, the displacement of the interference strips during the rotation by 90° is twice as large as in variant 2 with the same calculation method.

5.2. Conducted experiments, results and conclusions

Michaelson's experiment of 1881

The scheme of this variant was first implemented by A.A. Michaelson [3] in his experiments of 1881 in Berlin using the compensating plate *g*, Fig.12. Only the speed of the Earth's motion in its orbit was taken into account. Two beams of light in the interferometer travel twice a distance at right angles and interfere with each other. Beam 2 (Fig.11), which passes in the direction of the Earth's movement – to the mirror *c* (S_1), will actually pass for a fraction of the wavelength more than it would have passed, if the Earth had been in the state of rest. When setting the interferometer α=0°, the path of light going in the direction of the Earth's movement at Michaelson was:

$$ct_2' = \frac{L}{1-\beta} \text{ and } ct_2'' = \frac{L}{1+\beta}, \text{ and the sum } c\Delta t_2 = ct_2' + ct_2'' = L \cdot \left(\frac{1}{1-\beta} + \frac{1}{1+\beta} \right) \Rightarrow$$

$$c\Delta t_2 = \frac{2L}{1-\beta^2} .$$

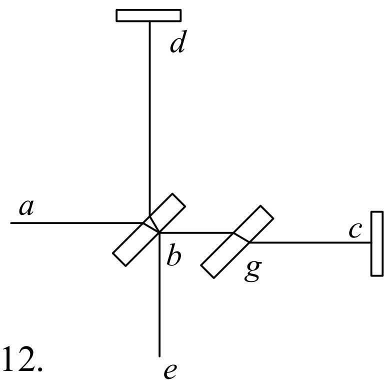

Fig.12.

However, if beam 1 has passed in a direction at right angles to the motion of the Earth, it will be free from influence of this motion. The path of light in the both forward and reverse directions was: $c\Delta t_1 = ct_1' + ct_1'' = 2L$.

According to this Michaelson's claim, the light moved not only at a right angle to the Earth's movement – to the mirror *d* (S_3), but also experienced movement by inertia in the direction of the Earth's movement together with the interferometer, that is, it propagated as a corpuscle and not as a wave, Fig.13.

In addition, he had a path difference when adjusting the interferometer α=0°:

$$c\Delta t_{0^\circ} = c\Delta t_2 - c\Delta t_1 = \frac{2L}{1-\beta^2} - 2L \Rightarrow c\Delta t_{0^\circ} = 2L\frac{\beta^2}{1-\beta^2}.$$

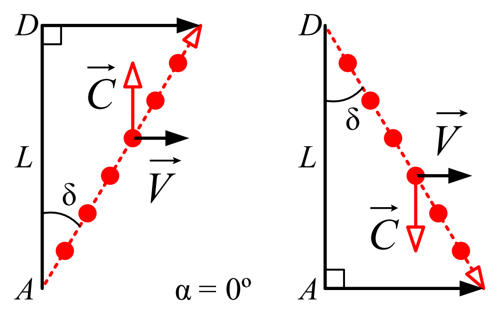

Fig.13.

When the interferometer is rotated by an angle α=90°, beam 2 moved now like a corpuscle, and beam 1 – like a wave:

$$c\Delta t_{90^\circ} = 2L - \frac{2L}{1-\beta^2} \Rightarrow c\Delta t_{90^\circ} = 2L\frac{-\beta^2}{1-\beta^2}.$$

The total difference $c\Delta t_{0^\circ\text{-}90^\circ}$ was doubled when turning the interferometer:

$$c\Delta t_{0^\circ-90^\circ} = c\Delta t_{0^\circ} - c\Delta t_{90^\circ} = 4L\frac{\beta^2}{1-\beta^2}.$$

The ethereal wind was not discovered in experiments, a physical intuition led Michaelson to this conclusion, more likely. In fact, a series of experiments in 1881 could not be considered convincing: with the length of the arms of the first interferometer 1,2m, expected displacement was 0,040 stripes, and the observed – 0,034.

In the winter of the same 1881, M.A. Potier, Paris, noted a mistake in the calculation. The same Michaelson error, as a result of which the amount of displacement was 2 times greater than the value following from the theory, was pointed out by G.A. Lorenz [4]. If you make this amendment, expected result will be the same order as the measurement error.

Michaelson experiment of 1887

In 1887, Michaelson [5] repeated the experience in Cleveland using the same scheme, Fig.14. However, to increase the displacement the path length using the mirror system was increased to 11m, what followed from his calculations. In the new article, he paid attention to the propagation of light in the direction of the Earth's movement again, describing in detail calculation of the path of beam 2 to mirror c (S_1) and vice versa. Time to move back and forth at Michelson was:

$\mathrm{T} = \frac{\mathrm{D}}{\mathrm{V} - v}$ and $\mathrm{T}_1 = \frac{\mathrm{D}}{\mathrm{V} + v}$. Full traveling time is: $\mathrm{T} + \mathrm{T}_1 = 2\mathrm{D} \cdot \frac{\mathrm{V}}{\mathrm{V}^2 - v^2}$,

the distance travelled during this time is:

$2\mathrm{D} \cdot \frac{\mathrm{V}^2}{\mathrm{V}^2 - v^2} = 2\mathrm{D} \cdot \left(1 + \frac{v^2}{\mathrm{V}^2}\right)$, with neglect of the members of the fourth order.

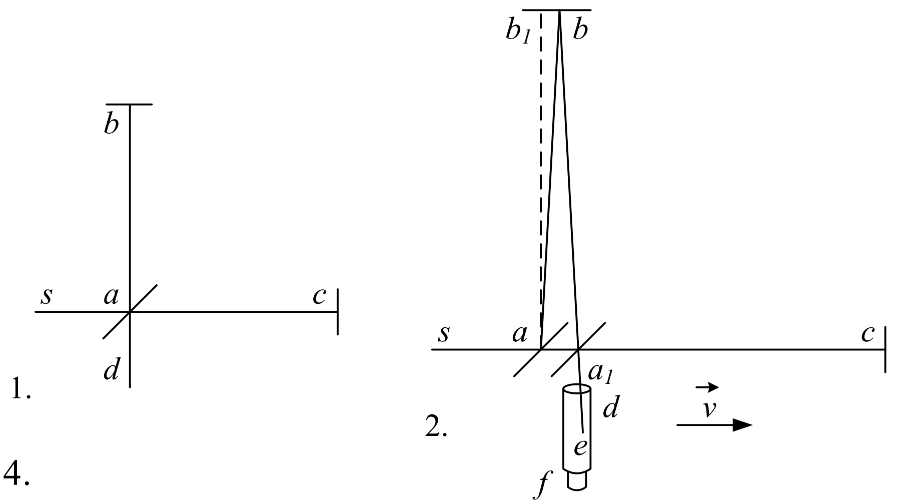

Fig.14.

Let us write down his formulas in a new way: D (L) – distance to mirrors c, b (S_1, S_3), V (c) – light velocity. Then the distance travelled by beam 2 will be:

$$c\Delta t_2 = 2L \cdot \frac{1}{1-\beta^2} \cong 2L \cdot \left(1+\beta^2\right).$$

Then, according to Michelson, "the length of the other path is *obviously* equal":

$$2D\sqrt{1+\frac{v^2}{\mathrm{V}^2}} \text{ or } c\Delta t_1 \cong 2L \cdot \sqrt{1+\beta^2}\ .$$

Then, according to its equation wrote in a new way, the path length of beam 1 will be:

$$c\Delta t_1 = 2L \cdot \frac{1}{\sqrt{1-\beta^2}} \cong 2L \cdot \sqrt{1+\beta^2}\text{ , or with the same precision } c\Delta t_1 \cong 2L \cdot \left(1+\frac{\beta^2}{2}\right).$$

Therefore, the path difference in the setting of the interferometer α=0° is:

$$c\Delta t_{0^\circ} = c\Delta t_1 - c\Delta t_2 = 2L \cdot \left(\frac{1}{\sqrt{1-\beta^2}} - \frac{1}{1-\beta^2}\right) \Rightarrow c\Delta t_{0^\circ} \cong L\beta^2\text{, and in his writing } \mathrm{D}\frac{v^2}{\mathrm{V}^2}.$$

Further, Michaelson writes: "If you turn the entire device now by 90°, then the difference will be observed in the opposite direction; therefore, the shift of interference band must be $2\mathrm{D}v^2/\mathrm{V}^2$" or $2L\beta^2$ in a new entry.

This calculation of Michaelson points to the remaining problem – unresolved question of the propagation of light in the transverse direction to the movement of the Earth. He writes: "The beam *sa* is reflected along *ab* (Fig.14.2.), and also the angle bab_1 is equal to the aberration angle α, returns along ba_1 ($aba_1 = 2\alpha$) and falls into the focus of the visual tube, *the direction of which does not change*".

Therefore, let us consider the phenomenon of astronomical aberration as it really is, Fig.15. The light receiver (telescope) T moves relative to the source S at a certain speed v. A distant star serve as a light source S, the speed of which can be neglected due to its remoteness in an accurate calculation. The telescope tube T should be directed at the star S in the true position at an angle δ, so that the beam incident perpendicular to the direction of movement of the telescope passes into the tube T'.

When the direction of movement of the telescope T is reversed, its tube should be deflected to the other side by the same angle δ. The difference in directions of telescope at an angle 2δ will be observed astronomical aberration. The angle of aberration δ is associated with both the speeds of the receiver v and the light c tangentially $tg\delta=\beta$. If the telescope tube T is directed perpendicular to its movement, then the light coming from the star also perpendicular will not pass into it. Of course, this is possible at comparable speeds of both receiver and light, or at a very small diameter of the telescope tube.

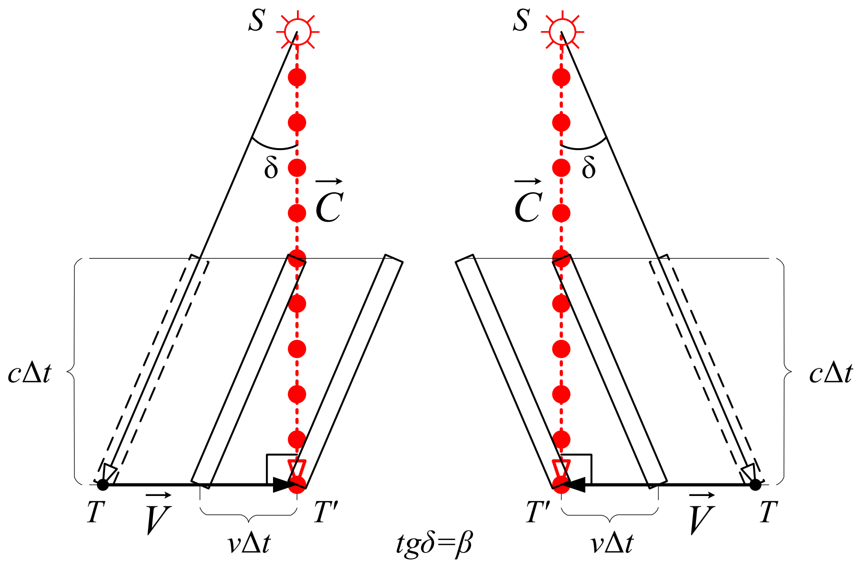

Fig.15.

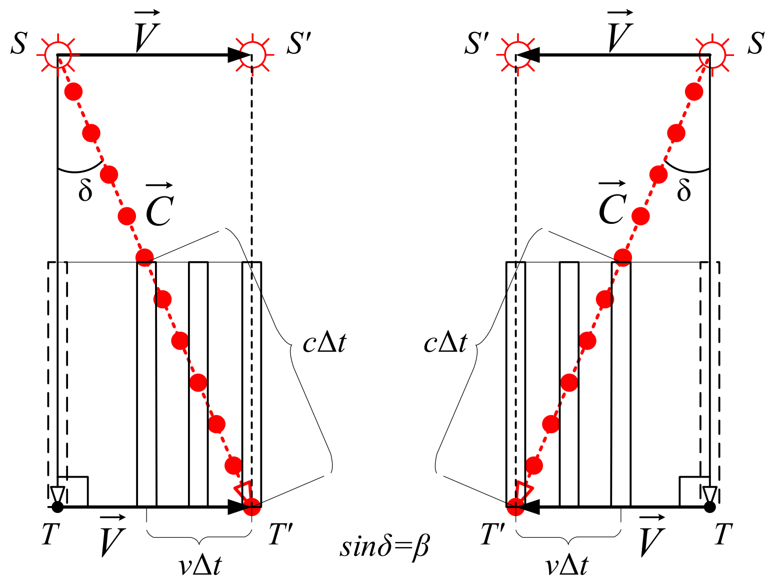

Fig.16.

Consider the second possible variant of this phenomenon, Fig.16. Receiver T and light source S or the light reflecting body move at equal speeds v. We assume that receiver T and light source S they are located on the line geometrically perpendicular to their movement, the distance between them is acceptable for observation. The receiver tube *T* should be directed to light source *S* in true position perpendicular to motion, so that the beam incident at an angle δ passes into it *T′*. Rays incident perpendicular or at other angles do not pass into the receiver tube.

After changing direction of motion of both receiver *T* and source *S*, the direction of the receiver tube will not change and the aberration discussed in the first case is not observed. This angle δ of the input of the beam into the tube is also associated with the speeds of both light *c* and receiver *v*, but sinusoidal $\sin\delta=\beta$. This fact has been repeatedly tested on experience. In addition, if such an "aberration" were observed, it would be noticed during construction in ancient times. However, buildings and structures built at different times of the day for different directions of the receiver and source speeds did not show deviations in geometry even with low construction accuracy. Thus, as it is impossible to detect the angle δ of the beam input to the receiver, the change in the difference in light paths by the interferometer of any classical circuit cannot be detected, and the distances between the receiver and the light source are not significant in this case.

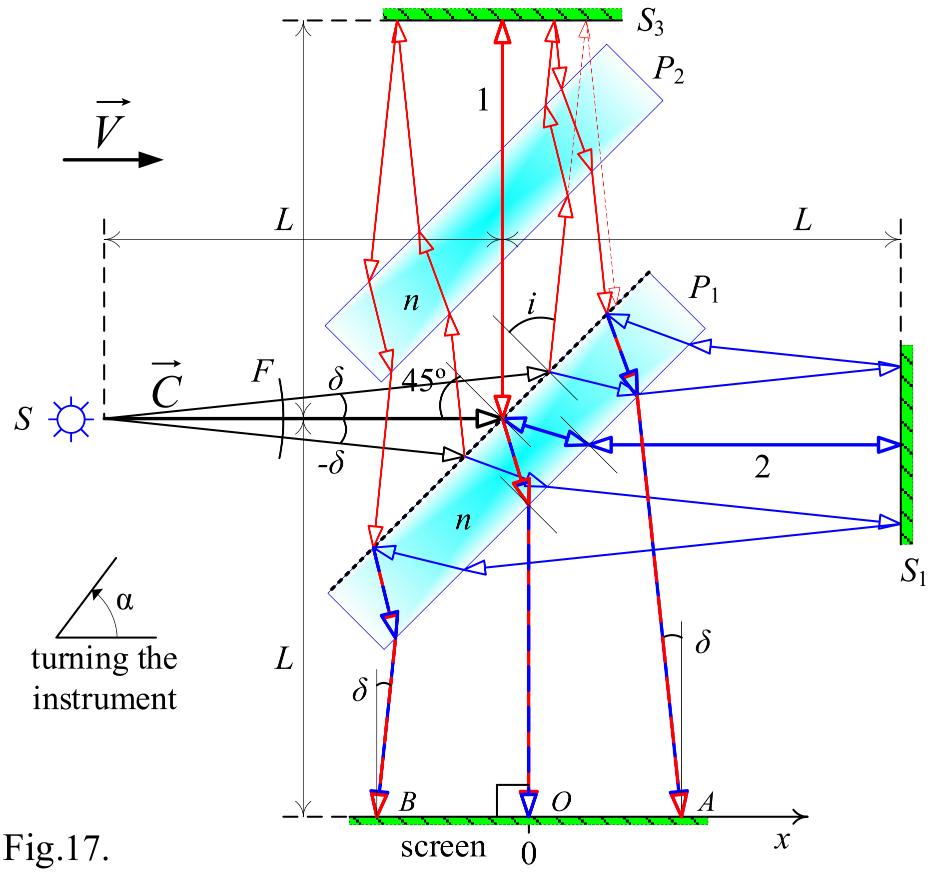

Fig.17.

The Michaelson interferometer is a second case of aberration, and he writes that the direction of the visual tube does not change. Therefore, the beam 1 selected by him and reflected by the plate P_1 to the mirror S_3, and the beam incident on the plate from the source *S* are beams of the front of the light *F* of an angle $i=45°+\delta$. The beam 2 going in the direction of the movement of the Earth is a beam of the front of the light of another angle i=45°. Let us follow the path of the rays in the interferometer before the fall on the screen according to the drawing made with an accuracy of ±1µm, Fig.17.

It can be seen from the drawing, that the rays of the front F are split into rays, which, having passed the plates and reflected from the mirrors, meet on the screen at the same points and interfere with each other. Michaelson has the same beam 2, as the beam split from the central beam of the front F with an angle of i=45°, falls on the screen at point O, and beam 1 – at an angle i=45°+δ, where δ the aberration angle, falls on the screen already at point A and therefore, they do not interfere with each other.

After turning the device, it reverses the selected beams for calculation so that beam 1 already with an angle of i=45° falls on the screen at point O, and beam 2 with an angle i=45°-δ – to the point B. Or if the instrument is rotated in the opposite direction, beam 2 with an angle i=45°+δ falls on the screen at point A and in both cases they do not interfere again with each other, Fig.18.

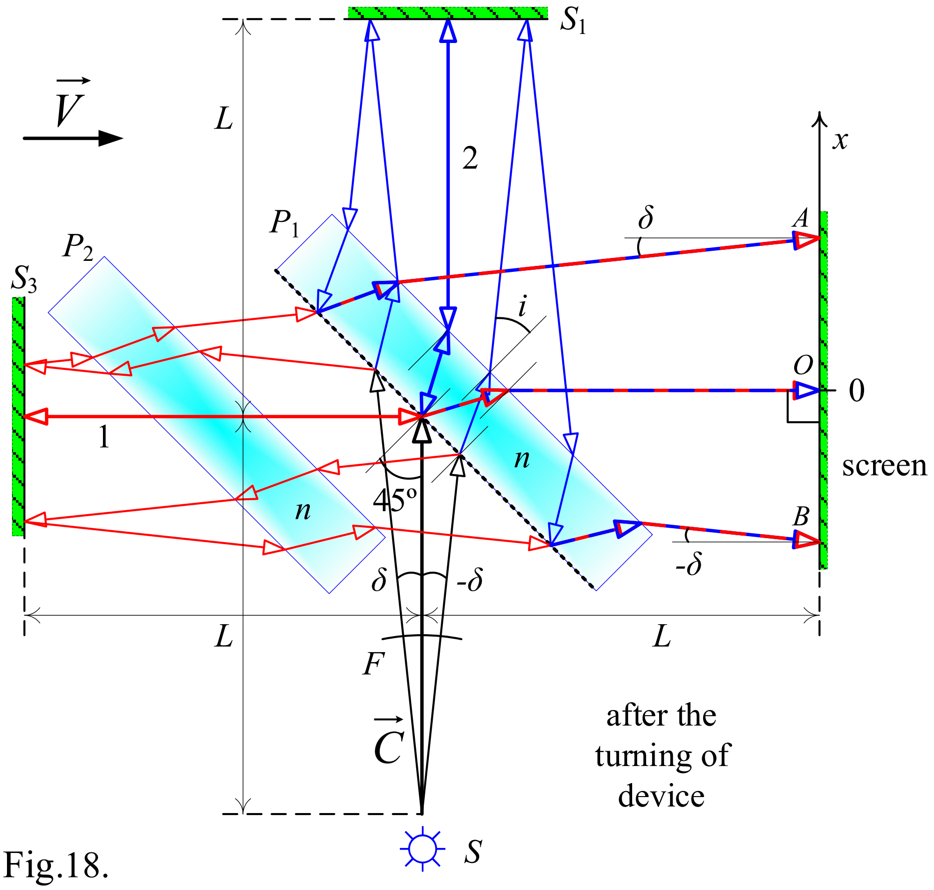

Fig.18.

From what follows that Michaelson's calculation is an exact copy of the method of physical formalism and, as was shown in the calculation of scheme 2, in his interferometer during rotation, the difference in the path of the rays with any angle of the front F will always remain initially set and the compensating plate P_2 affects this difference only when adjusting.

Results and conclusions

Thus, the Michaelson's calculating the displacement of the strips during the rotation of the interferometer served as the basis for Lorentz [6] to introduce the "Fitzgerald-Lorentz contraction" of the sizes of bodies in the direction of movement. He writes: "The difference in the passage times of perpendicular light beams in the Michaelson interferometer due to the influence of the Earth's movement can be compensated if the geometric length of the path, which takes longer to travel, decreases by an amount in relation $1:\sqrt{1-\beta^2}$ due to the movement. Then the rotation of device will not affect the position of the interference bands in any way, which corresponds to Michaelson's data". Subsequently, this interpretation has become a key in the coordinate transformations outlined by Lorentz. Since the example of calculating the scheme of variant 2 is completely similar to the method of physical formalism of variant 4, the exact calculation of variant 2, but applicable to the Michelson interferometer scheme should be taken in the same way. Then zero result of the experience will not require the reduction in the size of bodies in the direction of movement.

Thus, not completed by Michaelson accurate calculation before experience contributed to the appearance of the unreasonable Lorentz hypothesis, which led him to the incorrect transformation of coordinates.

Conclusions

1. An inaccurate calculation of Michaelson's experience led to an unjustified hypothesis – "Fitzgerald-Lorentz's contracting".
2. The erroneous hypothesis formed the basis of Lorentz incorrect transformations.
3. Classical interferometers do not measure the velocity of bodies.
4. Non-classical interferometers measure the absolute velocity of bodies.

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