THE MICHELSON-MORLEY EXPERIMENT

INTERPRETED AS IT SHOULD BE

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Summary. *In this paper I explain why interference fringes should not move when rotating Michelson's interferometer.*

The translational motions of the mirrors can produce rotating effects for these mirrors. When the interferometer rotates, the sections of the coherent beams that overlap and interfere, always change. Changes in the light beams travel time through the interferometer arms and the rotating effects of mirrors produce inverse effects on the fringes. These effects cancel each other out.

Keywords*: Michelson, interferometer, interference fringes, mirror rotation effect.*

INTRODUCTION

In order to understand and explain the complex phenomena taking place in a Michelson interferometer, the behaviour of the components of this device must be carefully analyzed: Mirrors, transparent medium, in various situations. The Huygens principle was used to treat reflections and refractions.

In the reflection case, the result of the process that occurs on a section of the mirror where the wavefront struck at a given time, is combined with the result of the process that occurs on the adjacent section of the mirror where the incident wavefront struck at the next moment, and so on.

If the mirror is at rest, or if the mirror moves on a line contained in its plane, or at normal incidence, the mirror sections touched by the incident beam, describe the surface of the mirror itself. This surface corresponding to the surface of the mirror reflects light.

If the mirror moves differently, the sections "swept" by the incident light beam, although they are of the mirror, but at different times and positions, describe a surface that no longer coincides with the surface of the mirror. Therefore, the motion of the mirror can generate rotating effect. The incident and reflection angles must be re-evaluated because the rotated surface actually reflects light.

The surfaces of the transparent media also undergo the rotational effect due to their movement, but when the light is refracted through them, the incident and refraction angles are re-evaluated, respecting the known laws.

The rotating effects of the mirrors, given the simultaneous movement with the Earth, bring new causes for the movement of the fringes in the case of Michelson-Morley experiment, but in the opposite direction, due to the change in the light beams travel time through the arms of the interferometer. When rotating the interferometer, the light travel time along the interferometer arms changes, as well as the angle between the directions of the interfering beams. After reflections and refractions, the axis of the beams reach the semi-silvered mirror at a different time point, i.e., in different positions.

However, there are positions of the interferometer for which the light beams travel times along its arms, are equal and the beams overlap perfectly. Such a position is presented in this study (the interferometer rotated at 45°).Passing this position, rotating the interferometer, the angle between the light beams that interfere increases. The beams swap their place, thus, the axis of the one that reaches the interference area faster, is always on the same side (on the right, for the case shown in this paper).The interference zone passes through the same states as before 45°, in which the fringes should not move. The same phenomenon occurs at the angles of rotation of the interferometer of 135°, 225° and 315°.

The angles are very important, they appear in calculations and must be expressed according to **c**-speed of light and **v** - speed of the Earth.

Regardless of the medium in which it is located, whether it is driving light or not, the interferometer shows the same thing: the fringes of interference do not move when rotating it.

In the excerpt of the paper presented, three positions of the interferometer are selected: at 0°, 90° and 45° with the corresponding calculations and analyses resulting from why the fringes should not move, and offer the possibility of practical verification of the theory exposed. It is considered that light is not driven by Earth, so it propagates independently of what the surrounding bodies do.

PART I

MICHELSON-MORLEY EXPERIMENT ANALYZED AGAINST THE REFERENCE SYSTEM CONSIDERED STATIONARY (SYSTEM S)

I.1 MICHELSON INTERFEROMETER BEFORE ROTATION

The interferometer, before rotation, is shown simplified in Figure 1.

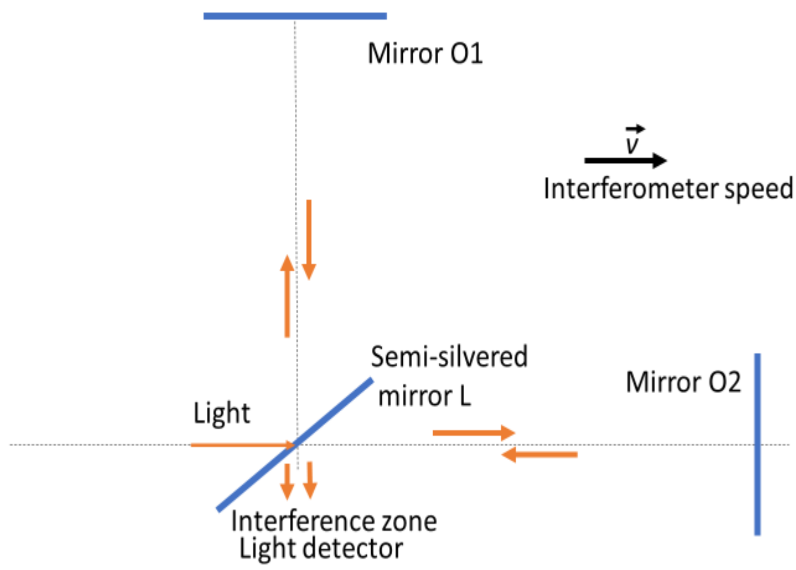

Fig.1

Each of its arms has the length ***l***. From the reference system considered to be stationary (SYSTEM S), the interferometer together with the Earth moves to the right at speed v. The light, not being driven, propagates independently.

The light beam with the plane wavefront (for simplification) is reflected by the semi-silvered mirror **L** according to the Huygens principle. At the initial moment, the beam touches the mirror **L** in section **A** emitting circular elementary waves (Fig. 2). After time $\boldsymbol{\theta}$, the beam touches the mirror **L** in section **B**. During this time, the light has travelled the distance $\boldsymbol{c\theta}$ and the mirror **L** the distance $\boldsymbol{v\theta}$. The incident beam is reflected by the surface with section **AB**, so moving the interferometer to the right results in a clockwise rotation of the mirror **L** at a $\boldsymbol{\psi}$angle. All the points located between **A** and **B** emit elementary waves whose tangent gives the reflected wavefron

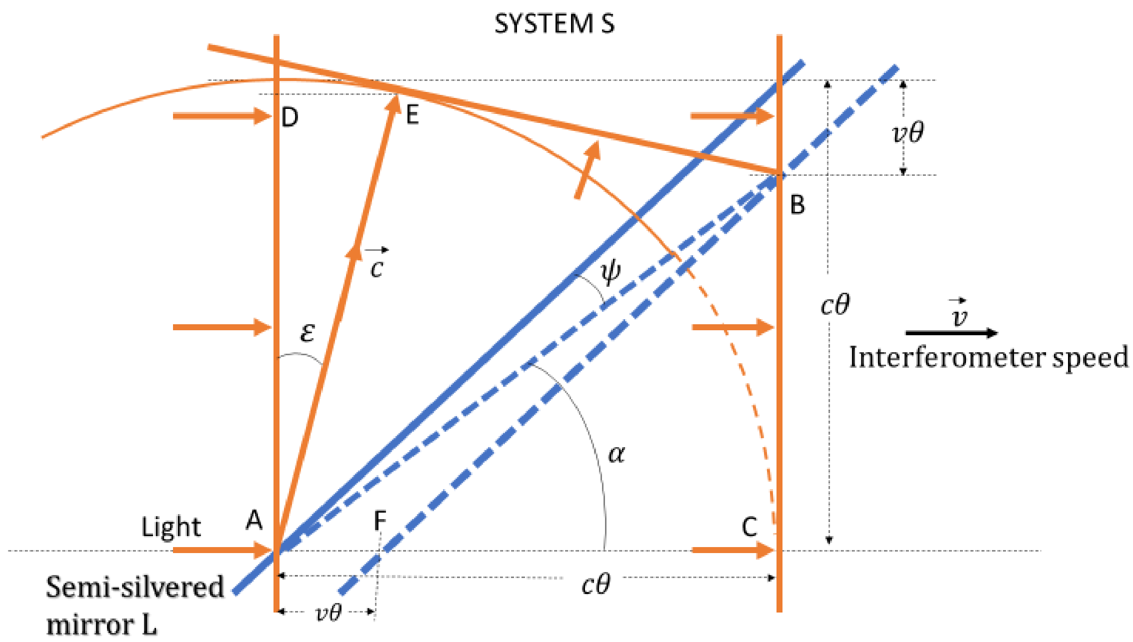

Fig. 2 The wavefront travels the distance AC and the mirror L, the distance AF. The wavefront successively touches the mirror L regions, between A and B. These regions determine the reflecting surface with section AB. The AE axis of the beam reflected towards the O1 mirror, forms the angle ε with the L-O1 interferometer arm.

The propagation direction of the reflected beam (perpendicular to the front) forms the angle $\boldsymbol{\varepsilon}$ with the perpendicular to the mirror **O1** and:

$$\varepsilon = 2\psi \qquad (1)$$

because the rotation of the **L** mirror, as a result of the movement with the $\boldsymbol{\psi}$ angle, causes the reflected beam to deviate with the $\mathbf{2}\boldsymbol{\psi}$ angle. The $\boldsymbol{\psi}$ angle may be expressed according to the $\boldsymbol{\alpha}$ angle:

$\psi = 45 - \alpha$ (Fig.2)

$\varepsilon = 90 - 2\alpha$ and then

$sin\,\varepsilon = sin(90 - 2\,\alpha\,) = cos2\,\alpha$

From the **ABC** triangle results:

$$tg\,\alpha = \frac{BC}{AC} = \frac{c\theta - v\theta}{c\theta} = \frac{c - v}{c}$$

Therefore:

$$sin\,\varepsilon = cos\,2\,\alpha = \frac{1 - tg^2\alpha}{1 + tg^2\alpha} = \frac{1 - \left(\frac{c - v}{c}\right)^2}{1 + \left(\frac{c - v}{c}\right)^2} = \frac{c^2 - (c - v)^2}{c^2 + (c - v)^2} \qquad (2)$$

If the right-hand component of the speed of light reflected by the **L** mirror would be ***v***, then we should have: $sin\,\varepsilon = \frac{v}{c}$ from the **ADE** triangle

But the wavefront has a different tilt (Fig. 2) and passes neither through **D,** nor at a **cθ** distance from **A**. Therefore:

$$\frac{c^2-(c-v)^2}{c^2+(c-v)^2} > \frac{v}{c}$$

therefore, the right-hand component of the speed of light reflected by the **L** mirror is greater than ***v***, i.e., greater than the **L** mirror speed. This component has the value of:

$$v' = c \cdot sin\,\varepsilon = \frac{c[c^2-(c-v)^2]}{c^2+(c-v)^2} \qquad (3)$$

The initial hypothesis, that the light is not driven by Earth (therefore neither by the interferometer), was followed. If the light is considered to be driven, then reflections occur differently. The right-hand component of the speed of light could be equal to the speed of the interferometer and of the Earth if the light were totally driven by Earth.

Applying the principle of Huygens to the reflection on the Mirror **O1**, which moves on a line contained in its plane, ε will also be obtained for the angle of reflection on this mirror. The surface reflecting light coincides with the surface of the **O1** mirror. After reflecting on the **O1** mirror, the section around point **A** of the incident beam reaches back to the level of point **A**, before the **L** mirror (Fig. 3).

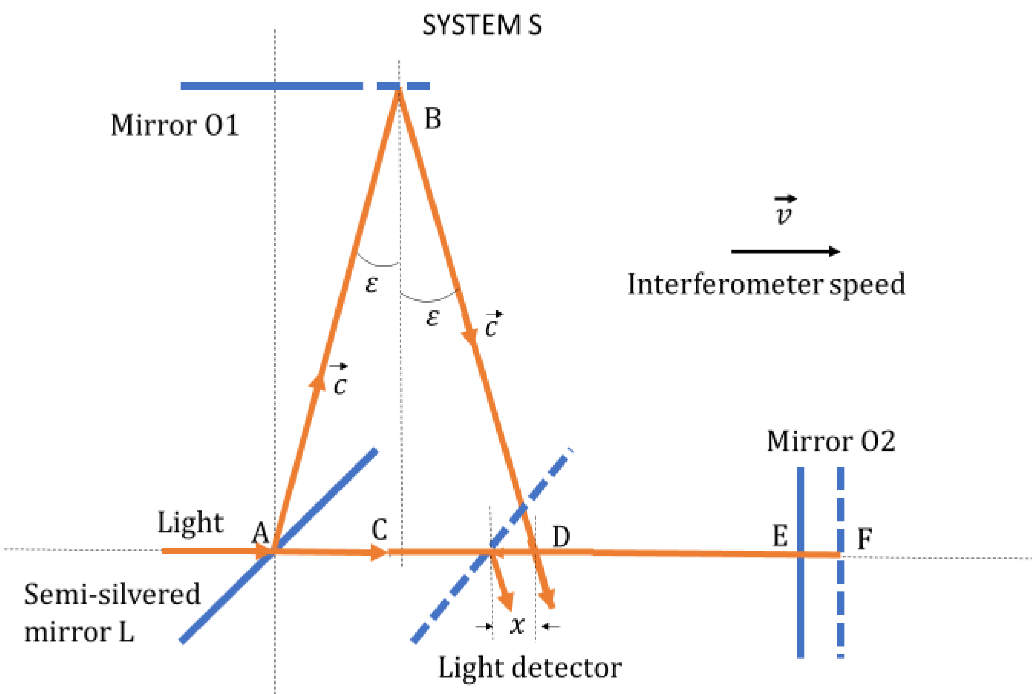

Fig. 3 The axis of the beam reflected by the **O1** mirror reaches the **L-O2** arm of the interferometer in point **D**, before the **L** mirror, on the right. The beam axis coming from the **O2** mirror touches the **L** mirror at distance **x** against **D**, on the left.

The $\boldsymbol{t_1}$ light travel time on the distance from **A** to the **O1** mirror and back to level **A** consists of:

$\boldsymbol{t'_1}$= the light travel time on distance **A to B**;

$\boldsymbol{t''_1}$= the light travel time on distance the distance from **B** to point **A**, in **D**:

$$t_1 = t'_1 + t''_1 \qquad (4)$$

From the right triangle **ABC**, can be written:

$$c^2 t'^2_1 = l^2 + v'^2 t'^2_1 \qquad (5)$$

Therefore

$$t'_1 = \frac{l}{\sqrt{c^2 - v\prime^2}} = \frac{l[c^2+(c-v)^2]}{2c^2(c-v)} \qquad (6)$$

Similarly, $\boldsymbol{t''_1}$ shall be determined from the **BDC** triangle congruent to the **ABC** triangle:

$$t''_1 = \frac{l[c^2+(c-v)^2]}{2c^2(c-v)} \qquad (7)$$

Therefore:

$$t_1 = t'_1 + t''_1 = \frac{l[c^2+(c-v)^2]}{c^2(c-v)} \qquad (8)$$

The $\boldsymbol{t_2}$ light travel time on **L-O2-L** distance, is easily calculated:

$$t_2 = \frac{l}{c-v} + \frac{l}{c+v} = \frac{2lc}{c^2 - v^2} \qquad (9)$$

In this situation $\boldsymbol{t_2}$ is greater than $\boldsymbol{t_1}$**,** the difference being:

$$\Delta t = t_2 - t_1 = \frac{2lc}{c^2-v^2} - \frac{l[c^2+(c-v)^2]}{c^2(c-v)} = \frac{lv^2}{c^2(c+v)}$$

The axis of the light beam coming from **O1**, undergoes a displacement to the right of the one coming from the **O2** on the distance ***x***.

$$x = v' \cdot t_1 - v \cdot t_2 = \frac{c[c^2-(c-v)^2]}{c^2+(c-v)^2} \cdot \frac{l[c^2+(c-v)^2]}{c^2(c-v)} - \frac{2lcv}{c^2-v^2} = \frac{lv^2}{c(c+v)}$$

Therefore, before rotation:

$$\Delta t = \frac{lv^2}{c^2(c+v)} \quad \text{and} \quad x = \frac{lv^2}{c(c+v)} \tag{10}$$

and the axis of the light beam that reaches faster (from **O1**) is deflected to the right against the other (from **O2**).

I. 2 THE MICHELSON INTERFEROMETER ROTATED BY 90°

The interferometer rotated by 90° in a counterclockwise direction is represented in Figure 4 in the same position as in Figure 1, but with the ***v*** direction changed accordingly, for easier comparison between the two situations: before and after rotation. The entire dynamic of the phenomenon is rendered in cases where the light reflected by the **O2** mirror reaches the center of the **L** mirror to facilitate comparisons.

Following the two refractions on the surfaces of the medium with the flat and parallel faces of the **L** mirror (rotated with the angle $\boldsymbol{\psi}$ as an effect of the movement), the light coming out towards **O2** is parallel to the light entering the **L**.

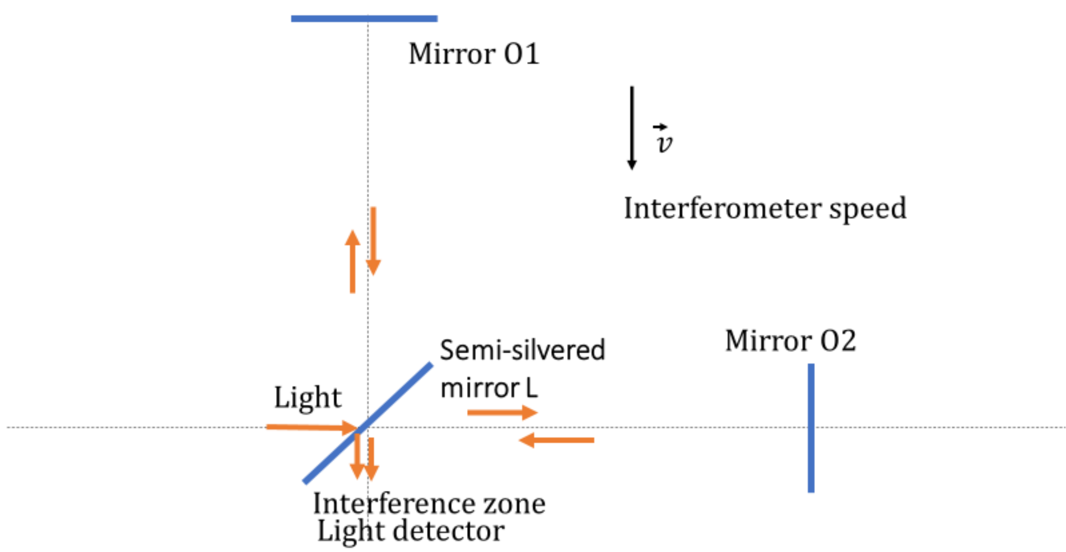

Fig. 4

The center of the **L** mirror, after reflection on the **O2** mirror, will be reached by the section of the initial wavefront passing through point **A** of the **L** mirror. Point **A** has the level located at distance ***d***, "below" the center of the mirror **L**. As the light travels the **L-O2-L** path, the center of the mirror, i.e., the **C** point, moves on the distance ***d***, coming towards the light reflected by **O2**. (Fig. 5)

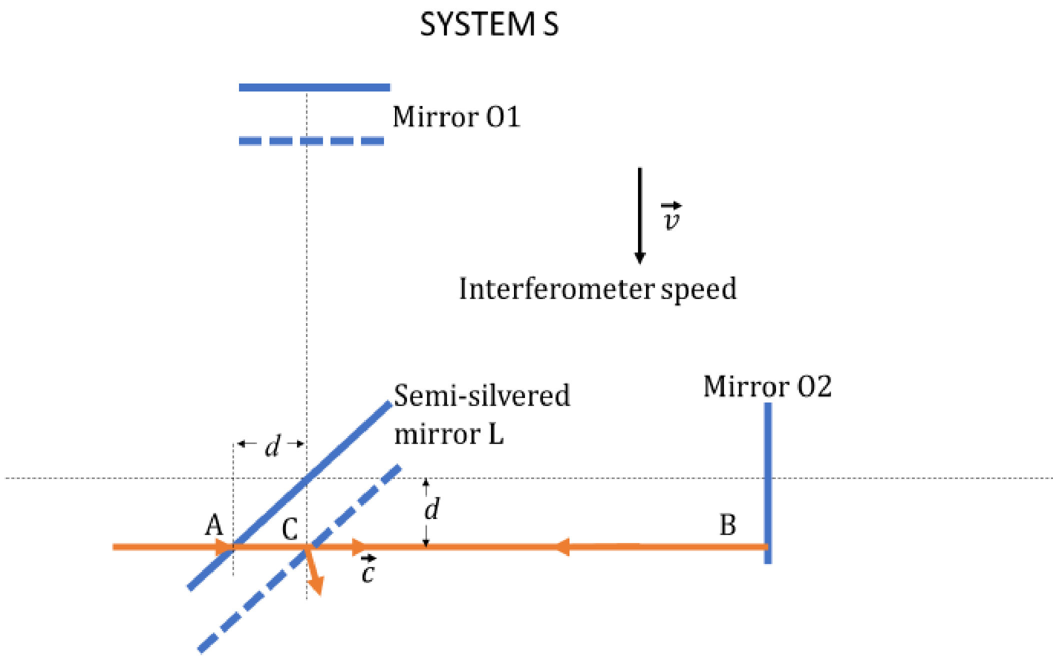

Fig. 5 The light is emitted in the direction of the L-O2 arm of the interferometer and propagates independently on the A-B-C path. Because the light comes perpendicular to the O2 mirror, it is reflected on the samepath. While the light travels the distance A-B-C, the mirror L moves on the distance d.

$\boldsymbol{\tau_2}$= the light travel time on the **A-B-C** distance is calculated as follows:

$$\tau_2 = \frac{2l+d}{c} \tag{11}$$

but: $$d = v \cdot \tau_2 \tag{12}$$

therefore: $$\tau_2 = \frac{2l+v\tau_2}{c}$$

where $\boldsymbol{\tau_2}$ and *d* become:

$$\tau_2 = \frac{2l}{c-v} \quad \text{and} \quad d = \frac{2lv}{c-v} \tag{13}$$

When the light is reflected on the **L** mirror, the same effect is observed as before the rotation: the movement of the **L** mirror has the effect of rotating it with the angle $\boldsymbol{\psi}$ clockwise. Thus, towards **O1**, the light falls under the angle of incidence ε. (Fig. 6).

The first point on the **O1** touched by the light coming from **L** is A**,** and the last point is **B**. The actual surface reflecting the light **together with the O1** mirror, forms the angle $\boldsymbol{\psi'}$. Given the movement of the **O1** mirror towards the light reflected by **L** and due to the rotating effect, the angle under which the light returns towards the **L** against the **L-O1** arm, will be $\boldsymbol{\varepsilon'}$. To calculate the right-hand component of the light speed reflected by **O1**, $\boldsymbol{sin\ \varepsilon'}$ is required.

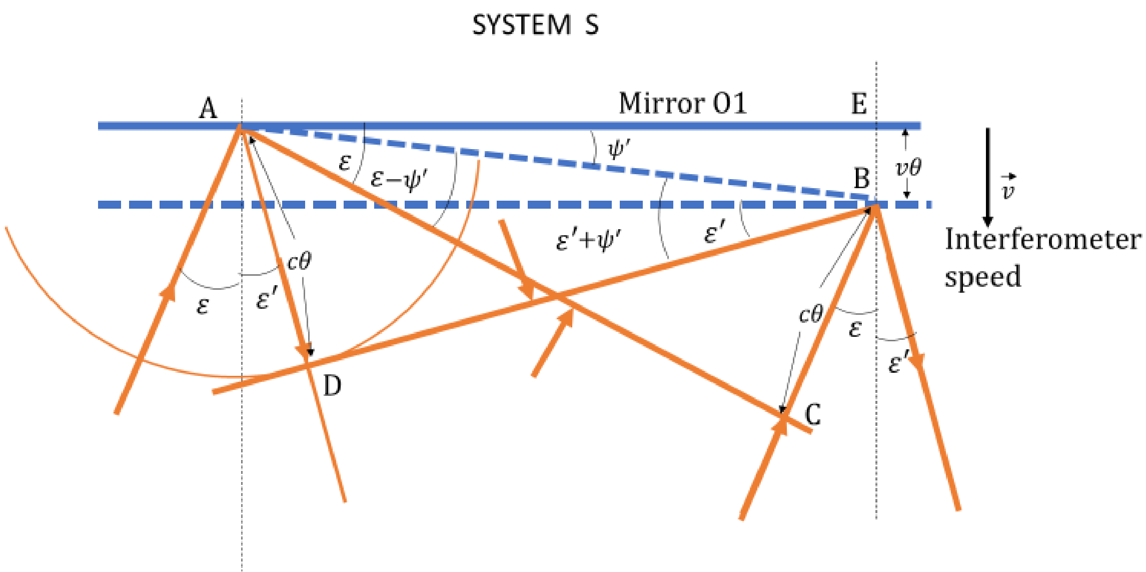

Fig. 6 The light travels the CB distance, and the O1 mirror, the EB distance. The AC incident wave-front successively touches the O1 mirror areas between A and B, determining the reflecting surface with section AB.

The equal **ABC** and **AVD** triangles, lead to:

$\varepsilon - \psi' = \varepsilon' + \psi'$ therefore:

$\varepsilon' = \varepsilon - 2\psi'$ (14)

and then:

$$sin\ \varepsilon' = sin(\varepsilon - 2\psi') = sin\ \varepsilon \cdot cos\ 2\psi' - sin2\psi' \cdot cos\ \varepsilon$$

From **ABE** triangle:

$$sin\psi' = \frac{v\theta}{AB}$$

and from the **ABC** triangle:

$$sin\ (\varepsilon - \psi') = \frac{c\theta}{AB}$$

By dividing the last two relationships we obtain:

$$\frac{sin\ \psi'}{sin(\varepsilon - \psi')} = \frac{v}{c}$$

hence:

$$c\ sin\ \psi' = v\ sin\ \varepsilon \cdot cos\ \psi' - v\ cos\ \varepsilon \cdot sin\psi'$$

and by dividing by *cos* $\boldsymbol{\psi}$'

$$c\cdot\ tg\,\psi' = v\cdot\sin\varepsilon - v\cos\varepsilon\cdot\ tg\,\psi' \qquad \text{and}$$

$$tg\,\psi' = \frac{\sin\varepsilon}{\frac{c}{v}+\cos\varepsilon}$$

In this situation:

$$\sin\varepsilon' = \frac{1-tg^2\psi'}{1+tg^2\psi'}\cdot\sin\varepsilon \;-\; \frac{2tg\,\psi'}{1+tg^2\psi'}\cos\varepsilon = \frac{\left[1-\frac{\sin^2\varepsilon}{(\frac{c}{v}+\cos\varepsilon)^2}\right]\sin\varepsilon-\frac{2\sin\varepsilon}{\frac{c}{v}+\cos\varepsilon}\cos\varepsilon}{1+\frac{\sin^2\varepsilon}{(\frac{c}{v}+\cos\varepsilon)^2}} =$$

$$= \frac{(c^2-v^2)\sin\varepsilon}{c^2+v^2+2cv\cdot\cos\ \varepsilon}$$

Is further calculated by:

$$\cos\varepsilon = \sqrt{1-\sin^2\varepsilon} \quad = \frac{2c(c-v)}{c^2+(c-v)^2} \tag{15}$$

therefore:

$$\sin\varepsilon' = \frac{c^2-(c-v)^2}{c^2+(c-v)^2}\cdot\frac{c^2-v^2}{c^2+v^2+2cv\frac{2c(c-v)}{c^2+(c-v)^2}} =$$

$$= \frac{(2cv-v^2)(c^2-v^2)}{2c^4+2c^3v-c^2v^2-2cv^3+v^4} \tag{16}$$

The right-hand component of the light speed reflected by the mirror **O1** towards **L**, is:

$$v'' = c\cdot\sin{}^{\varepsilon'} = \frac{c(2cv-v^2)(c^2-v^2)}{2c^4+2c^3v-c^2v^2-2cv^3+v^4} \tag{17}$$

The time needed for the light to travel the distance **L-O1-L** (Fig. 7) is $\boldsymbol{\tau_1}$**,** consisting of:

$\boldsymbol{\tau'_1}$= the light travel time on distance **AD** and

$\boldsymbol{\tau''_1}$= the light travel time on distance **DG**

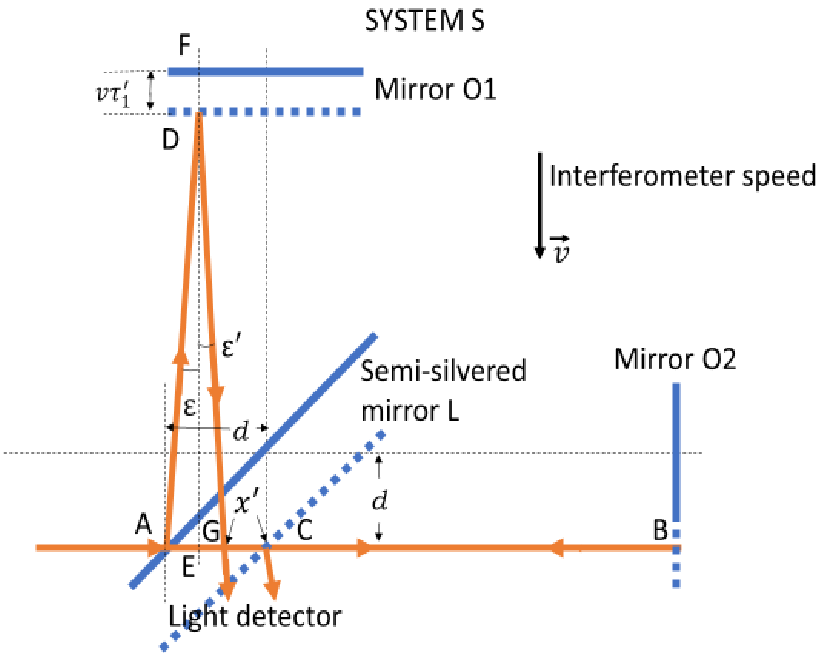

Fig. 7 While the light travels the AD distance, the O1 mirror moves over the FD distance. The light reflected by the O1 mirror passes through point G, located at the level at which the light enters the interferometer (AGB)

From the **ADE** triangle:

$$c^2\tau'^2_1 = (l + d - v\tau_1')^2 + v'^2\tau'^2_1 \qquad (18)$$

and from here:

$$\tau_1' = \frac{l+d}{\sqrt{c^2 - v'^2} + v} = \frac{l + \dfrac{2lv}{c-v}}{\dfrac{2c^2(c-v)}{c^2+(c-v)^2} + v} = \frac{l(c+v)[c^2+(c-v)^2]}{(c-v)(2c^3 - 2cv^2 + v^3)} \qquad (19)$$

From the **DGE** triangle:

$$c^2\tau''^2_1 = (l + d - v\tau_1')^2 + v''^2\tau''^2_1 \qquad (20)$$

therefore:

$$\tau_1'' = \frac{l + d - v\tau_1'}{\sqrt{c^2 - v''^2}}$$

In this expression:

$$\sqrt{c^2 - v''^2} = \frac{2c^3(c^2 + cv - v^2)}{2c^4 + 2c^3v - c^2v^2 - 2cv^3 + v^4} \qquad (21)$$

Meaning:

$$\tau_1'' = \frac{\frac{l+\frac{2lv}{c-v}-\frac{v(lc+lv)\left[c^2+(c-v)^2\right]}{(c-v)\left(2c^3-2cv^2+v^3\right)}}{1}}{\frac{2c^3\left(c^2+cv-v^2\right)}{2c^4+2c^3v-c^2v^2-2cv^3+v^4}} = \frac{l(c+v)\left(2c^4+2c^3v-c^2v^2-2cv^3+v^4\right)}{c(c^2+cv-v^2)(2c^3-2cv^2+v^3)} \tag{22}$$

and:

$$\tau_1 = \tau_1' + \tau_1'' = \frac{l(c+v)[c^2+(c-v)^2]}{(c-v)(2c^3-2cv^2+v^3)} + \frac{l(c+v)(2c^4+2c^3v-c^2v^2-2cv^3+v^4)}{c(c^2+cv-v^2)(2c^3-2cv^2+v^3)} =$$

$$= \frac{l(c+v)\left(2c^2-v^2\right)}{c(c-v)(c^2+cv-v^2)} \tag{23}$$

The time difference is:

$$\Delta\tau = \tau_2 - \tau_1 = \frac{2l}{c-v} - \frac{l(c+v)(2c^2-v^2)}{c(c-v)(c^2+cv-v^2)} = -\frac{lv^2}{c(c^2+cv-v^2)}$$

After rotating the interferometer, $\boldsymbol{\tau_1}$ is greater than $\boldsymbol{\tau_2}$**.** The light beam from **O2** shall have its axis to the right of that coming from **O1**, at distance $\boldsymbol{x'}$**.**

$$x' = d - v'\tau_1' - v''\tau_1'' = \frac{2lv}{c-v} - \frac{c[c^2-(c-v)^2]}{c^2+(c-v)^2} \cdot \frac{l(c+v)[c^2+(c-v)^2]}{(c-v)(2c^3-2cv^2+v^3)} -$$

$$- \frac{c(2cv-v^2)(c^2-v^2)}{2c^4+2c^3v-c^2v^2-2cv^3+v^4} \cdot \frac{l(c+v)(2c^4+2c^3v-c^2v^2-2cv^3+v^4)}{c(c^2+cv-v^2)(2c^3-2cv^2+v^3)} =$$

$$= \frac{lv^2}{c^2+cv-v^2}$$

Therefore, after rotating the interferometer:

$$\Delta\tau = -\frac{lv^2}{c(c^2+cv-v^2)} \qquad and \qquad x' = \frac{lv^2}{c^2+cv-v^2} \tag{24}$$

The axis of the beam that reaches faster (from **O2** this time) also comes to the right of the other, just as before the rotation. The beams have changed between them. In this case, the relationship should be:

$$\boldsymbol{\Delta\tau = \tau_1 - \tau_2}$$

Thus, the area of interference after rotating the interferometer, does not change significantly, practically remaining the same as before because:

- the time differences are almost insignificant;

- the movements of the beams are also very similar in value: the light beam that reaches the light detector faster comes with the axis always shifted to the right (on the same side), throughout the interference zone.

The situation remains the same for other rotation angles of the interferometer: 180°, 270°.

The after-rotation situation can be reached from the prior to rotation situation, by performing the following operations:

1. the condition $\boldsymbol{\Delta\tau < 0}$ shall be met.

   a. the **L-O1-L** path shall be increased because $\boldsymbol{\tau_1 - t_1 > 0}$**;** the fringes are moving in one direction.

   b. the **L-O2-L** path shall be increased less because $\boldsymbol{\tau_2 - t_2 > 0}$ and $\boldsymbol{\tau_2 - t_2 < \tau_1 - t_1}$

   c. the fringes move in the opposite direction to those of a) but less.

   Thus, at point 1., the fringes move in one direction: that of a).

2. The O1 mirror shall be rotated properly (clockwise - as shown in this paper). The interference fringes move in the opposite direction to the situation described at point 1.

The causes (plural!) that move the interference fringes when rotating the interferometer give reverse effects which practically cancel out. Anyone having a Michelson interferometer, can step-by-step check the behaviour of the fringes, at each operation indicated at points 1 and 2, and realize why the interference fringes practically do not have to move when rotating the interferometer.

The $\boldsymbol{x}$**,** $\boldsymbol{x'}$ displacements and angles between the axis of the reflected beams, all variable during the rotation of the interferometer, are so small that it was thought that they are inexistent. But it is precisely these elements that **must not be neglected** to explain the practical outcome of this important experiment.

I.3 THE MICHELSON INTERFEROMETER ROTATED BY 45°

The interferometer rotated by 45 degrees counterclockwise is shown in Figure 8, with the corresponding $\boldsymbol{v}$ direction. In the following calculations, some notations are repeated, but the sizes they represent have values that only match this case.

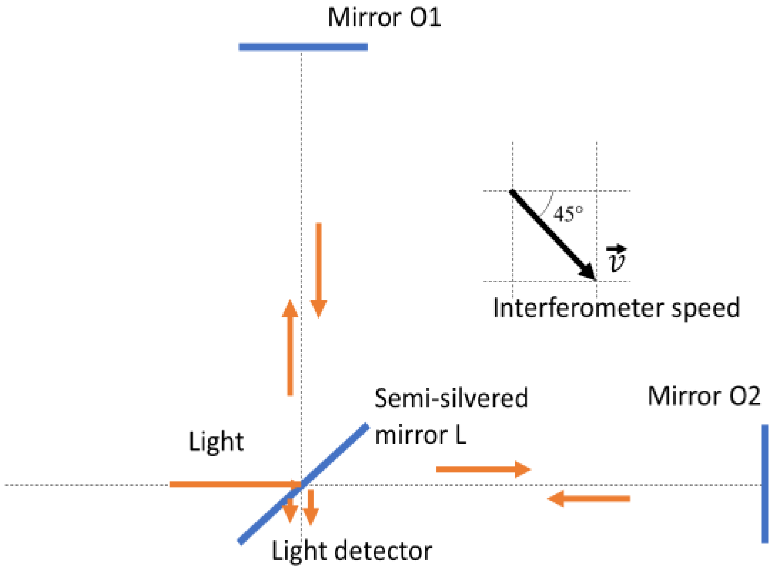

Fig. 8

In this case, the light beams overlap perfectly (Fig 9), their axis reach the semi-silver mirror in the same place, and the interferometer arms travelling times are equal.

The detector analyzes the light that reaches it, following reflections, from the region of the center of the mirror **L**. After reflection on the **O2** mirror, the center of the **L** mirror (**in C**) will be reached by the light that enters the interferometer at the distance ***d*** "below on figure 9" from the center of the mirror **L** (**through A**), thus, while the light travels the distance **L-O2-L**, the center of the mirror **L** meets the light reflected by **O2**.

It is convenient to perform calculations with ***v**** - the Earth speed component parallel to the **L-O2** or **L-O1** arm of the interferometer.

$$v* = \frac{v}{\sqrt{2}} \tag{25}$$

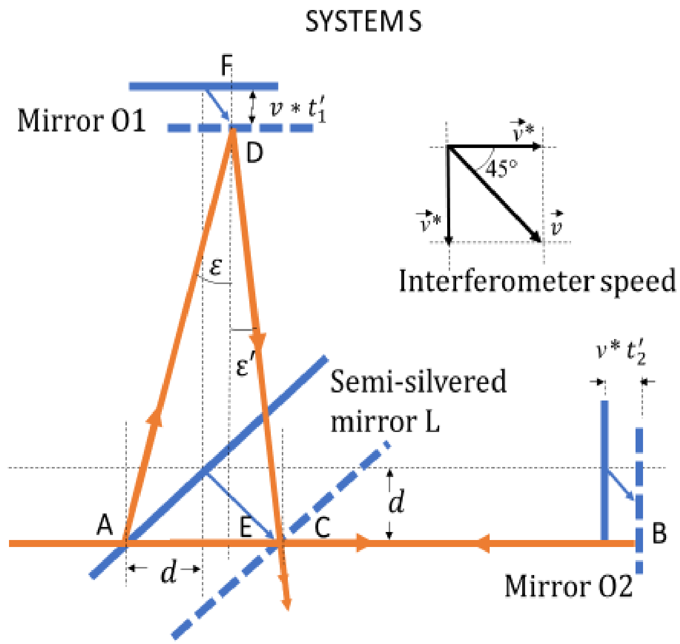

Fig. 9 Light beams start from area A of the L mirror. After reflections, they reach back to the center of the L mirror, overlapping perfectly.

The light travel time on the **L-O2-L** is:

$t_2 = t_2' + t_2''$

with $\boldsymbol{t_2'}$ - towards **O2** (on the AB path) and $\boldsymbol{t_2''}$ – backward to **L** (on the BC distance)

$ct_2' = l + d + v^* t_2'$ where: $t_2' = \dfrac{l+d}{c-v*}$

Backwards: $c\, t_2'' = l - d + v^* t_2'$ resulting:

$$t_2'' = \frac{l\,c - d\,c + 2d\,v*}{c\,(c-v*)} \qquad (26)$$

But: $d = v^* t_2$ and then:

$$t_2 = t_2' + t_2'' = \frac{2\,l\,c}{c^2 - c\,v* - 2\,v*^2} \qquad (27)$$

and

$$d = \frac{2\,l\,cv*}{c^2 - c\,v* - 2\,v*^2} \qquad (28)$$

The light reflected by the **L** mirror towards the **O1** mirror propagates towards the **O1** mirror below the angle **ε** (Fig.10) and:

$$\sin\varepsilon = \cos 2\,\alpha = \frac{1 - tg^2\alpha}{1 + tg^2\alpha} = \frac{c^2 - (c - 2\,v*)^2}{c^2\ +\ (c - 2\,v*)^2}\ = \frac{2\ \ v*(c - v*)}{c^2 - 2c\ v*\ +2\ v*^2} \qquad (29)$$

Therefore, the right-hand component on the speed of light which propagates towards **O1** mirror is:

$$v' =\ \ c\cdot\ sin\,\varepsilon = \frac{c[c^2 - (c - 2v*)^2]}{c^2\ +\ (c - 2v*)^2}\ \ = \frac{2\ c\ v*(c - v*)}{c^2 - 2c\ v*\ + 2\ v*^2} \qquad (30)$$

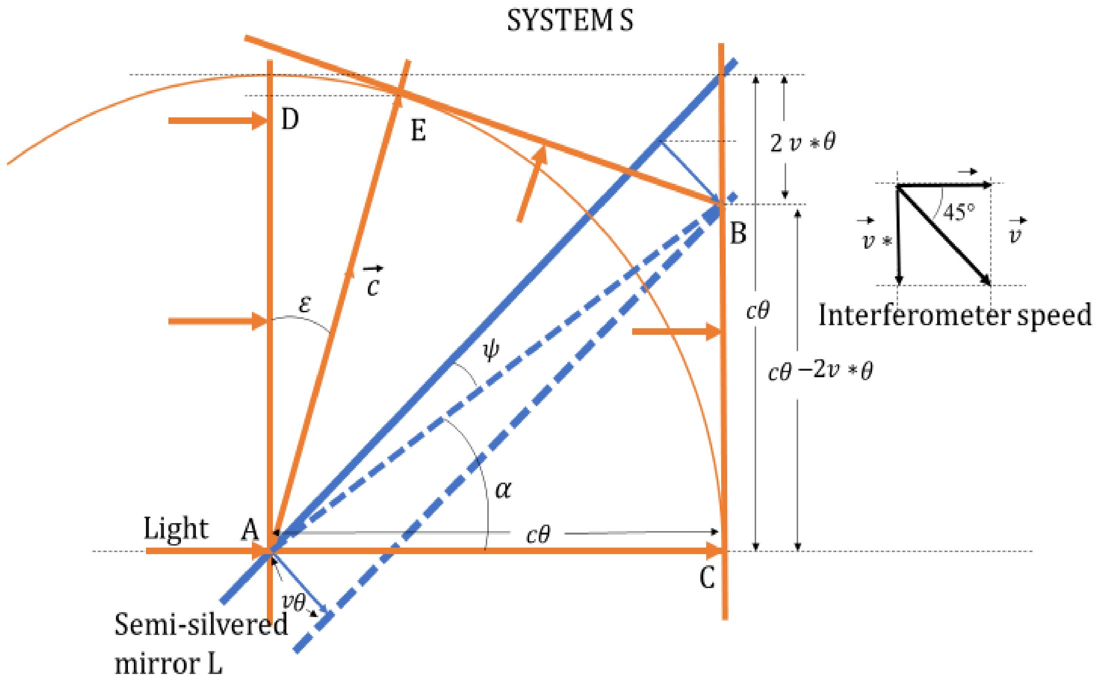

Fig. 10 The AD wavefront touches the mirror L areas, in turn, between A and B. These areas determine the reflecting surface with the AB section.

The light travel time on the **L-O1-L** path (Fig. 9) to the level at which the light enters the interferometer towards the **O2** mirror, consists of: $\boldsymbol{t_1'}$ towards (on AD), and $\boldsymbol{t_1''}$ backwards (on the DC distance).

$$t_1 =\ t_1' + t_1''$$

The component of the speed **v**, with which the mirror **O1** moves in the direction of the **L-O1** arm, is equal to ***v*.***

From figure 9, can be written:

$$c^2 t_1'^2 = (l\ \ +\ \ d\ \ - v*t_1')^2 + v'^2 t_1'^2$$

Therefore:

$$t_1' \ \ = \ \ \frac{l + d}{\sqrt{c^2 - v'^2}\ \ \ +\ \ v*}$$

In this equation:

$$\sqrt{c^2 - v'^2} = \sqrt{(c+v')(c-v')} = \quad \frac{c^2\ (c - 2v*)}{c^2 - 2c\ v* + 2\ v*^2}$$

Therefore, $\boldsymbol{t_1'}$ can be known after replacing ***d*** and the radical:

$$t_1' \quad = \quad \frac{l(c \quad + 2\,\mathrm{v}\,*)(c^2 - 2c\ v* \ + 2\ v*^2)}{(c^2 - 2v*^2)(c^2 - c\ v* \ - 2\ v*^2)} \qquad (31)$$

The light reflected by the moving **O1** mirror falls towards the **L** mirror at an angle $\boldsymbol{\varepsilon'}$ (Fig.11)

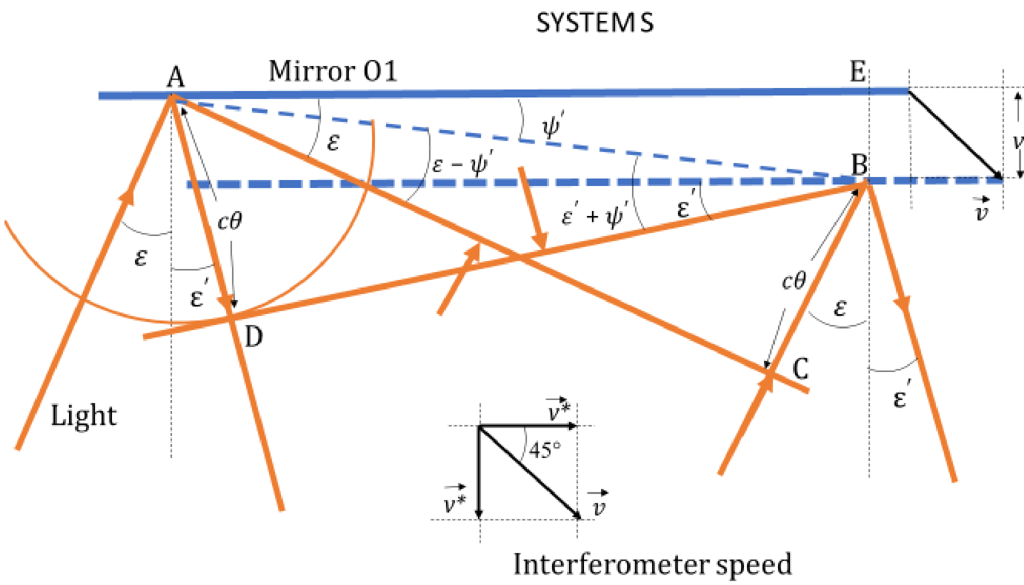

Fig. 11 The AC wavefront successively touches the areas of the O1 mirror, between A and B. The surface with section AB reflects the light towards the mirror L.

For this angle $\varepsilon' = \varepsilon - 2\psi'$ the calculations shall be carried out no different than for the case illustrated in figure 6, except that the component ***v**** appears in the new calculations.

$$\sin\varepsilon' = \quad \frac{(c^2 - v*^2)\sin\varepsilon}{c^2 + v*^2 + 2cv*\cdot\cos \quad \varepsilon}$$

By replacing the known sine and the cosine calculated as bellow:

$$\cos\varepsilon = \sqrt{1 - \sin^2\varepsilon} = \sqrt{(1 - \sin\varepsilon)(1 + \sin\varepsilon)} \ = \frac{c(c - 2v*)}{c^2 - 2cv* + 2\ v*^2}$$

We obtain:

$$sin\, \varepsilon' = \frac{2v*(c+v*)}{c^2 + 2cv* + 2\, v*^2} \tag{32}$$

Thus, the right-hand component of the speed of light that travels towards **L**, is:

$$v'' = csin\, \varepsilon' = \frac{2cv*(c+v*)}{c^2 + 2cv* + 2\, v*^2} \tag{33}$$

The equation containing the $\boldsymbol{t_1''}$ can be concluded from Figure 11:

$c^2 t''^2_1 = (\, l \;+\; d \;-\text{v} * \text{t}'_1)^2 + \text{v}''^2 \text{t}''^2_1$ therefore:

$t''_1 \;=\; \dfrac{l + d - \text{v}*\text{t}'_1}{\sqrt{c^2 - v''^2}}$ but here:

$$\sqrt{c^2 - v''^2} = \sqrt{(c+v'')(c-v'')} = \frac{c^2(c+2v*)}{c^2 + 2c\, v* + 2\, v*^2}$$

therefore, after replacing ***d***, the radical, and performing the calculations:

$$t''_1 = \frac{l(c-2v*)(c^2 + 2cv* + 2\, v*^2)}{(\text{c}^2 - 2\text{v}*^2\,)(c^2 - \; cv* - 2\, v*^2\,)} \tag{34}$$

and:

$$t_1 = t'_1 + \; t''_1 = \frac{l(c \;\; +2\, v*)(c^2 - 2c\, v* + 2\, v*^2)}{(c^2 - 2v*^2)(c^2 - c\, v* - 2\, v*^2)} \;+\; \frac{l(c-2v*)\left(c^2 + 2c\, v* + 2\, v*^2\right)}{(\text{c}^2 - 2\text{v}*^2\,)(c^2 - \; c\, v* - 2\, v*^2)} =$$

$$= \frac{2\, l\, c}{c^2 - c\, v* - 2\, v*^2} \tag{35}$$

Obviously: $t_1 = t_2$ therefore $\Delta\text{t} = 0$

Figure 9 shows that the axis of the light beams are separated at point **A** of the mirror **L** and overlap at point **C**. Distance AC = ***2d***. This shall be clearly verified if the following calculation is performed:

$$v' t'_1 \;+\; v'' t''_1 = \frac{2\, cv*(c-v*)}{c^2 - 2cv* + 2\, v*^2} \frac{l(c \;\; +2\, \text{v}*)(c^2 - 2c\, v* + 2\, v*^2)}{(c^2 - 2v*^2)(c^2 - c\, v* - 2\, v*^2)} \;+$$

$$+ \frac{2v*(c+v*)}{c^2 + 2cv* + 2\, v*^2} \frac{l(c-2v*)\left(c^2 + 2cv* + 2\, v*^2\right)}{(\text{c}^2 - 2\text{v}*^2\,)(c^2 - \; cv* - 2\, v*^2)} = \frac{4\, l\, cv*}{c^2 - c\, v* - 2\, v*^2} = 2\, d$$

The angle that the two beams form is null. The light coming from the **O2** mirror is reflected by the moving semi-silvered mirror **L**, at an angle $\boldsymbol{\beta}$ measured against the **L-O1** interferometer arm (Fig.12), as well as the angle $\boldsymbol{\varepsilon}'$

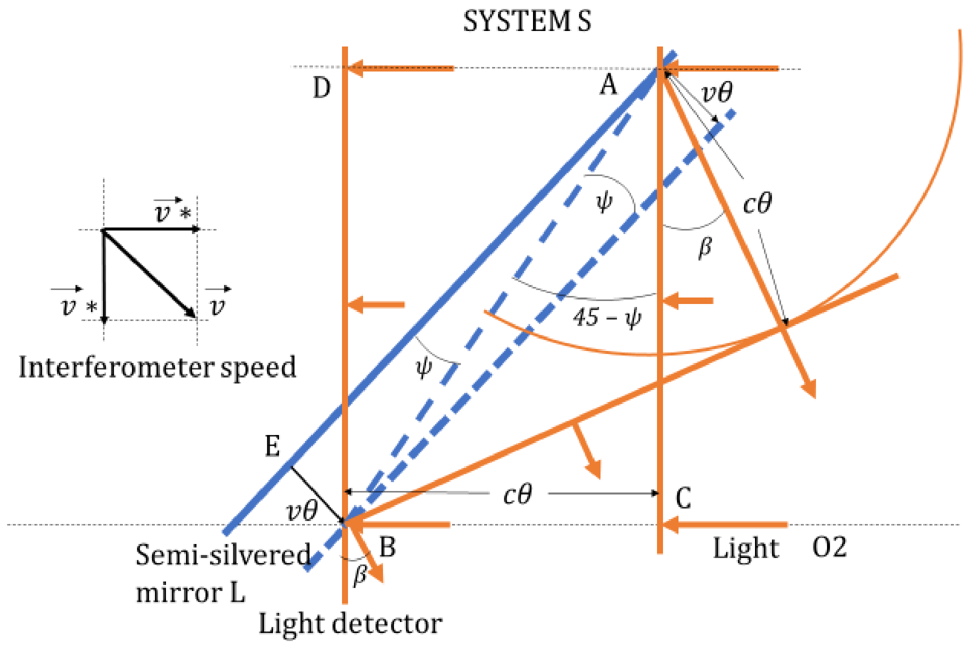

Fig. 12 The wavefront coming from the O2 mirror reaches the sections of the L mirror between A and B. These sections determine the surface that reflects light towards the light detector. Mirror L reflects light coming from O2 under the angle β with the L-O1 interferometer arm.

$\theta = 2\psi$ of figure 12

because the rotation of the mirror at the angle ψattracts the rotation of the reflected beam by **2**ψ. Therefore:

$$\sin\beta = \sin 2\,\psi \qquad (36)$$

Figure 12 also shows that:

$$\sin(45 - \psi) = \frac{c\,\theta}{AB} \quad \text{and} \quad \sin\psi = \frac{v\,\theta}{AB}$$

and by division:

$$\frac{\sin(45 - \psi)}{\sin\psi} = \frac{c}{v}$$

and by expansion:

$$c\,\sin\psi = v\ \sin 45\ \ \cos\psi -- \ v\ \sin\psi\ \ \cos 45$$

By dividing with $\boldsymbol{\cos\psi}$ and after performing numerical calculations considering that

$v = v * \sqrt{2}$, the following shall be obtained:

$$tg\,\psi = \frac{v *}{c + v *}$$

hence: $sin\ \beta = sin\ 2\ \psi = \dfrac{2tg\ \psi}{1+\ tg^2\psi} = \dfrac{2v*(c+v*)}{c^2+2cv*+2\ v*^2} = sin\ \varepsilon'$

$$sin\ \beta = \ sin\ \varepsilon' \qquad (37)$$

therefore, the angle between the axis of the two light beams coming from **O1** and **O2** and interferes, is null, i.e., the two beams overlap perfectly.

PART II

THE MICHELSON-MORLEY EXPERIMENT FOLLOWED FROM ITS OWN REFERENCE SYSTEM, LINKED TO THE INTERFEROMETER (SYSTEM S_P)

The distance that light travels from source S to a point P is measured from where S was located when it emitted light, to where P is located when the light reached it. If P moves away from where S was located, implies that the place where S was located also moves away from P. The source S location, at the moment of emitting light, can be seen from point P, although S is no longer there. Similar phenomena occur in many situations and, of course, in a Michelson interferometer.

II. 1 THE MICHELSON INTERFEROMETER BEFORE ROTATION

From the interferometer observer system of reference (SYSTEM S_P), the places where the optical phenomena occur travel to the left at a speed **v**.

The first section of the L mirror reached by the initial wavefront is **A**, and after, time $\boldsymbol{\theta}$, the last being **B** (Fig. 13). Within this time frame, from the interferometer observer system of reference t (SYSTEM S_P), the place where the first elementary waves (A) were emitted, moved to the left on the distance **v**$\boldsymbol{\theta}$, away from the mirror **L** (in D).For the observer on the S_P system, the first secondary waves were emitted from **D**. The other secondary waves are emitted by the sections of the **L** mirror touched by the incident wavefront between D and **B**. The tangent to these secondary waves determines the wavefront reflected towards the **O1** mirror.

The angle between the axis of this beam and the **L-O1** interferometer arm, is $\varepsilon = 2\psi$

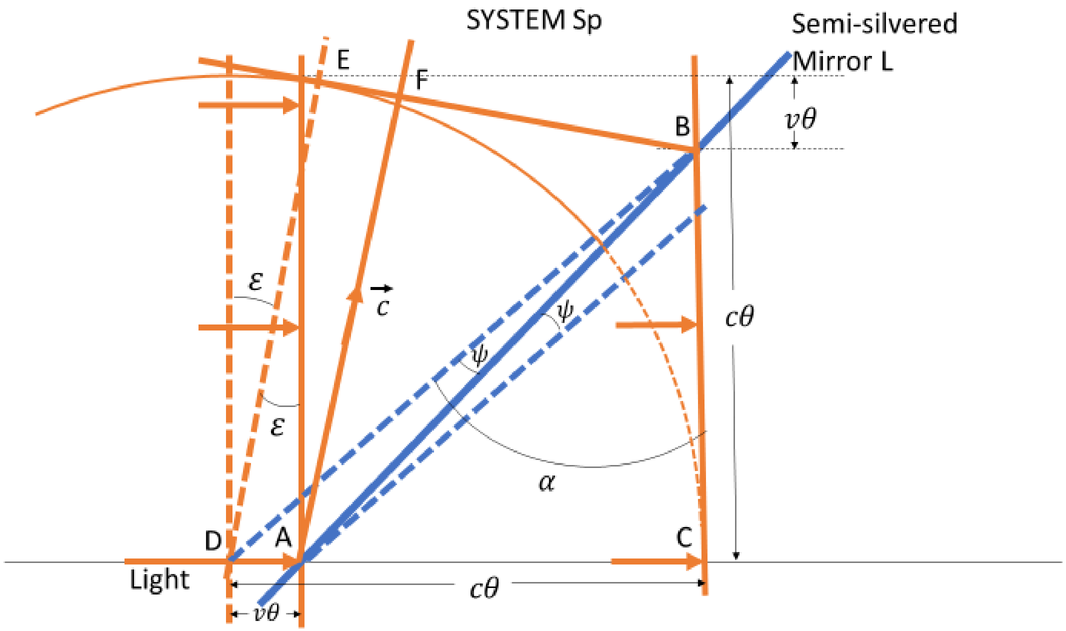

Fig. 13 While the AE wavefront propagated to the CB position, the A point on the L mirror where the first elementary waves were emitted, moved to the left on the distance AD. The light from A, reaching point C, is seen by the observer in the reference S_P system, as coming from D. The BFE reflected wavefront is tangent to the elementary wave emitted from D and therefore the reflecting surface has the DB section.

From the **BCD** triangle, results: $\psi = \alpha - 45$ therefore:

$sin\varepsilon = -\,cos2\,\alpha$ but:

$$tg\,\alpha = \frac{c}{c-v}$$

In which case: $sin\varepsilon = \frac{c^2-(c-v)^2}{c^2+(c-v)^2}$ as for the reference system considered stationary (SYSTEM S)

The component of the light speed reflected towards the mirror **O1**, on the **L-O2** arm direction, is:

$$v' = c \cdot sin\,\varepsilon = \frac{c[c^2-(c-v)^2]}{c^2+(c-v)^2}$$

From its own reference system, each location through which light passes on distance **A - B - C** (shown in Figure 14) moves to the left at a speed $\boldsymbol{v}$. Therefore, the observed path has the shape shown in Figure 14. Regardless of the displacements observed in the direction of the **L-O2** arm, from the interferometer observer system of reference, the component of the speed of light in the direction of the **L-O1** arm remains the same**:** $\boldsymbol{c \cdot cos\,\varepsilon}$

The light travel time on the **L-O1-L** path of the interferometer can be calculated from the equation: $c\,t_1 \cdot cos\,\varepsilon = 2l$

And the result is: $t_1 = \frac{l[c^2+(c-v)^2]}{c^2(c-v)}$ of the same value as for the stationary system observer (SYSTEM S)

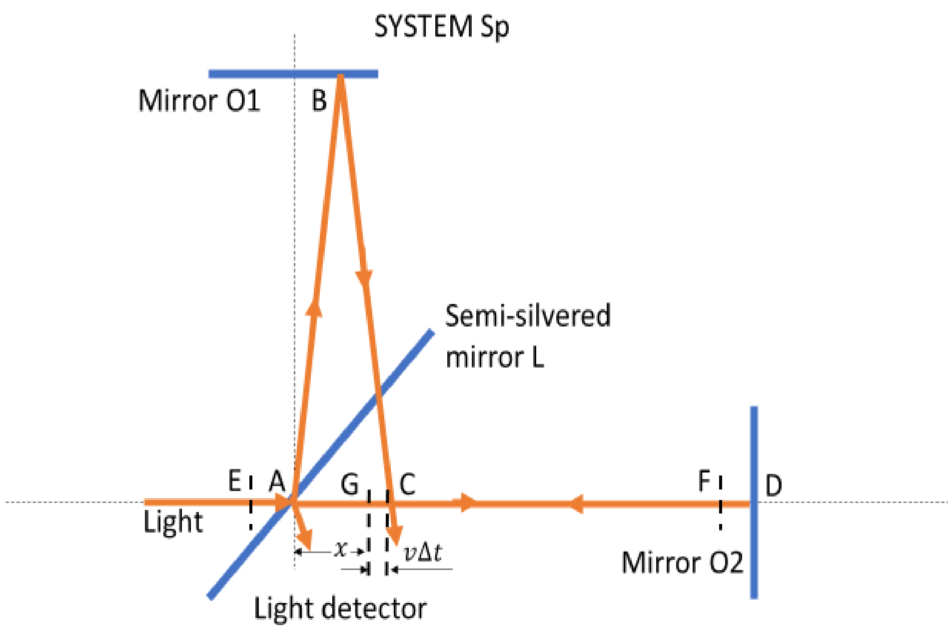

Fig. 14. Each point where the light passes undergoes a left-hand displacement at the speed v. The shape of the path is as shown in the figure. When the light reached O2 in D, the starting point A, moved to E. In fact, the light travelled the distance ED. When the light touches the mirror L in A, point D moves to F. The light reflected by the mirror O1 falls in C. But $t_2 > t_1$ therefore, when the light from O2 reaches A, point C has moved to G.

The **L-O2-L** path is travelled during the time $t_2 = t_2' + t_2''$ i.e., $\boldsymbol{t_2'}$ going forward and $\boldsymbol{t_2''}$ on the backward journey. After time $\boldsymbol{t_2'}$ the light reaches the **O2** mirror, in point **D**, and in the emitting point **A**, has moved to the left on the distance AE = $v \cdot t_2'$ The light has travelled the distance $v \cdot t_2' + l$ therefore: $ct_2' = v \cdot t_2' + l$ resulting: $t_2' = \frac{l}{c-v}$

After time $\boldsymbol{t_2''}$ the light reaches the mirror L in point A. The emitting point D, is moving to the left in point **F** and DF=$\boldsymbol{v} \cdot t_2''$ Therefore:

$ct_2'' = l - v \cdot t_2''$ Hence: $t_2'' = \frac{l}{c+v}$ It implies that: $t_2 = \frac{l}{c-v} + \frac{l}{c+v} = \frac{2lc}{c^2-v^2}$

Therefore: $\Delta t = \frac{lv^2}{c^2(c+v)}$ as for the stationary reference system (SYSTEM S)

$\boldsymbol{t_2 > t_1}$ therefore, until the light from **O2** reaches the mirror **L** in point **A**, the point reached by the light from **O1** at the level of **L-O2** arm, is moving to the left with: $\boldsymbol{v\Delta t}$

The distance between the axis of the reflected beams is calculated as follows:

$(v' - v)t_1 \ = \ x + v\Delta t$ therefore: $x \ = \ \frac{lv^2}{c(c+v)}$

The same distance $\boldsymbol{x}$ has also been measured against the reference system considered stationary (SYSTEM S).

II.2 THE INTERFEROMETER ROTATED BY 90°

The observer in the reference system linked to the interferometer (SYSTEM S_P) find that in the areas where the optical phenomena occur, the direction of the **L-O1** is moved away towards **O1** (in reverse to the movement detected by the stationary observer). As a result, the rotating effect of the mirrors will also occur against the interferometer system. The theory that the light propagates independently, is recalled.

$\varepsilon = 2\psi$

From figure 15, shall be noted:

$\psi = \alpha - 45$ therefore:

$sin\varepsilon = -\,cos2\,\alpha$ but: $tg\,\alpha = \frac{c}{c-v}$

Hence: $sin\varepsilon = \frac{c^2-(c-v)^2}{c^2 + (c-v)^2}$ as for the stationary reference system

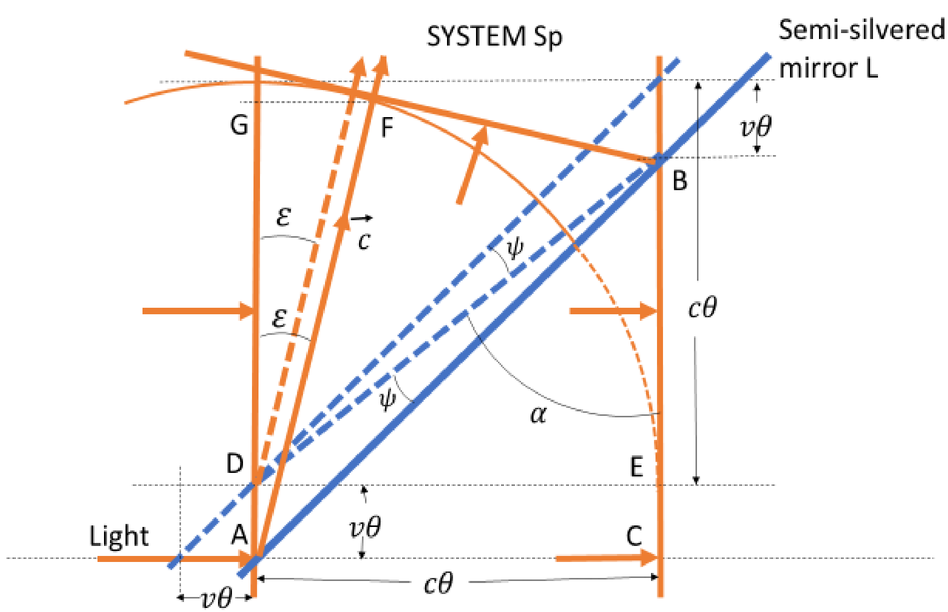

Fig. 15 While the initial wavefront ADG reaches the CEB position, zone A on the L mirror, where the first elementary waves were emitted from, moves on the distance AD. The surface reflecting the light towards the mirror O1 has the section passing through D and B. The reflected GB wavefront propagates in the AF direction.

On the **L-O1** arm direction, the component of the light speed reflected by the **L** mirror towards **O1**, is: $\mathbf{c}\ \boldsymbol{cos}\ \boldsymbol{\varepsilon}$**.**

The first section of the **O1** mirror touched by the wavefront coming from **L**, is **A** (Fig. 16). After time $\boldsymbol{\theta}$, the light reaches the **B** section of the **O1** mirror. Meanwhile, from the interferometer observer system of reference, it is found that point **A**, where the first secondary wave was emitted, moved with AC = $v\theta$ and the secondary wave with CE = $\boldsymbol{c}\ \boldsymbol{\theta}$. The surface that reflects the light has the **CB** section and is rotated towards the **O1** mirror at an angle $\boldsymbol{\psi'}$. The light sent to the mirror **L** together with the **L-O1** arm, forms the angle $\boldsymbol{\varepsilon'}$**.** The light speed component parallel to the **L-O1** arm is: $\boldsymbol{c}\ \boldsymbol{cos}\ \boldsymbol{\varepsilon'}$

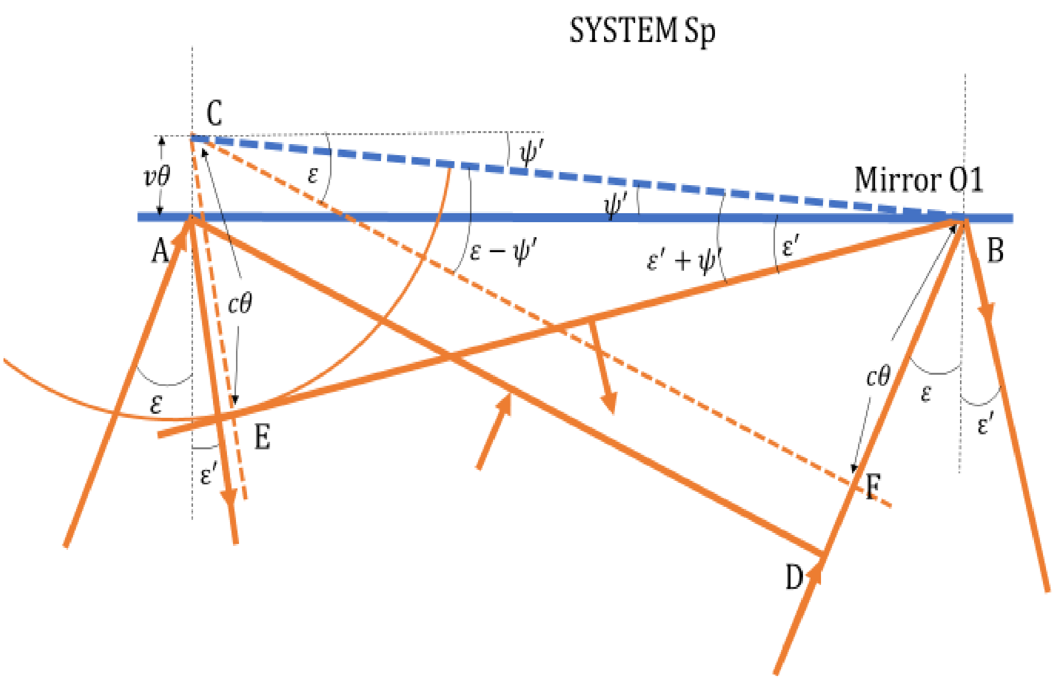

Fig.16 While the AD incident wavefront reaches the O1 mirror in point B, the center of the first elementary wave A moves to point C, and the the AD front in the position CF. The Light from point D, reaching point B, is seen by the observer in the S_P system as coming from F. Therefore, the reflecting surface passes through C and B.

From the congruent BCE and BCF triangles, shall result:

$\varepsilon - \psi' = \varepsilon' + \psi'$ therefore $\varepsilon' = \varepsilon - 2\psi'$ but:

$$sin\psi' = \frac{v\theta}{BC} \quad and \quad sin\ (\varepsilon - \psi') = \frac{c\theta}{BC} \quad \text{therefore} \quad \frac{sin\ \psi'}{sin(\varepsilon - \psi')} = \frac{v}{c}$$

These are the same relationships as in the reference system considered stationary (SYSTEM S)

Therefore:

$\sin \varepsilon' = \frac{(2cv-v^2)(c^2-v^2)}{2c^4+2c^3v-c^2v^2-2cv^3+v^4}$ and $\cos \varepsilon' = \frac{2c^2(c^2+cv-v^2)}{2c^4+2c^3v-c^2v^2-2cv^3+v^4}$

From the interferometer observer system of reference, the light beams propagate as shown in Figure 17.

The light time travel on the **L-O2-L** distance, is $\boldsymbol{\tau_2}$.

The displacements of event locations in the direction of the **L-O1** arm do not affect the components of light speed in the perpendicular direction **L-O2**. The component of the light speed, in the **L-O2** direction is exactly $\boldsymbol{c}$, because this direction it is emitted by the light source. Therefore:

$\tau_2 = \frac{2l+d}{c}$ and $d = v \cdot \tau_2$ therefore: $\tau_2 = \frac{2l}{c-v}$ and $d = \frac{2lv}{c-v}$

As for the reference system considered as stationary.

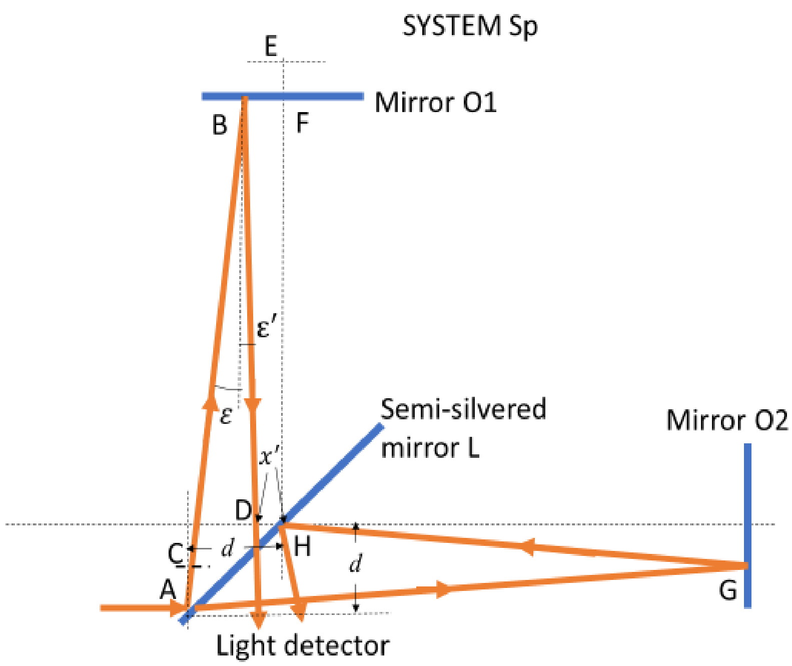

Fig. 17 Shows the propagation directions of the light beam fronts reflected by the interferometer. AC is the distance point A moves on, until the reflected light reaches the O1 mirror. Point B is moving on the distance E-F until the light reaches the level of the L-O2 arm.

The $\boldsymbol{\tau_1'}$ light travel time on distance L-O1, is calculated as follows:

$\tau_1' \, c \cos \varepsilon = l + d - v\tau_1'$ resulting: $\tau_1' = \frac{l(c+v)[c^2+(c-v)^2]}{(c-v)(2c^3-2cv^2+v^3)}$

The $\boldsymbol{\tau_1''}$ light travel time on distance **O1-L**, is found in the equation bellow:

c $\cos\varepsilon' \tau''_1 = (l+d-v\tau'_1) + v\ \tau''_1$ i.e. $\tau''_1 = \frac{l(c+v)(2c^4+2c^3v-c^2v^2-2cv^3+v^4)}{c(c^2+cv-v^2)(2c^3-2cv^2+v^3)}$

$\tau_1 = \tau'_1 + \tau''_1 = \frac{l(c+v)(2c^2-v^2)}{c(c-v)(c^2+cv-v^2)}$ represents the time the light travels the path **L-O1-L**

The time difference is expressed by: $\Delta\tau = -\frac{lv^2}{c(c^2+cv-v^2)}$

The distance between the beams axis is: $x' = d - v'\tau'_1 - v''\tau''_1 = \frac{lv^2}{c^2+cv-v^2}$ as in the reference system considered stationary.

II. 3 THE INTERFEROMETER ROTATED BY 45°

The observer in the S_P system finds that the points where optical events occur move at a speed $\boldsymbol{v}$, at an angle of **45°,** with the **L-O2** arm counterclockwise (directly trigonometric). Analysis and calculations can be performed similarly to those of the interferometer rotation by **90°,** using the component $v* = \frac{v}{\sqrt{2}}$

The path shape observed from S_P system is the one shown in figure 18.

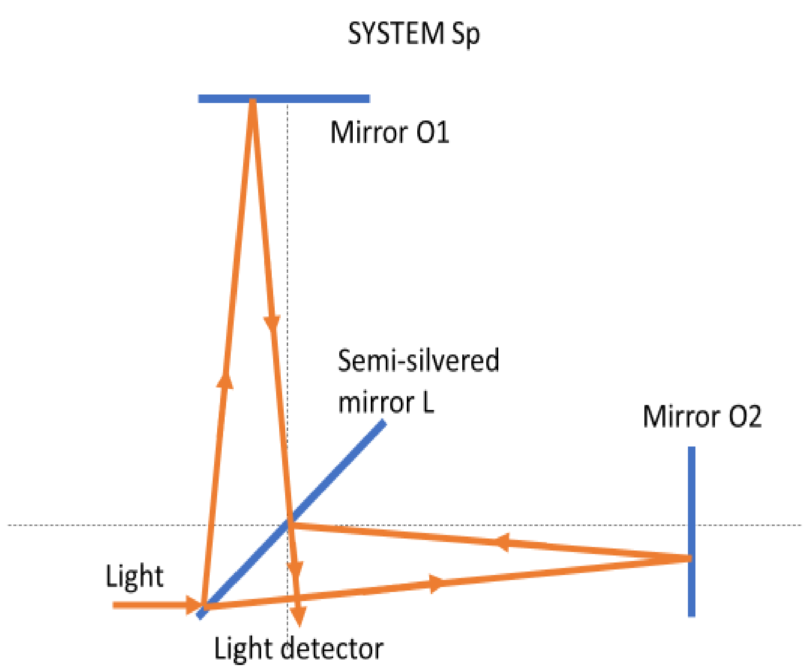

Fig. 18 The light beams reflected by the mirrors overlap perfectly in the center of the L mirror.

The light beams travel the arms of the interferometer in intervals equal to those determined from the system considered stationary. The angle between the axis of the beams is null.

CONCLUSIONS

In the Michelson-Morley experiment, the interference fringes should not move when rotating the interferometer, because the causes that would move them give reverse effects and cancel out. Under the theory that light is not driven by the medium where the interferometer is located, changes in the travel times through the interferometer arms and the additional rotations of the mirrors due to their movement with the Earth generate reverse effects on the interference fringes, which is proven to be experimental. The area of interference is described by **Δt** values (the light beams travel time difference through the interferometer arms), angle between the beams and **x** (distance between the axis of the interfering light beams), which we periodically retrieve during interferometer rotation and for which the fringes remain stationary.

If the medium drives the light, then the analyses and calculations are performed differently, but in full accordance with the experimental result.