**Michelson and Morley experiment's hidden error overlooked for 130 years**

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**Abstract**
This paper shows why the Michelson and Morley experiment did not give the expected result, and that the disappointment was due to a hidden error in Michelson's assumptions.

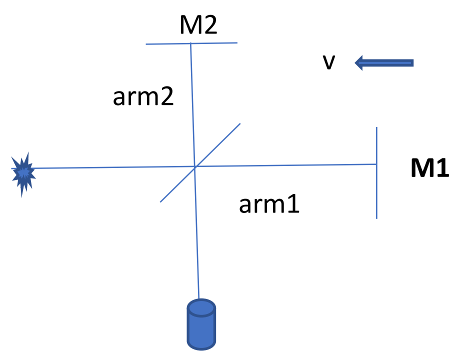
Keywords
Michelson-Morley experiment; Michelson interferometer; The famous failed experiment; ether

## Introduction

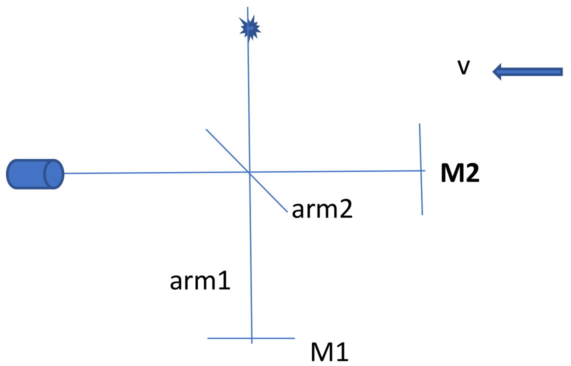
Physicists before the advent of the theory of relativity believed that space contained a substance called the ether that was the medium for the propagation of electromagnetic waves. In 1887, Michelson and Morley tried to detect it and measure the velocity of the earth through it by means of the Michelson interferometer. They performed the experiment many times but failed to get the expected result. Since then many other physicists over many decades have tried the experiment but they have also failed. This experiment became known as the "famous failed experiment." Many ad-hoc theories, some of them bizarre, were proposed to explain the null result of the experiment but were not accepted because they contradicted some known physical reality. This paper shows that the experiment contains an error that has been overlooked by physicists for 130 years. The explanation of the experiment is found in all university physics books. The reader may refer to them or to the original paper of Michelson and Morley about their experiment [1] for more details. Here, only a brief explanation is given.

## Michelson-Morley experiment

A beam of light from a source is split by a half-silvered mirror and sent through two perpendicular arms of the Michelson interferometer, which is fixed on earth. The earth moves through the ether with a velocity v relative to the ether and therefore experiences an ether wind. One beam is sent in the direction of the motion of the earth (parallel direction) and the other perpendicular to it (perpendicular direction). These beams are then reflected by mirrors fixed at the end of each arm returning to the half-silvered mirror. The beams are then transmitted to a telescope where they interfere and produce a fringe pattern. The interferometer is then rotated through $90^o$. The direction of v is unchanged, but the two paths in the interferometer are interchanged. This (according to Michelson) will introduce a path difference in the opposite sense to that obtained before. A fringe shift therefore is expected to take place but in fact no shift was observed.



Original Orientation



Rotated Orientation

Let the length of each arm be $l$. In the original orientation, the time for beam 1 to travel from the half-silvered mirror to M1 and back (transit time in parallel direction) is given by

$$t_1 = \frac{l}{c-v} + \frac{l}{c+v} = \frac{2l}{c}\left(\frac{1}{1-v^2/c^2}\right) = \frac{2l}{c}\left(1+\frac{v^2}{c^2}\right)$$

where c is the speed of light in the ether and $v$ is the velocity of the earth relative to the ether. The time $t_2$ for beam 2 to travel from the half-silvered mirror to M2 and back (transit time in perpendicular direction) is given by

$$2\sqrt{\left[t_2^2 + \left(\frac{vt_2}{2}\right)^2\right]} = ct_2$$

therefore

$$t_2 = \frac{2l}{c}\frac{1}{\sqrt{1-v^2/c^2}} = \frac{2l}{c}\left(1+\frac{v^2}{2c^2}\right)$$

The difference in transit times Δt is

$$\Delta t = t_1 - t_2 = \frac{2}{c}\left[\frac{l}{1-v^2/c^2} - \frac{l}{\sqrt{1-v^2/c^2}}\right] = \frac{l}{c}\frac{v^2}{c^2}$$

This multiplied by c the speed of light corresponds to a path difference of

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

**The error**

Michelson **without any justification stated that "if now the whole apparatus be turned through 90<sup>o</sup> the difference will be in the opposite direction. Hence the displacement of the interference fringes should be $2l\frac{v^2}{c^2}$". *The error is in this assumption*** as is shown below.

Consider a hypothetical case in which the transit time in each arm remains unchanged when the apparatus is rotated through 90 degrees, as if somehow the transit times are connected with the arms. In other words, as arms switch positions from perpendicular direction to parallel direction and from parallel direction to perpendicular, the corresponding transit times in them switch as well.

In this hypothetical case, let $t_2''$ be the transit time in arm2, which is now parallel to the motion of the earth in the rotated orientation, and $t_1''$ be the transit time in the perpendicular arm. Therefore, according to this hypothesis

$$t_2'' = \frac{2l}{c}\frac{1}{\sqrt{1-v^2/c^2}} = \frac{2l}{c}\left(1+\frac{v^2}{2c^2}\right)$$

and

$$t_1'' = \frac{l}{c-v} + \frac{l}{c+v} = \frac{2l}{c}\left(\frac{1}{1-v^2/c^2}\right) = \frac{2l}{c}\left(1+\frac{v^2}{c^2}\right)$$

Let Δt" be the transit time difference between the two beams in the rotated position in this hypothetical case.

$$\Delta t'' = t_2'' - t_1'' = -\frac{l}{c}\frac{v^2}{c^2}$$

Note: <u>The change in transit time differences of the two orientations (i.e., $\Delta t - \Delta t''$) multiplied by the speed of light shows the displacement of the interference fringes.</u>

In this hypothetical case, the rotation changes the differences by

$$\Delta t - \Delta t'' = \frac{l}{c}\frac{v^2}{c^2} - \left(-\frac{l}{c}\frac{v^2}{c^2}\right) = \frac{2l}{c}\frac{v^2}{c^2}$$

corresponding to a path difference of $\boldsymbol{2l\frac{v^2}{c^2}}$ as predicted by Michelson.

Alternatively, to get $\Delta t''$ we could subtract $t_2''$ from $t_1''$. We would then get $\Delta t'' = +\frac{l}{c}\frac{v^2}{c^2}$ and hence $\Delta t - \Delta t''$ = 0, which corresponds to zero path difference and hence no shift. But this is contrary to what Michelson had expected.

The above demonstration shows that the shift predicted by Michelson could only occur in this hypothetical case.

**However, this hypothetical case cannot be true. The time a beam of light takes to travel a given distance in the direction parallel to the earth's motion or perpendicular to it, through an arm, has nothing to do with, and is independent of, what the position of the arm has been in the previous orientation. In other words, the transit times in the arms are not connected with the arms. This is the fact that has been overlooked in this experiment.**

**The actual shift**

Looking at the apparatus, we can see that the two beams of light have the same situations in both the original and rotated orientations of the apparatus. In both situations one arm is parallel to the direction of the earth's motion and the other is perpendicular to it. The rays from the source are split and sent in the two directions. The two rays reach the field of vision with a time difference. The position of the light source differs in the two orientations. In the first orientation, it is along the direction of the earth's motion and in the rotated orientation it is along the perpendicular direction. But this is of no consequence, as the beam from the source in each orientation is split and sent in the two directions. **The two orientations are therefore equivalent**.

When the apparatus is turned through 90$^{0}$, arm2 will be in the direction of the motion of the earth and arm1 perpendicular to it. Let the transit time for the beam to travel from the half-silvered mirror to M2 and back in arm2, which is now parallel to the motion of the earth in the rotated orientation, be $t_2'$

$$t_2' = \frac{l}{c-v} + \frac{l}{c+v} = \frac{2l}{c}\left(\frac{1}{1 - v^2/c^2}\right) = \frac{2l}{c}\left(1 + \frac{v^2}{c^2}\right)$$

And let the transit time for the beam travelling in arm1, which is now perpendicular to the direction of the motion of the earth, be $t_1'$

$$t'_1 = \frac{2l}{c}\frac{1}{\sqrt{1 - v^2/c^2}} = \frac{2l}{c}\left(1 + \frac{v^2}{2c^2}\right)$$

The difference between the transit times of the two beams in the rotated orientation is

$$\Delta t' = t'_2 - t'_1 = \frac{2}{c}\left[\frac{l}{1 - v^2/c^2} - \frac{l}{\sqrt{1 - v^2/c^2}}\right] = \frac{l}{c}\frac{v^2}{c^2}$$

Which is the same as Δt, the time difference in the original orientation.
Hence

$$\Delta t' - \Delta t = 0$$

**corresponding to zero path difference. So, the rotation should not cause a shift in the fringe pattern.**

One may argue that if we subtract $t'_2$ from $t'_1$ we would get $\Delta t' = -\frac{l}{c}\frac{v^2}{c^2}$ and hence we would get $\Delta t - \Delta t' = \frac{2l}{c}\frac{v^2}{c^2}$. But this is equivalent to assuming that transit times in the arms remain the same in each arm when the apparatus is rotated, as shown in the hypothetical case above.

**Conclusion**

In this paper, it is shown mathematically that Michelson's expectation of the shift is *equivalent to assuming that the transit times of the beams in the arms are somehow related or connected with the arms, and hence as the arms switch positions, the corresponding travel times of the beams in them should also switch*. This assumption is obviously incorrect. The travel time of a beam of light in an arm in any direction is independent of what the position of the arm has been previously. It is also shown that the two orientations are equivalent and it is as if no rotation of the apparatus has taken place. Therefore, there is no reason the experiment should show a shift in the position of the interference pattern. **The null result of the Michelson-Morley experiment is what should have been expected. That is, this experiment, the way it is designed, could not detect the ether.**

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**Reference**

1. A. A. Michelson and E. Morley, *Am. J. Sci.,* 34, 333 (1887)