Analysis of the Michelson–Morley Experiment with a Hypothetical Propagation Medium

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Abstract

The Michelson–Morley experiment showed equal light travel times in the longitudinal and transverse arms of an interferometer, traditionally interpreted as evidence for the absence of a light-propagating medium. This paper analyzes the experiment in the reference frame of a hypothetical medium, modeled as a property of space or a field, without assuming its absence. We introduce longitudinal and transverse dilation/contraction factors and derive their relationship to reproduce the null result. This generalizes the Lorentz contraction and provides a framework for alternative medium-based interpretations consistent with the experimental outcome.

Keywords: Michelson–Morley experiment, Lorentz contraction, propagation medium, length dilation/contraction, special relativity, interferometry.

1 Introduction

The Michelson–Morley experiment [1] aimed to detect Earth's motion through a hypothetical medium for light propagation, historically termed the "ether." The experiment's null result, showing equal light travel times in orthogonal arms, challenged the existence of such a medium and paved the way for Einstein's special relativity [3]. However, alternative interpretations proposing a medium—modeled as a property of space itself or a field—have persisted [5, 6]. This paper reexamines the experiment in the reference frame of such a medium, deriving a general relationship between longitudinal and transverse dimensional changes that reproduces the null

result. We avoid the term "ether" to distance from classical connotations, instead considering the medium as an intrinsic property of space or a field, which may be isotropic or anisotropic in future analyses.

2   Historical Background

In the late 19th century, the luminiferous ether was hypothesized as the medium for light propagation. Michelson and Morley [1] designed an interferometer to detect Earth's motion relative to this medium, expecting interference fringe shifts due to differing light travel times. The null result contradicted expectations, prompting Lorentz [2] to propose length contraction in the direction of motion, later generalized by FitzGerald [4]. Einstein's special relativity [3] explained the null result without a medium, but medium-based models have been proposed [5, 6, 7], motivating this generalized analysis.

3   Definitions

We consider the interferometer in the reference frame of a hypothetical medium, modeled as a property of space or a field, through which light propagates at speed c. We define:

- k_{long}: longitudinal dilation/contraction factor, $L_{\text{long}} = k_{\text{long}} L_0$.

- k_{trans}: transverse dilation/contraction factor, $L_{\text{trans}} = k_{\text{trans}} L_0$.

- L_0: arm length in the rest frame of the interferometer.

Our goal is to find the relationship between k_{trans} and k_{long} that ensures equal light travel times in both arms.

4   Longitudinal Arm Analysis

In the medium frame:

- Forward trip:

$$t_{\text{forward}} = \frac{k_{\text{long}} L_0}{c - v}$$

- Return trip:

$$t_{\text{return}} = \frac{k_{\text{long}} L_0}{c + v}$$

- Total time:

$$t_{\text{longitudinal}} = k_{\text{long}} L_0 \left(\frac{1}{c - v} + \frac{1}{c + v} \right) = \frac{2 k_{\text{long}} L_0}{c \left(1 - \frac{v^2}{c^2} \right)}$$

- Distance traveled:

$$d_{\text{longitudinal}} = 2 k_{\text{long}} L_0$$

5   Transverse Arm Analysis

For the transverse arm:

- Vertical velocity: $v_y = c \sqrt{1 - \frac{v^2}{c^2}}$

- Forward trip time:

$$t_{\text{forward}} = \frac{k_{\text{trans}} L_0}{c \sqrt{1 - \frac{v^2}{c^2}}}$$

- One-way path length:

$$d_{\text{forward}} = \frac{k_{\text{trans}} L_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- Round-trip distance:

$$d_{\text{transverse}} = \frac{2 k_{\text{trans}} L_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- Total time:

$$t_{\text{transverse}} = \frac{2 k_{\text{trans}} L_0}{c \sqrt{1 - \frac{v^2}{c^2}}}$$

6   Equality Condition

Equal travel times require:

$$k_{\text{long}} = \frac{k_{\text{trans}}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Thus:

$$\frac{k_{\text{trans}}}{k_{\text{long}}} = \sqrt{1 - \frac{v^2}{c^2}}$$
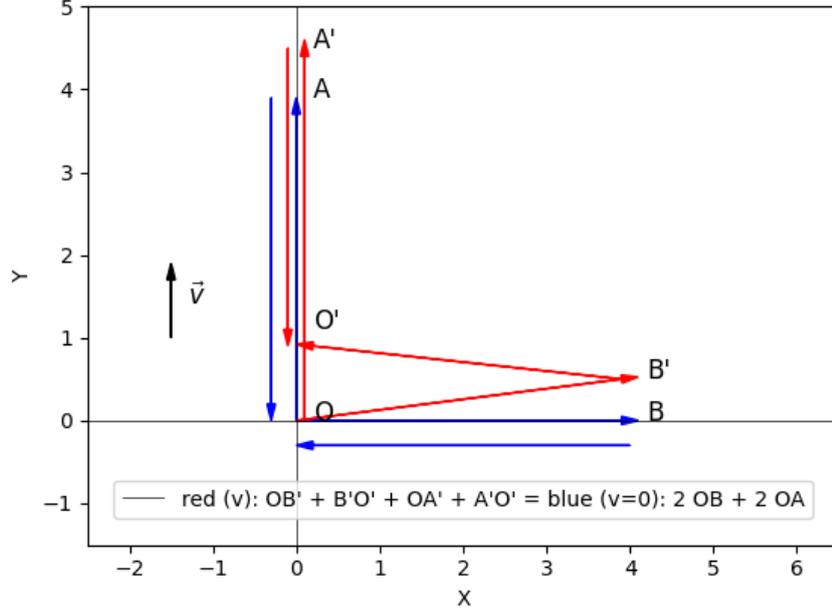
Figure 1: Photon Trajectories in the Stationary and Moving Michelson–Morley Interferometer

7 Discussion

The derived condition, $\frac{k_{\text{trans}}}{k_{\text{long}}} = \sqrt{1 - \frac{v^2}{c^2}}$, ensures the Michelson–Morley null result in a medium-based framework. Key features:

- At $v = 0$, $k_{\text{trans}} = k_{\text{long}}$, implying no dimensional changes in the absence of motion.

- For $0 < v < c$, the transverse arm contracts relative to the longitudinal arm, generalizing the Lorentz contraction ($k_{\text{trans}} = 1$).

- The condition becomes undefined at $v = c$, consistent with physical limits.

This framework complements special relativity's explanation by offering an alternative interpretation where a medium, conceptualized as space or a field, influences dimensional changes. Unlike special relativity, which eliminates the need for a medium, our model allows exploration of medium-based theories without contradicting the null result. For instance, the isotropic case (uniform medium properties) aligns with the derived ratio, while anisotropic cases could be explored in future work to test deviations from isotropy [7].

Potential implications include revisiting modern interferometry experiments, such as those extending the Kennedy–Thorndike test [8], to probe whether transverse effects could be detected with higher precision. This approach does not challenge special relativity but provides

a mathematical framework for alternative models, which could inspire theoretical developments in field-based or space-based propagation theories.

8   Conclusion

The Michelson–Morley null result can be reproduced in a medium-based framework if:

$$\frac{k_{\text{trans}}}{k_{\text{long}}} = \sqrt{1 - \frac{v^2}{c^2}}$$

This generalizes the Lorentz contraction and supports alternative interpretations where light propagates through a medium modeled as space or a field. Future work could explore isotropic versus anisotropic medium properties or design experiments to test transverse effects, enhancing our understanding of light propagation in alternative theoretical frameworks.

References

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