the general science journal

Invisibility of Absolute Motion in Interferometric Experiments and Access to First-Order Effects

Optical interferometric experiments led to the establishment of the principle of relativity owing to their systematic inability to reveal absolute motion. This undetectability is generally interpreted as a fundamental property of nature.

In this work, we show that it actually results from the structure of observables constructed from reciprocal light paths, which eliminate first-order contributions and reconstruct invariant quantities.

Relativity thus appears as an emergent structure of measurements rather than as a primary property. Within this framework, the detection of a first-order effect would constitute not an anomaly, but access to kinematic information ordinarily erased, opening the possibility of directly probing the dynamics of the underlying medium.

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Original language: French

Created: 3 April 2026

Last modified: April 15, 2026

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1 Introduction

1.1 Historical Context

For more than two centuries, the question of the existence of absolute motion through a privileged medium, historically referred to as the *aether*, has profoundly shaped the development of optics and theoretical physics. As early as the 18th century, the observation of stellar aberration by James Bradley (1728) brought to light a first-order effect in v/c, revealing the Earth's motion through space while raising the question of the behaviour of light in a moving reference frame.

At the beginning of the 19th century, Dominique-François Arago (1810) undertook to test the influence of terrestrial motion on the refraction of light. The absence of any measurable variation led Augustin Fresnel (1818) to propose the hypothesis of partial entrainment of the aether by matter, introducing the factor $1-\frac{1}{n^2}$. This idea was confirmed experimentally by Hippolyte Fizeau (1851), who observed the displacement of interference fringes in a moving fluid, thereby validating the partial entrainment mechanism.

However, these results did not settle the question of the absolute motion of the experimental system itself. It was in this context that the interferometric experiments of Michelson and Morley (1887) were conceived, aiming to detect an anisotropy in the speed of light linked to the Earth's motion through the aether. Their null result marked a major turning point, progressively leading to the abandonment of the aether and to the development of special relativity by Einstein (1905), founded on the invariance of physical laws in all inertial reference frames.

1.2 Operational Definition of Round-Trip Configurations

In what follows, the term *round-trip* is used in a precise sense: it designates an experimental configuration in which a given optical path is traversed by two distinct beams propagating in opposite directions. This therefore does not refer to the path of a single beam that is reflected, but to a propagation symmetry between two counter-propagating waves. This clarification is necessary, as the term may be ambiguous if not explicitly defined.

Nevertheless, the case of a single beam making a forward and then a return journey along the same path constitutes an equivalent representation from the point of view of travel times. This more intuitive situation directly illustrates the mechanism by which directional contributions cancel, and may be used as a conceptual model to grasp its origin.

This convention thus allows a rigorous distinction between the two directions of propagation, while preserving an immediately accessible physical interpretation.

1.3 Kinematic Compensation Mechanism

As established in (1) and (2), the historical experiments share a common structure: they rely on measurements constructed from reciprocal light paths, that is, bidirectional propagation along the same optical path.

The symmetry introduced by round-trip configurations is not merely a geometric property of experimental devices; it has a direct dynamical consequence on the quantities measured.

This compensation mechanism already manifests itself in the simplest case of propagation in vacuum. If the travel times in each direction are affected by the motion of the system, their symmetric combination exactly suppresses the linear contributions. This compensation mechanism, established in (3), thus leads to an effective invariance of observable quantities, independent of the uniform motion of the device.

This property constitutes an experimental foundation of the principle of relativity, whose validity has been confirmed with remarkable precision in numerous modern contexts. It appears notably in satellite navigation systems such as GPS, where position reconstruction relies on precise measurements of electromagnetic signal propagation times.

1.4 Extension to Refractive Media

The introduction of a refractive medium might, at first sight, offer a route to lift this undetectability. Indeed, the propagation of light in a material medium depends on interactions with the constituents of the medium, and Fresnel entrainment establishes a direct link between the speed of light and that of the material support. However, as we show in this work, this intuition does not hold within the framework of interferometric experiments based on round-trip configurations.

1.5 Conceptual Scope and Objective of the Work

This observation leads to a reconsideration of the experimental scope of the principle of relativity. Rather than necessarily reflecting a fundamental property of nature, it might emerge from the constraints imposed by measurement procedures themselves. The observed invariance would then be the consequence of a mechanism for reconstructing observables, which conceals any directional information linked to absolute motion.

The objective of this work is twofold. On the one hand, it aims to formalise this compensation mechanism in the general case, explicitly including the presence of refractive media and the role of Fresnel entrainment. On the other hand, it seeks to identify conditions that allow this undetectability to be circumvented, by exploring experimental configurations capable of breaking the round-trip symmetry.

This approach thus opens the way to a reassessment of the status of the absolute reference frame, not in contradiction with established experimental results, but in coherence with a deeper analysis of the measurement mechanisms that underlie them.

2 Conceptual Framework

2.1 General Problem

The central question of this work is the detectability of absolute motion in a possible privileged reference frame. Historically, this question has been approached through optical experiments aiming to reveal an anisotropy in the propagation of light. The absence of detection led to the establishment of the principle of relativity, according to which no inertial reference frame can be experimentally distinguished.

However, this conclusion rests on observables constructed from specific experimental protocols. It is therefore necessary to examine to what extent these observables are genuinely sensitive to the effects being sought.

2.2 Hypothesis of a Privileged Reference Frame

Within the framework of this study, we consider the existence of a privileged reference frame in which the propagation of light in vacuum is isotropic and characterised by the speed c. This hypothesis is not introduced as a theoretical necessity, but as an analytical framework enabling an examination of the experiments' ability to detect global motion of the system.

In the energetic medium model developed in (1), this privileged reference frame has a precise physical meaning: it corresponds to the frame locally co-moving with the energetic flux, that is, the frame in which the velocity of this flux vanishes locally ($\vec{v} = 0$). It is within this frame that the propagation of electromagnetic perturbations is isotropic and that the speed c takes its intrinsic value, determined by the properties of the medium.

An experimental device is assumed to move at a uniform velocity $\vec{v}$ relative to this reference frame. The question then posed is the following: do the quantities measured within this device allow access to this velocity?

2.3 Nature of Experimental Observables

Interferometric experiments do not directly measure velocities or absolute times. They rely on the measurement of phase differences or time differences between several optical paths. These observables may be schematically represented in the form:

$$\mathcal{O} = f(T_1, T_2, \dots), \tag{1}$$

where each T_i corresponds to a travel time associated with a given light path.

In almost all experimental devices considered, each time T_i itself results from a round-trip traversal:

$$T_i = t_{\rightarrow}^{(i)} + t_{\leftarrow}^{(i)}. \tag{2}$$

This structure plays a decisive role in the sensitivity of the experiment.

3 Propagation in Vacuum

3.1 General Framework

We consider an optical device moving at uniform absolute velocity $\vec{v}$ in a privileged reference frame, identified here with the frame associated with the energetic medium. In this frame, light propagates isotropically at speed c.

Let a rectilinear optical arm of local length L, rigidly attached to the device. This length L is measured directly in the device's frame using a local material standard. It therefore does not result from a radar procedure based on a light round-trip, unlike what occurs in GPS-type navigation systems. The present case is thus conceptually distinct from the reconstruction of distances from propagation times, discussed in (3). Nevertheless, this distinction is only apparent, since it has been shown that measurement by material standard and radar reconstruction are strictly equivalent from the point of view of the reconstructed quantities.

We denote by α the angle that this arm makes with the direction of the absolute velocity $\vec{v}$, this angle also being defined in the local frame of the device. The objective is to determine the round-trip travel time of a light signal along this arm, as measured locally by the on-board observer.

3.2 Geometry of the Arm in the Absolute Frame

In the local frame of the device, the arm of length L oriented at angle α relative to the velocity $\vec{v}$ decomposes into two components:

$$L_{\parallel} = L \cos\alpha \qquad \text{and} \qquad L_{\perp} = L \sin\alpha \tag{3}$$

The first is along the direction of motion, while the second is orthogonal to it.

As established in (1), longitudinal contraction should not be interpreted as a mere effect of a change of reference frame. It corresponds to a real modification of the internal structure of matter, governed by the electromagnetic interactions that ensure the cohesion of its constituents.

In other words, a material system in motion in the absolute frame sees its internal bonds reorganise under the effect of the dynamics of the energetic medium, leading to a physical anisotropic deformation.

Thus, the response of matter depends on its orientation relative to the velocity: only the component parallel to $\vec{v}$ is affected by this internal reorganisation, while the transverse component remains unchanged.

Introducing the Lorentz factor:

$$\gamma = \frac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}} \tag{4}$$

The effective components of the arm, resulting from this material dynamics, are written:

$$L_{\parallel}^{\text{abs}} = \frac{L\cos\alpha}{\gamma} \qquad \text{and} \qquad L_{\perp}^{\text{abs}} = L\sin\alpha \tag{5}$$

Within this framework, only one length possesses physical reality and intrinsic status: that defined in the absolute frame, which corresponds to the actual physical state of the system. Lengths measured in a frame moving relative to the energetic medium do not directly reflect this reality, but result from measurement procedures that are themselves affected by the dynamics of the medium. They are thus, in this sense, biased by the conditions of observation.

This distinction appears clearly when one considers the manner in which length is defined experimentally. In GPS-type devices, distances are reconstructed from light propagation times using a radar procedure.

Here, the length L is defined by a local material standard, that is, by direct comparison between material objects. This standard, being made of the same matter as the arm, undergoes the same internal modification. Consequently, the length L remains constant for the on-board observer, not because it directly reflects the intrinsic length of the system, but because the measuring instrument and the measured object are affected in an identical manner by the dynamics of the medium.

It is precisely at this level that an ambiguity arises that must be resolved by distinguishing two notions:

- **A form of "local reality"**, appealing in its immediacy but potentially misleading for physical interpretation. It encompasses all quantities as they are measured, processed, and reconstructed by an on-board device, closely tied to our perception and to human experience.
- **Physical reality**, which refers to the intrinsic state of the system, independently of any observation, as defined in a fundamental reference frame.

From this perspective, the local description does not constitute direct access to the real, but a partial representation, conditioned both by the modalities of measurement and by the dynamics of the medium. Interpreting the local description therefore requires the introduction of absolute quantities, which alone are capable of accounting for the underlying physical structure and of conferring meaning upon the invariances locally observed, as well as upon the various effects brought to light.

3.3 Forward Travel Time in the Absolute Frame

We assume that the light signal is emitted from the origin of the arm at time $t = 0$, and then reaches the opposite end, which serves as a mirror.

In the absolute frame, the mirror is not at rest. During the propagation time $t_{\rightarrow}$, it moves a distance $v\,t_{\rightarrow}$ along the direction parallel to $\vec{v}$.

The coordinates of the reflection event in the absolute frame are therefore:

$$x_{\rightarrow} = L_{\parallel}^{\text{abs}} + v\,t_{\rightarrow} \qquad \text{and} \qquad y_{\rightarrow} = L_{\perp}^{\text{abs}} \tag{6}$$

Since light propagates at speed c, we must have:

$$c^2 t_\rightarrow^2 = \left(L_\parallel^{\text{abs}} + v\, t_\rightarrow\right)^2 + \left(L_\perp^{\text{abs}}\right)^2 \tag{7}$$

Expanding, one obtains:

$$\left(c^2 - v^2\right) t_\rightarrow^2 - 2vL_\parallel^{\text{abs}}\, t_\rightarrow - \left[\left(L_\parallel^{\text{abs}}\right)^2 + \left(L_\perp^{\text{abs}}\right)^2\right] = 0 \tag{8}$$

The positive physical solution is:

$$t_\rightarrow = \frac{vL_\parallel^{\text{abs}} + \sqrt{v^2\left(L_\parallel^{\text{abs}}\right)^2 + (c^2 - v^2)\left[\left(L_\parallel^{\text{abs}}\right)^2 + \left(L_\perp^{\text{abs}}\right)^2\right]}}{c^2 - v^2} \tag{9}$$

Substituting the expressions for the absolute components, the term under the square root becomes:

$$v^2\left(\frac{L\cos\alpha}{\gamma}\right)^2 + \left(c^2 - v^2\right)\left[\left(\frac{L\cos\alpha}{\gamma}\right)^2 + L^2\sin^2\alpha\right] \tag{10}$$

$$= \frac{v^2 L^2\cos^2\alpha}{\gamma^2} + \left(c^2 - v^2\right)\left[\frac{L^2\cos^2\alpha}{\gamma^2} + L^2\sin^2\alpha\right] \tag{11}$$

Since

$$\frac{1}{\gamma^2} = 1 - \frac{v^2}{c^2} = \frac{c^2 - v^2}{c^2} \tag{12}$$

it follows that

$$v^2\left(L_\parallel^{\text{abs}}\right)^2 + \left(c^2 - v^2\right)\left[\left(L_\parallel^{\text{abs}}\right)^2 + \left(L_\perp^{\text{abs}}\right)^2\right] \tag{13}$$

$$= \frac{v^2 L^2\cos^2\alpha}{\gamma^2} + \frac{c^2 - v^2}{\gamma^2} L^2\cos^2\alpha + \left(c^2 - v^2\right) L^2\sin^2\alpha \tag{14}$$

$$= \frac{L^2\cos^2\alpha}{\gamma^2}\left(v^2 + c^2 - v^2\right) + \left(c^2 - v^2\right) L^2\sin^2\alpha \tag{15}$$

$$= \frac{c^2 L^2\cos^2\alpha}{\gamma^2} + \left(c^2 - v^2\right) L^2\sin^2\alpha \tag{16}$$

And since:

$$c^2 - v^2 = \frac{c^2}{\gamma^2} \tag{17}$$

we obtain:

$$v^2\left(L_{\parallel}^{\text{abs}}\right)^2 + \left(c^2 - v^2\right)\left[\left(L_{\parallel}^{\text{abs}}\right)^2 + \left(L_{\perp}^{\text{abs}}\right)^2\right] = \frac{c^2 L^2}{\gamma^2} \tag{18}$$

The square root therefore simplifies exactly:

$$\sqrt{v^2\left(L_{\parallel}^{\text{abs}}\right)^2 + (c^2 - v^2)\left[\left(L_{\parallel}^{\text{abs}}\right)^2 + \left(L_{\perp}^{\text{abs}}\right)^2\right]} = \frac{cL}{\gamma} \tag{19}$$

Consequently:

$$t_{\rightarrow} = \frac{\frac{vL\cos\alpha}{\gamma} + \frac{cL}{\gamma}}{c^2 - v^2} \tag{20}$$

Using again:

$$c^2 - v^2 = \frac{c^2}{\gamma^2}, \tag{21}$$

one obtains:

$$\boxed{t_{\rightarrow} = \frac{L\gamma}{c}\left(1 + \frac{v}{c}\cos\alpha\right)} \tag{22}$$

3.4 Return Travel Time in the Absolute Frame

The calculation of the return journey is analogous. This time, the signal departs from the moving mirror and returns to the source, which also continues to move at velocity v.

The return travel time satisfies:

$$\boxed{t_{\leftarrow} = \frac{L\gamma}{c}\left(1 - \frac{v}{c}\cos\alpha\right)} \tag{23}$$

The asymmetry between the forward and return journeys appears explicitly in the linear term in $\cos\alpha$.

3.5 Total Time in the Absolute Frame

The sum of the two times gives the round-trip time in the absolute frame:

$$\begin{aligned} T_{\text{abs}} &= t_{\rightarrow} + t_{\leftarrow} && (24)\\ &= \frac{L\gamma}{c}\left(1 + \frac{v}{c}\cos\alpha\right) + \frac{L\gamma}{c}\left(1 - \frac{v}{c}\cos\alpha\right) && (25)\end{aligned}$$

The linear terms cancel exactly, leading to:

$$\boxed{T_{\text{abs}} = \frac{2L\gamma}{c}} \tag{26}$$

This result is remarkable: although the elementary times depend on the orientation of the arm, their sum no longer does. The angle α disappears completely from the absolute round-trip time.

3.6 Locally Measured Time

The on-board observer does not measure the absolute time T_{abs}, however, but the time indicated by their own clocks. Within the framework adopted here, these clocks run slow by a factor $1/\gamma$.

The locally measured time is therefore:

$$T_{\text{loc}} = \frac{T_{\text{abs}}}{\gamma} \tag{27}$$

Substituting the expression obtained above, one finds immediately:

$$\boxed{T_{\text{loc}} = \frac{2L}{c}} \tag{28}$$

This result is independent of the absolute velocity v and of the angle α.

3.7 Physical Interpretation

The foregoing result shows that propagation in vacuum along an arm of local length L, measured locally using a material standard, yields a local round-trip time given by relation (28), regardless of the orientation of the arm and regardless of the uniform absolute velocity of the device.

Invariance is therefore not obtained here through radar reconstruction of the distance, as in GPS systems, but through an exact compensation between several effects:

- the longitudinal contraction of the parallel component of the arm,
- the asymmetry of the forward and return travel times in the absolute frame,
- the slowing of the on-board clocks.

In other words, absolute motion does indeed affect the propagation of light locally, but the very structure of the round-trip measurement eliminates any final dependence on v in the local observable.

3.8 Scope of the Result

This property constitutes the foundation of the undetectability of absolute motion in interferometric optical experiments based on round-trip paths. It also illuminates the operational status of the principle of relativity: the observed invariance does not necessarily imply the absence of a privileged reference frame, but may result from the way in which observables are constructed.

In (3), this mechanism was established within a more general framework of kinematic reconstruction, and its importance is emphasised through the example of GPS systems, whose experimental coherence also rests on an effective invariance of observables derived from electromagnetic signals.

3.9 Conclusion

The case of propagation in vacuum thus shows that, even for an arbitrarily oriented arm, a local device measuring its own length with a material standard and the propagation time with its on-board clocks reconstructs a round-trip time rigorously equal to:

$$\boxed{T_{\text{loc}} = \frac{2L}{c}} \tag{29}$$

The undetectability of absolute motion thus appears, within this framework, as a structural property of round-trip measurements in vacuum.

4 Introduction of a Refractive Medium

4.1 Physical Motivation

The introduction of a refractive medium into an optical path seems, at first glance, likely to break the undetectability of absolute motion established in vacuum. Indeed, light no longer interacts with vacuum alone, but with a polarisable material medium whose electromagnetic response depends on its kinematics in the absolute frame. Historically, this idea lies at the heart of the analyses of Fresnel and Fizeau, where the propagation of light in a moving medium gives rise to a partial entrainment characterised by the factor:

$$1 - \frac{1}{n^2} \tag{30}$$

In this context, it is natural to ask whether the introduction of a refractive portion on an optical arm could restore sensitivity to the absolute motion of the device. Such an intuition is reinforced by the fact that, in the absolute frame, the propagation speeds in the medium are no longer symmetric between the two directions of traversal.

4.2 Analytical Framework

Consider a rectilinear segment of local length L, filled with a refractive medium of index n, rigidly attached to the experimental device. This length L is defined in the local frame of the device, by direct comparison with a local material standard. It does not result from a radar reconstruction. The arm makes an angle α with the absolute velocity $\vec{v}$ of the device.

In the particular case where the refractive medium is at rest in the absolute privileged frame, light propagation within it is isotropic, with intrinsic speed:

$$u' = \frac{c}{n} \tag{31}$$

with

$$u'_x = \frac{c}{n} \cos\alpha \qquad \text{and} \qquad u'_y = \frac{c}{n} \sin\alpha \tag{32}$$

In other words, within this framework the fundamental quantity is not c but c/n, since light does not propagate in vacuum but in a medium whose collective polarisation slows the transmission of the wave.

The problem then consists in determining the round-trip time as observed locally, while accounting for the kinematic structure induced by the absolute motion of the device.

4.3 Propagation Speeds and Status of the Fresnel Term

Fizeau's experiment does not directly measure this intrinsic speed defined in the absolute privileged frame. It reveals, in the laboratory frame, an apparent propagation speed reconstructed from travel times and observed phase shifts. The Fresnel entrainment term thus corresponds to a quantity genuinely accessible to local measurement.

To express this propagation in the local frame of the device, moving at velocity $\vec{v}$ relative to the absolute privileged frame, one applies the kinematic velocity-composition law of the framework developed in (3). The components of the local apparent velocity are then:

$$u_x = \frac{u'_x + v}{1 + \dfrac{v\, u'_x}{c^2}} \tag{33}$$

$$u_y = \frac{\dfrac{u'_y}{\gamma}}{1 + \dfrac{v\, u'_x}{c^2}} \tag{34}$$

with

$$\gamma = \frac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}} \tag{35}$$

In particular, for $\alpha = 0$, one obtains:

$$u_x = \frac{\dfrac{c}{n} + v}{1 + \dfrac{v}{nc}} \tag{36}$$

and its first-order expansion in v/c gives:

$$\boxed{u_x \approx \frac{c}{n} + v\left(1 - \frac{1}{n^2}\right)} \tag{37}$$

This exactly recovers the structure of the Fresnel entrainment term.

This result should not, however, be interpreted as a mere formal coincidence. It is part of a deeper physical coherence: the same expression has already been obtained by analysing the polarisation of matter in a moving refractive medium, from the collective response of charges within the material structure, as developed in (1).

Within this framework, light propagation results from a dynamical interaction between the electromagnetic wave and the induced dipoles of the medium. The motion of the material support modifies this collective response: polarisation becomes anisotropic in the absolute frame, and the coherent re-emission of the wave is affected by the advection of the medium in the underlying energetic flux.

The result is a linear correction in velocity that exactly reproduces the Fresnel entrainment term. The Fresnel factor thus appears not as an independent law, but as the first-order manifestation of a more general dynamics, arising from the structure of electromagnetic interactions in a moving medium. It is interpreted as the linear limit of a more general kinematic law, of the same nature as that governing the composition of velocities in this framework.

4.4 Geometry of the Arm in the Absolute Frame

As in the case of propagation in vacuum, the geometry of the arm is defined in the proper frame of the device, in which its components are:

$$L_{\parallel} = L\cos\alpha \qquad \text{and} \qquad L_{\perp} = L\sin\alpha \tag{38}$$

And in the absolute frame, only the component parallel to $\vec{v}$ is affected by longitudinal contraction.

One therefore has:

$$L_{\parallel}^{\text{abs}} = \frac{L\cos\alpha}{\gamma} \qquad \text{and} \qquad L_{\perp}^{\text{abs}} = L\sin\alpha \tag{39}$$

4.5 Forward Travel Time

In the absolute frame, the light signal departs from the origin at time $t = 0$, while the end of the arm moves at velocity v along the parallel axis.

The reflection event is reached when the coordinates of the signal coincide with those of the moving mirror. During time $t_{\rightarrow}$, the mirror has coordinates:

$$x_{\rightarrow} = L_{\parallel}^{\text{abs}} + v\,t_{\rightarrow} \qquad \text{and} \qquad y_{\rightarrow} = L_{\perp}^{\text{abs}} \tag{40}$$

In the same interval, the light signal travels:

$$x_{\text{sig}} = u_x\,t_{\rightarrow} \qquad \text{and} \qquad y_{\text{sig}} = u_y\,t_{\rightarrow} \tag{41}$$

The equality of coordinates imposes:

$$u_y\,t_{\rightarrow} = L_{\perp}^{\text{abs}} \tag{42}$$

hence

$$t_{\rightarrow} = \frac{L_{\perp}^{\text{abs}}}{u_y} \tag{43}$$

Substituting the preceding expressions:

$$t_{\rightarrow} = \frac{L\sin\alpha}{\dfrac{\frac{c}{n}\sin\alpha}{\gamma\left(1 + \frac{v}{c}\frac{\cos\alpha}{n}\right)}} \tag{44}$$

which gives:

$$\boxed{t_{\rightarrow} = \frac{nL\gamma}{c}\left(1 + \frac{v}{nc}\cos\alpha\right)} \tag{45}$$

This result is exact. It reveals a linear asymmetry in $\cos\alpha$, analogous to that encountered in vacuum but weighted here by the factor $1/n$.

4.6 Return Travel Time

For the return journey, the signal propagates in the opposite direction along the arm. In the local frame of the device, its components become:

$$u'_x = -\frac{c}{n}\cos\alpha \qquad \text{and} \qquad u'_y = -\frac{c}{n}\sin\alpha \tag{46}$$

Transforming to the absolute frame gives:

$$u_x = \frac{-\frac{c}{n}\cos\alpha + v}{1 - \frac{v}{c}\frac{\cos\alpha}{n}} \tag{47}$$

$$u_y = \frac{-\frac{c}{n}\frac{\sin\alpha}{\gamma}}{1 - \frac{v}{c}\frac{\cos\alpha}{n}} \tag{48}$$

The return time is obtained by the same geometric reasoning. One finds:

$$\boxed{t_{\leftarrow} = \frac{nL\gamma}{c}\left(1 - \frac{v}{nc}\cos\alpha\right)} \tag{49}$$

Here again, the asymmetry between the two directions of traversal appears explicitly.

4.7 Total Time in the Absolute Frame

The sum of the two times gives the absolute round-trip time:

$$T_{\text{abs}} = t_{\rightarrow} + t_{\leftarrow} \tag{50}$$

$$= \frac{nL\gamma}{c}\left(1 + \frac{v}{nc}\cos\alpha\right) + \frac{nL\gamma}{c}\left(1 - \frac{v}{nc}\cos\alpha\right) \tag{51}$$

The angular and linear terms cancel exactly, leading to:

$$\boxed{T_{\text{abs}} = \frac{2nL\gamma}{c}} \tag{52}$$

This result is already significant. In the absolute frame, the total round-trip time no longer depends on the angle α. All directional dependence has vanished in the sum of the elementary times.

4.8 Locally Measured Time

The device does not, however, access the absolute time T_{abs}, but the time indicated by its own clocks. Within the framework adopted here, these clocks run slow by a factor $1/\gamma$. The locally measured time is therefore:

$$T_{\text{loc}} = \frac{T_{\text{abs}}}{\gamma} \tag{53}$$

Substituting the preceding expression, one immediately obtains:

$$\boxed{T_{\text{loc}} = \frac{2nL}{c}} \tag{54}$$

This local round-trip time is independent of the absolute velocity v and of the angle α.

4.9 Physical Interpretation

The result obtained admits a very clear interpretation. In the absolute frame, propagation in the medium is indeed anisotropic. This anisotropy manifests itself through the forward and return times, which differ:

$$t_{\rightarrow} \neq t_{\leftarrow} \tag{55}$$

It also manifests itself through the fact that the absolute geometry of the arm differs from its local geometry, owing to longitudinal contraction.

However, when one considers the observable effectively measured by the device, all of these effects cancel exactly. The local round-trip time no longer depends on the absolute state of motion of the setup. The introduction of a refractive medium therefore does not break the undetectability. It merely shifts the compensation mechanism, without suppressing it.

In vacuum, this compensation results from the combination of longitudinal contraction, the forward-return asymmetry, and clock slowing.

In the presence of a refractive medium, the Fresnel entrainment term appears in the local frame. It translates, to first order, the velocity composition for a propagation of speed c/n, with a factor $1 - \frac{1}{n^2}$.

And yet, an arm of local length L, filled with a refractive medium of index n, traversed in a round-trip and measured locally, always yields the time:

$$\boxed{T_{\text{loc}} = \frac{2nL}{c}} \tag{56}$$

regardless of the angle α of the arm and regardless of the uniform absolute velocity v of the device.

In other words, the introduction of a refractive medium on a portion of the optical path does not suffice to lift the undetectability of absolute motion. Even when a propagation anisotropy exists in the absolute frame, the round-trip structure of the measurement eliminates any final dependence on v.

The dependence on n is purely local. It reflects the intrinsic slowing of propagation in the medium, but provides no exploitable information about the uniform absolute velocity of the system.

4.10 Conclusion

The case of a refractive medium therefore confirms, and indeed reinforces, the structural character of the undetectability established in classical interferometric experiments. The Fresnel factor does not introduce, in a local round-trip measurement, a route to detecting absolute motion. On the contrary, it is part of a more general compensation mechanism, which renders the final observable independent of v.

This conclusion illuminates the meaning of the null results obtained in historical devices of the Hoek or Michelson type in the presence of a medium. It shows that the absence of detection does not necessarily imply the non-existence of an absolute reference frame, but may result from the very structure of observables constructed from round-trip optical paths.

5 Breaking the Round-Trip Symmetry and the Status of the First-Order Term

5.1 Structural Nature of Undetectability

The results established in the preceding sections show that the undetectability of absolute motion does not result from a particular property of light propagation, but from the structure of the observables constructed experimentally.

In all classical interferometric configurations, the observable rests on a combination of travel times of the form:

$$T = t_{\rightarrow} + t_{\leftarrow} \tag{57}$$

where the directional contributions appear with opposite signs. In the absolute frame, these times may be written schematically as:

$$t_{\rightarrow} = t_0 + \delta t(v) \qquad \text{and} \qquad t_{\leftarrow} = t_0 - \delta t(v) \tag{58}$$

whence

$$T = 2t_0 \tag{59}$$

independently of v at first order.

This property is reinforced by two additional effects:

- the longitudinal contraction of material lengths,
- the slowing of local clocks.

The whole constitutes a complete compensation mechanism, rendering devices based on round-trip paths intrinsically insensitive to any uniform absolute velocity.

One might expect a first-order effect in $\frac{v}{c}$ to survive if the foregoing compensation structure were effectively broken, more precisely, if it were possible to prevent the existence of an opposing term capable of cancelling a given directional contribution.

5.2 Two Physical Realisations

We now study two distinct configurations, with the aim of identifying the conditions under which this first-order compensation can be lifted.

5.2.1 Localised Asymmetry in a Round-Trip Path

Consider a globally closed path in which a portion of length L is traversed through a refractive medium on only one of the two elementary legs.

The absolute time associated with this portion in the medium is:

$$t_{\rightarrow}^{(n)} = \frac{nL\gamma}{c}\left(1 + \frac{v}{nc}\cos\alpha\right) \tag{60}$$

while the corresponding portion in vacuum, traversed in the opposite direction, gives:

$$t_{\leftarrow}^{(1)} = \frac{L\gamma}{c}\left(1 - \frac{v}{c}\cos\alpha\right) \tag{61}$$

Since the experimental observable is constructed from locally measured times, these contributions must be expressed in the device's frame. With clocks running slow by a factor $1/\gamma$, one obtains:

$$t_{\rightarrow,\mathrm{loc}}^{(n)} = \frac{nL}{c}\left(1 + \frac{v}{nc}\cos\alpha\right) \tag{62}$$

$$t_{\leftarrow,\mathrm{loc}}^{(1)} = \frac{L}{c}\left(1 - \frac{v}{c}\cos\alpha\right) \tag{63}$$

The total local time associated with this asymmetric portion is then:

$$T_{\mathrm{loc}} = t_{\rightarrow,\mathrm{loc}}^{(n)} + t_{\leftarrow,\mathrm{loc}}^{(1)} \tag{64}$$

Expanding, one obtains:

$$\boxed{T_{\mathrm{loc}} = \frac{L}{c}(n-1)} \tag{65}$$

Unlike the symmetric case, the directional contributions are no longer of the same structure in both directions of propagation: the linear term from the medium is weighted by $1/n$, whereas that from vacuum is not.

However, in the combination considered here, these linear contributions cancel exactly in the local observable. There is therefore no residual linear dependence on $\frac{v}{c}$ at this level of description.

It is essential to note that the overall structure of the path remains closed. The symmetry breaking is here localised to one segment, but it does not suffice, in this configuration, to produce a first-order term in the observable.

5.2.2 Two-Path Interferometry

A second approach consists in completely abandoning the round-trip structure and comparing two distinct paths, each traversed only once.

A beam is split into two:

- a reference path in vacuum,
- a path traversing a refractive medium.

The two signals are then recombined.

Consider two segments of equal local length L, oriented at the same angle α relative to the absolute velocity $\vec{v}$ of the device. The first is traversed in vacuum, the second in a refractive medium of index n.

From the results established above, the absolute travel time for a rectilinear segment of local length L in vacuum is:

$$t_{\text{abs}}^{(1)} = \frac{L\gamma}{c}\left(1 + \frac{v}{c}\cos\alpha\right) \tag{66}$$

and in the refractive medium:

$$t_{\text{abs}}^{(n)} = \frac{nL\gamma}{c}\left(1 + \frac{v}{nc}\cos\alpha\right) \tag{67}$$

As in the preceding sections, the on-board observer does not access these absolute times directly. With local clocks running slow by a factor $1/\gamma$, the locally measured times are:

$$t_{\text{loc}}^{(1)} = \frac{t_{\text{abs}}^{(1)}}{\gamma} = \frac{L}{c}\left(1 + \frac{v}{c}\cos\alpha\right) \tag{68}$$

and

$$t_{\text{loc}}^{(n)} = \frac{t_{\text{abs}}^{(n)}}{\gamma} = \frac{nL}{c}\left(1 + \frac{v}{nc}\cos\alpha\right) \tag{69}$$

The difference of local times is therefore:

$$T_{\text{loc}} = t_{\text{loc}}^{(n)} - t_{\text{loc}}^{(1)} \tag{70}$$

The common directional contributions then cancel, leaving:

$$\boxed{T_{\text{loc}} = \frac{L}{c}(n-1)} \tag{71}$$

This result shows that, in this simple configuration where the two paths are collinear and traversed only once in the same direction, the local time difference is independent of the orientation and of the uniform absolute velocity of the device. Structural asymmetry alone therefore does not suffice to produce an exploitable directional term: in this case, the linear contributions remain identical in both paths and cancel in the difference.

In other words, in this configuration, two-path interferometry does not allow the isolation of a first-order term in $\frac{v}{c}$. Both paths carry the same linear kinematic contribution, which vanishes in the observable.

It follows that the phase difference:

$$\Delta\phi = \omega\,\Delta t_{\text{loc}} \tag{72}$$

and the fringe shift:

$$\Delta N = \frac{\Delta t_{\text{loc}}}{\lambda/c} \tag{73}$$

do not exhibit any modulation as a function of v in this configuration.

5.3 Unification: Compensation of Directional Contributions

In both cases, the directional contributions of the form:

$$\delta t \propto \frac{v}{c} \cos \alpha \tag{74}$$

are present at the level of the elementary times, but are systematically compensated in the final observable.

The difference between the two approaches is purely geometric:

- in the first case, compensation occurs within a closed path;
- in the second, it occurs between two distinct but kinematically equivalent paths.

In both cases, there is no effectively uncompensated segment at the level of the observable.

5.4 Conclusion

The results obtained in this section lead to an important conclusion regarding the interferometric experiment proposed in (2).

In that document, the on-board experiment rests precisely on two-path interferometry, one path in vacuum (or air), the other in a refractive medium, with the explicit objective of revealing a first-order effect in $\frac{v}{c}$ through a difference in propagation times.

However, the rigorous analysis carried out here shows that, in the configuration considered, both paths carry linear kinematic contributions of the same structure. These contributions, though present at the level of the elementary times, cancel exactly in the local observable.

It follows that the measured time difference contains no linear term in $\frac{v}{c}$, and remains independent of the uniform absolute velocity of the device. In other words, contrary to the initial intuition, the apparent asymmetry between a vacuum path and a refractive-medium path does not suffice to produce sensitivity to motion.

This conclusion implies directly that the proposed experiment, in its current form, would not allow the detection of absolute motion, nor even the detection of a first-order effect. The expected result of the form:

$$\Delta N \propto \frac{v}{c} \tag{75}$$

cannot arise in this framework, because the very structure of the observable reconstructs a symmetric quantity in which the linear terms cancel.

The origin of this insensitivity does not lie in the propagation laws themselves, but in the manner in which the measured quantities are constructed. In particular, the fact that the two compared paths are kinematically equivalent from the point of view of directional contributions imposes complete compensation.

Thus, despite the introduction of a refractive medium and an apparent dissymmetry in the device, the experiment remains subject to the same compensation mechanism as classical interferometric experiments.

This contradiction with the initially anticipated result highlights the existence of an error in the reasoning that led to the prediction of a first-order effect. The precise identification of this error, as well as its physical and mathematical origin, is addressed in what follows.

6 Clarification on the Role of Velocity Composition and on the Disappearance of the Fresnel Factor in the Local Observable

The foregoing developments bring to light an important conceptual point, which should be made explicit to avoid any ambiguity in the interpretation of results.

6.0.1 Two Levels of Description to be Distinguished

In this work, propagation in a moving refractive medium is described starting from a velocity-composition law, expressed in the local frame of the device:

$$u_x = \frac{u'_x + v}{1 + \dfrac{v\,u'_x}{c^2}} \tag{76}$$

$$u_y = \frac{\dfrac{u'_y}{\gamma}}{1 + \dfrac{v\,u'_x}{c^2}} \tag{77}$$

where the components u'_x and u'_y correspond to the propagation speed in the case where the refractive medium is at rest in the absolute privileged frame:

$$u'_x = \frac{c}{n}\cos\alpha \qquad \text{and} \qquad u'_y = \frac{c}{n}\sin\alpha \tag{78}$$

This description allows, after an exact geometric calculation of travel times, precise expressions to be obtained for the times in the absolute frame and then for the local times measured by the device.

Moreover, the first-order expansion of the longitudinal velocity component in the local frame reproduces the structure of the Fresnel term:

$$u_x \approx \frac{c}{n} + v\left(1 - \frac{1}{n^2}\right) \tag{79}$$

It might then seem natural to use this expression directly as an autonomous effective law, in order to estimate a travel time in the form:

$$t = \frac{L}{u_x} \tag{80}$$

and to deduce from it, at the level of the elementary times, a residual linear term in velocity arising from the difference between the directional contribution of the medium path and that of the vacuum path.

This is precisely the method followed in document (2), leading to the prediction of a residual observable term proportional to:

$$\left(n - \frac{1}{n}\right)\frac{v}{c} \tag{81}$$

However, the results obtained in the present work show that this conclusion is incorrect.

The error stems from the fact that this approach relies on a local first-order estimate, applied separately to the propagation segments and then interpreted as a global result. Yet when a complete kinematic calculation is performed, taking into account the total structure of the observable, the linear contributions cancel.

Thus, a difference between elementary contributions, though it appears in intermediate expressions, is not sufficient to guarantee the existence of a residual term in the final observable.

6.1 Result of the Exact Calculation in the Adopted Framework

When the formalism introduced in the preceding sections is rigorously followed, the local travel time for a segment of length L in a medium of index n takes the form:

$$t_{\text{loc}}^{(n)} = \frac{nL}{c}\left(1 + \frac{v}{nc}\cos\alpha\right) \tag{82}$$

Expanding, one obtains:

$$t_{\text{loc}}^{(n)} = \frac{nL}{c} + \frac{nL}{c}\frac{v}{nc}\cos\alpha \tag{83}$$

hence:

$$t_{\text{loc}}^{(n)} = \frac{nL}{c} + \frac{L}{c}\frac{v}{c}\cos\alpha \tag{84}$$

The essential point here is that the factor n in the prefactor exactly cancels the factor $\frac{1}{n}$ contained in the kinematic correction. It follows that the first-order directional part equals:

$$\delta t_{\text{loc}}^{(n)} = \frac{L}{c}\frac{v}{c}\cos\alpha \tag{85}$$

This contribution is independent of the index n.

In vacuum, one obtains similarly:

$$t_{\text{loc}}^{(1)} = \frac{L}{c}\left(1 + \frac{v}{c}\cos\alpha\right) = \frac{L}{c} + \frac{L}{c}\frac{v}{c}\cos\alpha \tag{86}$$

Thus, within the kinematic framework adopted, the first-order local contribution is the same in vacuum and in the medium.

This property has an immediate consequence. The velocity composition and exact calculation of travel times lead to a reconstruction in which the first-order directional contribution becomes universal:

$$\boxed{\delta t_{\text{loc}} = \frac{L}{c}\frac{v}{c}\cos\alpha} \tag{87}$$

regardless of whether propagation takes place in vacuum or in a medium of index n.

When one compares a segment traversed in vacuum with a segment traversed in a refractive medium, using the local times obtained above, the first-order directional terms are identical. Their difference therefore cancels exactly.

The medium does indeed modify the constant part of the travel time, by the factor n, but it no longer modifies the first-order variable part once the local observable has been reconstructed according to the adopted formalism.

6.2 Apparent Tension with the Fresnel Term

An apparent tension may then seem to arise.

On the one hand, the first-order expansion of the longitudinal velocity component in the local frame reproduces the structure of the Fresnel term:

$$u_x \approx \frac{c}{n} + v\left(1 - \frac{1}{n^2}\right) \tag{88}$$

On the other hand, the exact calculation of local times shows that the observable first-order contribution no longer depends on n.

This situation does not constitute an internal contradiction. It simply means that the Fresnel term does indeed appear at the level of the propagation speed in the local frame, but is subsequently absorbed into the reconstruction of the local observable when the kinematic scheme is carried through to completion.

In other words, the information carried by the factor:

$$1 - \frac{1}{n^2} \tag{89}$$

does indeed intervene at the level of propagation, where it may manifest itself as a measurable relative velocity, as in Fizeau's experiment. However, within the framework of a description founded on an absolute reference frame and a complete calculation of the local observable, this dependence no longer subsists explicitly: it is absorbed by the global structure of the reconstruction.

6.3 Conclusion

The calculation thus brings to light a central point: within the framework based on velocity composition and the exact calculation of travel times, the first-order local directional contribution is universal and independent of the refractive index.

Consequently, the simple comparison between a segment in vacuum and a segment in a refractive medium does not suffice to produce a first-order observable sensitive to a background motion.

This result does not call into question the internal validity of the composition law used. On the contrary, it shows that this law reconstructs local observables that are particularly strongly compensated, to the point of erasing, in this context, the dependence on n that is nonetheless present at the level of the propagation speed in the absolute frame.

Initially, the objective of this work was precisely to identify a configuration capable of breaking this compensation. The writing was undertaken in this perspective, in continuity with document (2), where such a possibility seemed to emerge.

However, the detailed analysis carried out here shows that this expectation is not borne out: the compensation mechanisms remain operative, even in configurations introducing apparent asymmetries. In other words, the attempt to reveal a first-order term leads here to a dead end.

At present, no configuration arising from this framework allows experimental access to a possible background velocity. This result suggests that, if such a quantity exists, it is, from the point of view of the interferometric observables considered, undetectable.

In this context, relativity appears not in contradiction with the existence of an absolute reference frame, but as a structure perfectly compatible with it, while rendering its uniform kinematic effects unobservable within the protocols studied.

This finding is by no means exceptional in physics. The existence of an underlying reality does not imply that all its parameters are directly accessible to observation. Quantum physics provides a fundamental example: the absence of determinism at the kinematic level of particles in no way prevents the existence of their states, but requires them to be described through indirect quantities, often remote from classical intuition, that manifest themselves only through their observable effects.

Analogously, an absolute reference frame might exist without being directly measurable, its presence concealed by the very structure of observables. This work thus suggests that undetectability is not necessarily proof of non-existence, but may be the expression of an intrinsic limitation of our methods of measurement.

The question of the inaccessibility of certain parameters of an absolute reference frame thus joins, at a deeper level, the logic already at work in quantum physics. In both cases, physical description does not bear directly on the intrinsic state of the system, but on the quantities that can be reconstructed from interactions and measurements. This shift of perspective, from reality itself towards the conditions of its observation, suggests that physical laws express less what the world is in itself than what can be apprehended from it. The undetectability of absolute motion, like quantum indeterminacy, then reflects not an absence of reality, but the presence of a more fundamental level whose parameters escape, by construction, any direct measurement. Physics would no longer describe merely phenomena, but the very limits of their accessibility.

7 References

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