# On the Ether Problem in Physics: A Heuristic Viewpoint

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2025-01-02

**Abstract**

Inspired by Mach's philosophical standpoint, Einstein constructed the theory of special relativity, which has been shown to be reliable both theoretically and experimentally. However, the negative conclusion regarding the absolute equivalence of relatively moving inertial frames, as suggested by the twin paradox thought experiment, has not been explicitly reflected at the level of physical theory. The present work attempts to address this issue and includes the following investigations:

(1) a reconsideration of the ether problem; (2) derivations of the mass–energy relation and centrifugal acceleration based on an ether contraction framework; (3) a heuristic interpretation of the invariance of the speed of light and inertial forces.

It is hoped that this work may offer some conceptual insight to readers interested in this problem.

**Keywords** Ether; Relativity; Invariance of the Speed of Light

## 1 Introduction

As a fundamental postulate of special relativity, the invariance of the speed of light—like the parallel postulate in Euclidean geometry—cannot be derived, nor can it be deduced from special relativity itself. After abandoning the ether, explaining the invariance of the speed of light by analogy with the constant propagation speeds of classical water waves or sound waves in a medium can serve only as a pedagogical convenience. Under a classical particle model, however, photons give rise to a further difficulty: observers in different inertial frames all evaluate the velocity of the photon's motion to be exactly the same.

The effects of time dilation and length contraction in special relativity are usually attributed to relative velocity, whereas in general relativity the same effects are entirely ascribed to the influence of the gravitational field. Arriving at two fundamentally different explanations for what appears to be the same underlying phenomenon stands in tension with Newton's celebrated "Rules of Reasoning in Philosophy," which state: "Therefore, the causes assigned to natural effects of the same kind must, so far as possible, be the same"[5].

Mach's extension of the absolute equivalence of all relativity—according to which everything is relative—to inertial frames and even to gravitational systems[7, §1.16] is, much like Boltzmann's critique of the physical theories of his time in his famous work on gas theory, an instance of excessive generalization[1]. After the completion of the general theory of relativity, Einstein, although making further conceptual distinctions regarding the ether, shifted his view from regarding it as "superfluous" to affirming it in a qualified sense[2]. This change of position is also corroborated in Pauli's well-known treatise[6], yet it appears not to have attracted the attention it deserves among the majority of physicists.

## 2 General Principles

1. In electromagnetic theory and in general relativity, fields are regarded as objectively existing physical entities. Unlike the electromagnetic field, general relativity introduces curvature as a geometric attribute to characterize the field. Whether geometric methods can be extended to the description of the electromagnetic field remains an open question; nevertheless, it is reasonable to regard changes in geometric properties as evidence of material existence.

2. With respect to the consideration of continuity and discreteness in physics, Boltzmann[1, Mechanical Analogies of the Behavior of Gases], Maxwell[4, Continuity and Discontinuity in Physics], and Einstein[3, A Heuristic Viewpoint Concerning the Production and Transformation of Light] all made careful distinctions. In the present work, we summarize their insights as follows: discreteness corresponds to physical reality, whereas continuity is a mathematical assumption.

3. In his well-known paper on the photoelectric effect, Einstein included an interesting footnote: "This hypothesis is an arbitrary one. Naturally, so long as experiment does not compel us to abandon it, we shall adhere to this simplest assumption"[3]. In this paper, we extend this idea beyond the description of a specific problem, generalize it, and refer to it as the *Einstein principle of the simplest hypothesis*.

When we consider the physical situation in which spacetime as a substance exists everywhere in the universe, and within this substance light propagates freely, then, in conjunction with the principles stated above, we are led to the hypothesis that spacetime itself is the medium for the propagation of light.

## 3 The Principle of Relativity

### 3.1 Theoretical Difficulties of the Invariance of the Speed of Light

$$\begin{aligned} x' &= \gamma(x - vt), \\ y' &= y, \\ z' &= z, \\ t' &= \gamma\left(t - \frac{v}{c^2}x\right) \end{aligned} \tag{1}$$

The above equations are the well-known Lorentz transformations, where

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

By differentiating with respect to time, one obtains the velocity transformation formulas, from which the invariance of the speed of light $c$ under Lorentz transformations can be verified. This transformation was first discovered by Lorentz, and its physical meaning was subsequently clarified by Einstein. However, in the absence of the ether, the invariance of the speed of light cannot be explained within classical wave theory, which is precisely why Maxwell and many physicists of his era firmly believed in the existence of the ether.

During propagation, light exhibits wave-like behavior, while in interactions it manifests particle-like properties. The measurement of the speed of light is fundamentally based on its particle aspect; thus, one would

### 3.2 The Breakdown of the Absolute Equivalence of Inertial Frames

Although the twin paradox has been given a satisfactory resolution, the inequivalence between the moving frame—which has undergone acceleration—and the stationary frame stands in tension with the fundamental philosophical stance of special relativity, namely that all inertial frames are absolutely equivalent. This tension, however, is not explicitly reflected in current physical theory.

For an automobile traveling along a road, no one would regard it as reasonable to claim that the automobile is at rest while the road itself is in motion. At the level of physical theory, however, it is necessary to introduce appropriate thought experiments to clarify the general validity of this fact. Let us therefore consider a spacecraft capable of acceleration in space, equipped with instruments that register the energy consumption associated with its acceleration. If the spacecraft is allowed to accelerate slowly—by analogy with a quasi-static process in thermodynamics, such that at each moment the motion may be regarded as uniform—and is isolated from its surroundings, an observer inside the spacecraft would find that the fuel energy decreases spontaneously, apparently violating the law of energy conservation.

In order to preserve the validity of energy conservation, the observer inside the spacecraft must assert that the lost energy is distributed throughout the material contents of the spacecraft, since they cannot determine whether they themselves are in motion. In what form this energy exists, however, cannot be answered within this description.

Although all physical laws take the same form in the classical stationary–moving frame model, it must be recognized that the moving frame has, in its past history, undergone acceleration. The energy consumed during acceleration corresponds precisely to the kinetic energy acquired by the moving frame, as described by the following relation:

$$\gamma mc^2 - mc^2 \approx \frac{1}{2}mv^2 \tag{3}$$

In special relativity, the length contraction of a moving frame is given by

$$L' = \frac{L}{\gamma} \tag{4}$$

From this, we may conclude that the contraction of the moving frame is real and intrinsic, whereas the moving frame's perception of the stationary frame as being in motion is a relative effect. Given the arbitrariness of objects within the moving frame, it is reasonable to attribute this phenomenon to a contraction of the spacetime in which the matter resides. The contraction ratio $D$ is defined as

$$D = \frac{1 - 1/\gamma}{1} \approx \frac{v^2}{2c^2} \tag{5}$$

We further assume that, for an object of mass $m$, the energy stored as a result of motion-induced compression under the contraction ratio $D$ is proportional to $D$, with proportionality constant $k$. We then obtain

$$\Delta E = kmD = \frac{1}{2}mv^2 \approx km\frac{v^2}{2c^2} \tag{6}$$

from which it follows that

$$k = c^2 \tag{7}$$

Considering the limiting case of the contraction ratio $D = 1$, corresponding to complete contraction of matter to nothingness, we recover the well-known mass–energy relation:

$$E = mc^2 \tag{8}$$

This result is a satisfying one.

## 3.3 An Ether-Based Interpretation of the Michelson–Morley Experiment

In physics, the description of motion relies on the concept of a coordinate system, which is an artificially introduced construct and is not intrinsic to nature itself.

The distance required for determining the speed of light is measured within a coordinate system by the light source and the material detector. Under the assumption of the existence of the ether, light propagates through the ether once it leaves the source. If the invariance of the speed of light is interpreted as arising from proportional changes in the measured values of time and distance due to motion-induced spacetime contraction, then it is reasonable to regard all inertial frames as equivalent.

The null result of the Michelson–Morley experiment is often taken as decisive evidence against the ether. However, an equally satisfactory account can be obtained if the result is interpreted as reflecting a special property of the ether as the medium of light propagation. In the experiment, differences in optical path length arise from the differing relative motions between the two light paths and the ether, producing interference effects that are intended to reveal the absolute motion of the Earth with respect to the ether. We refer to the two light paths as the parallel arm and the transverse arm, respectively.

For the parallel arm, in addition to the conclusion of light-speed invariance discussed above, it is necessary to introduce the concepts of proper time and proper length. Although these notions are treated extensively in relativity theory, a brief recapitulation is required here for the sake of completeness. Under the premise that spacetime contracts along the direction of motion in a moving frame, time and distance within that frame remain homogeneous and isotropic. To account for this, it is essential to carefully distinguish between the measurement of distance, spacetime contraction, and the intrinsic contraction of material objects.

Any discussion of measurement requires the introduction of measuring instruments as physical entities distinct from the objects being measured. For distance measurements, these instruments may be either a graduated ruler or the propagation time of light. Whether in a gravitational field or in a moving frame, the time measured by an observer at rest at a given spacetime point is always that observer's proper time. The rate of temporal flow appears to constitute the fundamental interval of the local coordinate system: regardless of how different this interval may appear to external observers, the number of such intervals required for any process, as measured by the local observer, remains invariant. Distance exhibits an analogous property. For an observer comoving with the moving frame, distances are uniform in all directions, and spacetime contraction along the direction of motion cannot be directly perceived.

Before proceeding to an explanation of the transverse arm, it is necessary to clarify the notion of a medium. Taking sound waves as an example, a medium is a "through-which" concept: sound propagates through matter via the motion and deformation of the microscopic constituents of the material, so that the wave propagates by means of the medium. In the absence of a medium, sound cannot propagate. In contrast, even if the hypothesis of an ether is accepted for light propagation, we cannot verify the impossibility of light propagation by removing the ether as a medium—spacetime is omnipresent. This constitutes the distinctive character of the medium of light.

To make this point more concrete, consider the following scenario. In a dimly lit room, we switch on a brighter flashlight. Apart from the appearance of a bright beam, no other unusual phenomena are expected. However, if we were to claim that, prior to the propagation of the flashlight photons, the room was already filled everywhere with photons from the ambient light, and that the flashlight photons propagate "through" these photons, the situation becomes more intriguing. At any given spacetime point, owing to the presence of the cosmic background radiation, photons exist there even before any additional light passes through. This continuity leads us to further hypothesize that, for such a spacetime point, there is always at least one photon present that serves as a medium through which other photons propagate. The existence of a photon gas has likewise been confirmed in the well-known experiments on black-body radiation. Moreover, if the cosmic background radiation is interpreted as evidence of spontaneous radiation from the ether, such an interpretation also appears reasonable.

Under this view, it becomes easier to understand why the direction of light propagation along the transverse arm does not change in the manner of a boat drifting in a river: photons acting as the medium generally exert no directional influence on photons that propagate "through" them.

# 4 Derivation of Centrifugal Acceleration Based on Ether Contraction

According to Eq. (6), the change in kinetic energy can be associated with ether contraction. Consider a central body of mass $M$, with the gravitational potential taken to be zero at infinity. A body of mass $m$ starts from rest at infinity and undergoes free fall. By energy conservation, the decrease in gravitational potential energy equals the work done by gravity and is equal to the increase in kinetic energy. Substituting into Eq. (6), we obtain

$$W_{\infty \to r} = -\int_{\infty}^{r} \frac{GMm}{r'^2}\,\mathrm{d}r' = \frac{GMm}{r} = \frac{1}{2}mv^2 = mD(r)c^2 \tag{9}$$

Canceling $m$, we find

$$D(r) = \frac{GM}{rc^2} \tag{10}$$

We now consider the radial gradient of $D(r)$:

$$\begin{aligned}
\nabla D(r) &= \frac{D(r+\mathrm{d}r) - D(r)}{\mathrm{d}r}\,\hat{\mathbf{r}} \\
&= \frac{GM}{c^2}\left(\frac{1}{r+\mathrm{d}r} - \frac{1}{r}\right)\frac{1}{\mathrm{d}r}\,\hat{\mathbf{r}} \\
&= \frac{GM}{c^2}\,\frac{-\,\mathrm{d}r}{r^2}\,\frac{1}{\mathrm{d}r}\,\hat{\mathbf{r}} \\
&= -\,\frac{GM}{c^2}\,\frac{1}{r^2}\,\hat{\mathbf{r}} \\
&= \frac{1}{c^2}\,\mathbf{g}(r)
\end{aligned} \tag{11}$$

where $\mathbf{g}(r)$ denotes the gravitational acceleration vector.

Next, we consider the centrifugal acceleration of a rotating disk with angular velocity $\omega$:

$$\begin{aligned}
\mathbf{a} &= c^2\,\nabla D(r) \\
&= c^2\,\frac{\dfrac{\omega^2(r+\mathrm{d}r)^2}{2c^2} - \dfrac{\omega^2 r^2}{2c^2}}{\mathrm{d}r}\,\hat{\mathbf{r}} \\
&= c^2\,\frac{\omega^2}{2c^2}\,\frac{r^2 + (\mathrm{d}r)^2 + 2r\,\mathrm{d}r - r^2}{\mathrm{d}r}\,\hat{\mathbf{r}} \\
&= c^2\,\frac{\omega^2}{2c^2}\,(2r + \mathrm{d}r)\,\hat{\mathbf{r}} \\
&= \omega^2 r\,\hat{\mathbf{r}}
\end{aligned} \tag{12}$$

This derivation reproduces the familiar formula for centrifugal acceleration, but follows a line of reasoning based on ether contraction. The result suggests that the centrifugal force is a real force arising from ether contraction. More generally, one may assert that inertial forces arise as resistance associated with an attempt to induce ether contraction. In Newton's bucket experiment, which postulates absolute space and absolute motion, the global notion of absoluteness has been revised by Einstein; however, from a local perspective, absolute motion still exists.

# 5 Review

Although many of the views presented in this paper may not be entirely correct, once one is no longer satisfied with regarding the invariance of the speed of light as merely an empirical law of nature, the question of the ether inevitably reemerges. This mirrors the historical development of our understanding of light—from a particle, to a wave, and ultimately to Einstein's unification in the form of wave–particle duality. Such a progression is no more than a concrete illustration of Hegel's philosophical view that human cognition advances from one extreme to its opposite and finally achieves unity through the process of thesis, antithesis, and synthesis. At the same time, this process also reveals an undeniable fact: the inherent limitations of human understanding.

## References


[1] Ludwig Boltzmann. *Lectures on Gas Theory.* University of California Press, Berkeley, 1964.

[2] Albert Einstein. *Sidelights on Relativity.* Methuen & Company, London, 1922.

[3] Albert Einstein. *The Collected Papers of Albert Einstein, Volume 2: The Swiss Years: Writings, 1900–1909.* Princeton University Press, Princeton, 1989.

[4] James Clerk Maxwell. *A Treatise on Electricity and Magnetism*, volume 2. Clarendon Press, Oxford, 1873.

[5] Isaac Newton. *The Principia: Mathematical Principles of Natural Philosophy.* University of California Press, Berkeley, 1999.

[6] Wolfgang Pauli. *Theory of Relativity.* Pergamon Press, Oxford, 1958.

[7] Wolfgang Rindler. *Essentials of Relativity: Special, General, and Cosmological.* Springer, New York, 2 edition, 1977.