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Revising the Two Postulates of Special Relativity: Three Principles of Measurement Mechanics

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Abstract

Einstein's special theory of relativity rests on two postulates, the principle of relativity and the principle of the constancy of the speed of light, which together imply that all inertial frames are physically equivalent and that a state of rest cannot be operationally distinguished from a state of uniform motion. In this paper we point out that this axiomatic system overlooks the mechanical asymmetry between massive mechanical measuring instruments (rigid rulers and atomic clocks) and massless optical measuring instruments (light rulers). In place of Einstein's two postulates, we propose three principles of measurement mechanics: (i) the law of invariance of the two-way and borrowed peeds of light, (ii) the law of length invariance of rigid rods, and (iii) the period principle of atomic clocks. We define mechanical coordinates, established in the rest frame by rigid rulers, synchronized atomic clocks, and two-way light signals, and optical coordinates, which a uniformly moving frame equipped only with light sources and observers locally matches to the points of the rest frame. Without assuming the principle of relativity or Lorentz symmetry a priori, and applying only the law of invariance of the two-way and borrowed speeds of light and the law of length invariance of rigid rods, we derive the Lorentz transformation, its inverse, and the absolute time dilation $\tau=t/\gamma$ of a uniformly moving atomic clock. The formal reciprocity of the transformation is interpreted as a relativity between observers, which coexists without contradiction with the physical distinguishability of the rest frame and the uniformly moving frame. This work completes the program developed in the author's previous studies and establishes the framework of absolute relativity as a consistent reformulation of special relativity.

Keywords: Special Relativity, Lorentz Transformation, Two-Way Speed of Light, Borrowed Speed of Light, Clock Synchronization, Time Dilation, Preferred Frame, Measurement Mechanics, Absolute Relativity

1. Introduction

Newton, who laid the foundations of classical mechanics, distinguished in the Principia between absolute and relative time and space, and defined the inertial frame as a system on which no external force acts [1]. In modern physics, however, Einstein established the special theory of relativity by declaring all inertial frames physically equivalent and excluding an absolute rest frame [2].

The aim of this study is to overcome the conceptual limitation of special relativity expressed in the notion of the "relativity of inertial frames," and to construct the theoretical framework of absolute relativity, which unifies the concept of absolute space and time of classical mechanics with the operational principles of modern physical metrology. To this end, we analyze the mechanical asymmetry between massive mechanical measuring instruments (rigid rulers and atomic clocks) and massless optical measuring instruments (light rulers), and rederive the Lorentz transformation from a new axiomatic system. That the measurement of the speed of light is essentially a two-way measurement, and that the synchronization of distant clocks is conventional in character, have been widely discussed since Reichenbach [3], and Mansouri and Sexl [4] proposed a test theory of special relativity parametrized by a preferred frame and by the clock-synchronization procedure [3,4]. In previous work the author discussed a relative absoluteness that distinguishes the rest

frame from a uniformly moving frame on the basis of three principles, namely the invariance of rigid rulers and atomic clocks and the invariance of the speed of light [5]; showed that the relativity between observers coexists with the absoluteness of inertial frames [6]; and demonstrated that the Lorentz transformation can be derived from the invariance of the speed of light alone, the resulting third Lorentz transformation constituting a reformulation of special relativity [7]. The present paper completes this research program by replacing Einstein's two postulates with three principles of measurement mechanics and by clearly distinguishing, in operational terms, the mechanical rest frame from the optical uniformly moving frame [5-7].

The paper is organized as follows. Section II reviews the historical background. Section III presents the three principles of measurement mechanics, defines measured coordinates and borrowed coordinates, and derives the Lorentz transformation and its inverse. Section IV discusses the physical implications of the resulting absoluteness–relativity duality, and Sec. V summarizes the conclusions.

2. Historical Background

Galilean transformation: Classical mechanics presupposes absolute space and time and, by adopting the Galilean transformation $x' = x - vt$, $t' = t$ as the coordinate transformation between inertial frames, posits the absoluteness of time and space [1].

Michelson–Morley experiment (1887): This experiment attempted to detect the motion of the Earth relative to the stationary ether, i.e., the ether wind, but obtained a null result [8]. This result became the decisive occasion for abandoning the classical Galilean transformation and the ether hypothesis.

Derivation of the Lorentz transformation and its completion by Poincaré: In order to keep the form of Maxwell's equations invariant, Lorentz introduced the concepts of length contraction and local time and derived the Lorentz transformation [9]. Poincaré took this up and, by introducing the principle of relativity and the concept of spacetime invariance, completed the Lorentz transformation mathematically as a group [10].

Einstein's postulates of special relativity and their limitation: In 1905 Einstein abandoned the ether hypothesis and proposed two postulates: (1) the principle of relativity and (2) the principle of the constancy of the speed of light [2]. This axiomatic system, however, overlooked the mechanical asymmetry between massive mechanical measuring instruments and optical measuring instruments. As a result, all inertial frames came to be regarded as physically equivalent in every respect, which entails the limitation that the rest frame cannot be distinguished from a uniformly moving frame.

3. Lorentz Transformation from the Three Principles of Measurement Mechanics

A. Three Principles of Measurement Mechanics

In place of Einstein's postulates, we establish three new laws based on the operational procedures of actual physical measuring instruments.

- **Principle I (Law of Invariance of the Two-Way and Borrowed Speeds of Light):** In the rest frame the two-way speed of light is invariant, and since light signals that depart together arrive together, the borrowed speed of light is also invariant in a uniformly moving frame.
- **Principle II (Law of Length Invariance of Rigid Rods):** The proper length of a rigid ruler is invariant regardless of the inertial frame, and when the two ends of a rigid ruler are simultaneous, the rigid ruler coincides with the light ruler.
- **Principle III (Period Principle of Atomic Clocks):** Atomic clocks fixed in an inertial frame have identical periods, but their periods differ when they move relative to one another.

B. Invariance of the Two-Way Speed of Light and the Mechanical Rest Frame

Two-way light experiment and the rest frame. Among the inertial frames, we define as the rest frame the coordinate system in which the round-trip times measured in two-way light experiments agree, and we call any other inertial frame a uniformly moving frame. Consider a rigid rod of length L with a light source O at one end and a mirror P at the other. If T is the time taken for light emitted from the source O to be reflected by the mirror P and return to O, the two-way speed of light c satisfies

$$c = {}^{2L}/_{c}\,. \tag{1}$$

We call this the invariance of the two-way speed of light. The use of a rigid rod and an atomic clock in the two-way light experiment means that the coordinates of a point at rest can be measured with rigid rulers and atomic clocks. We write the coordinates of a point P at rest, measured with rigid rulers and atomic clocks, as $P(x,y,z,t)$, and call them measured coordinates. Here x, y, and z are three-dimensional Euclidean coordinates measured with rigid rulers, and t is the proper time of the atomic clock at rest at that position.

To assign coordinates to a moving point P', we first synchronize the atomic clocks at rest by means of rigid rulers and light as follows. Let t_O be the reading of the atomic clock at the origin O, and set the clock at the point $P(x,y,z,t)$, whose distance measured with rigid rulers is $r = \sqrt{x^2 + y^2 + z^2}$, to

$$t_P = t_O + {}^{r}/_{c}. \tag{2}$$

Since the rest frame is isotropic and homogeneous, repeating this procedure for every lattice point synchronizes the clocks throughout the entire frame. This is an operational implementation of Einstein's synchronization procedure [2] based on rigid rulers and the two-way speed of light. After synchronization, the distance r can be measured with light and the synchronized atomic clocks; we call this the light ruler. From Eq. (2),

$$r = c(t_P - t_O). \tag{3}$$

On the other hand, since $r = \sqrt{x^2 + y^2 + z^2}$ can also be measured with rigid rulers, we obtain

$$\sqrt{x^2 + y^2 + z^2} = c(t_P - t_O). \tag{4}$$

We call Eq. (4) the coincidence of the rigid ruler and the light ruler. That is, if the two ends of a rigid rod are simultaneous, the rigid ruler coincides with the light ruler; otherwise the two rulers do not coincide.

Borrowed coordinates and the law of invariance of the two-way and borrowed speeds of light. The coordinates of a moving point P' cannot be measured with fixed rigid rulers and synchronized atomic clocks. Therefore P' borrows the coordinates of the point at rest $P(x, y, z, t)$ through which it passes and is written as $P'(x, y, z, t)$. We call these borrowed coordinates. Meanwhile, light emitted together from a light source at rest and from a moving light source passing in its immediate vicinity arrives simultaneously at the rest-frame observer $P(x, y, z, t)$. That is, by coordinate borrowing, the rest-frame observer confirms that the speed of light is c regardless of the velocity of the source. An inertial frame that in this way determines the coordinates of points at rest and of moving points by means of rigid rulers, atomic clocks, and light is called the mechanical rest frame.

C. Invariance of the Borrowed Speed of Light and the Optical Uniformly Moving Frame

The rest frame installs rigid rulers, atomic clocks, and light (light sources and observers) at points at rest, whereas a uniformly moving frame installs only light (light sources and observers) at uniformly moving points. Now consider a uniformly moving frame O_0' moving with constant velocity $v > 0$ in the $+x$ direction relative to the rest frame O. In the rest frame O and the uniformly moving frame O_0', the x axis coincides with the ξ axis, and the y and η axes and the z and ζ axes are respectively parallel.

To construct the uniformly moving frame, the speed of light in that frame must be specified. Light emitted together from the rest-frame source $O(0,0,0,0)$ and the moving-frame source $O_0'(0,0,0,0)$ travels in straight lines and arrives together at the rest-frame observer $P(x,y,z,t)$ and the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$. Applying coordinate borrowing, the rest-frame observer P regards the two sources as identical and assigns the speed of light the value c. The moving-frame observer P', passing the rest-frame observer P, likewise applies coordinate borrowing, regards the two sources as identical, and concludes that the speed of light is c. To distinguish this from the invariance of the two-way speed of light, we call it the invariance of the borrowed speed of light. Therefore,

$$x^2 + y^2 + z^2 = c^2t^2 \Rightarrow \xi^2 + \eta^2 + \zeta^2 = c^2\tau^2. \tag{5}$$

The two equations in Eq. (5) are mathematically equivalent but physically distinct. The left equation uses the speed of light measured in a two-way experiment, whereas the right equation uses the borrowed speed of light transcribed according to the borrowed coordinates. In the rest frame the speed of light is determined independently, in accordance with the law of length invariance of rigid rods and the period principle of atomic clocks, whereas in a uniformly moving frame the speed of light is determined by the moving sources and observers borrowing coordinates. To distinguish this from the principle of the constancy of the speed of light that Einstein adopted as a postulate [2], we call it the "law of invariance of the two-way and borrowed speeds of light." This law states that, since light signals that depart together arrive together, the speed of light is c irrespective of the relative velocity of source and observer, but that this speed is measured by a two-way experiment in the rest frame and determined by coordinate borrowing in a uniformly moving frame. This resolves the problem addressed in Reichenbach's discussion of the dependence of the one-way speed of light on the synchronization convention [3] and in the test theory of Mansouri and Sexl [4], by assigning different statuses to the rest frame and the uniformly moving frame on the basis of the mechanical difference between the measuring instruments. Because the moving-frame observer, by applying the invariance of the borrowed speed of light, matches its own coordinates by means of light and atomic clocks in relation to the rest-frame observer,

we call such a frame an optical uniformly moving frame.

D. Derivation of the Lorentz Transformation

We now derive the Lorentz transformation and its inverse by applying only the law of invariance of the two-way and borrowed speeds of light. Unlike Einstein [2] or Lorentz [9], the present derivation excludes entirely any a priori assumption of the principle of relativity or of Lorentz symmetry.

Longitudinal coordinate and time: By the definition of the uniformly moving frame and the linearity of inertial frames, the longitudinal coordinate ξ and the time τ are written as

$$\xi = k(x - vt), \qquad \tau = \alpha x + \sigma t, \tag{6}$$

where k, α, and σ are functions of v only. At the instant $t = \tau = 0$ when the origins of the two coordinate systems S and S' coincide, a light signal is emitted from the origin along the x axis. By the invariance of the speed of light, $\xi = c\tau$ when $x = ct$, and $\xi = -c\tau$ when $x = -ct$. Substituting these conditions into Eq. (6) gives

$$k(c - v) = c(\alpha c + \sigma), \qquad k(c + v) = c(\sigma - \alpha c), \tag{7}$$

from which $\sigma = k$ and $\alpha = -kv / c^2$. Hence

$$\tau = k\left(t - \frac{vx}{c^2}\right). \tag{8}$$

Transverse coordinates: Next we determine the transverse coordinates. Since the moving-frame observer $P'(\xi, \eta, \zeta, \tau)$ moves along the x axis relative to the rest-frame observer $P(x, y, z, t)$, the transverse axes are affected only by the velocity. That is,

$$\eta = my, \qquad \zeta = mz, \tag{9}$$

where m is a function of v only.

From the moving-frame observer $P'(\xi, \eta, \zeta, \tau)$ and the rest-frame observer $P(x, y, z, t)$, drop perpendiculars to the $\xi\zeta$ plane and the xz plane, respectively, and let the feet of the perpendiculars be $S'(\xi, 0, \zeta, \tau)$ and $S(x, 0, z, t)$. The ends of the moving-frame rigid rod $P'S'$ and of the rest-frame rigid rod PS coincide with each other and are simultaneous. According to Eq. (4), the length y measured with the rigid ruler in the moving frame equals the distance η measured with the light ruler. Therefore $m = 1$ in Eq. (9); that is,

$$\eta = y. \tag{10}$$

Similarly, from the moving-frame observer $P'(\xi, \eta, \zeta, \tau)$ and the rest-frame observer $P(x, y, z, t)$, drop perpendiculars to the $\xi\eta$ plane and the xy plane, and let the feet be $T'(\xi, \eta, 0, \tau)$ and $T(x, y, 0, t)$. The ends of the moving-frame rigid rod $P'T'$ and of the rest-frame rigid rod PT coincide with each other and are simultaneous. According to Eq. (4), the length z measured with the rigid ruler equals the distance ζ measured with the light ruler, so that Eq. (9) gives

$$\zeta = z. \tag{11}$$

From Eqs. (10) and (11),

$$\eta = y, \qquad \zeta = z. \tag{12}$$

Synchronization of the atomic clocks of the uniformly moving frame and time dilation: Next, using the light of the two frames, we set the atomic clocks of the uniformly moving frame against those of the rest frame. Light emitted together from the moving-frame origin O_0' and the rest-frame origin O arrives at the moving-frame observer Q' on the transverse η axis and at the rest-frame observer Q passing in its immediate vicinity. For the light of the moving frame and the light of the rest frame we have, respectively,

$$\xi = 0, \quad \eta = c\tau, \quad \zeta = 0; \qquad x = vt, \quad y = \sqrt{c^2 - v^2}\,t, \quad z = 0. \tag{13}$$

From Eqs. (12) and (13),

$$\eta = c\tau = \sqrt{c^2 - v^2}t = y. \tag{14}$$

Substituting $x = vt$ into Eq. (8) gives $\tau = k(1 - v^2/c^2)t$ at $\xi = 0$, and combining this with Eq. (14) yields

$$k = \frac{1}{\sqrt{1-(v/c)^2}} \equiv \gamma. \tag{15}$$

From Eqs. (8) and (15), the reading of an atomic clock at rest in the uniformly moving frame is

$$\tau = \frac{t}{\gamma}, \qquad \gamma = \frac{1}{\sqrt{1-(v/c)^2}}. \tag{16}$$

Equation (16) expresses the time dilation whereby the atomic clocks of the uniformly moving frame run slower by a factor $1/\gamma$ than those of the rest frame, in agreement with Principle III. The time dilation of the uniformly moving frame relative to the rest frame is not relative but absolute.

Lorentz transformation and its inverse: From Eqs. (6), (8), and (15), $\xi = \gamma(x - vt)$ and $\tau = \gamma(t - vx/c^2)$. Combining these with Eq. (12), the complete Lorentz transformation becomes

$$\xi = \gamma(x - vt), \qquad \tau = \gamma\left(t - \frac{vx}{c^2}\right), \qquad \eta = y, \qquad \zeta = z, \qquad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}}, \tag{17}$$

and its inverse is

$$x = \gamma(\xi + v\tau), \qquad t = \gamma\left(\tau + \frac{v\xi}{c^2}\right), \qquad y = \eta, \qquad z = \zeta. \tag{18}$$

Relativity of observers: Equations (17) and (18) show that, mechanically, the moving-frame observer $P'(\xi, \eta, \zeta, \tau)$ moves with velocity v relative to the rest-frame observer $P(x, y, z, t)$, whereas, optically, the rest-frame observer $P(x, y, z, t)$ appears to move with velocity $-v$ relative to the moving-frame observer $P'(\xi, \eta, \zeta, \tau)$. To distinguish this from Einstein's relativity of inertial frames, we call it the relativity of observers, or the relativity between points. The relativity of observers expressed in the Lorentz transformation and its inverse holds because the moving-frame observer $P'(\xi, \eta, \zeta, \tau)$ and the rest-frame observer $P(x, y, z, t)$ share light and are therefore subject to the law of invariance of the speed of light. The Doppler effect is a good example of the relativity of observers.

Absoluteness of inertial frames: The absolute difference between the rest frame and the uniformly moving frame becomes apparent when rigid rulers and atomic clocks are used together with light.

First, in the rest frame the rigid ruler and the light ruler always coincide by Eq. (4), whereas in the uniformly moving frame, by Eq. (12), they coincide only along the η and ζ axes perpendicular to the direction of motion. For the ξ coordinate parallel to the direction of motion, Eq. (17) shows that the length $x' \equiv x - vt$ measured with the rigid ruler and the length measured with the light ruler do not coincide:

$$\xi = \gamma x' \neq x'. \tag{19}$$

A good example of the discrepancy between the rigid ruler and the light ruler in the uniformly moving frame is the Coulomb force. The Coulomb force exerted between two charges q_1 and q_2 separated by a distance r measured with a rigid ruler differs from one inertial frame to another. In the rest frame and in the uniformly moving frame it is, respectively,

$$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}, \qquad F' = \frac{q_1 q_2}{4\pi\varepsilon_0 \gamma^2 r^2}. \tag{20}$$

Second, synchronization in the rest frame is global, whereas synchronization in the uniformly moving frame holds only on planes perpendicular to the axis of motion. From Eqs. (16) and (17),

$$\tau = \gamma\left(t - \frac{vx}{c^2}\right) = \frac{t}{\gamma} - \frac{v\xi}{c^2}. \tag{21}$$

Here t/γ is called the time-dilation term of the atomic clock, and $-v\xi/c^2$ the light-travel-time correction term. The time of the moving-frame observer $P'(\xi, \eta, \zeta, \tau)$ consists of the sum of the time-dilation term of the invariant atomic clock, t/γ, and the light-travel-time correction term, $-v\xi/c^2$, which varies along the ξ axis. When $\xi = 0$ (or $x = vt$),

$$\tau = \frac{t}{\gamma}, \tag{22}$$

which is the time ratio of light signals sent perpendicularly from the origin of the uniformly moving frame. On the other hand, when $\xi = -v\tau$ (or $x = 0$),

$$\tau = \gamma t, \tag{23}$$

which is the time ratio of light signals sent perpendicularly from the origin of the rest frame.

Equations (22) and (23) exhibit a relativity of time, which arises because time is measured not with atomic clocks but with light clocks.

The relation between the light clocks and the atomic clocks in the *xy* plane is shown in Figure 1.

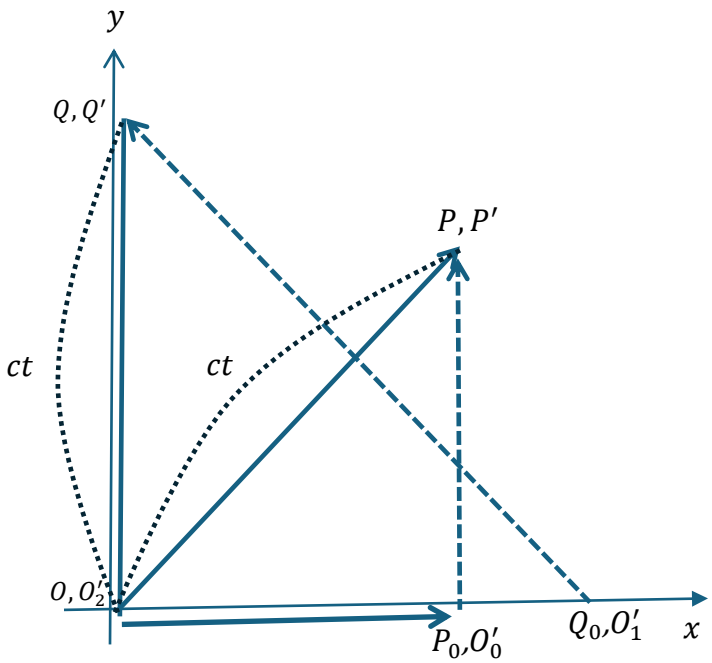


Figure 1: When one pair of light rays emitted from the two origins O and O_0' travels up the y-axis and reaches the two points Q and Q', another pair of light rays travels up the η-axis and reaches the two points P and P'. At that moment, the origin O_0', having departed from the origin O with velocity v in the $+x$-axis direction, passes through the stationary point P_0. The distance between the light source O, from which light Q departed, and the light source O_1' inferred by light Q' is γvt. The distance from the light source O, from which light P departed, to the light source O_0', from which light P' departed, is vt.

Figure 1 schematically shows two pairs of light rays leaving the two origins O and O_0' and arriving, at rest-frame time t, at Q and Q' and at P and P', respectively. Applying the Lorentz transformation to each, we obtain the coordinates of the two pairs of points. One pair of light rays, with direction cosines (0,1,0) and $\left(-\frac{v}{c}, \frac{1}{\gamma}, 0\right)$, travels up in the $+y$ direction and arrives at the two points $Q(0, ct, 0, t)$ and $Q'(-\gamma vt, ct, 0, \gamma t)$. The other pair, with direction cosines $\left(\frac{v}{c}, \frac{1}{\gamma}, 0\right)$ and (0,1,0), travels up in the $+\eta$ direction and reaches the two points $P\left(vt, \frac{ct}{\gamma}, 0, t\right)$ and $P'\left(0, \frac{ct}{\gamma}, 0, \frac{t}{\gamma}\right)$. The distance from the light $Q'(-\gamma vt, ct, 0, \gamma t)$ to the light source $O_1'(0,0,0, \gamma t)$ inferred by the light Q' is

$$\overline{Q'O_1'} = \gamma ct. \tag{24}$$

Accordingly, the uniformly moving point $Q'(-\gamma vt, ct, 0, \gamma t)$, applying the inverse Lorentz transformation, states that the point at rest $Q(0, ct, 0, t)$ runs slower than itself by a factor $1/\gamma$:

$$\tau = \gamma t. \tag{25}$$

The distance from the light $P'\left(0, \frac{ct}{\gamma}, 0, \frac{t}{\gamma}\right)$ to the light source $O_0'\left(0,0,0, \frac{t}{\gamma}\right)$ inferred by the light P' is

$$\overline{P'O_0'} = \frac{ct}{\gamma}. \tag{26}$$

The point at rest $P\left(vt, \frac{ct}{\gamma}, 0, t\right)$, applying the Lorentz transformation, states that the uniformly moving point $P'\left(0, \frac{ct}{\gamma}, 0, \frac{t}{\gamma}\right)$ runs slower than itself by a factor $1/\gamma$:

$$\tau = \frac{t}{\gamma}. \tag{27}$$

Equations (25) and (27) exhibit the relativity of observers already identified in the Lorentz transformation and its inverse. This is also confirmed in the Doppler effect, where the clocks used in common by the observers are light clocks.

Meanwhile, the clock $O_0'\left(0,0,0, \frac{t}{\gamma}\right)$, which leaves the clock at rest $O(0,0,0,0)$ and moves with velocity v in the $+x$ direction, passes the clock at rest P_0 $(vt,0,0, t)$. When the clock at rest P_0 $(vt,0,0,t)$, applying the Lorentz transformation, states that the moving clock $O_0'\left(0,0,0, \frac{t}{\gamma}\right)$ runs slower by a factor $1/\gamma$,

$$\tau_0 = \frac{t}{\gamma}. \tag{28}$$

this statement refers to atomic clocks.

That is, the time ratio between atomic clocks in Eq. (28), $\tau_0 = t/\gamma$, agrees with the time ratio between light clocks in Eq. (27), $\tau = t/\gamma$, whereas Eq. (25) expresses only the time ratio of light clocks, $\tau = \gamma t$. The light signals meeting in each other's vicinity, Q and Q', and P and P', exhibit relativity in time and distance, but between the rest-frame atomic clock P_0, located a distance vt from the origin O, and the moving-frame atomic clock O_0' passing it, an absolute time dilation $\tau = t / \gamma$ appears. Because Einstein did not distinguish light clocks from atomic clocks, he misinterpreted the relativity of time appearing in the light clocks of Eqs. (25) and (27) as a relativity between atomic clocks. When atomic clocks are compared in the Lorentz transformation and its inverse, the absoluteness of inertial frames is revealed; when only light clocks are compared, the relativity of observers holds. The Ives–Stilwell experiment is precisely an example that demonstrates both the time dilation of atomic clocks and the relativity of light clocks [11].

4. Discussion

Einstein's special theory of relativity established relativity in a physics that, since Newton, had been governed by absolute space and time, and it made the great contribution of establishing the Lorentz transformation as a fundamental law of spacetime. However, because it excluded absoluteness altogether, it could not fully describe the mechanical difference between the rest frame and a uniformly moving frame or the absolute time dilation of atomic clocks. In this paper we have discussed this limitation from the standpoint of revising the two postulates.

A. Revision of the principle of the constancy of the speed of light: invariance of the two-way and borrowed speeds of light Einstein assumed that the one-way speed of light is c in every inertial frame [2]. To measure the one-way speed of light, however, distant clocks must first be synchronized, and that synchronization is in turn defined by light. This postulate therefore rests on convention rather than on measurement [3,4]. Only two things are actually measured: the two-way speed of light of Eq. (1), and the independence of the speed of light from the velocity of its source, namely that light signals departing together arrive together. In the rest frame, rigid rulers and atomic clocks confirm the isotropy of the two-way speed of light, so the synchronization of Eq. (2) is physically justified (invariance of the two-way speed of light). A uniformly moving frame equipped only with light, by contrast, borrows the coordinates and the speed of light of the rest frame (invariance of the borrowed speed of light). Hence the two equations in Eq. (5) are mathematically equivalent, but the former involves a measured speed of light and the latter a borrowed one. Because Einstein regarded the two speeds as equivalent, he gave all inertial frames

the same status. The present revision reproduces the Lorentz transformation exactly without assuming the isotropy of the unmeasurable one-way speed of light.

B. From the relativity of inertial frames to the relativity of observers: If the speed of light in the uniformly moving frame is borrowed, the reciprocity of Eqs. (17) and (18) does not follow from the equivalence of inertial frames. It follows instead from the symmetry between the observers P and P', who share light. The relativity of time in Eqs. (25) and (27) is likewise a relation between light clocks. In contrast, a comparison of atomic clocks reveals the absolute time dilation $\tau = t / \gamma$ of Eq. (28), and in the uniformly moving frame the rigid ruler and the light ruler disagree according to $\xi = \gamma x'$ [Eq. (19)]. Because Einstein did not distinguish light clocks from atomic clocks, he extended the relativity of observers into a relativity of inertial frames. The principle of relativity should therefore be restricted to the relativity of observers, which holds for electromagnetic and optical phenomena, and the rest frame as a background is real. This conclusion is compatible with test theories that admit a preferred frame [4] and is consistent with the Ives–Stilwell experiment [11] and the Hafele–Keating experiment [12].

5. Conclusion

In this paper we have critically examined the two postulates of Einstein's special theory of relativity and reinterpreted the Lorentz transformation through three new principles based on the operational definitions of physical measuring instruments (rigid rulers, atomic clocks, and light rulers). By distinguishing the mechanical coordinates of the rest frame from the optical coordinates of the uniformly moving frame, we derived the Lorentz transformation and its inverse solely from the law of invariance of the two-way and borrowed speeds of light, without introducing the principle of relativity or Lorentz symmetry a priori.

As a result, we have shown that the absoluteness expressed by the existence of an absolute rest frame as the background of the physical universe coexists without contradiction with the relativity of observers that appears when electromagnetic phenomena are described among observers sharing light clocks. This revision of the two postulates of special relativity completes the framework of absolute relativity developed in the author's previous studies [5–7], and is expected to provide a firm foundation for resolving the fundamental inconsistencies among electromagnetism, quantum mechanics, and the theory of relativity.

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Author Contributions: H. Koh conceived the study, developed the theoretical framework, performed the derivations, and wrote the manuscript. Generative AI tools were used solely to assist with language editing and formatting; the author reviewed and revised all content and takes full responsibility for the content of the publication.

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