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Why and How Special Relativity Fails in the Second Spatial Dimension? An Introduction to the Preferred Frame Theory

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Abstract It is demonstrated by means of a thought experiment that the special theory of relativity (STR) leads to contradiction when applied to a spacetime with more than one spatial dimension. The underlying cause of inconsistency proves to be the symmetry of relativistic effects, in particular the symmetry of Lorentz contraction due to the relativity of simultaneity. In this context, the preferred frame theory (PFT) is proposed and discussed. PFT bases on the assumptions different from the two postulates of STR (principle of relativity and constancy of the velocity of light), relating instead to the ideas originated and developed mainly by FitzGerald, Lorentz, Larmor, Voigt and Poincaré, before the advent of Einstein's theory. However, contrary to the belief shared by the mentioned scholars, these ideas do not comply with the Lorentz transformation, but with the more than half a century later Tangherlini transformation, connecting time dilation and length contraction with the inconstant speed of light and the absolute simultaneity. Despite the fundamental differences, PFT and STR prove to be largely equivalent with each other as to the observational predictions; a significant albeit hardly detectable (on Earth) exception concerns energy. Unlike in the case of STR, in PFT the magnitude of the ratio between particular energies remains constant in all inertial frames (although specific values of energy vary from frame to frame), being thus an invariant of the Tangherlini transformation. This property makes PFT a Lorentz violating theory in a clearly defined way restricted to energy, which opens new perspectives in searching for an effective theory of quantum gravity.

Keywords: *special relativity, Lorentz transformation, relativity of simultaneity, Lorentz contraction, Tangherlini transformation, preferred inertial frame, quantum gravity*

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1. Introduction

It is no exaggeration to say that the special theory of relativity (STR), formulated by Albert Einstein in his two papers from 1905 [1,2] and complemented three years later by Hermann Minkowski with the geometrical model of spacetime [3] has largely determined the picture of modern physics. The core of relativistic dynamics, which is the increase of mass/energy due to velocity, provides the fundamental operating principle for all the most powerful experimental devices, such as LHC (CERN), RHIC (Brookhaven National Laboratory), Tevatron (Fermilab) or SLAC Linear Collider (Stanford). The limitations of Newtonian mechanics couldn't be more evident. STR has successfully passed a great number of experimental tests, to mention the classical ones: Michelson-Morley, Kennedy-Thorndike, Trouton-Noble, Ives-Stilwell, Hafele-Keating, or the observed on the Earth surface excess of muons of the cosmic origin over the expectations not taking the time dilation into account. They all, along with many others, form an imposing experimental basis of special relativity [4]. On the purely theoretical grounds, STR serves as benchmark for other (both classical and quantum) theories in which space and time play essential role. The Lorentz symmetry implemented by STR makes one of two pillars (the second is defining gravitation in geometric terms, as the spacetime curvature) that underpin the general theory of relativity (GTR). The theoretical models such as the Dirac equation, relativistic quantum mechanics (RQM), quantum electrodynamics (QED) and the Standard Model of particle physics meet the criterion of Lorentz symmetry (Lorentz invariance) and the related concept of Lorentz covariance – the formal property of the spacetime manifold, roughly defined as the ability of physical quantities to keep their form unchanged under the Lorentz transformation. The same requirement, i.e., compliance with STR, with a slight but significant exception (mentioned later in this section) applies to the future theories or the ones currently under construction. The Lorentz symmetry is considered to be a fundamental "feature of nature" [5]. Viewed as mathematical construct, Lorentz symmetry is defined as the Lorentz group of transformations (a subgroup of Poincaré group) or, in terms of analytic geometry, as the symmetries of Minkowski space. The Lorentz symmetry manifests itself within STR by different yet closely related to each other properties, jointly creating the special principle of relativity – the first postulate of STR. It states that *all fundamental laws of physics are the same and can be stated in their simplest form in all inertial frames of reference*. The Lorentz symmetry and the special principle of relativity are therefore like two sides of the same coin; the principle formulates certain demand, and the Lorentz symmetry shows how this demand comes into effect.

According to the second postulate of STR, *the velocity of light in vacuum is constant, regardless of the motion of the light source*. The modern formulation of this postulate usually contains the phrase: "for all inertial observers" or any equivalent one – in fact postulating invariance of c. Expressed this way, it does not consider the constancy of the velocity of light in isolation from the first postulate, treating instead this particular property as one of the fundamental laws mentioned therein. Thus, the so-formulated second postulate contains in itself the first postulate. This is logically awkward, although fully intentional. The purpose behind it is to cover up the traces of the Lorentz's theory of ether, which however goes against Einstein's original intention. To prove the last statement, let us quote the Einstein's original formulation: "Any ray of light moves in the stationary system of co-ordinates with the determined velocity c, whether the ray be emitted by a stationary or by a moving body" [1]. Let us also quote the more extensive (and more unequivocal in this regard) Einstein's formulation, included in his reply to the comment by M. Abraham concerning Einstein's theory of gravitation (then still in progress): "There exists a reference system K in which every light ray propagates in vacuum with the universal velocity c, regardless of whether the light-emitting body is in motion or at rest relative to K [6]".

It is quite clear that the second postulate of STR in both above formulations is independent from the first postulate. As Einstein explicitly stated [6]: "…the theory of relativity rests on two principles that are totally independent of one another". Later on, in the same paper, while justifying the necessity of introducing the second postulate, Einstein wrote: "…it is impossible to base a theory of the transformation laws of space and time on the principle of relativity alone. As we know, this is connected with the relativity of the concepts of simultaneity and the shape of moving bodies. To fill this gap, I introduced the principle of the constancy of the velocity of light, which I borrowed from the H.A. Lorentz's theory of the stationary luminiferous ether, and which, like the principle of relativity, contains a physical assumption that seemed to be justified only by the relevant experiments (experiments by Fizeau, Rowland etc.)".

From the two postulates of STR, the other symmetries follow: the formal symmetry of Lorentz transformation (we will consequently use this singular form to denote the respective set of equations), the symmetry of relativistic effects: length contraction, time dilation, and the resultant mass/energy increase – expected to manifest in the same way in every inertial frame of reference, the invariance of spacetime interval in the four-dimensional Minkowski space, and finally the relativity of simultaneity. The latter is particularly important for the whole rest; although it is not a postulate in the strict sense but rather a consequence of the mention two postulates of STR, it is however not by chance that Einstein devoted the first chapter of his seminal paper on STR [1] to the analysis of this extremely counter-intuitive concept. This is because, without the relative simultaneity, the whole rest would fall into pieces. Insofar as the two postulates of STR are the theory cornerstones (to use again architectural metaphor) the relativity of simultaneity acts as a keystone validating other STR symmetries, in particular the mutuality of relativistic effects and the invariance of c. We will develop this issue in the further parts of the paper.

The Lorentz symmetry, interpreted as the Lorentz covariance applied to the infinitesimally local curved spacetime of general relativity, is involved in the main unsolved problem in theoretical physics, namely the still lacking effective theory of quantum gravity. If considered as a strict and universal demand, the Lorentz symmetry seems to be the main obstacle in connecting GTR and QM into one whole. Being aware of that, physicists look for the violations of Lorentz symmetry, called in short Lorentz violations [7]. Some leading candidate theories for quantum gravity such as string theory and loop quantum gravity predict spontaneous violation of the Lorentz symmetry at Planck scale, due to hypothetical polarization of various fields originated at Planck era. An "aggregate" theory called Standard Model Extension provides theoretical framework for the respective experiments [8,9,10]. However, beyond this extremely narrow sector, STR is still widely considered to be experimentally correct and formally coherent. In particular, the Minkowski's geometrical model strongly suggests that special relativity is self-consistent in the way specific to the purely mathematical constructs such as Euclidean geometry.

Despite its apparent novelty, and regardless of what Einstein knew or admitted he knew (no references in [1]!), STR is strongly rooted in the earlier research, most directly in the pre-relativistic works by FitzGerald [11], Lorentz [12], Larmor [13], Cohn [14] and Poincaré [15,16] – the last one often mentioned as the co-author of STR. Most elements constituting special relativity were "ready and waiting" before the advent of STR: special principle of relativity (Poincaré), Lorentz transformation (Heaviside, FitzGerald, Lorentz, Larmor, Voigt, Poincaré), time dilation (Larmor, Cohn), length contraction (FitzGerald, Lorentz, Larmor), relativity of simultaneity (Poincaré). Even the authorship, or the priority, concerning the famous mass-energy equation derived by Einstein in his second paper on STR [2] is not as obvious as it is widely believed [17]. Einstein's "advantage" in inventing and developing special relativity consisted in gathering all these elements in the framework of a new paradigm, and to dispose of hesitation where others still had doubts. From the today's perspective, all the attempts aimed at explaining the "relativistic" effects in absolute terms have a historical significance only – in so far relevant as paving the way for special relativity. The common mainstream opinion is that any approach to STR based on "ethereal ontology", even if conceptually sound and formally correct, is nevertheless unnecessarily complicated, thereby not worth exploring.

However, the attempts to reinterpret or remodel special relativity in the ethereal framework have not ceased also after the release of Einstein's and Minkowski's papers. From the very beginning of its existence, STR raised doubts, also to Lorentz and Poincaré who both went far towards this theory, but even though remained faithful to the concept of ether. Despite spectacular success, STR became a target of criticism, widely diverse both as to the scientific level and motives. Most of arguments have been either neglected or deflected (usually justifiably) by the proponents of Einstein's theory – as based on logical errors typical for the common-sense approach motivated by the Newtonian point of view. Some experimental results questioning STR, in particular the improved M-M experiments performed by Dayton Miller (with Edward Morley and then alone), has been claimed to be obtained due to subtle technical errors related to the lack of modern algorithms of data processing [18]. In general, in the dispute on STR, lingering for decades up to the present day, the valuable arguments have been unfavorably treated on equal footing with the unsound or even totally unscientific allegations. There is no place and need here to go into details of this otherwise very extensive topic. Let us quote just a few papers/books inspiring the present work, or in some way related to it (also as noteworthy views not shared by the present author): Reichenbach's idea of the conventionality of measurement regarding velocity of light [19], Tangherlini transformation [20] and the related papers by Selleri [21,22], Mansouri & Sexl analyses concerning experimental equivalence between the putative theory based on Tangherlini transformation and STR [23,24,25]; finally, the thought-provoking analyses developing the Lorentz's research, performed by J.S. Bell, who is mainly known for the famous Bell's inequality – a theoretical tool to test the EPR paradox. This paradox, primarily formulated by Einstein, Podolski and Rosen as a thought experiment, has been intended to question the weird predictions of quantum mechanics from the positions of special relativity. The relevance of the real experiments using the Bell's inequality (in particular these performed by A. Aspect) consists in invalidating the Einstein's arguments based on STR. It turned out that the "spooky action at a distance" – a saying coined by Einstein – really takes place in the quantum entanglement, which can be interpreted (but is mostly not) as an argument for the absolute simultaneity. Besides, Bell made two other important contributions to special relativity, closely related to the problem considered in this paper. He namely developed a thought experiment first outlined by Dewan and Beran [26], called after him the "Bell's spaceship paradox". He also used the Maxwell's equations to reveal the tangible physical mechanisms of length contraction and time dilation at atomic level, which confirmed the pre-relativistic conjectures as to the real origin and nature of these effects [27]. The term "real" means here an opposition to the phrase "related to observer" – appropriate for STR. The present paper, in the part devoted to the theory alternative to STR, owes much to the research mention in this paragraph.

The paper is composed as follows. Sections 2 and 3 (complemented with Appendix A) contain presentation and discussion of a thought experiment invalidating STR as a physical theory applied to the space with more than one spatial dimension. Sections 4, 5 and 6 (complemented by Appendices B, C, D and E) contain an outline of a theory proposed to replace STR. It is called the preferred frame theory (PFT), which is a generic name used in the past to name different alternative to the STR theories. In this paper, however, it applies to a specific theory including some original author's findings, in particular concerning the question of experimental equivalence between STR and PFT in the realm of kinematics, and the difference in respective predictions concerning energy.

2. A thought Experiment Questioning STR: Preliminary Discussion

Our goal in this part is to prove that special relativity fails as a theory applied to the spatially two-dimensional spacetime, that is to Minkowski space with total dimension n = 3 (2+1). We will use for that purpose a simple thought experiment, outlined in few lines, below. This brief description will provide us with a reference point for the preliminary discussion.

Imagine a long straight rail stretched "vertically" in a free space, and a rod sliding upward alongside this rail. An inertial observer, due to the rank and name called Major Tom – a lonely pilot of a spaceship representing the MT reference frame – moves away from the rail in the "horizontal" direction, so that, in the MT frame, the straight "horizontal" trajectory of the rail and the straight "oblique" trajectory of the rod form together an acute angle. All relative speeds are assumed uniform and relativistic. We claim that Major Tom is unable to make a consistent report on his observations concerning rail and rod, while trying to base them on STR. This claim can be proved in a remarkably simple way using the concept of Lorentz contraction. However, making sure this simplicity is not just an undue simplification requires more detailed study, which makes the preliminary discussion pretty extensive. In order to avoid misconceptions due to the ambiguities in terminology, we will focus first on few concepts that may prove useful in discussion.

2.1. Kinematical Criterion of Spatial Dimensionality

Since we claim that STR fails in the second (and, by extension, third) spatial dimension, so we should start with specifying the concept of "spatial dimensionality". One can distinguish between two possible meanings of this term. The first refers to the inertial frames themselves and to the objects representing these frames. An inertial frame can be assumed one, two or three-dimensional, and thus be represented by the Cartesian coordinate system provided with one, two or three axes, respectively. Likewise, the objects considered in a thought experiment may vary as to the assumed number of spatial dimensions, usually from zero (geometrical point) to three ("full-size" object). Beyond the capability of a direct perception, but still in a mathematically consistent way, we can also consider objects (in fact the whole spacetimes) with more than three spatial dimensions (plus one temporal, so greater than 4D). The noted examples are the 5D Kaluza-Klein theory, 10D string/superstring theory and 11D M-theory.

The second meaning refers to kinematics; it is about the *number* and *configuration* of inertial frames (or the objects representing these frames) being in relative motion to one another. A given case can be spatially one, two or three-dimensional, regardless of the (equal for all) spatial dimensionality of particular frames or objects. For example, three particles interpreted (according to the first meaning) as zero-dimensional geometrical points moving relative to each other in different directions, would make the whole case spatially two-dimensional (second meaning) – same as the three-legged stool always fits the two-dimensional floor. Unless is stated otherwise, or the otherwise is clear from the context, the terms "spatial dimensionality" and "spatially *n*-dimensional" will be used in this second meaning, that is as *kinematically defined spatial dimensionality*.

Most of the thought experiments or the so-called paradoxes in STR use the images of two or three-dimensional objects such as trains, rockets, barns, etc. This might suggest that these experiments apply to the real spatially three-dimensional world or, at least, to the two-dimensional model of physical reality. For example, since the relativity of simultaneity provides, in combination with time dilation, a solution to the famous twin paradox, one might conclude that this solution is universally valid, regardless of the fact that respective explanation (by means of Minkowski diagram) employs a one spatial dimension only. In fact, most of the paradoxes in STR, including twin paradox, ladder paradox or the Bell's spaceship paradox are spatially one-dimensional in the above-defined kinematical terms. This is due to the *number of inertial frames* (two) or, in case of greater number, due to their *collinearity*. In Euclidean geometry, collinearity (of the set of points) is defined as the property of lying on a single straight line. As a kinematical property describing the set of inertial frames, collinearity should be defined a bit different – as the property relating to the only one direction of relative motion, where "one direction" includes both opposite velocity vectors. According to that criterion, any two inertial frames, regardless of their own (equal for both) spatial dimensionality, are collinear, thus one-dimensional. In order to make the case spatially two-dimensional, one needs at least three inertial frames: K, K', K" in the noncollinear configuration, which means that respective directions of the three relative motions: K – K', K – K" and K' – K" are coplanar but non-parallel to one another.

2.2. Trajectory and Position of a Moving Object

All motions considered in our thought experiment are, by assumption, constantly uniform and rectilinear, ergo inertial. Consequently, the concept of "trajectory" (meaning in general the line of motion of a basically free shape) becomes specified here as the *straight trajectory*. Defined this way, "trajectory" is closely related to another concept, namely *direction of motion* – in the sense that both assume rectilinearity. Trajectory/direction of motion is determined with respect to *inertial frame of reference*, defined as a physical system having the property of inertia (due to the Newton's first law of motion), and provided with Cartesian coordinates. Accordingly, a trajectory determined in the observer's frame can be classified as "horizontal" (parallel to x -axis), "vertical" (parallel to y -axis) or "oblique" (parallel to any intermediate xy direction). For better clarity of the thought experiment in question, "oblique" will refer to a trajectory roughly close to the bisector of the right angle between x and y axes.

Instead, by "position" we mean *spatial orientation of the observed object relative to the trajectory*. This complies with our main goal which is examining the position of a moving object in the context of Lorentz contraction. Since the objects considered in our thought experiment (rail and rod) are, by assumption, straight and one-dimensional, so position becomes specified as the direction they determine on the plane. When it is quite clear from the context, "position" may also mean direction with respect to the coordinate system or to the other object (e.g., position of the rod with respect to the rail). Besides, "position" refers to the *events* (as a *position four-vector*) and thus can also be used in that context.

2.3. Lorentz Transformation: Relativity of Simultaneity and the Symmetry of Relativistic Effects

For the sake of better insight into the issue under consideration, let us write the Lorentz transformation (Lorentz boost in xx' direction) in the most developed form:

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

In the reverse direction, we have:

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

As long as the dependence of space coordinates on the time coordinates is a self-explanatory property of any kinematic transformation (including Galilean and Lorentz transformations), an opposite relation, i.e., dependence of time coordinates on the space coordinates is a unique and exclusive property of the Lorentz transformation. This formal dependence makes a mathematical base for the relativity of simultaneity. Specifically, each of the two mutually symmetrical equations for time can be formulated as a function:

$$f(X) = a + bX \tag{2}$$

where: $f(X) \sim t$, $a \sim t'\left(1 - \frac{v^2}{c^2}\right)^{-1/2}$, $b \sim vc^{-2}\left(1 - \frac{v^2}{c^2}\right)^{-1/2}$ and $X \sim x'$, with " $\sim$ " meaning "corresponds to the term". By analogy, we can write $f(X) = a - bX$, replacing mutually the primed and unprimed coordinates. In that interpretation, the space coordinates form the domain of function, the time coordinate on the right side of each equation is fixed for a selected moment (thus plays the role of a variable of the preset value), and the resultant time coordinates on the left side of each time equation form the codomain of function.

All four nontrivial equations from Eqns. (1a) and (1b), i.e., the ones including the variables x and x', contain the Lorentz factor $\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-1/2}$ (written as a double reciprocal of γ, i.e., $\frac{1}{\gamma^{-1}}$) determining the relativistic effects. However, if we look only at two equations for the space coordinates *in isolation from other transformational equations* (in particular, not knowing how the time equations look like), we could wrongly presume that they predict not a contraction but elongation of the transformed object. It is only the interrelation between the equations for space and for time that gives an ultimate result, i.e., Lorentz contraction and time dilation manifesting in the same way in each frame, thus making together a symmetrical whole. In particular, the term $\frac{vx}{c^2}$ – responsible for the relativity of simultaneity – plays the role of a "pivot" making the Lorentz symmetry possible. In other words, the symmetry of relativistic effects and the relativity of simultaneity *mutually condition each other*, while the underlying cause is the constant (invariant) speed of light. Having said that, let us remind once again that every case consisting of two inertial frames is *spatially one-dimensional* in kinematical terms. Consequently, every single Lorentz transformation is spatially one-dimensional.

2.4. The length Defined in Terms of the Spacetime Interval

Let us consider the Lorentz transformation (boost) between two inertial frames of reference: K (t, x, y, z) and K' (t', x', y', z') being in standard configuration to each other (common origin of respective coordinate systems at $t = t' = 0$, collinearity of xx' axes, parallelism of yy' and zz' axes). Any specific combination of the coordinates t, x, y, z forms the *position four-vector* applying to an *event* in spacetime, as determined in K. After being transformed to K', these coordinates form another position four-vector: t', x', y', z', referring to the same event, e.g., particle collision, or the astronaut's sneeze while landing on Mars. This is just the way a single event is transformed from one inertial frame to another.

Assume now that, instead of one, the two different events determined in K are transformed from K to K'. To be considered different, they have to be separated in space or in time, or both in space and in time. The defining property of the Lorentz transformation (and, consequently, of the Minkowski space) is the invariance of a "distance" in spacetime between any pair of events, called the *spacetime interval* – an analogue to the spatial distance in Euclidean space, based on the Pythagorean theorem. It is defined as the 4-vector of the length equal to the difference between two position four-vectors: t_1, x_1, y_1, z_1 and t_2, x_2, y_2, z_2, where, e.g., $x_2 - x_1 = \Delta x$. When using the sign convention based on metric signature ($-+++$), the squared spacetime interval reads:

$$\Delta s^2 = -(c\Delta t)^2 + \Delta x^2 + \Delta y^2 + \Delta z^2 \tag{3}$$

where $\Delta s^2 = (c\Delta\tau)^2$, τ – *proper time* (time measured by the clock comoving with an object). The invariance of the spacetime interval under the Lorentz boost means that any pair of events transformed from K to K' satisfies the equation:

$$\begin{aligned} &-(c\Delta t)^2 + \Delta x^2 + \Delta y^2 + \Delta z^2 = \\ &-(c\Delta t')^2 + \Delta x'^2 + \Delta y'^2 + \Delta z'^2 \end{aligned} \tag{4}$$

that is $\Delta s = \Delta s'$. Assume the rod (at rest or in motion) in K, in a free position (parallel or diagonal) to xx' direction of the relative motion between K and K'. The measured in K nonzero extent of the rod in x direction (which coincides with the rod's length, defined as the size measured along the rod, for the parallel position only) is equivalent to the spacetime interval between two events determined in K, containing two different space coordinates: x_1, x_2, corresponding to the rod's endpoints, and only one time coordinate t_0 combined separately with these space coordinates. As a result, we have a certain spatial distance: $x_2 - x_1 = \Delta x > 0$ and the null time difference $\Delta t = 0$, which reduces the spacetime interval in K to the purely spatial form:

$$\Delta s^2 = \Delta x^2 + \Delta y^2 + \Delta z^2 \tag{5}$$

In the special case when the rod is arranged in K in parallel to x -axis, the other spatial dimensions also equal zero: $\Delta y = \Delta z = 0$, so the spacetime interval additionally reduces to:

$$\Delta s^2 = \Delta x^2 \tag{6}$$

Expressed this way (i.e., by Eqns. 5 or 6), the x oriented "size" of the rod can be defined as the *spacetime interval between two simultaneous events*. This definition in fact applies to any theory and to any clear-cut object, in compliance with the concept of "length" defined as the distance between two extreme points measured in the direction of motion *at one moment*. This means that the length of a diagonally positioned rod is measured *not* along the rod itself (which only applies to the parallel position corresponding to Eq. 6), but along x direction, assuming motion in that direction. With regard to STR, the condition "at one moment" becomes nontrivial due to the relativity of simultaneity predicted by this theory. From the Lorentz transformation it follows that two events simultaneous in one frame are usually not simultaneous in the other frame. In the spatially one-dimensional cases with the events differing by x coordinates, the phrase "are usually not simultaneous" turns into "are never simultaneous". In particular, the two simultaneous events in K: x_1t_0 and x_2t_0, determining the rod's length in K, are no longer simultaneous as transformed to K' – differing not only by space coordinates, but also by time coordinates, namely: $t_1' = \gamma\left(t_0 - {vx_1}/{c^2}\right)$ and $t_2' = \gamma\left(t_0 - {vx_2}/{c^2}\right).$ Therefore, these two events, being expressed by the coordinates of K', do not determine the rod's length in K'.

When using the sign convention $(-+++)$, every two spatially separated events fulfilling the condition $\Delta s^2 > 0$ make the respective spacetime interval "spacelike", i.e., connecting the *causally disconnected* events, situated outside the light cone on Minkowski diagram. For any such pair of events, there can be found a frame in which these events are simultaneous, hence respective spacelike interval can be identified with length. When an object fulfills the condition of simultaneity in given frame, we call it (in this paper) *integral*. The property of being integral is not dependent on whether given object is at rest with respect to observer; the only criterion is the simultaneity of all events constituting this object in the observer's frame. The difference between "integral" and "simultaneous" is not due to the physical property itself, but due to different designata of this property; both terms mean that $\Delta t = 0$, however "simultaneous" refers to the particular points (events) constituting given object, whereas "integral" describes this object as a whole.

Understandably, the condition of simultaneity is not essential to determine the length of an object at rest in the frame in which the measurement is taken. This is due to the constant (in time) location of respective points, e.g., the rod's endpoints. However, if the coordinates of these endpoints are to be transformed from the rod rest frame K to the observer's frame K', then the condition of simultaneity in K must be respected. Otherwise, we couldn't say it is the rod (and not just a set of free events) that is an object of transformation. The fact that the rod, being integral in K, is no longer integral as transformed (by the Lorentz boost) to K' is described here as a *discrepancy between the Lorentz transformation and observation.* Although it is clear that also the non-simultaneous events can be observed (over a period of time) in given frame, it is just as much clear that such events do not form integral objects. As it turns out in the further analysis, the consequences of the said discrepancy are of crucial importance to the question of consistency of STR in two spatial dimensions.

2.5. Conclusions Drawn from the Previous Consideration

Terminological note 1: For the sake of brevity, we introduce the terms "source frame" and "target frame", meaning respectively the frame from which and to which the transformation (Lorentz boost) is performed.

Terminological note 2: In special relativity, the concepts of "Lorentz contraction" and "length contraction" mean exactly the same. However, we'll treat them and use separately, to denote respective effects as alternatively defined according to STR and PFT. Leaving the details for later, let us agree for now that "Lorentz contraction", as specifically connected with the Lorentz transformation, will be used exclusively in the context of STR, whereas "length contraction" will apply to PFT to denote an effect specifically connected with the Tangherlini transformation.

With the aim to perform the right (compliant with STR) analysis of the thought experiment, let us summarize in an orderly manner the most important conclusions. They are namely:

(1) The length (as well as any other spatial dimension) of the spatially extended object has to meet the *condition of simultaneity*, defined as identity of the time coordinates of all events constituting given object. The condition of simultaneity (making the observed object *integral*) is particularly essential when the measurement concerns an object in motion. In order to meet this condition, the Poincaré-Einstein synchronization has to be applied.

(2) In the case of an object in motion, the concept of length strictly corresponds to the Lorentz contraction: the observed (coordinate) length is equal to the proper length measured in parallel to the relative velocity vector, divided by respective Lorentz factor.

(3) The relativity of simultaneity does not amend (does not impact on) the way Lorentz contraction manifests itself in a particular observer's frame – no matter if this effect is detected using the measurements based on the Poincaré-Einstein synchronization, is obtained from velocity using the Lorentz factor, or is indirectly deduced from the Lorentz boost (see point 7). The contracted object is by definition integral. The only notable impact of the relativity of simultaneity on the Lorentz contraction consists in making this effect *mutual*, ergo *symmetrical* within any pair of inertial frames, in compliance with the formal symmetry of Lorentz transformation.

(4) Lorentz contraction always, i.e., regardless of the "proper" shape and position of the moving object, manifests itself in the same simple way, namely as the shortening along the direction of motion, depending on relative velocity according to the Lorentz factor. This "shortening" can be understood as follows. Imagine a flat figure of a free shape drawn on the Cartesian plane. Let the whole Cartesian plane be compressed along certain direction and to a certain degree (which is equivalent to viewing this plane at a definite acute angle). Of course, the drawn figure will become compressed together with the plane, i.e., in the same direction and to the same degree. That's exactly how the Lorentz contraction works.

(5) The above conclusion determines the prediction referring to a specific arrangement: the Lorentz contraction of a line segment (rod) whose position is diagonal to the trajectory delineated in the observer's

frame, results in the increase of the (acute) angle between the rod and trajectory – so that position becomes "more transverse" compared to a position the rod would take if it stops in the observer's frame (Figure 1). Quantitatively (in trigonometrical terms), this effect is developed in Appendix A.

(6) The above rule is also working in the opposite direction: in the rod rest frame, the angle between the rod and the trajectory (of the moving observer) is smaller than respective angle in the observer's frame.

(7) An object of a nonzero length, being *integral* in the source frame (i.e., fulfilling the condition of simultaneity in this frame), is no longer integral as being *transformed* by the Lorentz boost to the target frame. This is because the events separated in space (differing by x -coordinates) that are simultaneous in the source frame, are no longer simultaneous in the target frame. To put it jokingly, an exemplary rod AB boosted from the source frame to the target frame becomes defined in the latter in such a way that point A finds itself "in yesterday" while point B finds itself "in tomorrow". Hence, the so-defined object cannot be identified with the rod *observed* (in any single moment) in the target frame.

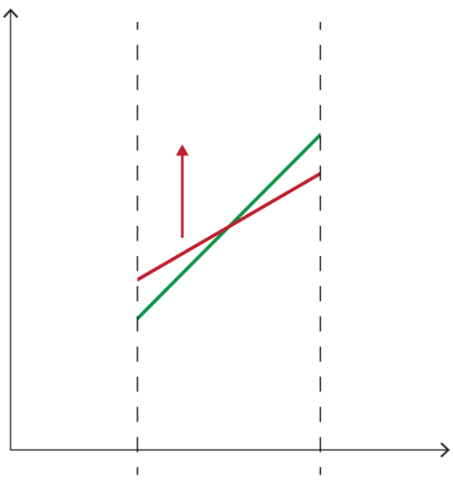

Figure 1. The rod diagonally positioned to the trajectory (green) changes its position (from green to red) due to the Lorentz contraction. The green line can be interpreted either as a position the rod would take if it stops in the observer's frame (in which it is actually moving) or as a position viewed in the rod rest frame (in which the observer is moving). These two interpretations are equivalent by virtue of the principle of relativity

Let us elaborate on the last point. Say, the rod at rest in the inertial frame K is transformed by the Lorentz boost to the inertial frame K'. Let this rod, regardless of being *transformed* to K', be also *observed* in K' by means of the measurements performed in this frame, based on the Poincaré-Einstein synchronization. As a result, we obtain in K' two different virtual objects: the first, non-integral – obtained from the Lorentz boost, and the second, *integral* – obtained from observation. This entails *discrepancy between transformation and observation*. Let us note that this discrepancy is, due to the relativity of simultaneity, specific to the Lorentz transformation only.

It follows that the Lorentz boost alone does not tell us directly how the transformed object "looks like" being contracted in the target frame. To figure it out, it is not enough to transform respective events, e.g., simultaneous locations of the rod's endpoints, from the source frame to the target frame. This is only half the job. In order to adjust the results of Lorentz boost to the results of observation, we must additionally infer the simultaneous positions of the rod's endpoints in the target frame (at a basically free moment) – from the non-simultaneous positions obtained from the sole Lorentz boost. We can achieve that by doing simple calculations regarding velocity and time. In that roundabout (compared to the direct measurements) way, we are able to extract from the Lorentz boost of particular events an integral object (rod), shortened according to the usual rules of Lorentz contraction.

The discrepancy between Lorentz transformation and observation is of crucial importance to the question of internal consistency of STR in the two (and hence three) spatial dimensions. Mainstream presentations usually tend to misconstrue this issue. When faced with this problem, a typical line of argument is the following: "In the case described by this thought experiment, the rod cannot be contracted in such a straightforward naive way! Defining the Lorentz contraction as the shortening along direction of motion in the observer's frame is a rough simplification of the otherwise complex nature of this effect, hidden in the Lorentz transformation. This simplified interpretation surely cannot be applied to all kinematical cases, in particular to the complex cases like this one. One cannot just "compress" the rod along the line of its motion; the only reliable way in dealing with Lorentz contraction is to strictly follow the Lorentz transformation of particular events constituting given object. Accordingly, the space-time coordinates of essential points, which in this case means the rod's endpoints, have to be transformed *one by one* from the source frame (especially from the rest frame of the rod) to the target frame, the latter identified with the observer's frame. Only such proceeding allows avoiding fallacies, and thus enables us to find the right way Lorentz contraction comes into effect in the observer's frame." Another claim, closely related to the previous one, reads: "The alleged contradiction is only due to incorrect understanding of special relativity; it is well-known that, besides the Lorentz contraction, one should also include the relativity of simultaneity!" As for the latter, it is just the opposite: one has to exclude (eliminate) the effects of relativity of simultaneity from the results of Lorentz boost, so as to make the object, being integral in the source frame, again integral in the target frame. Concluding, both above "guidelines", although seemingly sound reasonable, are nevertheless totally wrong.

3. Major Tom Observes the Rail and the Rod: A Thought Experiment Disproving STR in the Second Spatial Dimension

The whole previous consideration, in particular the conclusions listed in s-sec. 2.5, provide us with adequate tools for analyzing the thought experiment and to answer the title question "Why and How?" Let us remind the relevant data: the experiment consists of three "elements" specified as rail, rod and Major Tom, representing three inertial frames in the noncollinear coplanar configuration. Let us start with the brief analyses of the observations made in the rail and rod frames; then we'll move on to the crucial observations performed by Major Tom.

Both the rail and the rod are interpreted as the spatially one-dimensional objects. The proper length of the rod is interpreted as the unit length; accordingly, the rail is divided into the line segments of that unitary proper length. Instead, Major Tom is depicted as a point-like object. However, because all three objects represent three different inertial frames, the bold lines (for rail and rod) and the bold dot (for Major Tom) are complemented by thin lines – the x and y axes of the respective coordinate systems attached to these objects. Each coordinate system, apart from being a tool to measure spatial locations of the observed objects, is itself a "rigid" object being observed and thus subject to the Lorentz contraction in other frames. The figure 2a, figure 2b (below) and figure 2c (on the right) show the mentioned above three objects, each one as observed in its own inertial frame of reference.

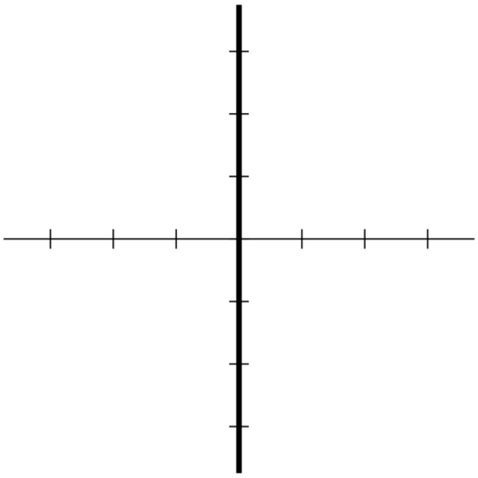

Figure 2a. The rail (bold vertical line) as observed in its own inertial frame of reference. The rail is identified with the y -axis of respective coordinate system. Each line segment (both vertical and horizontal) determines the unitary proper length, defined as "unit length"

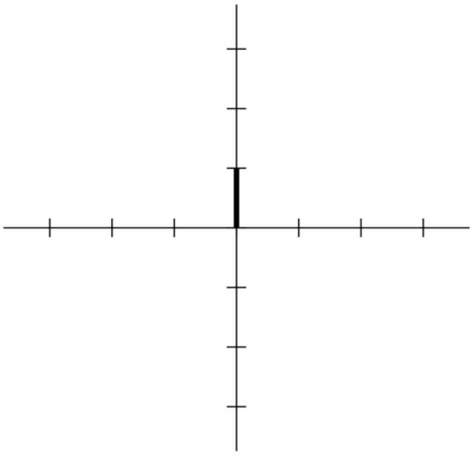

Figure 2b. The vertical rod (bold line segment) as observed in its own inertial frame of reference. The rod's proper length is equal to the unit length, as defined in the previous figure

According to the experiment's scenario, in each of three frames, the observed two objects move uniformly and rectilinearly at relativistic speeds in different directions, thus being subject to the Lorentz contraction. In the figure 3, figure 4 and figure 5, the observer's rest frames (each time marked in black) are successively: the rail frame, the rod frame and the Major Tom's frame. All three cases are spatially two-dimensional in kinematical terms, due to the total number of inertial frames and their noncollinearity.

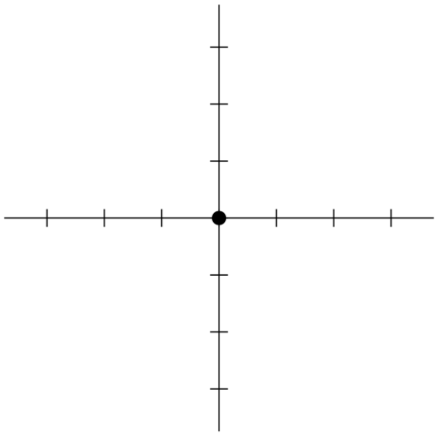

Figure 2c. Inertial observer Major Tom (MT) as observed in his own stationary inertial frame of reference. Major Tom can be identified – as a point observer – with the bold dot located at the origin of the MT coordinate system, or with the entire inertial frame represented by this coordinate system

An observation made in the rail rest frame (Figure 3) does not cause any controversy. This is because the trajectories of Major Tom and of the rod are perpendicular to each other. These trajectories intersect at one point in the MT coordinate system; however, the objects themselves (as limited in size) may, or may not, collide with each other, just as two cars approaching a crossroads from the mutually perpendicular directions. In either case, however, there is no *logical* collision.

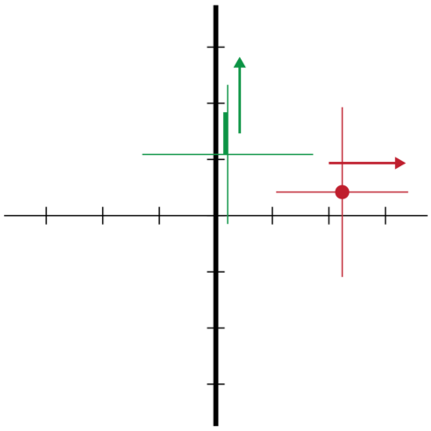

Figure 3. In the rail rest frame (black), the vertical rod (green) moves upward in the position parallel to the trajectory, being thus contracted along its length. Instead, Major Tom (red) travels horizontally to the right, so the MT coordinate system is contracted along x -axis, while its vertical-horizontal position remains unchanged

In turn, in the rod rest frame (Figure 4), the vertical rail is moving downwards, so it undergoes Lorentz contraction along the entire length. This contraction manifests itself by the equal compression of every single line segment (and of every set of neighboring segments), consequently becoming shorter than the unit length. The contraction of the rail in the rod frame is fully symmetrical to the contraction of the rod in the rail frame. Instead, Major Tom travels in the oblique bottom-right direction (red arrow), so the MT coordinate system becomes contracted along that direction. As a result, the x and y -axes of the MT coordinate system are no longer perpendicular to each other, as well as no longer parallel to the respective axes of the rod coordinate system.

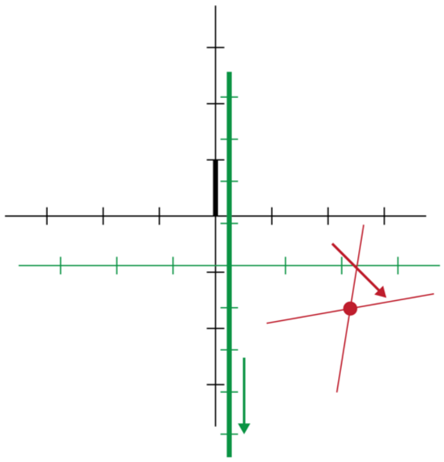

Figure 4. In the rod rest frame (black), the vertical rail (green bold line) moves downwards, being thus contracted along its length. Instead, Major Tom (red) moves in the bottom-right oblique direction, so the MT coordinate system is contracted along that direction

Finally, let us consider the observations performed by Major Tom (Figure 5). In the MT frame, the vertical rail moves horizontally to the left. Instead, the rod, diagonally positioned to the trajectory, moves to the top-left (red arrow). The horizontal component of the rod's velocity is equal to the velocity of the rail, which results in the constant proximity of these objects. Because the rail is spatially one-dimensional, so it does not undergo any visible Lorentz contraction. Instead, the rod being in the diagonal position to trajectory is contracted along this trajectory (as shown in Figure 1), in result of which it changes its position, i.e., deviates from the vertical. Consequently, the rod is not parallel (does not adhere) to the vertical rail. As it can be clearly seen by comparing figures 5 and 4, the deviation of the rod from vertical (identified with deviation of the whole y -axis, and complemented by a similar skew of x -axis) is exactly the same as the respective distortion of the MT coordinate system, observed in the rod reference frame.

The observation made by Major Tom is in conflict with the observations concerning spatial relation between rail and rod, made in the rail and the rod frames of reference (Figure 3 and Figure 4); in both cases, the rod and the rail adhere to each other. This means a contradiction, since the property of *constant adherence* must be indisputably an invariant of *any* transformation.

Let us notice that, from the formal point of view, an equal contradiction refers to the observation performed in the rod frame (Figure 4) – although in this case, it does not concern the relation between specific "objects" (such as rail and rod), but between x -axis of the rail coordinate system and x -axis of the MT coordinate system. The first (of these axes) is equivalent to the rail, and the second is equivalent to the rod – both as observed in the MT frame (Figure 5).

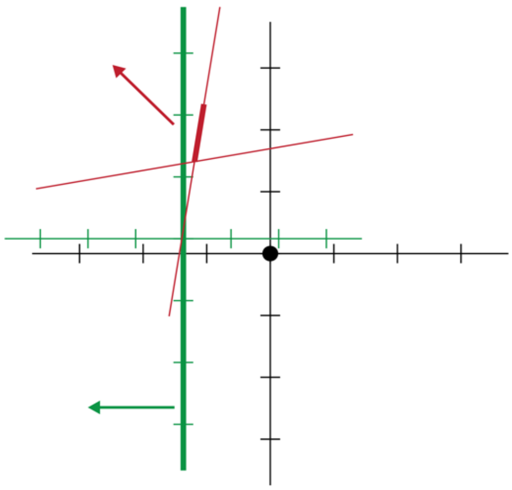

Figure 5. In the Major Tom's rest frame (black), the vertical rail (green bold line) moves horizontally to the left, thus remains unchanged due to its position and spatial one-dimensionality. Instead, the rod moving in the oblique top-left direction in the position diagonal to trajectory, becomes contracted along that direction (bold red line segment, red arrow). In result, it deviates from the vertical and thereby from the rail

It has to be clearly stated that contradiction revealed in this thought experiment does not relate to the nature itself (the nature, as it were by definition, cannot be self-contradictory), but to a specific description of nature, which in this case means STR.

We intentionally leave aside in this paper the effect known as Thomas-Wigner rotation, and its specific manifestation called Thomas precession [28,29]. This is because much attention has been devoted to this issue in the author's previous two papers on the same topic [30,31] – partly in reaction to some attempted criticism using this effect to argue against the presented proof. This is however a false lead. As interpreted according to STR, Thomas-Wigner rotation can be simply explained as a consequence of the relativity of simultaneity, in application to the *curvilinear motion* due to the (continuous or discrete) action of net lateral force [32]. Meanwhile, all motions in the thought experiment are constantly uniform, rectilinear, ergo inertial. No force and, consequently, no longitudinal or transverse acceleration is assumed and thereby considered. Therefore, we will stop at quoting an ultimate conclusion drawn from the analysis of this issue in the author's above-mentioned papers: Thomas-Wigner rotation does not apply to the thought experiment in question.

4. Preferred Frame Theory: Preliminary Remarks

4.1. PFT Postulates vs STR Postulates

The consequences of the evidence taken in the previous sections are of great importance to physics. The two postulates of STR (principle of relativity and the constancy of the velocity of light) have to be replaced by different postulates based on a different paradigm. At the same time, the theory based on these new postulates has to meet the challenge of the already existing experimental tests confirming STR. In other words, the new theory must be experimentally equivalent to STR in the range of all previous experiments, including the ones mentioned in introduction. However, in order to be recognized as a distinct theory, it should also make some specific predictions, other than derived from STR, being thus falsifiable in the Popper's sense. Eventually, the postulated theory has to be internally consistent in formal and logical terms. Although a thorough verification in that regard requires extensive research, we aim to prove in general and yet formally consistent way that the preferred frame theory (PFT) meets these stringent demands.

The theoretical differences between STR and PFT are indeed radical, since they affect the basic postulates. Let us quote once again the Einstein's paper from 1912 [6]: "This theory [i.e., STR)] is correct to the extent to which the two principles upon which it is based are correct. Since these seem to be correct to a great extent, the theory of relativity in its present form seems to represent an important advance; I do not think that it has hampered the further development of theoretical physics!" The above opinion is exactly what requires revision. Indeed, STR complies with the postulates upon which it is based. However, these postulates do not comply with the nature – if they are considered not as an approximation but, as they claim to be, the exact rules. STR indeed did not hamper the physics development in the past, but it does so "at present", that is since the quantum gravity became the holy grail of theoretical physics. The special principle of relativity stating:

All fundamental laws of physics express themselves in the same way in all inertial frames of reference

becomes replaced in PFT by its negation, namely:

Physical laws do not express themselves in the same way in every inertial frame of reference. In particular, length contraction, time dilation and the mass-energy increase manifest differently in different inertial frames, being basically referred to the preferred frame.

Also, the second postulate of STR stating:

The velocity of light in empty space has the same value c in all inertial frames of reference, independently of the state of motion of the source and independently of the direction of emission

becomes replaced in PFT by its partial negation, namely:

The one-way velocity of light in empty space depends both on the absolute velocity of inertial observer and on the direction of emission. Instead, the two-ways velocity of light (an averaged velocity along the free closed path) is always constant and equals c.

In STR, the relative simultaneity links up with the constant velocity of light and the symmetry (mutuality) of relativistic effects due to the relativity principle; instead, in PFT, the absolute simultaneity links up with the anisotropy of the one-way velocity of light and the asymmetry of relativistic effects (covering the mutually opposite effects), all of them originating from the absolute motion, i.e., the motion relative to the preferred frame.

4.2. The Properties of Inertial Observer According to PFT

In a nutshell, PFT can be specified as a theory in which the term "inertial" does not unambiguously define the observer or the frame. Various inertial observers may differ from each other in the physically important terms. In particular, the preferred inertial observer differs from any non-preferred inertial observer. Likewise, two non-preferred inertial observers may differ physically from one another due to their different "proximity" to the preferred frame.

Imagine you are a *preferred* inertial observer, which means you are at rest relative to the preferred frame. Compared with your stationary clocks and rulers, the (absolutely) moving clocks go slower and the rulers are shrunken along the line of their motion. These two effects depend in a specific way (quantitatively defined by the Lorentz factor) on their absolute velocities, always definable as a proper fraction of c – the limiting speed in the preferred frame. The constant velocity of light in the preferred frame makes this frame similar to every inertial frame as defined according to STR. The PFT predictions formulated in the preferred frame are identical to the STR predictions.

Imagine now, you occupy one of the objects previously observed from the preferred frame as uniformly moving, say a comfortable spaceship equipped with standard clocks and rulers (measuring sticks). Now, you are still an *inertial* observer, however not the *preferred inertial* observer. If you set your rulers in the direction parallel to that of your absolute motion, they will become contracted in maximal degree compared to the other possible positions; the same applies to all spatial objects including the whole spaceship and yourself. The basic property of the contracted ruler is that it indicates an "improper" length of the measured objects. Namely, whether they move or not, they all lengthen in the direction of absolute motion of your (i.e., observer's) frame. This apparent *elongation* combines with the "basic" length contraction of any measured object, caused by its own absolute velocity – although both effects do not necessarily take place along the same direction. Seemingly paradoxical, but in fact entirely obvious consequence is that the length contraction of the absolutely moving observer's inertial frame is not directly, i.e., by means of measurements of any object at rest to observer, detectable in this frame. This is because the contracted ruler "measuring itself" by definition cannot detect any contraction! The same refers to any slowed down clock "measuring" its own pace. In result, all inertial frames become similar to the preferred frame, which, as we shall see in Sec. 6, wrongly suggests that all inertial frames are fully equivalent (physically identical) to one another – as it is postulated by the special principle of relativity.

Both time dilation and length contraction primarily occur due to the absolute motion. However, the final result of measurement follows from the fact that these effects apply both to the observed object and the observer. Consequently, one has to distinguish between *direct* *measurements* (e.g., of the length of a body at rest) and *indirect measurements* (of the length of a body in motion). The indirect measurements depend on the assumptions specific to given theory (STR or PFT), in particular concerning the velocity of light (the second STR postulate or its partial negation in PFT). As we shall see in s-sec. 5.2 (and in more detail in Appendices B and C), this “ambiguity” results in the *observational equivalence* between STR and PFT in the range of kinematics.

The above rules suffice for the consistent description of the thought experiment discussed in previous sections, as formulated according to PFT. However, we’ll leave the detailed analysis for another occasion, for now referring the Reader to the previous author’s papers [30,31]. One thing however is worth mentioning here. The paradox behind, unsolvable by STR, can be effectively solved within PFT *in various ways*, depending on the assumed arrangement. Because we don’t deal here with a “real” experiment, so the preferred frame can be arbitrarily set. Basically, it can be identified with any inertial frame, in particular with one of three frames represented by Major Tom, rail, and rod. In combination with the same three frames alternatively chosen as the observer’s frames, this gives nine distinct scenarios, all of them free from contradiction – unavoidable in the case of STR. The absolute reference of both the observer and the observed object so to say “ensures” internal consistency.

5. Basics of the PFT Kinematics

5.1. Tangherlini Transformation vs Lorentz Transformation

Let us derive the Tangherlini transformation starting from the hypothesis of length contraction formulated by FitzGerald and Lorentz, and the related concept of time dilation primarily advanced by Larmor, with application to electrons orbiting the atomic nucleus. It has been conjectured that both these effects occur due to the absolute motion, i.e., motion with respect to the preferred frame identified with the motionless medium then called “luminiferous aether”. Let us also assume that Maxwell’s equations hold good in the preferred frame, which means in particular that velocity of light is isotropic in that frame. Based on these premises, let us derive the transformational equations applying to the simplest case of two inertial frames with one of them being preferred.

Let K be the preferred frame, and K' be the frame in absolute motion. If we measure the duration time of any physical process using the clocks at rest in K and in K', we’ll obtain the relations: $\Delta t' = \Delta t / \gamma$ and $\Delta t = \Delta t' \gamma$, where γ is the Lorentz factor. Owing to Lorentz, Voigt and Poincaré (and to Einstein, of course) we already know the right shape of that factor, namely $\gamma = \left(1 - v^2 / c^2\right)^{-1/2}$.

Hence, assuming that respective time is measured starting from $t_0 = t_0' = 0$, we obtain the time transformation formulae: $t' = t / \gamma$ and $t = t' \gamma$.

Assuming that both frames are in the standard configuration, we also obtain for $t_0 = t_0' = 0$ the “static” spatial relations: $x' = x\gamma$ and $x = x' / \gamma$. In order to complete the transformation for space (as a function of time), we have to include the velocity combined with time, thus introduce an element analogous to the component vt in the Galilean transformation (GT). Considering that v is the velocity of the frame K' measured in K, and having regard to $t = t'\gamma$, we obtain the equation for the spatial coordinates in the preferred frame: $x = x'/\gamma + vt'\gamma$.

If the speed of K' measured in K equals v , while v corresponds to a distance $l = \Delta x$ covered during time t , that is $v = l / t$, then the speed of K measured in K' will be $l\gamma / \left(t/\gamma\right)$. Consequently, the reciprocal velocities between K and K' are not equal, but relate to each other as:

$$v' = v\gamma^2 \tag{7}$$

Finally, because $t' = t/\gamma$, so we get $x' = x\gamma - v\gamma^2 t / \gamma$, which reduces to $x' = x\gamma - vt\gamma$. We thus arrived at the Tangherlini transformation [20], the only transformation consistent with ontological assumptions shared by FitzGerald, Lorentz, Larmor and (to some extent) by Poincaré. The complete Tangherlini transformation (TT) reads:

$$\begin{aligned} x' &= x\gamma - vt\gamma \\ y' &= y \\ z' &= z \\ t' &= t/\gamma \\ x &= x'/\gamma + vt'\gamma \\ y &= y' \\ z &= z' \\ t &= t'\gamma \end{aligned} \tag{8}$$

Let us compare it with the Lorentz transformation (LT):

$$\begin{aligned} x' &= x\gamma - vt\gamma \\ y' &= y \\ z' &= z \\ t' &= t\gamma - \left(vx/c^2\right)\gamma \\ x &= x'\gamma + vt'\gamma \\ y &= y' \\ z &= z' \\ t &= t'\gamma + \left(vx'/c^2\right)\gamma \end{aligned} \tag{9}$$

In both transformations, γ denotes the Lorentz factor $\gamma = \left(1 - v^2/c^2\right)^{-1/2}$. However, unlike in LT, in TT this factor has an absolute reference, i.e., relates to the preferred frame, which means that v is the absolute velocity. Tangherlini transformation is non-symmetrical in the sense of negation of the Lorentz symmetry. LT and TT can be considered as two different amplifications of the Galilean transformation, since they both reduce to GT for $v \to 0$. However, the relation of each of these two transformations to GT is basically different: the Lorentz transformation extends the principle of relativity to all velocities up to $v < c$: $v \to c$, thus transmutes the Galileo's principle of relativity (Galilean invariance) into the special principle of relativity (Lorentz invariance). Instead, Tangherlini transformation defines the Galileo's principle of relativity as an approximate law for $v \ll c$, whereas, in a strict sense, the relativity principle, in whatever form, proves to be invalid as a universal law applicable to the whole range of velocities.

Any two inertial frames connected by the Tangherlini transformation are considered to be physically *inequivalent*; one of them is the preferred frame, thus determines absolute rest, and the other (by convention the primed one) is absolutely moving. The general shape of TT (then called "inertial transformations") has been derived by the present author [33]. Accordingly, a specific relation between any two inertial frames results from their absolute relations, as taken separately due to respective absolute velocities, and from the angle between respective velocity vectors measured in the preferred frame. In the particular cases, when two frames move with equal absolute velocities in different directions (opposite or any others), they are physically identical, despite moving against each other. Owing to this property, TT could be described as representing the axial symmetry, with the preferred frame acting as the "axis of symmetry" In that context, it is important to realize that Lorentz symmetry is a specific exemplification of the general concept of symmetry, and not just a universal pattern of symmetry. In both LT and TT, the velocity of light c is treated as the physical constant of a fixed value. However, the resulting from LT and TT predictions as to the *real* velocity of light in various inertial frames are different, and therefore may serve as a defining property of each transformation. Namely:

Lorentz transformation (LT) connects together any pair of inertial frames in such a way that the one-way velocity of light is always constant (isotropic) in both frames.

Tangherlini transformation (TT) connects the preferred frame with any other inertial frame in such a way that the two-way velocity of light is always constant (isotropic) in both frames, whereas the one-way velocity of light is constant (isotropic) in the preferred frame only.

In the case of Lorentz transformation, the assumed constant one-way velocity of light links up with the Lorentz contraction and time dilation, in connection with the *relativity of simultaneity* – making these effects symmetrical. Instead, the constancy of the two-way velocity of light predicted by the Tangherlini transformation (with the one-way constancy restricted solely for the preferred frame) links up with the corresponding effects of length contraction/elongation and time slowing/speeding, in connection with the *absolute simultaneity*. The latter is formally expressed in TT in such a way that, unlike in LT, the time coordinates do not depend on the space coordinates.

5.2. Kinematical Equivalence Between PFT and STR in the Spatially One-dimensional Cases

In this subsection, we will consider the property announced in s-sec. 4.2, described as the "observational equivalence between STR and PFT in the range of kinematics". In short, the point is as follows. PFT predicts, besides length contraction and time dilation, also the opposite effects, here called: *length elongation* and *time speeding*; nevertheless, the direct results (readings of the measuring instruments) are identical to these predicted by STR. This is because, both in PFT and STR, the conclusions as to the "real" nature of these effects do not follow from the readings alone, but from these readings combined with specific (to STR or PFT) synchronization conventions, each one based on a different assumption as to the velocity of light (considered in next subsection).

Let us analyze in that regard the kinematically one-dimensional case (assuming the motion along xx' direction), described alternatively by the Lorentz and Tangherlini transformations. Both these transformations determine elementary relationships between basic kinematical quantities: distance/length, time and velocity. If the respective coordinate systems remain in the standard configuration, then the space and time coordinates are identifiable with the covered distance and elapsed time, starting from the position four-vector $\{t_1, x_1, y_1, z_1\} = 0$, implying $\Delta x = x$, $\Delta t = t$ – so that all quantities become expressed in a simple way: $x = tv$, $t = x/v$ and $v = x/t$. The same pertains to the primed coordinates.

As an inertial observer you cannot directly measure all three quantities: length, time and velocity. Assume, you intend to measure the velocity of a point-like body (particle) moving in your stationary reference frame along x -axis, using equation $v = x/t$, where x denotes the covered distance. This task, trivial in the range of small velocities ($v \ll c$) to which the Galilean transformation effectively applies, is not as obvious for $v \sim c$. The point is that you can't reliably measure the velocity using two distant stationary clocks. To be suited for that goal, they should be synchronized, thus able to determine simultaneity in your frame. Basically, synchronization consists in sending the light signal from one clock to another. However, the Reichenbach's conventionality of measurement [19] comes into play; in order to make the light synchronization credible, you must know the velocity of light. In turn, to *measure* this velocity (hence, not just to *postulate* it!), your clocks have to be synchronized. And so on; the vicious circle ends up.

Assume next, you want to measure the velocity of a meter-stick (rod) moving parallel to x -axis, using a single stationary clock. Now another difficulty arises. To make the measurement credible, you should know the length of the moving rod as measured in your frame. Knowing it, you might compare the indications of your single stationary clock in the moments of passing it by the rod's front and rear ends, then divide the rod's length by the elapsed time. But, to find the length of the rod, you need (at least) two synced clocks indicating equal times while being passed by the front and rear ends of this rod, respectively. However, in order to synchronize the clocks… etc.; the vicious circle ends up again. It follows that you cannot unambiguously infer from the direct measurements whether and how the length of the rod is affected due to its motion relative to your frame.

Also, the other than "standard synchronization" (i.e., using light signals) methods: (1) the slow transport of one standard clock and (2) the symmetrical transport of two standard clocks at equal speeds in opposite directions, face the same difficulties. Namely, the first method requires itself synchronization to determine the exact velocity of the transported clock; by the same token, the second method requires prior synchronization to settle if the opposite velocities of two clocks are indeed equal. A brief preliminary discussion of this issue can be found in [34]. As shown below and developed in Appendix B, different numerical results of synchronization according to STR and PFT do not however translate into different predictions concerning *directly* observed results obtained in the kinematical experiments. Likewise, as shown in Appendix C, there is no *effective* difference between velocity-addition formulae according to STR and PFT – although their shapes are different. This is just what we mean by "kinematical equivalence".

Hence, what we actually know "for sure"? Two things in fact. The first are the indications of a single stationary clock. The second is the length of an object at rest measured using the stationary rod (meter-stick). Let us call these two quantities "direct", due to the direct mode of acquiring them – *independent* from any related-to-theory assumptions. The other quantities: velocity of the moving objects, pace of the moving clocks and length of the moving extended bodies, are *theory-dependent*, thus we call them here the "indirect" quantities. Although we cannot directly measure the "indirect" quantity, we may postulate its value (based on *direct* measurements) according to the predictions of given theory, i.e., STR or PFT. Until it is done, the "indirect" quantity remains "unspecific"; instead, once this is settled, the "indirect" quantity becomes "specific". Understandably, every "direct" quantity is by definition "specific". According to this naming convention, we obtain three classes of quantities, denoted as:

direct quantities: x , t (assuming standard configuration)

indirect unspecific quantities: V , L , T

indirect specific quantities, alternatively: V_{STR} , L_{STR} , T_{STR} – postulated by STR, and V_{PFT} , L_{PFT} , T_{PFT} – postulated by PFT.

Using this classification, we are able to express the general scheme of kinematical equivalence between STR and PFT. Let us consider the two modes of measuring the velocity mentioned in the beginning of this subsection, defined as: (a) measuring the velocity of a single point object using two distant stationary clocks; (b) measuring the velocity of the moving rod (two distant fixed points) using one stationary clock. When written in general terms, the relations between distance/length, time and velocity have the form: *direct quantities + indirect unspecific quantities*, so that the (a) and (b) modes are expressed respectively:

$$V = x/T \tag{10a}$$

$$V = L/t \tag{10b}$$

Once the predictions of respective theories are applied, these two equations turn into the *direct + indirect specific* form. In the first case (10a), we have alternatively:

$$V_{STR} = x/T_{STR} \qquad V_{PFT} = x/T_{PFT} \tag{11}$$

The equivalence consists in the fact that one has always:

$$x = V_{STR} \cdot T_{STR} = V_{PFT} \cdot T_{PFT} \tag{12}$$

This is because, in the case of STR, we have:

$$L' = v'T' = vT\gamma \tag{13}$$

whereas PFT gives:

$$L' = v'T' = v\gamma^2\, T/\gamma = vT\gamma \tag{14}$$

Likewise, in the second case (10b), we have alternatively:

$$V_{STR} = L_{STR}/t \qquad V_{PFT} = L_{PFT}/t \tag{15}$$

One has always:

$$t = L_{STR}/V_{STR} = L_{PFT}/V_{PFT} \tag{16}$$

This is because, in the case of STR, we have:

$$T' = L'/v' = L/v\gamma \tag{17}$$

whereas PFT gives:

$$T' = L'/v' = L\gamma/v\gamma^2 = L/v\gamma \tag{18}$$

The above general relationships between STR and PFT determine the more specific applications, namely the experimental (empirical) equivalence between the STR and PFT synchronization conventions and the equivalence of respective velocity-addition formulae. These are bit more complicated issues, although they are governed by the same general rules. They are developed in Appendices B and C.

5.3. Velocity of Light

Each of the two above discussed attempts to measure the velocity in the observer's frame faced the problem of synchronization connected with the "indirect" (theory-dependent) measurability of the velocity of light. Once this velocity is settled according to given theory, all other velocities also become unambiguously defined. In STR, the constant isotropic velocity of light is set by the postulate. Consequently, in any frame, the wave-front connected with the photons emitted radially from the point-source is thought to form the sphere increasing in time (4D light cone in the Minkowski space). Instead, according to PFT, the wave-front of the radially emitted light has the exact shape of a sphere in the preferred frame only. In all other (absolutely moving) inertial frames, regardless of the state of motion of the emitter, the wave-front forms the prolate spheroid (ellipse in 2D depiction), with the source of emission located in the "frontal" focus (Figure 6).

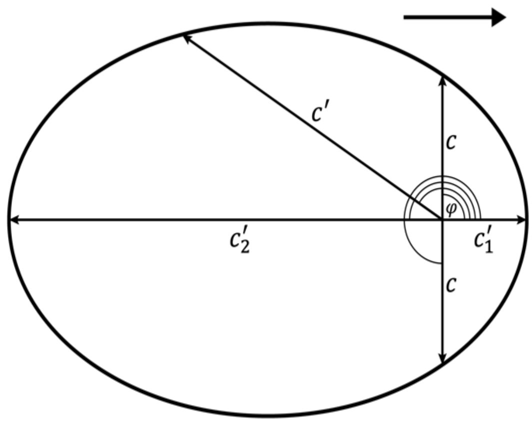

Figure 6. Velocity of light in the absolutely moving observer's inertial frame. The light front forms the prolate spheroid (ellipse in 2D representation), with the source of emission located in the "frontal" focus, compatible with the direction and sense of the absolute velocity vector

One of the properties of ellipse is that *harmonic mean* of the lengths of the oppositely directed radii is identical for all such pairs of radii. Let us identify the radii with the photon velocity vectors, whereas identical opposite radii (vertical arrows in Figure 6) would refer to the unitary velocity vector of the magnitude c. Consequently, regardless of the absolute velocity and the direction of emission, the averaged two-way velocity of light always equals c. The general PFT formula for the velocity of light is

$$c' = \frac{c - v\cos\varphi}{1 - \left(\frac{v}{c}\right)^2 \cos^2\varphi} \quad (19)$$

(φ – angle of propagation related to the direction of absolute motion, measured in observer's reference frame). For the angles of propagation $\varphi = 0$ and $\varphi = 180^\circ$, i.e., for the light rays parallel to x-axis, one has respectively:

$$\begin{aligned} c_1' &= (c - v)\gamma^2 \\ c_2' &= (c + v)\gamma^2 \end{aligned} \quad (20)$$

The further consequence of the above equations is that, for the observer's absolute velocity $v \to c$ (corresponding with extreme flattening of the ellipse depicted in Figure 6), the speed of light emitted in parallel to vector v does not tend to zero (as Einstein conjectured in the inspiring youthful thought experiment in which he considered the observer chasing the light beam), but to $0.5c$. This clearly follows from the upper Eq. (20) – resulting from the Tangherlini transformation, and not from $c - v$ specific to the Galilean transformation, assumed by Einstein in that experiment. Instead, the velocity of photon moving in the opposite direction (lower Eq. 20) tends to infinity. Therefore, like for all other values of the opposite angles φ and $\varphi + 180^\circ$, the harmonic mean (denoted H) of the two-way velocity of light equals c:

$$v \to c \Rightarrow \left(c_1' \to 0.5c; c_2' \to \infty\right) \Rightarrow H = c \quad (21)$$

6. Towards the PFT Dynamics

6.1. Corresponding Velocities Instead of a One Relative Velocity

The kinematical equivalence between STR and PFT, although important and symptomatic, is however also deceptive. It namely strongly suggests that a theory based on the idea of preferred frame must be, as a whole, equivalent to STR. It would indeed be so if the theory in question were based on the Lorentz transformation; but, as we know, PFT (in the present formulation) is based on the Tangherlini transformation. As it will be demonstrated in the next subsections, the PFT experimental predictions concerning dynamics prove to be *partly different* from the STR predictions. This fact, apart from the otherwise crucial conclusions resulting from the thought experiment considered in Sec. 3, makes STR and PFT fundamentally different, also in experimental terms.

In STR, the symmetry of relativistic effects corresponds, apart from the relativity of simultaneity, with the identity of "relative velocity" measured by each of the two inertial observers. Same as in Newtonian physics, this identity has a status of self-explanatory axiom:

The velocity of B relative to A is identical to the velocity of A relative to B.

By contrast, in PFT, the effects of length contraction and time dilation, to which the name "relativistic" can be attached by the pure convention only, are basically unsymmetrical. In particular, in the case of two inertial frames with one of them being the preferred frame, the *length contraction* and *time dilation* observed by the preferred inertial observer, correspond with *length elongation* and *time speeding* of the objects at rest in the preferred frame, observed by the absolutely moving inertial observer. This asymmetry is not directly measurable in the kinematical experiments (as was shown in s-sec. 5.2); however, it manifests itself indirectly in dynamics, specifically in the predictions concerning mass/energy. It is associated with the *asymmetry* (inequality) of mutual velocities. Namely, the concept of *relative velocity* relevant for both relativistic and Newtonian mechanics, becomes replaced in PFT by the usually different *corresponding velocities*, namely:

Except the cases when both frames have identical absolute velocity, the velocity of B relative to A differs from the velocity of A relative to B.

An obvious reason for this asymmetry is the following. All standards of length and time used to measure mutual velocities are differently affected by the absolute motion in each of the frames constituting given pair. In particular, in the case with one frame *preferred* and the other one moving at absolute velocity v, the corresponding speeds relate to each other according to Eq. (7), i.e., $v' = v\gamma^2$. This relationship largely determines both kinematical and dynamical relations between STR and PFT.

6.2. Identical Predictions of STR and PFT Concerning Momentum

Consider the uniformly and rectilinearly moving massive particle observed in an inertial frame of reference. The only thing required to describe its motion in kinematical terms is the velocity. However, by including dynamics, e.g., while considering possible collision with another particle, we also need to know the effective masses. Despite the difference connected with the fact that velocity is a vector and mass is a scalar, these two quantities combine together into the third one: the momentum vector. The magnitude of momentum vector is a product of two scalars: the length (magnitude) of the velocity vector and the mass. Instead, direction and sense of the momentum vector replicate direction and sense of the respective velocity vector.

The complex nature of momentum is the reason for which kinematical equivalence between STR and PFT steps into the area of dynamics. Despite different predictions of STR and PFT as to the mass and velocity taken in isolation, their product (momentum) is always the same. For instance, if a body at rest in the preferred frame is observed in the absolutely moving frame, then, according to PFT, its mass *decreases* compared with the rest mass, hence all the more as compared with the increased mass predicted by STR. However, this loss is compensated „with interest" by the gain in velocity, due to the difference between the *corresponding* velocities predicted by PFT (Eq. 7) and the (equal for both frames) *relative* velocity predicted by STR. Besides this specific arrangement (i.e., with one frame preferred), also all other ones, namely with the rest frames for the observer and for the observed object freely related to the preferred frame, give identical momenta – as alternatively predicted by PFT and STR. This is because, each time, the combinations of differently defined effective masses (due to the different Lorentz factors), and the differently defined velocities of these masses, always give the same result (product), that is identical momentum. This can be written in a form of general rule:

$$P = M_{STR}V_{STR} = M_{PFT}V_{PFT} \tag{22}$$

The specific derivations (also regarding momentum of photon) are performed in Appendices D and E.

6.3. PFT vs STR: Different Predictions Concerning Energy

Just as it is with STR, energy in PFT is equivalent to mass, according to the famous mass-energy formula derived by Einstein in his second 1905 paper on STR [2]. However, because in PFT the increase of mass/energy is basically due to the absolute velocity, so, unlike in STR, the total energy of a moving body may both *increase* or *decrease*, compared with energy of this body at rest in the observer's frame. Let us write the Einstein's mass-energy formula in the form distinguishing between *rest mass* and *relativistic mass*:

$$E = \gamma m_0 c^2 \tag{23}$$

In the above notation, the "relativistic mass" $m_0\gamma$ (in the equation below replaced by symbol m, meaning "mass") is unambiguously defined by the quotient of total energy and the squared speed of light:

$$m = E/c^2 \tag{24}$$

This definition is important because the mass of a moving body considered as a quotient of force and acceleration (i.e., inertial mass, ergo mass resisting the applied force) is not identical with the mass interpreted as the carrier of energy, obtained as a quotient of momentum and velocity. In the first case, the value of mass depends on the direction of acting force, ranging from $m_0\gamma$ (*transverse mass*) to $m_0\gamma^3$ (*longitudinal mass*). According to STR, only the transverse mass $m = m_0\gamma$ is strictly equivalent to energy. The velocity-dependent increase of energy is interpreted in STR in the purely kinematical terms, as a consequence of time dilation, thought to originate "not in the object but in the geometric properties of space-time itself" [32]. Basically, this is not at odds with the PFT perspective, although in PFT we have both *increase* and *decrease* of energy, due to the kinematical effects of time slowing and time speeding, respectively.

Although energy is a scalar, we can speak in a certain definite sense about *isotropy* or *anisotropy* connected with energy. To explain this claim, let us return to momentum. Consider the set of identical elementary massive particles moving inertially in 3D space, radially outwards with respect to the *absolutely moving* inertial point-observer. Imagine that all velocity vectors are caught at a common point identified with that observer. Let all these particles have equal momenta in the observer's frame. According to STR, this simply implies equal velocities (because the proper (rest) masses are identical), hence equal length of all virtual velocity vectors, forming thus together a spherical bundle. Instead, according to PFT, equal momenta of identical particles neither imply equal masses nor equal velocities. The latter are anisotropic due to the inequality of *corresponding* velocities, as a result of which, the respective velocity-vectors bundle forms a *prolate spheroid*.

Having regard to directions, equal momenta link basically (except crosswise directions) with different masses, each time multiplied by respective velocity. In turn, according to the mass-energy equivalence, different masses mean different energies, which finally results in the *asymmetry of energy distribution*. Eventually, this determines the *disparity between energy and momentum* in the frames being in absolute motion. In analogy to the isotropy of the two-way velocity of light in PFT, the arithmetical average of energies connected with the oppositely directed velocities is also isotropic, being quantitively equal to the total energy of the moving body – as predicted by STR. However, unlike in the case of the one-way velocity of light, the "one-way" energy is basically measurable, making possible direct experimental tests of PFT. The PFT equation of energy for the general case reads:

$$E = \gamma\delta^{-1}m_0c^2 \tag{25}$$

where: $\gamma = \left(1 - {v_1^2}/{c^2}\right)^{-1/2}$ and $\delta = \left(1 - {v_2^2}/{c^2}\right)^{-1/2}$, v_1 – absolute velocity of the observed object, and v_2 – absolute velocity of observer. In this equation, in a sense most important for PFT, the Lorentz absolute factors γ and δ have the following designates: the lowercase gamma refers (like in STR) to the inertial frame of observed object; instead, the lowercase delta refers to the inertial frame of observer. Therefore, only their quotient (dimensionless – since γ and δ are both dimensionless) makes an appropriate "relative" Lorentz factor determining energy of a body in the observer's frame. It is clear that for the objects at rest in any inertial frame of reference, one has always $v_1 = v_2$ and consequently $\gamma\delta^{-1} = 1$, implying $E = m_0c^2$, in agreement with the STR prediction of the rest energy.

Although the PFT predictions concerning the energy measured in experiments performed on Earth very slightly differ from the respective STR predictions (the next subsection explains why that is so), they fundamentally differ as to respective predictions in the general case. Namely, in STR, energy strongly depends on the choice of reference frame; in other words, same as length and time, it is a *relative* quantity. Basically, one can determine a hypothetical frame in which energy of a single particle in motion would be comparable to the energy of a planet at rest; it is only a question of the parameter fit. Instead, according to PFT, the *relation* of total energies between any pair of massive bodies moving relative to each other (which means that each body travels with a definite absolute velocity) is identical in all inertial frames. In other words, the *hierarchy of energies* is invariant under Tangherlini transformation – although particular energies taken separately depend (quantitatively to the same degree) on the Lorentz factor for the observer δ. This property seems to be a significant advantage of PFT over STR in the context of a sought theory of quantum gravity. Let us briefly explain why. Say that, for the theoretically sound reasons, at the extremely great speeds (greater than these currently obtainable in the particle accelerators), the quantum effects connected with total energy of given particle are expected to appear. However, the quantum effects – whatever they might be – should be absolute, which means that they simply either appear or do not appear (exactly as the Schrödinger's cat must be dead or alive after opening the box), regardless of the choice of reference frame. Meanwhile, according to STR, the velocity is relative, hence energy – no matter how great in given particular frame – is also relative, which implies that quantum effects are relative too. This unacceptable conclusion explains why the Lorentz symmetry creates the fundamental obstacle in searching for an effective theory of quantum gravity.

6.4. Possibility of Experimental Test of Energy According to PFT (Popper's Falsifiability)

As far as the predictions of STR and PFT concerning energy are identical in the preferred frame, they differ from each other in all other inertial frames to a various extent depending on the absolute velocity of given frame. Assuming that the physically preferred frame coincides with the strictly isotropic CMB radiation, we deal (on Earth) with the close similarity of the respective PFT and STR predictions, but *not* with their *entire identity*. Let us look at specifics. Apart from the intrinsic inequalities in the CMB radiation resulting from the quantum fluctuations preceding the cosmic inflation, we observe on Earth the global Doppler effect of the CMB anisotropy connected with the peculiar motion of Earth through cosmic space. The respective "dipole pattern" obtained from the WMAP data gives the Earth peculiar velocity 368 ± 2 km/s, i.e., $1.23\times10^{-3}c$, or 627 ± 22 km/s, i.e., $2.0\times10^{-3}c$ – the second result estimated as the resultant velocity of Local Group with respect to isotropic CMB. This discrepancy (not really essential in the context of our present analysis) results from the precise calculations based however on inexact data connected with the uncertainties of some basic estimates. Anyway, the peculiar velocity of Earth corresponds to a very small Lorentz factor $\gamma \approx 1 + 10^{-7}$. Meanwhile, the typical values of the energy increase gained in the largest particle accelerators usually exceed the values: $\gamma \approx 10^3$ for protons and $\gamma \approx 10^5$ for electrons. The resulting corrections to energy are therefore of the order of 10^{-4} – 10^{-2} parts of the particles' rest energy; hence, are far beyond the current possibilities of detection. This "practical" indistinguishability between energy predictions according to STR and PFT explains why STR has not been questioned so far (as a side effect) in the real accelerator experiments dedicated to other goals. However, detecting this difference could be likely achievable in the specially dedicated experiments.

7. Conclusions

Two points of this paper are of paramount importance. First, we have proved by means of a thought experiment that STR fails in formal terms as a theory applied to the spacetime with at least two spatial dimensions. Let us quote (in a slightly shortened form) the statement from Section 3: *The revealed contradiction does not relate to the nature itself, but to a specific description of nature, namely STR*. With no doubt, if the rod constantly adheres to the rail in both rail and rod frames, it does the same as observed in any other frame. That's how the real-world works; to expect otherwise would be absurd. Consequently, the presented thought experiment does not provide us with a basis for the real experiment aimed at testing STR; instead, it shows, using logic, that STR lacks internal consistency. In the sense, this thought experiment is a real paradox – where "real" means that it reveals true contradiction within STR.

Second, we have put forward and discussed a theory proposed to replace special relativity. The respective preferred frame theory turns out to be: (1) experimentally equivalent to STR in the range of kinematics – despite different predictions regarding particular kinematic quantities taken separately, including the velocity of light; (2) identical to STR, both numerically and experimentally, as to the predictions of momentum; (3) different from STR regarding predictions of energy. The last property can be used to test PFT in the real experiments, which makes PFT falsifiable in the Popper's sense.

The evidence taken in this paper seems to settle the further fate of STR, at least in the purely scientific terms. Eventually, this theory, due to specific (Lorentz) symmetry, turns out to be a kind of kaleidoscopic illusion of physical reality. It is perfectly consistent as applied to the spatially one-dimensional model, but fails as applied to the real physical world with the second and third spatial dimensions included. The scientific intuition shared by Lorentz and other eminent scholars in the times directly preceding the appearance of STR (and partly at a later time) was the right one; however, the fact that the same scholars were involved in formulating the Lorentz transformation (rederived by Einstein from the two postulates) determined the future development of physics for nearly 120 years. The current attitude towards STR, despite conventional signs of respect, seems however to evolve or even erode, mostly due to the pressure caused by ineffectiveness of the quantum gravity research, which manifests itself by intensive attempts to detect the Lorentz violations.

The findings reported in this paper reveal the basic inadequacy of STR, not only in application to the Planck scale (as the current searches for the Lorentz violation presume), but in the entire range of physical phenomena. Once this result is confirmed, it would make necessary to draw the right conclusions. While the general proposal is to replace STR with PFT, one should specifically: (1) develop PFT to the form including electrodynamics and other forces; (2) review other modern theories, paying special attention to their relations with STR; in particular: (2a) revise the general relativity so as to make it reducible to PFT in the limit of negligeable gravity – as is the case with STR, (2b) revisit the quantum gravity theories in the context of invalidation of Lorentz symmetry; (3) elaborate and carry out an experiment testing the specific PFT predictions concerning energy. Besides, considering that Minkowski space is inherently connected with STR, it would be interesting to find respective space for PFT. This short list certainly does not exhaust the complete range of a great work to be done.

Appendices

Appendix A. Lorentz Contraction of a Rod in the Diagonal Position to Trajectory

Let $L_{\|(bef)}$ be the parallel to trajectory component of the rod's length (dimension measured in the direction of motion) before contraction, $L_{\|(aft)}$ – the respective component after contraction, and $L_{\perp}$ – perpendicular component of the rod's length (obviously the same before and after contraction). Then the Lorentz factor determining the Lorentz contraction becomes defined as:

$$\gamma = \frac{L_{\|(bef)}}{L_{\|(aft)}} \tag{A.1}$$

So:

$$L_{\|(aft)} = \frac{L_{\|(bef)}}{\gamma} \tag{A.2}$$

where $\gamma = \left(1 - V^2/c^2\right)^{-1/2}$; V – velocity of the rod in the observer's frame. Let the angle of deviation before contraction be denoted α_{bef}, and respective angle after contraction – α_{aft}. From the above relations it follows:

$$\tan\alpha_{bef} = \frac{L_{\perp}}{L_{\|(bef)}} \tag{A.3}$$

and

$$\tan\alpha_{aft} = \frac{L_{\perp}}{L_{\|(aft)}} = \frac{L_{\perp}\gamma}{L_{\|(bef)}} \tag{A.4}$$

Let α_{dif} be the angle by which the deviation increases due to the Lorentz contraction: $\alpha_{dif} = \alpha_{aft} - \alpha_{bef}$. This angle is trigonometrically defined as:

$$\tan\left(\alpha_{dif}\right) = \frac{\tan\alpha_{aft} - \tan\alpha_{bef}}{1 + \tan\alpha_{bef}\,\tan\alpha_{aft}} \tag{A.5}$$

where $\tan\alpha_{bef}$ and $\tan\alpha_{aft}$ are defined according to Eqns. (A.3) and (A.4).

Appendix B. Equivalence of the STR and PFT light Synchronizations

Assume a particle at rest in the preferred frame $\mathcal{K}$ traveling in the frame $\mathcal{K}'$ along the stationary measuring rod L' ended with two clocks: C_1 and C_2. Let v be the velocity of $\mathcal{K}'$ relative to $\mathcal{K}$. We synchronize both clocks by sending the light signal from C_1 to C_2, having regard to the velocity of light defined alternatively by STR and PFT. Likewise, let the velocity of the particle traveling on distance L' from C_2 to C_1 be alternatively defined. An ultimate criterion of the experimental equivalence of both synchronizations, is the indication of clock C_1 in the moment of passing it by the particle. Let's get into details:

Synchronization according to STR: While sending the light pulse from the clock C_1 showing $t_1^{'}$ to the clock C_2 located at distance L', we set C_2 in the moment of reaching it by the ray for the time:

$$t_2^{'} = t_1^{'} + L'c^{-1} \tag{B.1}$$

The velocity of a particle moving along the distance L' from C_2 to C_1 is v; hence, the (denoted by $t_3^{'}$) indication of clock C_1 in the moment of passing it by the particle is

$$t_3^{'} = t_1^{'} + \frac{L'}{c} + \frac{L'}{v} = t_1^{'} + \frac{L'(v+c)}{vc} \tag{B.2}$$

Synchronization according to PFT: In order to synchronize the clocks C_1 and C_2 in the direction from C_1 to C_2 one has to set the clock C_2 in the moment of reaching it by the light beam for:

$$t_2^{'} = t_1^{'} + \frac{L'}{(c-v)\gamma^2} \tag{B.3}$$

Because, according to PFT (TT), the velocity of a particle traveling along L', from C_2 to C_1 is $v\gamma^2$, so the clock C_1 will indicate in the moment of passing it by the particle the time:

$$\begin{aligned} t_3^{'} &= t_1^{'} + L'/(c-v)\gamma^2 + L'/v\gamma^2 \\ &= t_1^{'} + \frac{L'\left(1 - v^2/c^2\right)}{(c-v)} + \frac{L'\left(1 - v^2/c^2\right)}{v} \\ &= t_1^{'} + \frac{L'\left(c - v^2/c\right)}{vc - v^2} = t_1^{'} + \frac{L'(v+c)}{vc} \end{aligned} \tag{B.4}$$

The empirical equivalence between synchronizations according to STR and PFT (despite different predictions as to the velocity of light) is confirmed by identity of the results of Eqns. (B.2) and (B.4).

Appendix C. Equivalence of the STR and PFT Velocity-addition Formulae

Consider three collinear inertial frames: $\mathcal{K}$, $\mathcal{K}'$ and $\mathcal{K}''$. The frame $\mathcal{K}'$ moves with respect to $\mathcal{K}$ with the velocity v in x positive direction. The particle at rest in $\mathcal{K}''$ moves with respect to $\mathcal{K}'$ with the velocity V in x' positive direction. The resultant velocity σ of the particle velocity in $\mathcal{K}$, derived from LT, is

$$\sigma = v + V\left(1 + vV/c^2\right)^{-1} \tag{C.1}$$

which is the well-known STR velocity-addition formula. Let us find an analogous formula for PFT, assuming that $\mathcal{K}$ is the preferred frame. Since we consider the result of summation referred to $\mathcal{K}$, so velocities v and σ, as the absolute velocities of $\mathcal{K}'$ and $\mathcal{K}''$ respectively, will remain unchanged compared to the respective values according to STR. However, the question of velocity V looks different. This velocity refers to frame $\mathcal{K}'$ that, unlike in STR, differs from $\mathcal{K}$. From the fact that σ and v remain intact, it follows that velocity of the particle relative to $\mathcal{K}'$ is

$$V_{\mathcal{K}} = \sigma - v \tag{C.2}$$

Because the stationary rods and clocks in $\mathcal{K}'$ are shortened and slowed by the Lorentz factor (respectively: $l' = l/\gamma_{(v)}$ and $t' = t\gamma_{(v)}$), so in the frame $\mathcal{K}'$ the velocity of particle is

$$V_{\mathcal{K}'} = \gamma_{(v)}^2 V_{\mathcal{K}} \tag{C.3}$$

Eventually, the PFT velocity-addition formula applied to summation in the preferred frame $\mathcal{K}$ takes the form:

$$\sigma = v + V_{\mathcal{K}'}/\gamma_{(v)}^2 \tag{C.4}$$

Let us compare this equation with the STR velocity-addition formula. Our goal is to test whether velocity V, defined according to LT, is empirically equivalent to the velocity $V_{\mathcal{K}'}$, defined according to TT. Let's convert the STR velocity-addition formula to the form:

$$\begin{aligned} \sigma &= \frac{v+V}{1 + vV/c^2} = v + V\left(\frac{1 - v^2/c^2}{1 + vV/c^2}\right) \\ &= v + \frac{V}{\left(1 + vV/c^2\right)\gamma_{(v)}^2} \end{aligned} \tag{C.5}$$

Now, the STR velocity-addition reminds Eq. (C.4); moreover, both formulae will totally coincide if we define velocity $V_{\mathcal{K}'}$ as:

$$V_{\mathcal{K}'} = V\left(1 + vV/c^2\right)^{-1} \tag{C.6}$$

Hence, the question of equivalence between the STR and PFT formulae reduces to another question, namely if velocities V and $V_{\mathcal{K}'}$ are distinguishable in the kinematical experiments. To answer it, let us consider the following example. Let the "added" velocity (defined by STR as V, and by PFT as $V_{\mathcal{K}'}$) be the velocity of a rod at rest in $\mathcal{K}''$ of the length L, as measured in $\mathcal{K}$. Let this rod pass the clock at rest in $\mathcal{K}'$. The criterion of empirical equivalence between STR and PFT are the readings of the clock in the moment of passing it by the rear end of the rod. To meet this criterion, the respective readings should be identical despite different STR and PFT predictions as to the rod's length and its velocity, both inserted to the equation for time. We assume that the clock, when passed by the front end of the rod, in both cases indicates identical time $t_0 = 0$. According to STR, the rod's length in $\mathcal{K}'$ is $L' = L/\gamma_{(V)}$. Instead, according to PFT, the rod's length results from the mutual relation of the observer's frame and the rod rest frame, expressed by the quotient of respective absolute Lorentz factors:

$$L' = {L\gamma_{(v)}} \big/ {\gamma_{(\sigma)}} \tag{C.7}$$

The requirement of identical clock indications is tantamount to the requirement of equality between respective times according to STR and PFT. Hence, we need to see if the following equality holds:

$$\frac{L}{\gamma_{(V)}V} \overset{?}{=} \frac{L\gamma_{(v)}}{\gamma_{(\sigma)}V_{\mathcal{K}'}} \tag{C.8}$$

Considering that:

$$V = V_{\mathcal{K}'}\left(1+ {vV}\big/{c^2}\right) \tag{C.9}$$

we have:

$$\frac{L}{\gamma_{(V)}V_{\mathcal{K}'}\left(1+{vV}\big/{c^2}\right)} = \frac{L\gamma_{(v)}}{\gamma_{(\sigma)}V_{\mathcal{K}'}} \tag{C.10}$$

Simplifying and rearranging gives:

$$\frac{\gamma_{(v)}\left(1+{vV}\big/{c^2}\right)}{\gamma_{(\sigma)}} = \frac{1}{\gamma_{(V)}} \tag{C.11}$$

After rewriting the Lorentz factors, we get (for $c = 1$):

$$\begin{aligned} &\frac{1}{\sqrt{1-v^2}}\sqrt{1-\left(\frac{v+V}{1+vV}\right)^2}\left(1+vV\right) \\ &= \sqrt{\frac{\left(1+vV\right)^2-\left(v+V\right)^2}{1-v^2}} \\ &= \sqrt{\frac{1+\left(vV\right)^2-v^2-V^2}{1-v^2}} \\ &= \sqrt{\frac{\left(1-v^2\right)\left(1-V^2\right)}{1-v^2}} = \frac{1}{\gamma_{(V)}} \end{aligned} \tag{C.12}$$

which confirms empirical equivalence between STR and PFT velocity-addition formulae.

Eq. (C.4) is however not the general formula for the PFT velocity-addition since (first of all) it applies exclusively to summation in the preferred system $\mathcal{K}$. This in particular means that the final velocity (σ) is identical for STR and PFT. Meanwhile, in a more general case of summation in x positive direction performed in a frame different from the preferred one (here: $\mathcal{K}''$), the final velocities derived alternatively from LT and TT might be different. Apart from the absolute Lorentz factor for the "intermediate" frame ($\mathcal{K}'$ in Eq. C.4) we must also take into account the absolute Lorentz factor for $\mathcal{K}''$ i.e., the one in which the summation is executed. In other words, Eq. (C.4) applies to the particular case in which the Lorentz factor for the observer equals 1, while in the general case it may differ from 1. The generalized "collinear" velocity-addition formula is

$$\sigma = \gamma_{(O)}^2\left(V_1 + {V_2}\big/{\gamma_{(V_1)}^2}\right) \tag{C.13}$$

where $\gamma_{(O)}$ denotes the absolute Lorentz factor for the observer's frame $\mathcal{K}''$, $\gamma_{(V_1)}$ – absolute Lorentz factor for "intermediate" frame $\mathcal{K}'$, and V_1 – velocity of "intermediate" frame $\mathcal{K}'$ relative to $\mathcal{K}''$, as measured in the preferred frame $\mathcal{K}$. The velocity V_1 corresponds to the velocity v in Eq. (C.4). Instead, V_2 denotes the velocity of the particle in "intermediate" frame $\mathcal{K}'$:

$$V_2 = \left(\sigma - V_1\right)\gamma_{(V_1)}^2 \tag{C.14}$$

corresponding to the velocity $V_{\mathcal{K}'}$ in Eq. (C.4).

Appendix D. Identity of Momenta of a Massive Body According to STR and PFT

Let the massive object at rest in the frame $\mathcal{K}'$ fall apart into two equal parts (here called "forward" and "backward" particles, denoted respectively $\mathcal{F}$ and $\mathcal{B}$) receding in opposite directions along x'-axis, so that net momentum in $\mathcal{K}'$ amounts to zero. Let "forward" means the direction compatible with the motion of $\mathcal{K}'$ relative to the preferred frame $\mathcal{K}$, and "backward" – the opposite direction. Let the rest mass of each particle be m_0. According to STR, the momentum of each particle in $\mathcal{K}'$ (for $c = 1$) is

$$p = m_0 V\gamma_{(V)} = m_0 V\left(1-V^2\right)^{-1/2} \tag{D.1}$$

where V is the relative velocity between each of the considered particles and $\mathcal{K}'$. Instead, in accordance with PFT, the respective momentum is

$$p' = m_0\left({\gamma_B}\big/{\gamma_A}\right)v_{(\text{diff})}\gamma_A^2 \tag{D.2}$$

The term $m_0\left({\gamma_B}/{\gamma_A}\right)$ denotes the mass of a given particle as measured in frame $\mathcal{K}'$, where $\gamma_A = \left(1-v^2\right)^{-1/2}$ is the Lorentz factor for the observer's frame $\mathcal{K}'$, and $\gamma_B = \left(1-\sigma^2\right)^{-1/2}$ is the Lorentz factor for the particle, both related to the preferred frame $\mathcal{K}$. Instead, $v_{(\text{diff})}$ denotes the measured in $\mathcal{K}$ relative velocity between each of (alternatively considered) particles: $\mathcal{F}$ or $\mathcal{B}$ and frame $\mathcal{K}'$ (precisely: the absolute value of the vector difference between the velocity of given particle and the velocity of $\mathcal{K}'$, each time measured in $\mathcal{K}$; hence $v_{(\text{diff})} = |\boldsymbol{\sigma} - \mathbf{v}|$). Because both mass and velocity of $\mathcal{F}$ and $\mathcal{B}$ depend on the direction of their motion in $\mathcal{K}'$, hence γ_B and $v_{(\text{diff})}$ are defined separately for each particle, hereinafter denoted respectively $\gamma_{(\mathcal{F})}$, $\gamma_{(\mathcal{B})}$ and $v_{(\mathcal{F})}$, $v_{(\mathcal{B})}$. Instead, the Lorentz factor γ_A remains unchanged in both cases. Our goal is to check whether the momenta of $\mathcal{F}$ and $\mathcal{B}$ equal each other, and whether they both equal the momentum defined according to STR. Before entering to analysis, let us make an obvious reduction of Eq. (D.2) obtaining:

$$p' = m_0 \gamma_A \gamma_B v_{(\text{diff})} \tag{D.3}$$

Taking advantage of the equivalence of the velocity-addition formulae according to the STR Eq. (C.1) and the PFT Eq. (C.4), we define the particles velocity in $\mathcal{K}$ as:

$$\sigma(\mathcal{F},\mathcal{B}) = \frac{v \pm V}{1 \pm vV} \tag{D.4}$$

with positive signs for $\mathcal{F}$ and negative signs for $\mathcal{B}$. Hence, the respective absolute Lorentz factors are:

$$\gamma_{(\mathcal{F})} = \left(1 - \left(\frac{v+V}{1+vV}\right)^2\right)^{1/2} \qquad \gamma_{(\mathcal{B})} = \left(1 - \left(\frac{v-V}{1-vV}\right)^2\right)^{1/2} \tag{D.5}$$

After substituting to Eq. (D.3), we obtain the momentum p_1' for particle $\mathcal{F}$:

$$p_1' = m_0 \gamma_A \gamma_{(\mathcal{F})} v_{(\mathcal{F})} = \frac{m_0\left(\frac{v+V}{1+vV} - v\right)}{\sqrt{\left[1-\left(\frac{v+V}{1+vV}\right)^2\right]\left(1-v^2\right)}} = \frac{m_0 V\left(1-v^2\right)}{\sqrt{\left[1-\left(\frac{v+V}{1+vV}\right)^2\right](1+vV)^2\left(1-v^2\right)}} = m_0 V \gamma_{(V)} \tag{D.6}$$

Similarly, we derive the momentum p_2' for particle $\mathcal{B}$:

$$p_2' = m_0 \gamma_A \gamma_{(\mathcal{B})} v_{(\mathcal{B})} = \frac{m_0\left(\frac{v-V}{1-vV}\right)}{\sqrt{\left[1-\left(\frac{v-V}{1-vV}\right)^2\right]\left(1-v^2\right)}} = \frac{m_0 V\left(1-v^2\right)}{\sqrt{\left[1-\left(\frac{v-V}{1-vV}\right)^2\right](1-vV)^2\left(1-v^2\right)}} = m_0 V \gamma_{(V)} \tag{D.7}$$

Identity of these results means equality of momenta of the particles $\mathcal{F}$ and $\mathcal{B}$, as well as equality of both these momenta with the momentum defined according to the STR equation (D.1).

Appendix E. Identity of the Photon Momenta According to STR and PFT

According to STR, the momentum of photon is

$$p = h\lambda^{-1} = hfc^{-1} \tag{E.1}$$

(h - Planck constant, f - frequency, c - speed of light, λ - photon wavelength) Let the source of emission be at rest in the absolutely moving frame $\mathcal{K}'$. According to PFT, the velocity of light in $\mathcal{K}'$ depends on the absolute velocity of $\mathcal{K}'$ in connection with the direction of emission. For the source of emission at rest in $\mathcal{K}'$ the frequency observed in $\mathcal{K}'$ is isotropic, which is a consequence of the homogeneity of time in any inertial frame. More specifically, for any particular absolute velocity of $\mathcal{K}'$, each time combined with any arbitrary frequency of the source (f_0) and the angle of emission (φ), one has:

$$\frac{c'_{(\varphi)}}{\lambda'_{(\varphi)}} = f_{(\varphi)} = f_0 = const. \tag{E.2}$$

where φ denotes the angle of emission, and f_0 – frequency of the source. Rearranging and implementing the Planck constant gives

$$E' = \frac{hc}{\lambda'_{(\varphi)}} = hf_0 \frac{c}{c'_{(\varphi)}} \tag{E.3}$$

It follows:

$$p' = \frac{E}{c^2} c'_{(\varphi)} = hf \frac{c}{c'_{(\varphi)} c^2} c'_{(\varphi)} = hfc^{-1} \tag{E.4}$$

The obtained result is identical with the STR prediction given by Eq. (E.1).

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