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Collapse of Special Relativity in the Two-dimensional Space

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Abstract Special Theory of Relativity (STR) is tested by a thought experiment involving the Lorentz contraction of two one-dimensional objects interrelating in the two-dimensional space. The assumed two-dimensionality is due to observation performed in the third inertial frame of reference, noncollinear with the previous two. The detailed analysis leads to the conclusion that STR cannot be consistently applied to the spacetime with two and, by extension, three spatial dimensions; therefore, fails as a theory applicable to the real world. While the consequences of this finding are developed in the author's previous papers, this study focuses on the thought experiment and respective theoretical background.

Keywords: *Special relativity, Lorentz contraction, Lorentz transformation, Tangherlini transformation, Preferred frame, Quantum gravity*

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1. Introduction

This paper analyzes a thought experiment invalidating special theory of relativity (STR) as a theory applied to the real spatially three-dimensional world. The previous two papers on the same topic [1,2] besides dealing with the experiment, discussed in more detail an alternative to STR called the preferred frame theory (PFT). In the present paper, PFT is mentioned only occasionally (the main equations together with brief comments are to be found in the Appendix), while the main attention is focused on the thought experiment itself, including broader preliminary discussion of the involved concepts. Nevertheless, a brief characteristic of PFT carried out right now may prove useful in perceiving the experiment in a proper context.

Preferred frame theory is a generic name for several theories; however, from now on, the acronym PFT denotes specific theory developed by the present author. In a nutshell, PFT is a theory that connects the Lorentzian ontology with the Tangherlini transformation. The term "Lorentzian ontology" applies both to the nonstandard interpretations of STR (with intact formalism, i.e., based on the Lorentz transformation) and to the alternative theories (with modified formalism). Their common feature is appealing to the concepts of absolute space and absolute time, and to the related concepts, in particular the preferred (privileged) inertial frame, customarily identified with "ether". It has been shown [3,4] that Lorentz theories based on the Lorentz transformation, in particular the Lorentz's theory of electrons and the related Lorentz ether theory – LET [5,6] are in fact identical with STR. Like other "Lorentzian theories", PFT is rooted in the pre-relativistic research originated from the Maxwell's equations, and subsequently developed theoretically, most of all by Heaviside, Lorentz, FitzGerald, Larmor, Voigt and Poincaré, as well as in the empirical way, with the Michelson-Morley experiment in the lead. PFT stands however apart from this imposing background, because of being only *almost* experimentally equivalent to STR, where "almost" means except predictions concerning mass/energy. This makes PFT a separate theory, different from STR.

The Tangherlini transformation [7,8] (Appendix, point 1), formulated over half century after the release of Einstein's papers on STR [9,10], binds together two inertial frames, with one of them considered as preferred. Similar to the Lorentz transformation, the Tangherlini transformation contains the Lorentz factor γ defining length contraction, time dilation and the mass/energy increase. However, unlike the Lorentz transformation, it relates these effects to the absolute space and absolute time, determined in the preferred frame. Another defining property of the Tangherlini transformation is that it connects inconstant (depending on the absolute velocity of observer and the direction of emission) one-way velocity of light with the absolute simultaneity. This clearly distinguishes PFT from STR connecting constant (isotropic) velocity of light with the relative simultaneity.

The choice of Tangherlini transformation as the basis for PFT makes a substantial difference compared to all previous attempts aimed at reconciling the ether-based ontology with the formalism determined by the Lorentz transformation. An outstanding example is the research by J.S. Bell [11], who promoted "Lorentzian pedagogics" in teaching and interpreting special relativity. Bell developed the Lorentz's findings by proving that length contraction and time dilation are explainable as the real physical effects at atomic level. This stands in opposition to the Einstein-Minkowski model suggesting the purely relative character of these – aptly called – "relativistic" effects. However, despite his disagreement to such interpretation, Bell didn't decide to abandon the Lorentz transformation, presumably because this would mean denying STR in general (in a sense, Bell's attitude towards STR reminds respective hesitations by Poincaré). For this very reason, his inspiring ideas cannot be identified with PFT.

PFT does also not originate (at least directly) from the Reichenbach's idea postulating conventional element behind the measurement of the one-way velocity of light [12]. Instead of Einstein's convention based on the second postulate of STR, express by the equation:

$$t_2 = t_1 + \frac{1}{2}\left(t_3 - t_1\right) \tag{1}$$

(t_1 – time of emission of the light signal at point A, t_2 – time of reflection of this signal at point B, t_3 – time of returning this light signal to A), Reichenbach proposed the generalized form:

$$t_2 = t_1 + \varepsilon\left(t_3 - t_1\right) \tag{2}$$

where ε is a coefficient of free value such that $0 < \varepsilon < 1$. Consequently, the opposition between absolute and relative simultaneity would be only a matter of respective convention adopted. However, the Reichenbach's convention fails for two reasons. The first reason is not quite obvious until the relation between PFT and STR is properly analyzed. Unlike Reichenbach assumed, the difference between STR and the putative ether theory is not conventional but real, because of differing predictions concerning the *directly measured* mass/energy. The second reason is connected with the question: If the Einstein's convention expressed by Eq. (1) implies (in conjunction with the principle of relativity) the relativity of simultaneity, then what value of ε complies with the absolute simultaneity? Eq. (2) does not provide a good answer to this question. This is because in order to obtain the velocity of light consistent with the absolute simultaneity, the value of ε cannot be arbitrary established and cannot be constant, i.e., independent from the direction of emission. Instead, it has to be determined in a strictly defined way, namely as the function of absolute velocity (taken as the function preset value) and the direction of emission, according to the equations A2 and A3 (Appendix 2).

Finally, PFT opposes the established opinion (rooted in the Reichenbach's conventionalism) according to which Tangherlini transformation is entirely equivalent to the Lorentz transformation when it comes to the expected experimental results [13,14]. The present author proved in the already mentioned papers [1,2] that, despite the large area of experimental equivalence (the whole kinematics and momentum), PFT differs from STR in the realm of dynamics (energy).

Similar to STR, PFT predicts length contraction, time dilation and the mass/energy increase. However, in contrast to STR, PFT basically relates these effects to the preferred frame. As a consequence, also the opposite effects: length expansion, time speeding and the mass/energy decrease are expected to occur under definite conditions in the non-preferred inertial frames. The kinematical equivalence between PFT and STR is due to the formal interactions between particular indirectly measured quantities contributing to the directly observed results, e.g., time and distance as contributing to velocity, and so forth. The characteristic example refers to momentum, in which the predicted by PFT values of mass and velocity differ separately from respective quantities predicted by STR, however their product (i.e., momentum) is always identical. The only but crucial exception eluding experimental equivalence refers to mass/energy, which makes PFT experimentally different from STR. However, this difference is hardly detectable in the experiments performed on Earth, in particular as the possible side-effects of the experiments dedicated to other goals. This is due to the proximity of Earth's frame, roughly identifiable with the International Celestial Reference System (ICRS) – to the preferred frame, most likely determined by the strictly isotropic radiation of CMB (see respective chapter in [2]). In theoretical terms, the absolute reference of energy provides a promising hint to the quantum gravity problem. Simply put, there is no need to seek for the Lorentz violation at Planck scale, if, as PFT predicts regarding energy, Lorentz symmetry is violated at all scales. Hence, PFT may pave the way to the effective theory of quantum gravity.

The past discussions concerning validity of the thought experiment in question (reported in [15]) mostly missed the point by focusing on the tangential issues that rather obscure than clarify the problem. Nonetheless, these discussions appeared helpful for the present author to improve the argument. In fact, the proof of inconsistency of STR as a theory applied to the real spatially 3D world, and even to the reduced 2D model used in the thought experiment, is shockingly simple, but still fully effective. It turns out that STR is self-consistent only as applied to the kinematically one-dimensional cases, considered in all notable "relativistic paradoxes".

The paper is composed as follows. The (next) Section 2 contains a brief description of the thought experiment. Section 3 (divided into seven subsections) contains discussion concerning different issues related to the experiment. Section 4 contains an analysis of the thought experiment, based on conclusions obtained in the previous section. The paper ends with Conclusion (Sec. 5).

2. Brief Description of the thought Experiment

The case we are going to analyze is very simple, at least at first sight. The imaginary experimental setup consists of two objects, by assumption spatially one-dimensional, referred to as "rail" and "rod", representing two inertial frames: $\mathcal{O}'(x', y')$ and $\mathcal{O}''(x'', y'')$. Each of these two objects moves at a certain relativistic constant velocity with respect to the other object, and to the third inertial frame $\mathcal{O}(x, y)$, called "observer's frame". The vertically positioned rail moves along straight trajectory in the horizontal direction (parallel to x -axis), and hence is positioned perpendicularly to the direction of motion in the observer's frame. Instead, the rod, basically (i.e., if considered as not contracted) also vertical in $\mathcal{O}(x, y)$ frame, moves along straight trajectory in the oblique (*x*-*y*) direction, separated from the rail's trajectory by a certain acute angle. Consequently, it is positioned diagonally to its own trajectory in $\mathcal{O}(x, y)$. The respective velocities and directions in $\mathcal{O}(x, y)$ are, by assumption, tuned in such a way that x component of the rod's velocity in $\mathcal{O}(x, y)$ is equal to the rail's horizontal velocity in the same frame. As a result, both objects remain at all times in the close proximity, namely both in the rail frame $\mathcal{O}'(x', y')$ and in the rod frame $\mathcal{O}''(x'', y'')$ these objects slide in parallel to each other. At the same time, both rod and rail are subject to the Lorentz contraction in $\mathcal{O}(x, y)$ along each one's direction of motion in this frame: horizontal (rail) and oblique (rod). We aim to prove that this leads to a contradiction. First however, let us discuss different issues important to the experiment.

3. Terms and Concepts Related to the Thought Experiment

3.1. Thought Experiment Vs Real Experiment: Two Ways of Verifying a Physical Theory

We intend to disprove special relativity by a thought experiment. In general, this method consists in revealing internal contradiction of a theory (provided there is any) in a logical way, by proving that different predictions of one and the same theory are mutually exclusive when applied to a specific case. That means the use of the theory predictions as the tools against the theory itself. An obvious condition to be met by this method is that respective argumentation must stick to the rules of given theory (in this case, to the rules of STR). On that account, all substantial claims below, unless clearly stated otherwise, implicitly include the clause "according to STR".

Let us consider this issue in more detail (though still concisely). The difference between the *real* and *thought* experiments, apart from the obvious distinction between something really executed and merely conceived, consists in the fact that in the first case the answer is given by nature, while in the second case – by logic. However, this division is not as simple for several reasons. Any real experiment has to be precisely designed, which means that it should be preceded by some kind of a thought experiment. The reasonable answers may only be obtained to the reasonable questions – and the latter require definite theoretical framework. The necessity of theory (model, hypothesis) behind the real experiment is a common feature of all experiments starting from the Galileo's balls rolling down the inclined plane, and ending with extremely sophisticated experiments performed in the accelerators like CERN or SLAC.

The thought experiment itself may represent one of two types, regarding possible relation to the real experiment. A thought experiment of the first type, besides fulfilling its main purpose to test the logical consistence of a given theory, can also serve as a basis for the real experiment. A classic example is the famous Twin Paradox and its implementation in the really conducted Hafele-Keating experiment [16]. By the way, this experiment proved the existence of time dilation, but not necessary the purely relative character of this effect, as predicted by STR. The second type of a thought experiment tests the formal consistence of a theory, but its implementation to a real experiment is pointless. This is just the case of a thought experiment here considered. Let's think of a train moving on the tracks. No matter if this train is observed by an inside passenger, a person on a platform, or by a pilot of a spacecraft flying by, it is quite obvious that in either case the train will move on the tracks and not just next to them or transversely across. There is no need to apply sophisticated physics to be sure about it. The property of adhering to the track (as well as adhering of the rod to the rail in our experiment) is an obvious example of the invariant of transformation, in the sense that this property *must be* invariant under *any* transformation. In the case of specific transformation subjected to the test, "must be" does not mean that invariance is fulfilled "by definition" (and that therefore considering this question is pointless), but that it *has to do* so. In that sense, this particular condition of invariance is the criterion of correctness of the transformation and the respective theory. Referring this to our thought experiment: while the internal coherence of nature itself is, by definition, beyond any doubt, we may legitimately ask whether the Lorentz transformation (and STR in general) can consistently interpret the case described in this experiment.

3.2. Spatial Dimensionality Defined in Kinematical Terms

Unlike most of the "paradoxes" in STR (to mention twin paradox and ladder-barn paradox as the representative examples) that are spatially one-dimensional, the present case is spatially two-dimensional *in kinematical terms*. This should not be confused with the *static* spatial dimensionality featuring particular objects or the whole inertial frames of reference. The static spatial dimensionality can be determined based on two criterions referred to as *internal* and *external* spatial dimensionality. The first applies to the object as described "from inside". Instead, the second refers to the (smallest) number of spatial dimensions needed to describe given object "from outside", hence to the dimensionality of space in which given object is directly embedded. For instance, the *internally* one-dimensional geometrical object: (any) line can be *externally*: linear (straight line), flat (any flat curve, e.g., sinusoid or circumference), or solid (e.g., helix). We may also classify the coordinate systems in view of the number of spatial dimensions they apply to: single axis (usually x), double axis (x y), triple axis (x y z). All the above-defined concepts fall under the category of "static spatial dimensionality".

In contrast, the *kinematically defined* spatial dimensionality does not refer to particular objects, but to their arrangement as the objects in relative motion. For example, the ladder-barn paradox will remain valid (although not just as suggestive) if both ladder and barn were interpreted as the one-dimensional objects. The solution to this paradox is based on the relativity of simultaneity that itself does not require more than one spatial dimension to operate. Instead, *kinematical spatial dimensionality* refers to a definite set of objects being (along with their comoving frames) in the mutual relative motion, in connection with the spatial arrangement they together make. Two objects (e.g., earth-twin and cosmic-twin or ladder and barn) are, regardless of their *static dimensionality*, spatially one-dimensional in kinematical terms due to a single direction of relative motion. Instead, three objects in the noncollinear arrangement make the case spatially two-dimensional, irrespectively of their (common) *static dimensionality*. *Kinematical spatial dimensionality* provides a decisive criterion for the question of the self-consistence of special relativity. As long as a single Lorentz transformation can always consistently describe the interrelation of two inertial frames, we'll show that it fails as applied the noncollinear arrangement of at least three frames.

3.3. Inertial Frame Vs Coordinate System (in the Context of Rotation)

There is an accepted flexibility in using the terms: frame, inertial frame, inertial frame of reference, inertial system, inertial space, coordinate system or just coordinates. As long as the right meaning is clear by the context, everything is fine. However, the present author experienced in some critical moments of past discussions that the lack of precision in this regard may lead to misunderstandings resulting in the drastically wrong conclusions. A particular example is the following statement: "Two inertial frames may differ not only by velocity, but also by rotation; hence, the one-off action consisting in axial rotation of an inertial observer means exchanging one inertial frame for another". That's absurd; however, absurdity can be easily accepted if it supports someone's belief (we'll develop this question in s-sec. 4.2). It is therefore important to become aware of the two substantially different entities behind the concept of *inertial frame of reference*, namely: *inertial frame* and *coordinate system*. It might sometimes go unnoticed, since we usually think of inertial frame as already equipped with the coordinate system, so that "inertial frame" is synonymous with "inertial frame of reference". Anyway, to make things clear enough, let us define these concepts: (1) *Inertial frame* – a physical entity related to the Newton's first law of motion; it is also definable as a physical state (of inertia) described by the absence of fictious forces; (2) *coordinate system* – an auxiliary geometrical construct, used to describe the space-time phenomena in mathematical terms, in particular to parametrize them. The *coordinate system* can be shifted and/or rotated (then becomes a new one), whereas *inertial frame* is not subject to any of these operations. Einstein reportedly compared inertial frame to a coat in the coatroom and coordinate system to the number labelling that coat.

A specific kind of coordinate system is the Minkowski space-time diagram, inherently and exclusively connected with special relativity. The concept of *spacetime* [17] not only provides a geometrical interpretation of STR (Newtonian mechanics can also be expressed this way), but rather shows that STR basically refers to space and time. This makes substantial difference compared to the original Einstein's papers on STR ([9,10]) – not only due to algebraic tools used there, but, first of all, because of their saturation with specific physical concepts, of both mechanics and electrodynamics. Meanwhile, Minkowski proved that STR can basically be deprived of all physical "baggage", except for space and time – fused in the abstract concept of *spacetime*. This explains Einstein's initial distrust towards Minkowski's model. In particular, the four-dimensional electrodynamics expressed in tensor form was rated by him as overly complicated "superfluous learnedness" [18]. As is known, Einstein appreciated Minkowski's model soon after, and used it as a framework for general relativity.

3.4. Three Properties of the Lorentz Contraction: Relativity, Symmetry and Isotropy

In special relativity, the terms *Lorentz contraction* and *length contraction* mean exactly the same. In this paper, however, we separate them, using "Lorentz contraction" to denote an effect predicted by STR (i.e., defined by the Lorentz transformation), and "length contraction" to denote an effect predicted by PFT (i.e., defined by the Tangherlini transformation). The difference between these concepts is experimentally negligible in certain specific conditions (e.g., on Earth), but fundamental in general. While referring for more detailed discussion of this point to [2], we'll focus now on three substantial properties of the Lorentz contraction. They may seem self-evident, and thus not worth analyzing in detail. But in fact, they are not obvious given that none of these properties applies to the PFT-defined length contraction.

The first property of the Lorentz contraction, to which the term *relative* seems to be most adequate (although the term *relational* also seems suitable) is that this effect is due to *relative* motion, that is, it occurs only in relation to inertial observer. According to the Lorentz contraction, nothing affects the internal structure of the contracted body. Let's use a simple example. Assume an object of the asymmetric shape, being at rest in a certain inertial frame. To be observed as contracted, it does not need to move, i.e., change its original inertial frame for another frame. It is enough to assume several inertial observers moving in different directions at different (constant) velocities relative to this object. Each of them will observe this object contracted in a specific way, depending on the direction of motion (due to the asymmetric shape) and the relative velocity.

However, in every inertial frame, the moving objects are contracted according to the same rules; in the sense, Lorentz contraction is *symmetrical*. This means that, similar to other fundamental laws of physics, Lorentz contraction is governed by the Lorentz symmetry. When comparing it to the length contraction, we may say that Lorentz contraction manifests itself in all inertial frames in the same way, namely the way in which the length contraction manifests itself in the preferred frame only. In formal terms, symmetry of the Lorentz contraction is a consequence of the relativity of simultaneity and, at the fundamental level, of the (special) principle of relativity, formally expressed by the Lorentz transformation. However, as considered in each observer's frame separately, the Lorentz contraction is by no means impacted by the relativity of simultaneity. We'll return to this claim in the next subsection.

A consequence of the *relativity* and *symmetry* of the Lorentz contraction is its *isotropy*. This property (essential to our argument) means that, in each particular frame, the way Lorentz contraction is carried out does not depend on the direction in which the observed object is moving – provided that position (spatial orientation) of this object with respect to each particular direction of motion is always the same. In other words, *isotropy* means that Lorentz contraction does not depend on the direction of motion with respect to any specific coordinate system. Consequently, rotation of the coordinate system does not impact on the "physical content" of Lorentz contraction. The only result of rotation is the (purely formal) change of coordinates used to describe the observed physical effect – each time one and the same. Some other properties of Lorentz contraction will be discussed in the next subsections.

3.5. Lorentz Contraction and the Lorentz Transformation: Input of the Relativity of Simultaneity

This subsection is about the relation between the Lorentz transformation and the Lorentz contraction. The key concept of STR involved in this relation is the relativity of simultaneity. We are going to explain why the Lorentz contraction cannot be usually obtained by means of the Lorentz transformation applied to particular points (events), altogether constituting given object in the initial frame. In other words, we aim to prove that the Lorentz transformation of an exemplary spatially extended object taken as a whole cannot be identified with the sum of particular transformations applied to the separate points constituting this object. In the case considered in our thought experiment, this means that the one-dimensional rod cannot be transformed (using the Lorentz transformation) by mapping its endpoints – except for the case when the position of this rod is perpendicular to the direction of motion.

Let us elaborate on the claim stated in the previous subsection: "As considered in each observer's frame separately, the Lorentz contraction is by no means impacted by the relativity of simultaneity". The question arises: how is that possible, given that relativity of simultaneity is an inherent prediction of STR, being formally encoded in the Lorentz transformation? In particular, the factor vx/c^2 and its primed equivalent vx'/c^2, both present in the mutually symmetric transformational equations for time are, in connection with the respective equations for space, formally responsible for this fundamental prediction of STR. The answer is however quite obvious, not to say trivial: for the relativity of simultaneity to appear as the STR prediction, one needs at least two inertial frames of reference (two inertial observers) connected by the Lorentz transformation. The way the relativity of simultaneity and the Lorentz contraction relate to each other in the double-frames arrangement is crucial to understanding why (sticking all the time to STR), this effect does not contribute to the case described in our thought experiment.

Assume two one-dimensional frames $\mathcal{O}(x)$, $\mathcal{O}'(x')$ in the parallel configuration, moving with respect to each other at a relativistic speed. Let $\mathcal{O}'$ be the rest frame for the rod $A'B'$ extending in the xx' direction, and $\mathcal{O}$ – the observer's frame in which this rod (denoted AB) is moving, being thus subject to the Lorentz contraction. The space and time coordinates of the rod's endpoints at rest in frame $\mathcal{O}'$ make at any moment two simultaneous *events*, say, $A'\left(x_1', t_0\right)$ and $B'\left(x_2', t_0\right)$. The spatial coordinates are different due to the assumed nonzero length of the rod; instead, the time coordinates are identical (t_0), since simultaneity of all points constituting the rod is the condition sine qua non to observe this rod at rest in $\mathcal{O}'$ as an *integral* object. The condition of integrity applies not only to the object at rest (actually, in this case it is not indispensable to determine the length) but, most of all, to the object in motion – due to the varying (in time) positions of respective points.

Now, the following question arises: What are the coordinates of the rod's endpoints observed (in given particular moment) in $\mathcal{O}$ – as an object in motion, thus being subject to the Lorentz contraction? Seemingly (the present author encountered such an opinion during discussions), to find this out, we have to apply the Lorentz transformation to each endpoint, so as to transform the $\mathcal{O}'$ coordinates $\left(x_1', t_0'\right)$, $\left(x_2', t_0'\right)$ into respective coordinates of $\mathcal{O}$. After all (according to this opinion), the Lorentz contraction is, in formal terms, a consequence of the Lorentz transformation. This, however, puts us on the wrong track (or at least not on the direct track), since then, in all cases except the rod's position perpendicular to the direction of motion in $\mathcal{O}$, we'll obtain in $\mathcal{O}$ two events differing not only by space coordinates, but also by time coordinates, say, $\left(x_1, t_1\right)$ and $\left(x_2, t_2\right)$ – so the condition of integrity will not be fulfilled in this frame. A non-integral object obtained this way, i.e., the one whose endpoints (and all other points) are not simultaneous in the observer's frame, is certainly not the contracted rod observed in $\mathcal{O}$! One cannot consistently observe the moving rod in the way that one of its endpoints "is present on Monday" and the other one "is present on Tuesday". Therefore, in order to complete the task of determining the rod's coordinates as an object contracted in $\mathcal{O}$, we have to find simultaneous positions of its endpoints. This means that, if we start with the Lorentz transformation of particular points, we must "additionally" find their simultaneous positions. This is how the relativity of simultaneity and the Lorentz contraction relate to each other in STR.

The consequences of this otherwise obvious conclusion are however not as much obvious to everybody, all the more when it turns out that they strike at STR. When faced with this problem, the notable physicists with whom

I had the opportunity to discuss this issue [15] emphatically objected to define Lorentz contraction as a shortening by the Lorentz factor along the direction of motion in the observer's frame. According to respective opinion, such definition is merely a simplified construal applicable to the basic cases only, in particular not applicable to the case considered in this "troublesome" thought experiment. Instead – they insisted – the Lorentz contraction should be interpreted as a complex phenomenon manifesting itself in different ways, depending on specific circumstances. Whatever "specific" could mean in this context, the attention was paid to the relativity of simultaneity, either considered directly or as involved in the effect called the Thomas-Wigner rotation (we'll return to it in s-sec. 4.2). Still according to this view, the only sure way to get the rod correctly contracted in the observer's frame is to transform the space-time coordinates (events) of the rod's endpoints from the rod rest frame $\mathcal{O}'$ to the observer's frame $\mathcal{O}$. The so-obtained coordinates would reveal the "real shape" of Lorentz contraction, that is, would reliably show how the rod is *really* contracted rod in $\mathcal{O}$. However, the only thing this "recipe" reliably shows is that a blind trust in the correctness of given theory may lead astray the otherwise smart brains.

3.6. Modus operandi of the Lorentz Contraction: Property of the Matter Irrelevance

Unlike the case of length contraction (PFT), the right object of the Lorentz contraction (STR) is not the moving body itself, that is as taken in isolation from the empty space it travels through. On the contrary, Lorentz contraction basically applies to the space itself, understood as the space *at rest to the moving body*, thus moving uniformly relative to the space *at rest to inertial observer*. In other words, Lorentz contraction affects the whole *inertial frame* defined as a homogenous space to which certain nonzero velocity vector (of the direction and magnitude specified in relation to the observer's frame) is attached at every point. Only as a consequence of this primal effect, Lorentz contraction applies to the moving body interpreted as a definite "piece of space". It therefore becomes clear that the only physical property of the moving body relevant in the context of Lorentz contraction is that it occupies a part of the comoving space. We can even risk saying that the most fundamental feature of special relativity is that it substantializes space and time "at the expense" of the substantiality of material objects. At the same time (in fact, in contrast to this feature), the space has in STR the property of being multiple and relative, which differs from the concept of one (thus unique) absolute space, postulated by PFT. Hence, the space in STR always refers to a *particular* inertial space, one of infinitely many inertial spaces. It is only the (Minkowski) *spacetime* that is postulated to have the property of being one and absolute.

To be formally cognizable, inertial frame is provided with the coordinate system, allowing to define Lorentz contraction (and other phenomena) in mathematical terms. We may conceptualize the two-dimensional coordinate system in a form of dense orthogonal grid provided with space coordinates. Let us call it the *2D lattice*, considering it as a quasi-material object – some kind of materialization of inertial space. In the sense restricted to kinematics, inertial motion can be conceived in STR as the motion of one lattice relative to another (observer's) lattice. As for the Lorentz contraction, each lattice may play a twofold role. The lattice at rest to the inertial observer is a coordinate system in the strict sense; it serves as a tool to describe this effect in a quantitative manner. Instead, the lattice at rest to the moving body is the primal object subject to the Lorentz contraction; the shape of the moving lattice tells us how the "empty space" (i.e., the space itself) is contracted, together with the objects embedded in (at rest to) this space.

Assume the Lorentz contraction of a certain flat figure. The right way of conceptualizing it is to imagine this figure as plotted on the *2D lattice*. Let the whole lattice be compressed along certain direction, by definition parallel to the direction of motion. Obviously, the figure fixed to the lattice becomes contracted in exactly the same degree and direction. The same applies to all full-dimensional material objects embedded in the *3D lattice*. This implies another important property of the Lorentz contraction: the way it occurs does not depend on any specific properties of a material body. In each case, regardless of different physical qualities such as mass, charge, inner structure or outer geometry, the Lorentz contraction takes the same simple form of shortening along the direction of motion. Let us call this property the *matter-irrelevance* of Lorentz contraction.

The property of *matter-irrelevance* applies only partially to the length contraction (PFT). Let's explain what "partially" means here. First, the length contraction is originally due to the interaction between the moving body and the absolute space. Therefore, unlike the Lorentz contraction, it manifests itself as a pure contraction in the *preferred frame* only. In this sense, length contraction is not *relative*, being *isotropic* in the preferred frame only. Second, the *matter-irrelevance* as a property of length contraction is attained not because the internal structure of a contracted body is insignificant (and thus is not a part of respective rationale), but because, at the most fundamental level, all material bodies are composed in the same way, thus behave identically while moving through absolute space. Based on the Maxwell's electrodynamics, Lorentz [5] and Larmor [21] explained length contraction and time dilation as the phenomena due to electromagnetic forces; much later, Bell derived this effect in application to a single hydrogen atom [11]. Paradoxically, all these findings, despite logically sound and physically correct, have been considered either (before the advent of STR) as an *ad hoc* hypothesis to explain the Michelson-Morley experiment, or (after the release of Einstein's relevant papers) as already useless for STR. As a result, these explanations (collectively referred to as "Lorentzian approach to relativity"), although not rated wrong, have been however considered "needlessly complicated" and "redundant". It has been taken for granted that Lorentzian approach is fully equivalent to STR. Meanwhile, this is indeed true only when this approach goes hand in hand with the Lorentz transformation.

3.7. Lorentz Contraction of the One-dimensional Objects: Property of the Positional Dependence

We'll now consider the kinematical description of Lorentz contraction in application to the one-dimensional rod (line-segment), in three characteristic *positions* with respect to the trajectory in the observer's frame. The figures below demonstrate *isotropy* of the Lorentz contraction (identical result of contraction for different alternative directions of motion) and another property (also shared by the length contraction predicted by PFT) called *positional dependence* – an obvious geometrical consequence of the Lorentz contraction applied to the straight one-dimensional objects. Depending on the position "before" contraction, position is either preserved (Figure 1, Figure 2) or changes (Figure 3). Each of the three cases below is somehow present in the thought experiment (as relating either to the rail or to the rod), so we'll recall them in the analysis performed in Sec. 4.

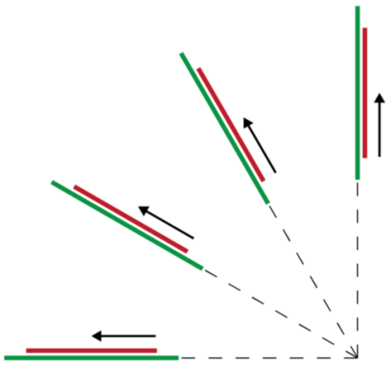

Figure 1. Lorentz contraction of the one-dimensional rod moving in four alternative directions, each time positioned in parallel to the respective direction of motion. Red and green colors mark the same rod – contracted and uncontracted, respectively. The result of Lorentz contraction does not depend on the direction in which the rod moves in the observer's frame (isotropy). The rod becomes shorter due to Lorentz contraction, but the parallel position remains unchanged after contraction

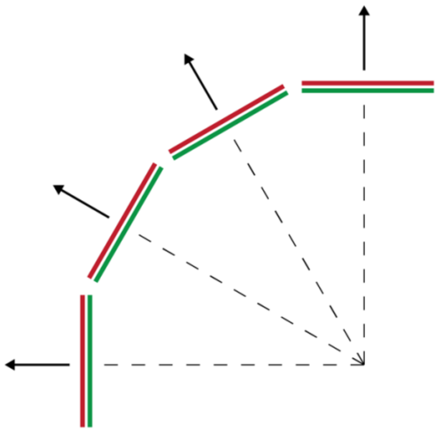

Figure 2. Lorentz contraction of the one-dimensional rod moving in four alternative directions, each time positioned perpendicularly to the respective direction of motion. Red and green colors mark the same rod – contracted and uncontracted, respectively. The result of Lorentz contraction does not depend on the direction in which the rod moves in the observer's frame (isotropy). Since the rod is assumed one-dimensional, so there's no visible effect of the Lorentz contraction. The perpendicular position remains unchanged after contraction

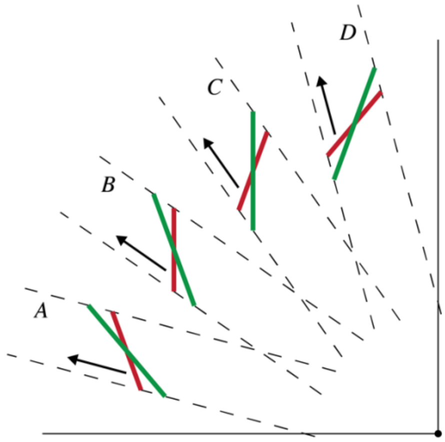

Figure 3. Lorentz contraction of the one-dimensional rod moving in four alternative directions, each time positioned diagonally to the respective direction of motion. Red and green colors mark the same rod – contracted and uncontracted, respectively. The result of Lorentz contraction does not depend on the direction in which the rod moves in the observer's frame (isotropy). The rod changes its diagonal position due to the Lorentz contraction. Hence, in this case, the positional dependence gives a visible result

4. Analysis of the Thought Experiment

4.1. First Version: Rod Vertical "before" Contraction

Let us return to the thought experiment introduced in Section 2 – making use of conclusions drawn in the previous sections. In order to show that the revealed contradiction is not due to a specific position of the contracted object, we'll consider two characteristic cases differing with respect to the initial position.

First, let's consider the, in a sense main version of the experiment, in which the rod adheres to the rail as observed in the rail frame and in its own (comoving) rod frame. The property of constant mutual adherence of the rod and the rail (assumed here as the experiment's arrangement) should obviously be an invariant of *any* transformation, including the Lorentz transformation. Thus, it should be as well observed by the inertial observer moving in the direction nonparallel to that of the relative motion between the rail and the rod. Meanwhile, the Lorentz contraction along two directions separated by a certain acute angle proves to not fulfill this requirement. The rod adhering to the rail as observed both in the rail and rod frames, deviates from the rail in the observer's frame $\mathcal{O}$. This is clearly impossible in reality, so it means a contradiction within the Lorentz transformation and STR as applied to the kinematically two-dimensional case.

According to the property of *isotropy* (s-sec. 3.4), the oblique direction of the rod's motion in the reference frame $\mathcal{O}(x,y)$ is entirely equivalent to the respective horizontal direction; "oblique" and "horizontal" (directions) are the fully conventional concepts defined in relation to the fully arbitral arrangement of the observer's coordinate system. Neither of these directions and respective Lorentz contractions is "more essential" than the other one. In particular, an appropriate clockwise rotation of the coordinate system $\mathcal{O}(x,y)$ would replace respective spatial orientations, making the rod's trajectory "horizontal" and the rail's trajectory "oblique" (in bottom-left direction). Instead, the *positions* of both objects "before" and "after" contraction will remain the same (as before rotation), since they are defined in relation to their trajectories in the observer's frame, and not to any specific coordinate system. Consequently, according to the *positional dependence* of Lorentz contraction affecting the one-dimensional objects (s-sec. 3.7), the diagonal position of the rod changes to a more transverse diagonal one, whereas the perpendicular position of the rail remains unchanged. This version of experiment (Figure 4) corresponds with the "nine o'clock" (horizontal) case shown in Figure 2 – as for the rail, and with the variant *C* shown in Figure 3 – as for the rod.

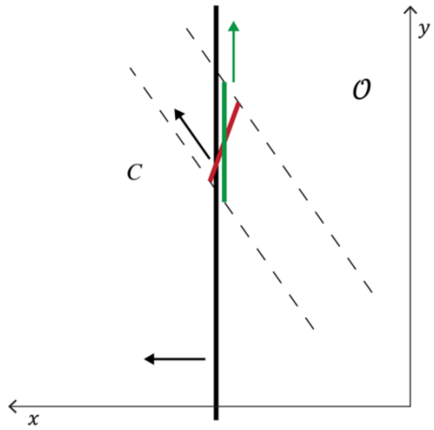

Figure 4. The vertical rail (black) and the vertical rod (green) are differently positioned to each one's direction of motion (black vectors) in the observer's frame $\mathcal{O}(x, y)$. Consequently, they differently react to Lorentz contraction along these directions: the rod changes its diagonal position (from green to the red one), while the rail's perpendicular position remains unchanged. This leads to incompatibility between observations made in the rail and rod frames (adherence), and in the observer's frame (deviation from the rail). Green vector points direction of the rod's motion as observed in the rail frame

4.2. Second Version: Rod Vertical "after" Contraction

The second version of the experiment is the aftermath of the extensive discussion held few years ago [15], concerning similar (to the above one) thought experiment, differing by the secondary "props" only (instead of rod and rail, a square elevator moving on two parallel rails). For the sake of consistency, I'm not quoting here all the statements of my interlocutor literally, however I do convey precisely the respective meaning and intention, adjusting the argumentation to the rod-and-rail arrangement. The argument set out by my distinguished converser (ranked in the top ten of living physicists; let's name him "X") was as follows: "How is the rod oriented *before* contraction? You assume that it is vertical. But why should it be so? Why cannot it be slightly diagonal, i.e., not aligned to the *y* direction as being at rest in the observer's frame (before contraction), and hence becoming vertical only in motion (after contraction), so parallel to the vertical rail? The mistake you are making is an assumption about the orientation of the rod before contraction". This statement was followed by another one: "The frame in which the rod is not aligned to the *y* direction before contraction (that is, if it stopped in observer's frame) is the one of many possible frames, all at rest to each other, differing *by rotation only*. This frame is connected with the comoving frame of the contracted rod not only by boost, but also by rotation. Therefore, it is only a question of the right fit; if you chose the rod properly oriented before contraction, you will then obtain the contracted rod adhering to the rail *in all three frames* (i.e., rail, rod and observer's). In general: inertial frames may differ not only by velocity, but also by velocity *and rotation*, or even by *pure rotation*. Hence, if you boost physically the rod from one frame to the other, it will differ from the original one not only by velocity, but also by rotation". At the same time, X agreed that – because at all times the rod is moving uniformly and rectilinearly, and therefore constantly occupies one and the same inertial frame – it is not subject to the Thomas-Wigner rotation. My converser confirmed this claim emphatically: "This has nothing to do with the Thomas-Wigner rotation!".

The question of alleged rotation of inertial frame has been already addressed in s-sec. 3.3 and in the previous subsection. In order to better realize fallacy of this concept (i.e., that inertial frames can vary by rotation) let us consider its consequences. Assume an observer's inertial frame. Assume a rod at rest in this frame, in a certain position described as "vertical" (no gravity involved!). Now, let the inertial observer at rest to this rod make a (purely formal) one-shot operation consisting in rotation of the coordinate system in which the position of the rod was described "vertical" before rotation. The angle of rotation is matched so that, after rotation, the "vertical" position changes to a "diagonal" position. The same effect can be obtained through real rotation of the rod by the same angle, in the opposite direction. According to X, the rod after rotation does no longer represent the same inertial frame it did before rotation; instead, it then determines another frame, differing from the former one by pure rotation. Likewise, the observer becomes a different observer due to rotation of the coordinate system. With all due respect to X, it is a nonsense in its purest form. Arguably, (despite my interlocutor's emphatic denial) the concept of rotation of inertial frame results, after all, from the misguided interpretation of the Thomas-Wigner rotation and respective Thomas precession. Meanwhile, we deal in this effect with the *real rotation* of an object due to *curvilinear trajectory* (occurring in the opposite direction to that of the trajectory curvature), which can be described in terms of rotation of the *coordinate system* fixed to the moving object. In other words, the coordinate system is (can be) identified with the object itself – just as a lattice described in s-sec. 3.6. But, for pity's sake, there's nothing like rotation of inertial frame! As a side note: this shouldn't be confused with the dynamic effect due to continuous rotation of the (then non-inertial) reference frame).

The Figure 5 below refers to the above-described case: the rod is not vertical before contraction (i.e., if it was at rest in the observer's frame), but becomes vertical, ergo adheres to the rail, after contraction. Accordingly, the rod is supposed to adhere to the rail in all three frames; however, it is a mere wishful thinking, at odds with the rules of STR. This case differs from the previous version (Figure 4) by the otherwise inessential property, namely the assumed position of the rod “before” the Lorentz contraction. If, instead of one-dimensional rod, we assume a certain two or three-dimensional object, the respective difference of positions would be even less important – since in any 2D or 3D object, there can be determined different spatial directions identifiable with vertical, horizontal and (various) diagonal lines. In this regard, “position” of the contracted object is important only insofar as the object’s dimensionally is reduced to less than three dimensions.

This version corresponds (same as the previous one) with the left-bottom example in Figure 2 – as for the rail, and with the variant B in Figure 3 – as for the rod.

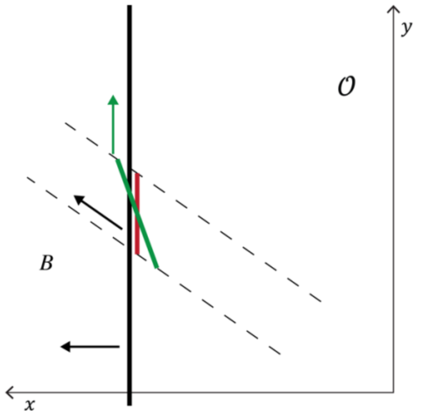

Figure 5. The vertical rail (black) and the diagonal rod (green) are differently positioned to each one’s direction of motion (black vectors) in the observer’s frame $\mathcal{O}(x, y)$. Consequently, they differently react to Lorentz contraction along these directions: the rod changes its diagonal position (from green to the red one). As a result, it adheres to the rail whose perpendicular position remains unchanged. Like in the previous version, this means incompatibility between observations made in the rail and rod frames (deviation from the rail) and in the observer’s frame (adherence). Green vector indicates direction of the rod’s motion observed in the rail frame

Both above versions reveal the same contradiction and imply the same conclusion: STR fails as applied to the kinematical cases involving two and three spatial dimensions. To avoid this contradiction, a different description of nature (theory) has to be formulated. PFT seems to be the right solution.

5. Conclusion

The contradiction revealed by this thought experiment does not refer to nature itself, but to a specific description of nature, namely STR. Nature cannot be self-contradictory, instead theory is never risk-free in this respect, and thus always should be subject to verification. These two claims are entirely obvious; however, they are worth considering, given certain argument recurring in part of discussions held by the present author. It allegedly disqualifies implications of the thought experiment on logical grounds, thus without involving specific physical reasons. The argument is as follows: it is ridiculous to expect that in one reference frame the rod will constantly adhere to the rail, and will constantly deviate from the rail in the other frame. This particular property cannot depend on the choice of reference frame, but must be, and surely is, invariant under Lorentz transformation. There is no need to delve into physical details to be sure that specific physical explanation will confirm the verdict of logic. In particular, if adhering is constant in time, then it excludes contribution of the relativity of simultaneity; only the momentaneous adhering may occur in one frame and not occur in the other frame (ironically, some other attempts to invalidate this thought experiment did appeal to the relativity of simultaneity). Eventually, this thought experiment does not prove any inconsistency of STR.

The fallacy of the above argument is that it confuses nature with theory and premise with conclusion. It presupposes this what is only to be proved. Indeed, the property of constant adhering, as it is described in this experiment, has to be the invariant of transformation. This however does not imply that Lorentz transformation meets this demand, but only that it should do so. The logic behind this argument is erroneous, while the correct chain of reasoning should proceed as follows: (1) The property of constant adhering is undoubtedly an invariant of transformation; ergo (2) the right transformation has to fulfil the condition of this specific invariance; ergo (3) it is a matter of examination if the Lorentz transformation works well in this respect.

The thought experiment considered in this paper is just designed to complete the task stated in above point (3). It turns out that Lorentz transformation does not fulfil this particular condition of invariance, which ultimately implies the general conclusion, namely that STR collapses in two and (by extension) three spatial dimensions, so is inapplicable to the real world. It should be therefore replaced by a different theory based on different transformation and different postulates from the two ones founding STR: the principle of relativity and the constancy of the speed of light. This conclusion is obtained from the thought experiment in the purely logical way, whereas using this thought experiment as the base for a real experiment is pointless for the reasons stated in the third paragraph of s-sec. 3.1.

As shown in the other author’s papers on this subject (and, in a nutshell, in the Appendix below), PFT based on the Tangherlini transformation deals effectively with the considered thought experiment and meets other indispensable conditions for a theory intended to replace STR (and thus to modify GTR). This point is however a matter of further examination, in particular when it comes to electrodynamics. PFT seems to fit better with the quantum mechanics due to the predicted absolute reference of energy, which may open new perspectives in searching for the effective quantum gravity theory.

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APPENDIX

1. Tangherlini transformation

$$x' = x\gamma - vt\gamma$$
$$y' = y$$
$$z' = z$$
$$t' = t/\gamma$$

$$x = x'/\gamma + vt'\gamma$$
$$y = y'$$
$$z + z'$$
$$t = t'\gamma \qquad \text{(A1)}$$

The above transformation refers to the basic (simplest) arrangement of two inertial frames, one of them being preferred and the other (primed) absolutely moving. Unlike in the case of STR, the Lorentz factor $\gamma = \left(1 - v^2/c^2\right)^{-1/2}$ has an absolute reference, i.e., relates to the preferred frame. The effects of time dilation and length contraction, observed in the preferred frame (right column) are complemented by the opposite effects of time speeding and length elongation, observed in the absolutely moving frame (left column). The underlying property of the Tangherlini transformation is connecting the absolute simultaneity with the inconstant one-way velocity of light.

2. Velocity of light

According to PFT, the velocity of light is constant (isotropic) in the preferred frame only. In all other inertial frames, only the averaged two-way velocity of light is constant, while the one-way velocity of light depends on the absolute velocity of inertial observer, and – if the latter has a nonzero value – on the direction of emission. In the general case, the light front forms the prolate spheroid (with the source of emission located in the "frontal" focus), while the exact sphere occurs in the preferred frame only. The general formula is

$$c' = \frac{c - v\cos\varphi}{1 - \left(\frac{v}{c}\right)^2 \cos^2\varphi} \qquad \text{(A2)}$$

(v – absolute velocity of inertial observer, φ – angle of propagation related to the direction of absolute motion, as measured in the observer's frame). In the one-dimensional cases of the light propagating along x-axis, i.e., for $\varphi = 0$ and $\varphi = 180^\circ$, one has respectively:

$$c_1' = (c - v)\gamma^2$$
$$c_2' = (c + v)\gamma^2 \qquad \text{(A3)}$$

When the absolute velocity of inertial observer approaches the velocity of light, the velocity of rays emitted in the direction of motion, and in opposite direction, are respectively:

$$v \to c \Rightarrow c_1' \to 0.5c,\ c_2' \to \infty \qquad \text{(A4)}$$

3. Corresponding velocities

The seemingly self-evident concept of the common relative velocity between two inertial observers (relevant both to Newtonian mechanics and STR) is replaced in PFT by the concept of usually different *corresponding velocities*. The respective claim is:

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

In the case where one frame is preferred and the other frame moves with the absolute velocity v, the corresponding velocities relate to each other as:

$$v' = v\gamma^2 \qquad \text{(A5)}$$

4. Compound Lorentz Factor

In STR, the Lorentz factor is always relative due to the purely relative concept of inertial motion. Instead, in PFT, every inertial frame has certain absolute velocity (defined as relative to the preferred frame), and thus, basically, the Lorentz factor has an absolute reference. However, relativistic effects (time dilation and length contraction) affect both the observer and the observed object. Hence, in most cases, we have not one, but two Lorentz factors, making together (as a quotient) the *compound Lorentz factor*. This requires using two separate symbols, the used so far: γ – denoting an absolute Lorentz factor for the observed object, and the new one: δ – an absolute Lorentz factor for the inertial observer. Consequently, if both observer and the observed object move at some (usually different) absolute velocities, then, irrespectively of directions of these motions in the preferred frame, the resultant compound Lorentz factor is γ/δ, 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 observed object, v_2 – absolute velocity of observer).

From that it follows that, in all cases when $\delta > \gamma$, the relativistic effects (as they are defined in STR) change to their opposite: length expansion, time speeding and the mass/energy decrease. However, due to the mathematically explainable mechanism (called *observational equivalence* between PFT and STR, described in [1] and [2]), only the mass/energy decrease can be directly observed.

5. PFT Energy Formula for the General Case

The Einstein's famous mass-energy formula is $E = mc^2$ or, after distinguishing between *rest mass* and *relativistic mass*, $E = \gamma m_0 c^2$. Instead, the respective PFT formula is

$$E = \gamma\delta^{-1} m_0 c^2 \qquad \text{(A6)}$$

where $\gamma\delta^{-1}$ is the compound Lorentz factor. This formula expresses the PFT prediction, according to which mass/energy of the observed moving body can either increase or decrease, depending on the absolute velocities of the body and the observer. For any case of the observed body being at rest with respect to inertial observer, one has $v_1 = v_2$, implying $\gamma\delta^{-1} = 1$ and therefore $E = m_0 c^2$, in agreement with the STR prediction of rest energy.