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Chapter 11

Is There an Alternative to the Block Universe View?

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Abstract

This paper pursues two aims. First, to show that the block universe view, regarding the universe as a timelessly existing four-dimensional world, is the only one that is consistent with special relativity. Second, to argue that special relativity alone can resolve the debate on whether the world is three-dimensional or four-dimensional. The argument advanced in the paper is that if the world were three-dimensional the kinematic consequences of special relativity and more importantly the experiments confirming them would be impossible.

1. Introduction

If one can talk about a widely (explicitly or implicitly) accepted view on reality it is presentism — the view that it is only the present (the three-dimensional world at the moment "now") that exists. This common-sense view, which reflects the way we perceive the world, has two defining features: (i) the world exists only at the constantly changing present moment (past and future do not exist) and (ii) the world is three-dimensional.

Our immediate perception of the external world reveals it as being in a constant change. The concept of time and its three components — past, present, and future — are deduced from what we directly perceive. And indeed, in ancient Greece Heraclitus argued that the world is perpetually changing, but did not explicitly discuss the relationship between change and time (as the excerpts from his writings that reached us appear to show). According to him everything flows (*panta rhei*), everything moves (*panta chorei*) (Barnes, 1982, p. 65). Later, Aristotle effectively arrived at the conclusion that everything exists only at the moment ''now'' since it is this moment that ''connects past and future time'', (Aristotle, 1993, p. 301) which themselves do not exist: ''one part of (time) has been and is not, while the other is going to be and is not yet''. (Aristotle, 1993, p. 297) Aristotle made another contribution to the presentist view by arguing that the world is three-dimensional: ''A magnitude if divisible one way is a line, if two ways a surface, and if three a body. Beyond these there is no other magnitude, because the three dimensions are all that there are''. (Aristotle, 1993; see also Galileo, 1967)

The two defining features of presentism — the world exists only at the present moment and the world is three-dimensional — are intrinsically linked: if the world is three-dimensional it exists only at one moment of time and vice versa. Saint Augustine made the first step toward the realization of that link by trying to determine the duration of the moment ''now''. He concluded that the present moment cannot have any duration: ''In fact the only time that can be called present is an instant … . For if its duration were prolonged, it could be divided into past and future. When it is present it has no duration'' (Augustine, 1993, p. 119). In order to see the link between the three-dimensionality of the world and its existence only at the moment ''now'', assume that the present moment has a finite duration. For the sake of the argument let that duration be 10 s. As these 10 s are not further divisible into past, present, and future they are all present. Therefore, every object and the whole world would exist *at once*[1] *at all seconds* of the finite moment ''now''. This means that all objects would be extended in time. For instance, a moving object would exist at once at all points of a distance it travels for 10 s. However, objects that are extended in time are four-dimensional, not three-dimensional. The presentist view is based on the fact that we seem to perceive three-dimensional objects, i.e. objects that do not appear to exist at more than one instant of time. So, on the presentist view the fact that the world is regarded as three-dimensional implies that the present moment must be an instant with no duration.

Saint Augustine could not have possibly realized that the duration of the moment ''now'' must be zero (as he concluded) in order that the world be three-dimensional. But presentists should see this clearly. The realization of the link between the three-dimensionality of the world and its existence *only* at the present moment (whose duration is zero) shows that the past and the future do

[1]Obviously, here ''at once'' does not mean ''simultaneously''. Throughout the paper ''at once'' will be used timelessly to mean ''given as a whole'' or ''given in its entirety''.

not exist in any sense in the framework of the presentist view. The past and the future are merely sets of previous and forthcoming *states* of the three-dimensional world, which exists *solely* at the present moment. But states do not exist on their own without the entity they are states of.

Another view on reality that is *ontologically* different from presentism and for this reason is completely counter-intuitive is the block universe view. It can be traced back to the eternal and unchanging being of the Eleatic school of philosophy (Barnes, 1982, Chapter X). Saint Augustine also believed in an ever-present eternity which, however, was not accessible to humans (Augustine, 1993). In 1884, Hinton wrote about a four-dimensional world in which the ordinary particles are regarded as threads (Hinton, 1884, 1980. The scientific birth of the block universe view, however, was in 1908 when Minkowski proposed that space and time should be united into an inseparable four-dimensional entity — spacetime — which he called *the world*. He began his talk at the 80th Assembly of German Natural Scientists and Physicians with the now famous introduction: "The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality"(Minkowski, 1952; Lorentz, Einstein, Minkowski, & Weyl, 1952, p. 75).

It should be pointed out that Minkowski viewed the idea of the world as being not objectively split into space and time as deduced from the experimental evidence and not just as an alternative representation of special relativity. That is why a genuine understanding of special relativity could not be achieved without regarding spacetime as a four-dimensional space whose four dimensions are *entirely given*[2] (like the two dimensions of a plane). Minkowski left no doubt that the idea of spacetime should be understood in this way by pointing out one immediate consequence of that idea, namely that one could not talk about *one* space any more. He noticed that "neither Einstein nor Lorentz made any attack on the concept of space" (Minkowski, 1952, p. 83) and stressed that the idea of many spaces is inevitable in special relativity: "We should then have in the world no longer *space*, but an infinite number of spaces, analogously as there are in three-dimensional space an infinite number of planes.

[2]It might appear tempting to regard the temporal dimension as not entirely given, but if this were the case spacetime would not be four-dimensional–one cannot talk about a four-dimensional entity if all dimensions are not equally existent. Spacetime is not like space since the nature of the temporal dimension is different from the nature of the spatial dimensions, but this has nothing to do with the equal existence of all dimensions of spacetime (like the different nature of physical objects and phenomena has nothing to do with their existence). In this respect I completely share the position of Taylor and Wheeler regarding the temporal and spatial dimensions of spacetime: "Equal footing, yes; same nature, no" (Taylor & Wheeler, 1992).

Three-dimensional geometry becomes a chapter in four-dimensional physics. Now you know why I said at the outset that space and time are to fade away into shadows, and only a world in itself will subsist''. (Minkowski, pp. 79–80) But although Minkowski demonstrated that the consequences of special relativity (length contraction, for instance) found a natural explanation in the four-dimensional spacetime, he did not find it necessary to argue that these consequences were possible only in a four-dimensional world.

Unfortunately, the depth of Minkowski's idea does not seem to have been immediately and fully appreciated as evident from Sommerfeld's notes on Minkowski's paper: ''What will be the epistemological attitude towards Minkowski's conception of the time–space problem is another question, but, as it seems to me, a question which does not essentially touch his physics''. (Sommerfeld, 1952)

About two decades after Minkowski's four-dimensional formulation of special relativity Weyl appeared to have realized that Minkowski spacetime is not merely a mathematical space but represents a four-dimensional external world which is not directly reflected in our perceptions: ''The objective world simply is, it does not *happen*'' (Weyl, 1949). In 1952, Einstein added the fifth appendix ''Relativity and the problem of space'' to the 15th edition of his book ''Relativity: The Special and General Theory'' in which he seemed to have arrived at the same conclusion: ''It appears … more natural to think of physical reality as a four-dimensional existence, instead of, as hitherto, the *evolution* of a three-dimensional existence'' (Einstein, 1961). However, neither Weyl nor Einstein showed that the four-dimensionality of the world unavoidably follows from the consequences of special relativity.

The first argument designed to demonstrate that one of the basic consequences of special relativity — relativity of simultaneity — inescapably implies a four-dimensional world was advanced by Rietdijk (1966) and Putnam (1967). Later, the same argument was rediscovered by Maxwell (1985). However, it was criticized twice by Stein, (1968, 1991) — in 1968 after Rietdijk and Putnam published their papers and in 1991 after the appearance of Maxwell's paper. This double criticism appears to have created the impression that Stein ''has settled the issue'' (Clifton & Hogarth, 1995).

Stein's criticism of the Rietdijk–Putnam argument is revisited in Section 2. A closer examination of this argument shows that Stein's objections not only does not disprove it but also, in fact, further reinforce it. Section 3 develops a more general argument, which demonstrates that the consequences of special relativity and the experiments, which confirm them, would be impossible if the world were three-dimensional and if the existence of the objects involved in these experiments is absolute. This shows that only the block universe view does not contradict the experimental evidence, which supports special relativity. The issue of whether or not an equivalence of three- and four-dimensional presentations of special relativity implies an equivalence of three- and four-dimensional ontologies is discussed in Section 4.

2. Has Stein disproved the Rietdijk–Putnam argument?

To analyze Stein's objections let us briefly describe a version of the argument he criticized. Consider three inertial observers A–C in relative motion whose worldlines are shown in Fig. 1. Observers A and B meet at event M. The third observer C is represented by a vertical worldline in the figure, which means that A is approaching C, whereas B is receding from C.

Two events P and Q happen with C at different moments of his proper time. Since an event in relativity is defined as an object, a field point, or a space point at a given moment of time, the events P and Q are simply the observer C existing at the moments t_P^C and t_Q^C of his proper time, respectively. As event P is simultaneous with event M according to B and therefore lies in observer B's present, both events M and P are equally real for B (according to Putnam) or equally determinate for B (according to Rietdijk). Event Q is simultaneous with event M in A's reference frame; that is, it belongs to observer A's present. This means that both events M and Q are equally real and determinate for A. Since Putnam and Rietdijk assumed that the reality and determinateness of an event are *absolute* (observer-independent) they arrived at the conclusion that if event Q is real (determinate) for observer A, it should be as real (determinate) for observer B and for observer C as well. Therefore, observer C should exist *at once* at both moments t_P^C and t_Q^C of his proper time since events P and Q (corresponding to the two moments) are equally real. But such a situation is not possible in the common-sense (pre-relativistic) view according to which it is only the present — the three-dimensional world at the moment "now" — which exists. This led Rietdijk and Putnam to conclude that relativity of simultaneity,

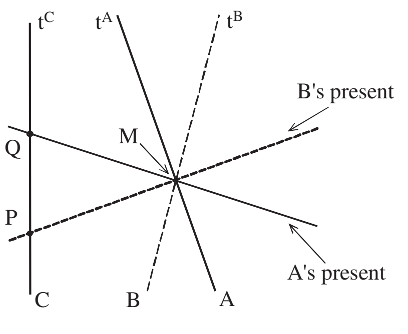

Fig. 1. Three inertial observers A–C are in relative motion. Events M and Q belong to A's present and are therefore real and determinate for A, whereas for B real and determinate are events M and P, since they lie in B's present.

when applied to what exists, contradicts the presentist view and is possible only in a four-dimensional world, where the histories of the physical objects are entirely realized in their four-dimensional worldtubes. In such a view the presents of observers A and B are equally real because they are merely three-dimensional cross-sections of the four-dimensional world.

Stein criticized the Rietdijk–Putnam argument since it incorrectly used the concept of *distant present events* (i.e. the concept of the present), which is based on the pre-relativistic division of events into past, present, and future. He pointed out that ''in the theory of relativity the only reasonable notion of 'present to a space–time point' is that of the mere identity relation: present to a given point is that point alone — literally 'here-now'''. (Stein, 1991, p. 159). This is a valid objection but it does not affect the ultimate conclusion of the Rietdijk–Putnam argument — that the world is four-dimensional. The reason is the following.

In fact, Stein's criticism of the Rietdijk–Putnam argument supports the first part of the argument — that presentism contradicts special relativity and is therefore wrong. And indeed the present, i.e. the three-dimensional world at the moment ''now'', can be defined only in terms of the pre-relativistic division of events into past, present, and future. More specifically, the present is defined in terms of *simultaneity* — as everything that exists *simultaneously* at the present moment. Therefore, Stein's argument that one cannot talk about distant present events in the framework of special relativity is an argument against presentism. So, Stein's criticism is effectively directed against the three-dimensionality of the world since a three-dimensional world consists of distant present events (everything that exists simultaneously at the moment ''now''). But, unfortunately, he did not address the most fundamental question Rietdijk and Putnam had raised — what is the dimensionality of the world according to special relativity? Had he done that he would have had two options:

- accept the conclusion of Rietdijk and Putnam that we live in a four-dimensional block universe,
- regard the event ''here-now'' as the only real one.

The latter option, however, does not appear realistic since such a view clearly amounts to event solipsism — for every observer the world would be reduced to a single event (the event ''here-now''). Once the question ''What is the dimensionality of the world''? is asked, one could not hold the view that only the event ''here-now'' is real because that would mean that for every observer the world would be zero-dimensional (just one event). It should be stressed that it amounts to a contradiction in terms to say that the world is four-dimensional, but for every observer only the event ''here-now'' is real. If the world is four-dimensional all its events are equally real; otherwise it would not be four-dimensional[3]. This shows that in spacetime it is impossible to have an event, representing the event "here-now", which is "more real" than the other events. Therefore, objective flow of time and objective becoming are impossible in a four-dimensional world, if they imply that there are events which are "more real" than the other spacetime events. For this reason, the question of the dimensionality of the world clearly precedes, in my view, the questions of time flow and becoming and should be resolved first.

Stein could not argue that existence should be relative (frame- or observer-dependent), which would preserve the three-dimensionality of the world and would allow two observers in relative motion to have different presents, i.e. different three-dimensional worlds, because this would mean that he would be again using the concept of distant present events applied to each observer. In such a way Stein's criticism of the Rietdijk–Putnam argument not only does not disprove it but also effectively constitutes another argument for the block universe view: the world cannot be three-dimensional since a three-dimensional world is defined in terms of the pre-relativistic division of events and therefore the only option that remains is a four-dimensional world. This argument appears to be even more rigorous than the Rietdijk–Putnam argument because both Rietdijk and Putnam used the pre-relativistic concept of distant present events to arrive at the conclusion that the world is four-dimensional, whereas by pointing out the meaninglessness of that concept in special relativity Stein effectively demonstrated the contradiction between the presentist (three-dimensionalist) view and relativity which meant that it is the four-dimensionalist view that is in agreement with relativity.

In terms of its real value, Stein's criticism is similar to Weingard's criticism of the Rietdijk–Putnam argument. Weingard (1972) wrote:

> In his 1967 [paper] Hilary Putnam concludes that all events in special relativistic spacetime, whether past, present, or future, are equally real, i.e. that a tenseless concept of existence is the appropriate concept of existence in a special relativistic world. Although I believe this conclusion is correct, I think Putnam's argument is not.

Weingard, like Stein, pointed out that Putnam's argument is wrong because it is based on the pre-relativistic concept of the distant present events[4]. Despite being formulated in terms of pre-relativistic concepts I think, the Rietdijk–Putnam argument is perfectly valid for the reason given in the next section.

[3]Similarly, one could not say that only one point of a line is real because that would mean that the line would be reduced to a point and there would be a zero-dimensional, not a one-dimensional space.

[4]Formally, Stein's and Weingard's objections are different but they boil down to the same point — that the pre-relativistic division of events makes no sense in special relativity.

3. Only the four-dimensionalist view is compatible with special relativity

The Rietdijk–Putnam argument can be easily generalized if the question of the *dimensionality* of the world according to special relativity is explicitly addressed. One can start to discuss that question by pointing out that on the pre-relativistic (presentist) view the world is three-dimensional — it is the present (Fig. 2). Then there are two ways to demonstrate the impact of special relativity on this view. First, one can point out that the world cannot be three-dimensional since such a world is defined in terms of the pre-relativistic division of events into past, present, and future as seen in Fig. 2. Therefore, the debate over the dimensionality of the world is resolved in favor of the four-dimensionalist view. This is the conclusion that follows from Stein's argument against the Rietdijk–Putnam argument.

The second approach to determining the dimensionality of the world according to relativity is precisely the generalization of the Rietdijk–Putnam argument. One starts with the pre-relativistic view of the world. Then it inescapably follows that having different sets of simultaneous events two observers in relative motion have different presents, i.e. different three-dimensional worlds. If existence is absolute, it follows that the world must be four-dimensional in order that the relativity of simultaneity be possible: the two observers will have different three-dimensional cross-sections of the four-dimensional world, which they will regard as their presents. If we assume that the world were three-dimensional, two observers in relative motion would have a common three-dimensional world and therefore a common set of simultaneous events, which means that simultaneity would be absolute in contradiction with special relativity.

So, the generalized version of the Rietdijk–Putnam argument does make use of the pre-relativistic concept of present events but that is a completely

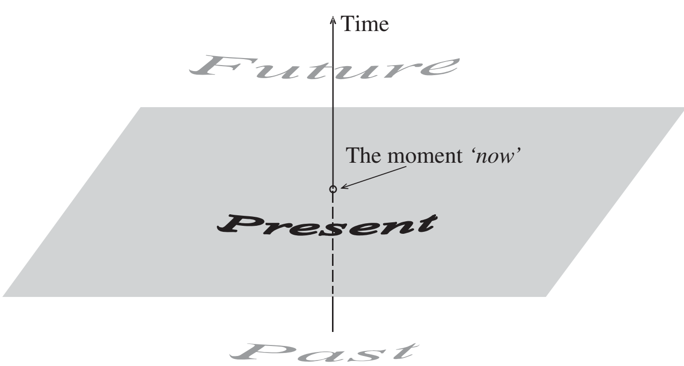

Fig. 2. On the presentist view it is only the present — the three-dimensional world at the moment "now" — that exists.

legitimate and natural approach — one starts with the pre-relativistic (three-dimensionalist) view of the world (defined in terms of that concept) and by taking into account relativity of simultaneity wants to see how special relativity affects this view. Moreover, the kinematic relativistic effects (with the exception of the twin paradox) can be formulated only in terms of the pre-relativistic division of events if the *existence* of the objects involved in these effects is explicitly taken into account. And indeed as we have seen relativity of simultaneity makes sense only in terms of the pre-relativistic concept of present events when we ask what *exists* simultaneously. If one objects that the question "What exists simultaneously?" does not appear to be well defined, it will be shown below that the length-contraction effect makes sense only in terms of the pre-relativistic concept of present events.

When the issue of the dimensionality of the world according to relativity is explicitly addressed, it does appear that there is no alternative to the four-dimensionalist view. This is best seen if one assumed that the world were three-dimensional. Then not only relativity of simultaneity but all kinematic relativistic effects would be impossible (Petkov, 2005, 1986, 1988). This is immediately evident for the cases of length contraction and time dilation since these effects are merely manifestations of relativity of simultaneity.

To demonstrate the impossibility of the kinematic relativistic effects in the framework of the presentist (three-dimensionalist) view consider, for example, the length-contraction effect. Two observers A and B in relative motion meet at event M. The observers are represented by their worldlines as shown in Fig. 3. A rod at rest in A's reference frame is represented by its worldtube.

At event M the two observers determine the length of the rod in their reference frames. For B, the rod is of shorter length $L_B < L_A$. As seen in Fig. 3 the contraction of the rod is only possible if the worldtube of the rod is a real four-dimensional object, which means that the rod exists equally at all moments of its history. The instantaneous three-dimensional spaces of A and B intersect the

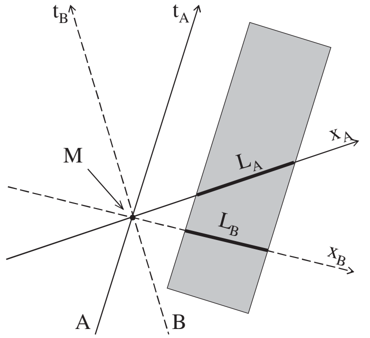

Fig. 3. A rod represented by its worldtube is at rest in observer A's reference frame.

worldtube of the rod at two different places and B's cross-section is smaller than A's cross-section. If the rod's worldtube were not a real four-dimensional object, i.e. if the rod existed only at its present moment and therefore were a three-dimensional object (say, A's rod which is represented by the cross-section L_A), no length contraction would be possible — A's rod of length L_A would exist for B as well[5] and B would measure the same rod with the same length L_A.

It seems little attention has been paid to the fact that A and B do not measure the *same* three-dimensional rod; the rod which B measures is a *different* three-dimensional object. This is clearly seen in Fig. 3 — at event M both A and B know that the rod exists for each of them, but this is only possible if there are two different three-dimensional cross-sections of the rod's worldtube, i.e. *two different* three-dimensional rods. If one decides not to trust spacetime diagrams too much, it is easily demonstrated that the same conclusion follows directly from relativity of simultaneity. The different parts of the spatially *extended* three-dimensional rod constitute a set of events that exist *simultaneously* for A. As B has a different set of simultaneous events (the events constituting the cross-section L_B) it unavoidably follows that B measures a different three-dimensional rod. In order that this be possible, the rod's worldtube must be a real four-dimensional object. So, when we say that A and B measure the *same* rod we refer to the worldtube of the rod, but the observers regard different three-dimensional cross-section of the rod's worldtube as their rod, which means that they do measure *different* three-dimensional rods.

The fact that B measures a different three-dimensional rod appears to rule out any explanation of the length-contraction effect that involves a deformation of the rod caused by forces acting on the rod's atoms along the lines of the original Lorentz–FitzGerald proposal and what Bell (1987) called "Lorentzian pedagogy" (see also Brown & Pooley, 2001). The reason is that the deformation (or dynamical) explanation of the length contraction implies that A and B measure the *same* three-dimensional rod, whereas relativity of simultaneity requires that A and B measure *different* three-dimensional rods. Perhaps, the most convincing argument that the deformation explanation of the length contraction is wrong, however, is that this explanation cannot account for the contraction of *space* itself where there are no atoms and no forces that can cause its deformation. For instance, the muon experiment (Rossi & Hall, 1941) cannot be explained if it is assumed that space does not contract (Ellis & Williams, 1988).

Let us now see why the length contraction can be formulated only in terms of the concept of distant present events, which demonstrates that this concept is

[5]If the rod existed only at its present moment, which would mean that it is *ontologically* a three-dimensional object (retaining its identity as a three-dimensional object in time), it would not exist in its past and future. Therefore, B's cross-section of length L_B would lie in the rod's past and would not exist.

still used in special relativity when the *existence* of the physical objects involved in this relativistic effect is described in three-dimensional language. When A and B meet at M what everyone of them measures is what *exists* for him — his *present* rod, that is, all parts of the spatially extended three-dimensional rod which exist simultaneously at the moment "now" of the observer. Therefore the three-dimensional rod constitutes (is defined as) a set of *distant present events* and both observers must use this pre-relativistic concept in order to talk about a three-dimensional rod. The same situation occurs in the time dilation effect — it too can be formulated only in terms of distant present events when one considers the existence of the physical objects that take part in this effect (Petkov, 2005, Chapter 5). But the very fact that this concept has no meaning in special relativity implies that there is nothing three-dimensional in the objective world. In the case of length contraction each of the observers A and B in Fig. 3 measures a three-dimensional rod, but it is not a real three-dimensional object in the sense that it is not an object, which retains its identity through time as the *same* three-dimensional object. What is real is the rod's worldtube. Its existence is deduced from the existence of length contraction — if the worldtube did not exist no length contraction would be possible (below I will provide further arguments for this strong claim).

A's and B's rods are not real three-dimensional objects because the rod's worldtube is an indivisible four-dimensional entity which is not objectively divided into three-dimensional cross-sections[6]. Therefore, the three-dimensional rod every observer measures is just a *description* of the rod's worldtube in terms of the ordinary three-dimensional language. This situation is analogous to the one that arises when the x–y planes of different coordinate systems "cut" different two-dimensional cross-sections of a cylinder — those sections are not real two-dimensional objects since the cylinder itself is not objectively divided into different two-dimensional cross-sections.

Our commonsense belief in the existence of three-dimensional objects and a three-dimensional world originates from the way we interpret what we perceive. For instance, we believe that we see three-dimensional objects and a three-dimensional world. However, this is clearly not the case as seen in Fig. 4. Observers A and B, who are in relative motion, have different sets of simultaneous events and therefore different three-dimensional worlds, but at event M they both see the *same* thing — the past light cone. They interpret all images contained in the light signals, which constitute the past light cone in a sense that at event M they perceive a three-dimensional world. This is an obvious misconception since the past light cone does not form a three-dimensional space or a three-dimensional world, which is defined in terms of simultaneity — a

[6]This is a direct consequence of the fact that spacetime is not objectively divided into different spaces, i.e. different three-dimensional cross-sections.

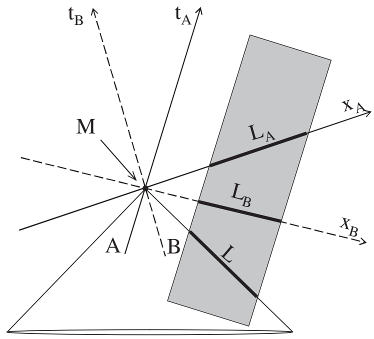

Fig. 4. What observers A and B see is the same cross-section L of the rod's worldtube. In general, when two observers A and B in relative motion meet at event M they see the past light cone.

three-dimensional world is defined as all space points and all three-dimensional objects that correspond to the *same* moment of time. It is obvious that the points of the past light cone do not correspond to the same moment of the time of each of the observers. In particular, A and B have different three-dimensional rods, but they see the *same* three-dimensional cross-section L which, however, cannot be regarded as a three-dimensional rod since all parts of a three-dimensional object exist *simultaneously* at one moment (the moment "now"). By contrast, the parts of the three-dimensional cross-section L correspond to different moments of the time of each observer[7]. It follows from here that it is not possible to interpret the length contraction in a sense that it is the *same* three-dimensional rod that exists for A and B, but they see it differently.

The fact that A and B have different three-dimensional rods means that the two rods of lengths L_A and L_B, respectively, belong to the presents of A and B that correspond to event M. However, it is obvious that the observers do not usually measure the length of their rods at M since in most cases a measurement takes some time and each of the observers sees his rod a little later, not at the moment when light signals left simultaneously the end points of the rod. But when the observers take into account that delay, they arrive at the conclusion that at the event M they had different sets of simultaneous events and therefore *different* three-dimensional rods. So, the fact that observers are not usually in an immediate contact with what they measure does not affect the conclusion that A and B have different three-dimensional rods — a conclusion which demonstrates that on the presentist view the length-contraction effect is impossible since on that view the rod exists only at its present moment as a *single*

[7]The fact that what we see are images, which cannot be interpreted to represent three-dimensional objects is itself another indication that our senses cannot be fully trusted especially when it comes to such fundamental questions as the dimensionality of the world.

three-dimensional object, which means that A and B cannot have different three-dimensional rods as relativity of simultaneity requires.

Although the realization of the physical meaning of length contraction — that A and B have different three-dimensional rods — is a direct consequence of relativity of simultaneity, it is so counter-intuitive that it is worth to consider a thought experiment (Petkov, 2005, p. 137) in which the measurement of the rod's length is instantaneous in A's and B's reference frames. This thought experiment will also provide additional arguments supporting the claim that the three-dimensionalist view contradicts the experiments which confirmed the kinematic relativistic effects.

Let the rod again be at rest in A's reference frame (Fig. 5). There are lights mounted on the end and the middle points of the rod. At every instant the color of the lights changes simultaneously in A's reference frame: an instant before the meeting of A and B all three lights are green at the moment t_A^g, at the moment of the meeting $t_A^M = t_A^r$ the lights are red, and an instant after the meeting they are blue at t_A^b. As seen in Fig. 5, A and B move along their x axes and the rod is positioned parallel to A's x axis. Both A and B place cameras at different points of their x axes. All cameras have clocks that have been synchronized in advance in each frame by using the Einstein rule (assuming that the back and forth velocity of light in A's and B's frame is the same). The cameras have been

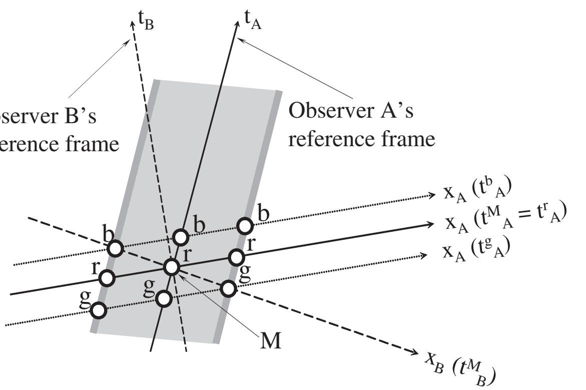

Fig. 5. Observers A and B, who are in relative motion, meet at event M. A rod at rest in A's reference frame has lights mounted on its two end points and on its middle point. In A's frame all lights of the rod were simultaneously green an instant before the meeting with B; they are all red at the moment of the meeting, and their color changes simultaneously to blue, for A an instant after the meeting. Each of A and B determines the rod's length instantaneously in his frame by taking snapshots of the rod's end and middle points with cameras placed at different points on A's x-axis and on B's x-axis along which the rod moves. The rod, which B measures, consists of parts of A's past rod (with the green light), present rod (with the red light), and future rod (with the blue light).

synchronized in such a way that all clocks in each frame show zero at the event of the meeting M.

When A and B meet at M at the moment $t_A^M = 0$ of A's time and at $t_B^M = 0$ of B's time they determine the length of the rod instantaneously in their reference frames by taking snapshots of its end and middle points. Some time after the meeting A and B collect all pictures from their sets of cameras to see the results of their experiments. Observer A sees that the three pictures (showing the middle and the two end points of the rod) display the same time $t_A^M = 0$ and the same color — red, red, and red. Observer B also sees that the three pictures show the same time $t_B^M = 0$, but the colors in the three pictures are green, red, and blue.

Let us now ask what exists for A and B at M. As at the instant of the meeting all three red lights of the rod are simultaneous for A, at his present moment $t_A^M = t_A^r$ what exists for him at M is the red rod which lies in A's present. The green rod existed for A one instant *before* the meeting and is in his past while the blue rod will exist one instant *after* the meeting and is in his future. According to the presentist view the green and blue rods do not exist for A at $t_A^M = t_A^r$ since they belong to A's past and future, respectively.

As observer B has a different class of simultaneous events at M, it does follow that at the moment t_B^M the lights of the rod will not all be red for B. The fact that at M in B's present lies a three-dimensional rod whose front end point, middle point, and rear end point are green, red, and blue, respectively (B is moving to the left in Fig. 5) means that the green–red–blue rod, which is present for B, consists of part of A's past rod (the front end point with green light), part of A's present rod (the middle part of the rod, which is also present and therefore exists for A at the moment of the meeting), and part of A's future rod (the rear end point with blue light). As all parts of a spatially extended three-dimensional object exist *simultaneously* at the present moment of an observer, the three-dimensional rod that exists for B at his present moment t_B^M is *different* from the three-dimensional rod of A existing at his present moment $t_A^M = t_A^r$. (The event of the meeting M in Fig. 5 is the only common present event for both observers.) The rod of each observer is composed of a mixture of parts of the past, present, and future rods of the other observer. Therefore, the conclusion that each of the observers A and B measures a *different* three-dimensional rod is indeed inevitable.

Imagine now that this experiment has been performed and, as expected, confirmed both the length contraction and the relativity of simultaneity. What conclusions can be drawn from it? The observers A and B will be convinced that the only way to explain their pictures is to assume that the rod they measured exists equally (at once) at all moments of its history in time. Their reason is that the experiment directly confirmed this conclusion: parts of the rod's past, present, and future (which are also A's past, present, and future since the rod is at rest in A's frame) exist *simultaneously* as B's present rod. A's present rod also contains parts of B's past, present, and future rod[8]. This would not be possible if the rod did not exist equally in its past, present, and future[9]. Therefore, A and B conclude that their experiment has a profound physical meaning — it proves that all physical objects are extended in time, which means that they are four-dimensional.

A and B believe they can claim that a single experiment, which allowed a single interpretation, proved the four-dimensionality of the world. However, a philosopher of science would immediately disagree. He will point out that the claim is based on an implicit ontological assumption — that the existence of the physical objects is *absolute* (observer- or frame-independent). Since this claim is deduced from an experiment no other ontological assumptions seem to be needed. For instance, it does not appear necessary to assume (i) that A's and B's sets of simultaneous events are ontologically equivalent since both A and B used the same rule to synchronize the clocks of their cameras, and (ii) that A and B are ontologically equivalent since they carried out identical experiments[10].

The philosopher of science will explain that the experiment performed by A and B allows two interpretations:

(i) if existence is absolute, the simultaneous existence of parts of A's past, present, and future rod as B's present rod (and vice versa) does lead to the conclusion that the rod must exist equally at all moments of its history;
(ii) if existence is relative (observer- or frame-dependent), each observer will claim that it is only his three-dimensional rod that exists.

A and B admit that their experiment allows a second interpretation, but since the experiment is, in their view, the ultimate judge they are convinced that it is only the experiment that can decide whether the world is three- or

[8]This specific experiment would allow A and B to arrive at the idea of the rod's worldtube even if they never heard of Minkowski.

[9]The experiment depicted in Fig. 5 deals only with the immediate past and future of the rod, but one can add other observers that also meet A at M but their velocities relative to A are greater than B's velocity. The present rods of these observers will contain parts of more distant past and future of A's rod.

[10]Even if A and B are not equivalent (inertial) observers the same conclusion will be drawn. Imagine that two inertial observers A and B and an accelerated observer C meet at M (but A's frame is not C's comoving inertial reference frame at M). C's present rod will again be a mixture of A's past, present, and future rod and the conclusion that the rod's worldtube must exist follows. In this case, C will use (before the meeting) the same synchronization procedure but with a small correction to the velocity of light (proportional to C^{-2}) (Petkov, 2005) which, however, does not affect the final conclusion. This is immediately seen if B's frame is C's comoving inertial reference frame at M which means that B and C have a common set of simultaneous events at M. Therefore, B and C will have the same contracted rod that consists of parts of A's past, present, and future rod.

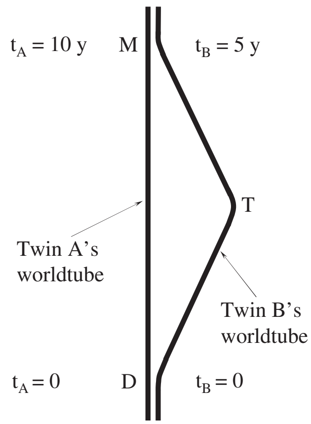

Fig. 6. Twins A and B are represented by their worldlines. At the event of departure D twin B starts a journey at a speed that is close to the speed of light. At event T he turns back and meets his brother at event M.

four-dimensional. They agree that, formally, existence can be regarded as relativized. A and B realize that such an assumption preserves the three-dimensionality of the world, but it is an alternative option to the conclusion of a four-dimensional world only in the case of the *reciprocal* length contraction and time dilation which are based on relativity of simultaneity. That is why A and B concentrate their attention on the twin paradox since it is an absolute, not a reciprocal effect, which means that no relativity of simultaneity is involved in its explanation and therefore the relativization of existence should not be an alternative explanation.

And indeed the derivation and the explanation of the twin paradox (Fig. 6) are based on the triangle inequality in the pseudo-Euclidean geometry of spacetime, which *presupposes* the existence of the twins' worldlines (in order to be able to talk about a triangle in spacetime). In other words, the explanation of the twin paradox is in the framework of the four-dimensionalist view: the length of twin B's worldline between the event of the departure D and the event of the meeting M is shorter than the length of twin A's worldline between the same events (in Fig. 6 twin B's worldline is longer but this is caused by the representation of a pseudo-Euclidean relation on the Euclidean surface of the page). This means that B measures less time between D and M than his brother.

Let us now see, how the view of relativized existence contradicts the experiments that confirm the twin paradox[11]. Assume that the world is objectively three-dimensional as this view states. This is an ontological assumption; the *description* of the world in a three-dimensional language is a completely different issue. Obviously, in such a world the twins exist as three-dimensional bodies

[11]This is a summary of an argument which is given in Petkov (2005).

at their moments 'now' only. When A and B meet at event M they both will exist at this event and nowhere else — neither in their pasts not in their futures. As seen in Fig. 6 at M twin A's clock shows that 10 years have passed between events D and M, whereas according to twin B's clock only 5 years have elapsed between the same events. Both twins agree that B is younger. As on both the pre-relativistic and the relativized three-dimensionalist view time objectively flows, the only way for the twins to explain the 5-year difference of their clocks' readings at M is to assume that twin B's time has slowed down. The acceleration to which B is subjected appears to be the only cause for the slowing down of B's time. However, that cause has been ruled out by (i) the so-called "clock hypothesis" according to which the rate of an ideal clock is not affected by its acceleration (Misner, Thorne, & Wheeler, 1973; d'Inverno, 1992; Naber, 1992) (and the experiments which confirm it, Mould, 1994), and (ii) the three-clock version of the twin paradox (see, for instance, Kroes, 1983). Hence the three-dimensionalist view cannot explain why twin B is younger which means that this view cannot explain the twin paradox[12].

Another argument, which, in my view, even more clearly shows that the three-dimensionalist view contradicts the twin paradox, is the following. What A's and B's clocks show is their *proper times*. So at M the twins compare their proper times. Given the fact that on the three-dimensionalist view time objectively flows, the twin paradox and the time dilation make sense only in terms of a *change of the rate of the time flow*. But this is precisely the problem for the three-dimensionalists — the rate of the proper time does not change[13] according to special relativity (proper time is an invariant), which means that when A and B meet at M their clocks should show the *same* time.

I believe this argument convincingly shows that the three-dimensionalist view contradicts not only the twin paradox as a theoretical result, but more importantly all experiments that confirmed it. These experiments also rule out the ontological assumption that existence should be relativized since this assumption requires that the world be three-dimensional[14].

I think nature has given us the twin paradox as a valuable gift — the interpretation of the experiments, which confirm it, does not appear to need any ontological assumptions and for this reason these experiments allow a single interpretation and *alone* resolve the debate over the dimensionality of the world.

[12]It may appear inviting to "explain" the different readings of the twins' clocks by saying that time is frame-dependent in relativity. However, this is not an explanation at all since the very question is: Why is time frame-dependent in relativity?

[13]What is relativistically dilated is not the proper time, but the time of a clock, which is determined by a second clock with respect to which the first clock moves uniformly.

[14]This means that the length contraction experiment depicted in Fig. 5 has just one interpretation — the rod's worldtube must be a real four-dimensional object in order that the observers A and B have different three-dimensional rods.

As we have seen, the analysis of relativity of simultaneity, length contraction, and the twin paradox leaves no doubt that we live in a four-dimensional block universe in which the whole histories of all objects are realized in their worldtubes[15]. The same conclusion is reached when time dilation is analyzed (Petkov, 2005). What indicates that special relativity *alone* resolves the issue of the dimensionality of the world at the macroscopic[16] level is the fact that not only would the kinematic relativistic effects be impossible if the world were three-dimensional, but also the experimental evidence which confirms them would not be possible either. And indeed any experiments designed to test the three relativistic effects we discussed — relativity of simultaneity, length contraction, and the twin paradox — would detect absolute simultaneity, no length contraction, and no time difference in the twins' clocks' readings if the world were three-dimensional. For instance, the muon experiment (Rossi & Hall, 1941) which proves both length contraction and time dilation would be impossible if the world were three-dimensional.

It is a widely accepted view "that relativistic mechanics does not carry a particular ontological interpretation upon its sleeve" (Balashov, 2000), but the conclusion that the relativistic effects are possible only in a four-dimensional world demonstrates that special relativity does contain just one ontology — the four-dimensional ontology — which is deducible from those effects. In light of the arguments presented here, I believe this widely accepted view should be made more explicit. Here is how Balashov (2000) presents it:

> It is a well-known fact that one could accept all the empirical consequences of SR (including length contraction, time dilation, and so on) and yet insist that there is a privileged inertial reference frame, in which meter sticks really have the length they have and time intervals between events refer to the real time.

What should be made more explicit is the physical meaning of such a privileged inertial frame. In my view, this can be best achieved by asking what is the *dimensionality* of the world in which such a frame can exist. Then, as a privileged inertial frame means a privileged three-dimensional space, it becomes evident that there are two options: (i) a three-dimensional world, and (ii) a four-dimensional world in which "associated with this reference frame would be a set of hyperplanes of simultaneity uniquely slicing space–time into equivalence classes of absolutely simultaneous events". (Balashov, 2000)

I think it is obvious that option (i) contradicts special relativity and in this sense is empirically distinguishable from it. Option (ii) is, in fact, a block universe in which the privileged three-dimensional cross-sections (i.e. the privileged

[15] An independent argument for the four-dimensionality of the world comes from the conventionality of simultaneity (Petkov, 1989).

[16] The macroscopic level of the world is specified here in order to distinguish the issues of dimensionality of the world in relativity and in string theory, for example.

hyperplanes of simultaneity) should be objectively distinguishable from the three-dimensional cross-sections of the other reference frames. That this does not appear to be the case is demonstrated in Fig. 5 where both observers measure directly and instantaneously the length of the rod without the need of any assumptions or calculations. Assume that A's rod lies on such a privileged three-dimensional cross-section, whereas B's rod lies on an "ordinary" three-dimensional cross-section. How can the privileged rod of observer A be objectively distinguishable from the "ordinary" rod of B if that privileged state cannot be discovered experimentally? Note that due to the direct measurement of the rod's length the following explanation would not work[17]: "A suggested privileged reference frame would not be distinguished in any empirical sense and would not be identifiable in any real experience. Thus the speed of light measured in any inertial frame would still be exactly *C*, the number obtained by dividing the apparent distance covered by light by the apparent time spent". (Balashov, 2000)

4. Different descriptions versus different ontologies

The arguments advanced in this paper were concerned with the question of what ontology — three- or four-dimensional — is compatible with special relativity. The reason for placing the emphasis on this question is that it is this question, in my view, which is most fundamental in the interpretation of special relativity.

However, McCall and Lowe have recently argued that if the world can be equivalently described in a three- and four-dimensional language, the debate over the three-dimensional versus four-dimensional ontologies should not reflect a real problem: "the three-dimensional and the four-dimensional descriptions of the world are equivalent" and therefore "it is not a question of one being true and the other false" (McCall & Lowe, 2003). There are two objections to this claim. First, it is not completely clear in what sense one can talk about a three-dimensional description of the world. At first sight it appears that the 1905 Einstein paper is an example of how relativity can be described in a three-dimensional language. However, upon a closer examination it turns out that this description presupposes a four-dimensional ontology. To see that assume the opposite — that the original Einstein presentation of special relativity implies a three-dimensional ontology. But simultaneity is absolute in a three-dimensional world which means that it is impossible to regard the times t and t' of two observers in relative motion on equal footing. Hence, special relativity does not work in a three-dimensional world. It can be argued that it is Lorentz's description of moving bodies, not Einstein's theory, that implies a

[17] It should be noted that the constancy of the velocity of light is not determined as stated in the quote. Every inertial observer measures the velocity of light in his reference frame; so no apparent distance and no apparent time are involved in his calculations.

three-dimensional ontology since it regards only one of the times t and t' as the true time. Then due to the different ontologies (involving different dimensions of the world) behind Lorentz's and Einstein's theories a rigorous and consistent application of Lorentz's ideas would lead to predictions which differ from the predictions of special relativity[18]. Lorentz himself admitted the failure of his approach (Lorentz, 2003):

> The chief cause of my failure was my clinging to the idea that the variable t only can be considered as the true time and that my local time t' must be regarded as no more than an auxiliary mathematical quantity. In Einstein's theory, on the contrary, t' plays the same part as t; if we want to describe phenomena in terms of x',y',z',t' we must work with these variables exactly as we could do with x,y,z,t.

The second objection to McCall's and Lowe's claim is based on the superiority of an ontology over a description. It is a fact that the kinematic consequences of special relativity can be expressed in three-dimensional language, but this does not mean that for special relativity a three-dimensional ontology is as good as the four-dimensional ontology. If a three-dimensional ontology is consistently presupposed, no three-dimensional description of the kinematic relativistic effects would be possible since the effects themselves would be impossible. This situation can easily be visualized in a two-dimensional space. Consider a strip on a plane. The x axis of a coordinate system "cuts" the strip at a given location. One can describe the whole strip by taking into account the one-dimensional cross-sections that correspond to different values of y. That the strip can be equivalently described in one- and two-dimensional language, does not imply equivalence of the one- and two-dimensional ontologies — the strip is either a strip or a line.

The major objection regarding the three- and four-dimensionalist views as equivalent is that such an equivalence amounts to regarding a three- and a four-dimensional world as equivalent.

5. Conclusions

It has been shown that the three-dimensionalist view contradicts special relativity and more importantly the experiments, which confirm its consequences. To demonstrate this contradiction relativity of simultaneity, length contraction, and the twin paradox were analyzed and it was shown that if one assumed that the world were three-dimensional, neither of these relativistic effects would be possible.

[18] For instance, no reciprocity of the length contraction is possible in a three-dimensional world. Most importantly, however, the experiment shown in Fig. 5 will rule out Lorentz's theory if it does presuppose a three-dimensional world.

In this sense special relativity *alone* appears to provide a definite proof of the block universe view. One may argue that the arguments discussed here are insufficient for rejecting the presentist view since those arguments demonstrated that presentism contradicts only special relativity, not the other established theories (quantum mechanics, for instance). Such a position could hardly be defended because if a view contradicts the experimental evidence it is definitely wrong. There is just one way to prove that the presentist view does not contradict the relativistic effects — to demonstrate that the experiments, which confirm the kinematic consequences of special relativity can be *explained* (not merely described) if it is assumed that the world is three-dimensional.

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References

Aristotle (1993). Physics, Book IV. In M. J. Adler (Ed.), *Great books of the Western world*, Vol. 7 (pp. 257–355). Chicago: Encyclopedia Britannica.

Aristotle (1993). On the heavens, Book I. In M. J. Adler (Ed.), *Great books of the Western world*, Vol. 7 (pp. 357–405). Chicago: Encyclopedia Britannica.

Augustine, S. (1993). The confessions, Book XI. In M. J. Adler (Ed.), *Great books of the Western world*, Vol. 16 (pp. 1–159). Chicago: Encyclopedia Britannica.

Balashov, Y. (2000). Enduring and perduring objects in Minkowski space–time. *Philosophical Studies*, *99*, 129–166.

Barnes, J. (1982). *The presocratic philosophers*. London, New York: Routledge.

Bell, J. S. (1987). How to teach special relativity. In J. S. Bell (Ed.), *Speakable and unspeakable in quantum mechanics* (pp. 67–80). Cambridge: Cambridge University Press.

Brown, H. R., & Pooley, O. (2001). The origin of the spacetime metric: Bell's 'Lorentzian pedagogy' and its significance in general relativity. In C. Callender, & N. Huggett (Eds), *Physics meets philosophy at the Planck scale* (pp. 256–272). Cambridge: Cambridge University Press.

Clifton, R., & Hogarth, M. (1995). The definability of objective becoming in Minkowski spacetime. *Synthese*, *103*, 355–387.

d'Inverno, R. (1992). *Introducing Einstein's relativity* (p. 33). Oxford: Clarendon Press.

Einstein, A. (1961). *Relativity: The special and general theory* (p. 150). New York: Crown Publishers.

Ellis, G. F. R., & Williams, R. M. (1988). *Flat and curved space times* (p. 104). Oxford: Oxford University Press.

Galileo, G. (1967). *Dialogue concerning the two chief world systems — Ptolemaic and Copernican* (pp. 9–10) (2nd edn). Berkeley: University of California Press.

Hinton, C. H. (1884). *What is the fourth dimension?*. London: W. S. Sonnenschein and Co..

Hinton, C. H. (1980). *Speculations on the fourth dimension: Selected writings*. New York: Dover.

Kroes, P. (1983). The clock paradox, or how to get rid of absolute time. *Philosophy of Science*, *50*, 159–163.

Lorentz, H. A. (2003). *The theory of electrons and its applications to the phenomena of light and radiant heat* (p. 321) (2nd ed.). Mineola, New York: Dover.

Lorentz, H. A., Einstein, A., Minkowski, H., & Weyl, H. (1952). *The principle of relativity: A collection of original memoirs on the special and general theory of relativity*. New York: Dover.

Maxwell, N. (1985). Are probabilism and special relativity incompatible? *Philosophy of Science*, *52*, 23–43.

McCall, S., & Lowe, E. J. (2003). 3D/4D equivalence, the twins paradox and absolute time. *Analysis*, *63*, 114–123.

Minkowski, H. (1952). Space and time. In: Lorentz, Einstein, Minkowski, & Weyl (Eds), pp. 75–91.

Misner, C. W., Thorne, K. S., & Wheeler, J. A. (1973). *Gravitation* (p. 164). San Francisco: Freeman.

Mould, R. A. (1994). *Basic relativity* (p. 83). Berlin: Springer.

Naber, G. L. (1992). *The geometry of Minkowski spacetime* (p. 52). Berlin: Springer.

Petkov, V. (1986). The flow of time according to eleatic philosophy and the theory of relativity. In C. Toegel (Ed.), *Structur und Dynamik wissenschaftlicher Theorien* (pp. 121–149). New York: P. Lang.

Petkov, V. (1988). Weyl's view on the objective world. In W. Deppert, K. Huebner, A. Oberschelp, & V. Weidemann (Eds), *Exact sciences and their philosophical foundations* (pp. 519–524). New York: P. Lang.

Petkov, V. (1989). Simultaneity, conventionality, and existence. *British Journal for the Philosophy of Science*, *40*, 69–76.

Petkov, V. (2005). *Relativity and the nature of spacetime*. Berlin: Springer.

Putnam, H. (1967). Time and physical geometry. *Journal of Philosophy*, *64*, 240–247.

Rietdijk, C. W. (1966). A rigorous proof of determinism derived from the special theory of relativity. *Philosophy of Science*, *33*, 341–344.

Rossi,, B., & Hall, D. B. (1941). Variation of the rate of decay of mesotrons with momentum. *Physical Review*, *59*, 223–228.

Sommerfeld, A. (1952). Notes on Minkowski's paper "Space and Time". In: Lorentz, Einstein, Minkowski, & Weyl (Eds), p. 92.

Stein, H. (1968). On Einstein–Minkowski space–time. *Journal of Philosophy*, *65*, 5–23.

Stein, H. (1991). On relativity theory and the openness of the future. *Philosophy of Science*, *58*, 147–167.

Taylor, E. F., & Wheeler, J. A. (1992). *Spacetime physics: Introduction to special relativity* (p. 18) (2nd edn). New York: Freeman.

Weingard, R. (1972). Relativity and the reality of past and future events. *British Journal for the Philosophy of Science*, *23*, 119–121.

Weyl, H. (1949). *Philosophy of mathematics and natural science* (p. 116). Princeton: Princeton University Press.