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The necessity of the second postulate in special relativity

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ABSTRACT

Many authors noted that the principle of relativity together with space–time homogeneity and isotropy restricts the form of the coordinate transformations from one inertial frame to another to being Lorentz-like. The equations contain a free parameter, k (equal to c^{-2} in special relativity), whose value is claimed to be merely an empirical matter, so that special relativity does not need the postulate of constancy of the speed of light. I analyze this claim and argue that the distinction between the cases $k=0$ and $k \neq 0$ is on the level of a postulate and that until we assume one or the other, we have an incomplete structure that leaves many fundamental questions undecided, including basic prerequisites of experimentation. I examine an analogous case in which isotropy is the postulate dropped and use it to illustrate the problem. Finally I analyze two attempts by Sfarti, and Behera and Mukhopadhyay to derive the constancy of the speed of light from the principle of relativity. I show that these attempts make hidden assumptions that are equivalent to the second postulate.

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1. Introduction

In 1905, Albert Einstein published what became eventually known as the theory of special relativity (SR). He based it on two principles, or postulates (Einstein, 1905):

1. The laws governing the changes of the state of any physical system do not depend on which one of two coordinate systems in uniform translational motion relative to each other these changes are referred to.
2. Each ray of light moves in the coordinate system “at rest” with the definite velocity V independent of whether this ray of light is emitted by a body at rest or in motion. (Einstein, 1905, p. 895, English translation from The Collected Papers, Vol. 2, 1989, p. 143)

Einstein implicitly assumed also that space and time are homogeneous and isotropic, a fact quickly pointed out and stressed by several writers. These symmetries seem so natural, however, that SR is still said to be based on Einstein's two postulates: the principle of relativity (postulate 1) and the principle of the constancy of the speed of light (postulate 2).

Almost immediately, the necessity of the second postulate was questioned (Frank & Rothe, 1911; Ignatowski, 1910, 1911). Recognized as fundamental and deep, the principle of relativity seemed appropriately general for such a fundamental theory. Contrariwise, the second postulate struck many investigators as too particular and contingent to merit its elevated position (Lévy-Leblond, 1976; Mitvalsky, 1966; Pal, 2003; Schwartz, 1984; Sen, 1994; Srivastava, 1981; Weinstock, 1965).

In 1965, for example, Robert Weinstock thought that

> …the status of the theory of relativity would be rendered somewhat more secure if it were to be based on an experiment less accessible to interpretative controversy than that of Michelson and Morley. (Weinstock, 1965, p. 641)

His own suggestion was to replace the second postulate by another experimental fact, viz

> The crucial experimental result on which the theory of relativity is based in this paper is the nonconstancy of the mass of a body as a function of its speed relative to the inertial frame in which the mass is measured. (Weinstock, 1965, p. 641)

Most other writers on the subject, on the other hand, feel that a second postulate – *any* kind of second postulate – is unnecessary. Thus, Srivastava (1981) begins his derivation of the Lorentz transformations by stating that

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> It has been pointed out by many authors that the postulate of the constancy of the speed of light is not necessary for arriving at the space-time transformations in special relativity (Srivastava, 1981, p. 504)

Similarly, Lévy-Leblond (1976) declares

> …I intend to criticize the overemphasized role of the speed of light in the foundations of the theory of special relativity, and to propose an approach to these foundations that dispenses with the hypothesis of the invariance of c. (Lévy-Leblond, 1976, p. 271)

David Mermin (1984) expressed most clearly the reason behind these concerns

> Relativity …. is not a branch of electromagnetism and the subject can be developed without any reference whatever to light. (Mermin, 1984, p. 119)

I believe that here lies the source of the discontent with the second postulate. Special relativity is one of the deepest theories of physics, a revolutionary reworking of our understanding of space and time – the fundamental stage on which the physical universe is played out. Surely, such a fundamental theory must proceed from similar fundamental and deep postulates. Yet while the principle of relativity possesses the required generality, the second postulate appears to be too incidental and specific to play such a fundamental role. As Mermin points out, the second postulate seems to reduce special relativity to being a mere branch of electromagnetism rather than a fundamental theory from which electromagnetism can actually be derived by applying the Lorentz transformations to electrostatics (for an approach to electromagnetism along these lines, see for example, Schwartz, 1987).

It seems to me that this feeling is the reason why the necessity for the second postulate has been repeatedly challenged over the years, and so much effort dedicated to trying to prove that SR follows from space–time symmetries and the principle of relativity alone. In particular, various derivations of the Lorentz transformations along those lines obtain as a *result* the existence of an invariant (and maximal) velocity.

I shall name "generalized Lorentz transformations" the coordinate transformations obtained from the space–time symmetries and the principle of relativity alone, in order to distinguish them from the transformations used in SR that make direct reference to the speed of light. The generalized transformations contain an undetermined universal parameter, here denoted k, which is equal, in standard SR, to $1/c^2$. In these views, the content of the second postulate is no more than a report of the experimental value of k, or equivalently, of the maximal invariant velocity, which happens – for no particular reason, one might think in the context of these derivations – to be the velocity of light. By this I mean that light itself appears to play no particular role in these presentations; the identification of the invariant velocity with that of light is viewed as being a claim of electromagnetism, but one not inherent to SR itself.

These various derivations are undoubtedly of great interest. That the mathematical form of the possible coordinate transformations is as restricted as it is by the relativity principle and the space–time symmetries is hardly obvious and remains surprising to the physicists and philosophers who are unaware of this result. Other insights also originated from similar reflections, such as the role of isotropy in SR in Feigenbaum's own attempt to derive SR from relativity alone (Feigenbaum, 2008). The abstract of Feigenbaum's paper reads in part "No reference to light is ever required: The theories of relativity are logically independent of any properties of light", a view very close to the one espoused by Mermin.

Yet despite these interesting insights, I believe that these derivations fail in their avowed aim. My position is not new. Such was already the opinion of Pauli, quite early on (Pauli, 1958). Having quickly reviewed the derivation of the generalized Lorentz transformations, he wrote

> Nothing can naturally be said about the sign, magnitude and physical meaning of [k]. From the group-theoretical assumption, it is only possible to derive the general form of the transformation formulae, but not their physical content. (Pauli, 1958, p. 11)

Unfortunately Pauli offered no elaboration of this claim, which led many subsequent investigators to think that they had managed to overcome this criticism. I believe this is not the case, and that indeed the content of the second postulate (in one form or another) cannot be reduced to the mere experimental determination of some parameter in a theory derivable from the principle of relativity alone. Instead, as Pauli noted, the constancy of the speed of light is necessary in order to make *physical* sense of the theory (as opposed to mere formal structure), particularly of what might count in it as "experimental determination". There are several aspects to this claim, and the present paper is intended to be the first in a series exploring the various roles fulfilled by the second postulate (Drory, 2014).

Section 2 sets the ground rules for my analysis. Section 3 presents a derivation of the generalized Lorentz-transformations, which is in my opinion simple and direct enough to justify its inclusion here. In Section 4, I argue that the non-vanishing of k must be taken as an extra-assumption, i.e., another postulate. Sections 5 and 6 critique two attempts to derive the actual value of k (including its non-vanishing) without assuming it, i.e., attempts to prove the second postulate. The final section presents a summary of the arguments. An appendix contains the derivation of anisotropic transformations that are used as an analogy in the analysis in Section 4.

2. Ground rules

What is the nature of the claims made by supporters of the one postulate vision? In order to evaluate properly the value of the arguments and their problems, we must first agree on some basic rules.

First, the claims that are put forwards have no relation to the historical processes leading up to the discovery of the theory of relativity. That the second postulate was historically crucial to Einstein's thinking is of no consequence here. It is the logical structure of the theory, assessable in retrospect, which is under discussion. Thus the proper aim seems to be the following:

Assume only the following three postulates:

(A) *Homogeneity of space and time*: The laws of physics are invariant under a translation of the origin of coordinates of space and time.

(B) *Isotropy of space*: The laws of physics are invariant under rotations of the axes in which they are described.

(C) *The principle of relativity*: The laws of physics are invariant when referred to different frames of reference, when these are in uniform motion with respect to each other.

It is traditional to consider the principle of relativity to imply the law of inertia, although formally it should be treated as a separate axiom. The rationale for this inclusion is apparently that one takes for granted something along the lines of a principle of sufficient cause - specifically, that a body at rest that is sufficiently isolated from other bodies (and hence from external influences) remains at rest. The property "being at rest" is not invariant to different observers, however, and if one accepts the rest principle