Is relativity principle consistent with electrodynamics?

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Abstract

The basic postulate/hypothesis of special relativity, the relativity principle, requires the physical equations to take the same form in all inertial frames of reference. In a more explicit form [2] it says the following:

(RP) The laws of physics describing the behavior of a system co-moving as a whole with inertial frame K, expressed in terms of the results of measurements obtainable by means of measuring-rods, clocks, etc., co-moving with K takes the same form as the laws of physics describing the similar behavior of the same system when it is co-moving with inertial frame K', expressed in terms of the measurements with the same equipments when they are co-moving with K'.

From the assumption, that (RP) holds for the propagation of light, that is, the velocity of light in K' must have the same value as in K, one can derive the Lorentz transformation rules for the space and time coordinates. From the additional assumption that (RP) holds for the whole Maxwell's electrodynamics, one can derive the Lorentz transformation rules for the electrodynamical quantities. This is the way we usually find in textbooks.

These derivations, however, leave open the following questions:

(1) Is (RP) a true law of nature for electrodynamical phenomena?

(2) Are, at least, the transformation rules of the fundamental electrodynamical quantities, derived from (RP), true?

(3) Is (RP) consistent with the laws of electrodynamics in one single frame of reference, say in K, at all?

(4) Are, at least, the derived transformation rules consistent with the laws of electrodynamics in one single frame of reference?

Obviously, (1) and (2) are empirical questions. In this paper, we will investigate problems (3) and (4).

Interestingly, to answer the questions of consistency requires the prior clarification of semantical notions; namely, the operational definitions of the fundamental electrodynamical quantities. Having these definitions clarified, we can apply what J. S. Bell calls "Lorentzian pedagogy", according to which "the laws of physics in any one reference frame account for all physical phenomena, including the observations of moving observers" [1].

As to question (4), we will show that the transformation rules of the electrodynamical quantities are indeed the ones derived by assuming the covariance in advance; and that the covariance of the coupled Maxwell–Lorentz equations are indeed satisfied.

As to problem (3), the situation is much more complex. As it was pointed out in [2], it is a common misunderstanding that relativity principle is equivalent to the covariance of the physical equations. Relativity principle is not simply a consequence of a symmetry of the physical laws, but a consequence of the contingent facts of nature that characterize the behavior of physical systems *co-moving, as a whole,* with different inertial frames. This finding, as it will be discussed, throws new light upon the role of the initial/boundary conditions coupled to the physical equations and gives rise to a conceptual problem concerning the meaning of the phrase "co-moving as a whole".

[1] J.S. Bell: How to teach special relativity, in *Speakable and unspeakable in quantum mechanics*, Cambridge University Press, Cambridge, 1987, p. 77.

[2] L.E. Szabó: On the meaning of Lorentz covariance, *Foundations of Physics Letters*, **17**(2004), pp. 479–496.