On Misconceptions Regarding Special Relativity and Acceleration

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Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.

Abstract

We discuss the extension of special relativity to noninertial reference frames. It is commonly believed that special relativity can only be applied to inertial systems of reference and that noninertial systems should be approached with general relativity. We explain that this is a common misconception. The local application of Lorentz transformations to noninertial frames is essential for extending special relativity and relativistic gravitation theory.

1. Introduction

Ron A. Pepino and Risley W. Mabile [1] have pointed out some common misconceptions regarding the applicability of special relativity (SR) to accelerated reference frames. They report the result of a survey carried out in more than 22 physics departments of prestigious institutions in the United States and the United Kingdom. Surprisingly, their survey revealed that only 37% of faculty members and 10% of graduate students correctly responded *"yes"* to the question *"Is SR capable of describing physics in accelerated reference frames? (yes or no)"*. Part of the confusion, they explain, stems from the fact that physicists who do not specialize in general relativity (GR) believe that accelerated frames can only be dealt with through GR. We support their arguments but also sustain that the confusion is, to a certain extent, justified. Pepino and Risley's survey discloses a peculiar hole in the teaching of relativity theory. We propose the conventional teaching of SR should include an explicit approach to noninertial SR with the introduction of a little-known principle.

We briefly comment on the historical context under which SR and GR emerged because part of the prevailing confusion may have its roots in those days. We mention how the extension of SR to noninertial frames is commonly presented in textbooks. We contrapose that a smooth and coherent transition from inertial SR to noninertial SR requires a link usually absent in standard presentations. The missing link needs to be explicitly stated as an additional principle. Mashhoon called it *"the hypothesis of locality"*[2].

2. SR and Inertial Reference Frames

In 1905, Einstein postulated the universality of the speed of light and the physical equivalence of all inertial reference frames. The last hypothesis is known as the "Principle of Relativity." Those two axioms allowed him to derive the Lorentz transformations. It is clear that the principle of relativity only involves inertial systems of reference [3]:

> *"The laws by which the states of physical systems undergo change are not affected, whether these changes of state be referred to the one or the other of two systems of coordinates in uniform translatory motion."*

Therefore, it is uncontroversial the SR and the Lorentz transformations, as conceived by Einstein, were intended to relate only coordinates of inertial reference frames. That should not be misinterpreted as implying the motion of accelerated objects cannot be described in inertial frames. It means the laws describing those arbitrary motions are Lorentz invariant only when the new reference frame is also inertial.

3. Inertial and Noninertial Reference Frames

The inertial frames have the advantage of simplicity. If we choose an arbitrary frame of reference, space would be inhomogeneous and anisotropic. In general, the same would be true of time. It would be inhomogeneous, and different instants would not be physically equivalent [4].

Why, then, would we complicate the description of the laws of physics by referencing them to noninertial systems? An experimental physicist could argue that any laboratory on earth is indeed noninertial, so it is necessary to consider that. There might be other reasons, such as the case of observers in an accelerated spacecraft. But perhaps the most fundamental reason is what Einstein used to refer to as *"the happiest thought of my life"*, i.e., the principle of equivalence.

Although inertial and gravitational mass represent two different properties of matter, their empirical indistinguishability led Einstein to postulate the principle of equivalence. According to that principle, a gravitational field in an inertial frame is locally equivalent to an accelerated frame with no gravitation. So, at least locally, gravitation is equivalent to acceleration.

4. The Road to GR and a Subtle Mistake

A little historical context is necessary to understand some mistakes that nonspecialists in GR may commit even to this day. The principle of equivalence reduces gravitation to inertial acceleration and vice versa. Thus, the idea that gravitation could explain acceleration is not so farfetched after all, and, as the authors of [1] observed, that can easily mislead the student. For instance, Pepino and Mabile pointed out the mistake of believing that the celebrated twin paradox can only be explained by GR because acceleration is involved.

That Einstein fell prey to a similar mistake is ironic. In his long struggle to find a gravitation theory compatible with SR, Einstein conceived the principle of general covariance. That led him to believe he had accomplished a general principle of relativity, turning all motion "relative" getting rid of Newton's absolute space. Presumably, that would make GR explain inertia and acceleration according to what he called Mach's principle. Although he succeeded in formulating a theory of gravitation, it turned out that such an interpretation of general covariance was incorrect. In 1917, Erich Kretschmann pointed out that the general covariance principle was tautological and devoid of physical meaning. Experts in the foundations and history of GR have observed that Einstein had to change his views on GR several times during his lifetime [5].

Thus, GR is not a generalization of the principle of relativity but a theory of gravitation. The name general relativity stayed for historical reasons. The renowned physicist Vladimir Fock, in his book *The Theory of Space, Time & Gravitation*[6], wrote:

> *We call the theory of Einstein space the Theory of Gravitation, not the "general theory of relativity", because the latter name is nonsensical.*

5. The Need to Extend SR to Noninertial Frames

Finally, it turned out that is not gravity that explains acceleration but it is rather the other way around, as Misner, Thorne, and Wheeler [7] clearly explain:

> *A tourist in a powered interplanetary rocket feels "gravity." Can a physicist by local effects convince him that his "gravity" is bogus? Never, says Einstein's principle of the local equivalence of gravity and accelerations. But then the physicist will make no errors if he deludes himself into treating true gravity as a local illusion caused by acceleration. Under this delusion, he barges ahead and solves gravitational problems by using special relativity.*

But wait, wasn't SR initially conceived to treat only uniformly moving frames without acceleration? Absolutely, but we will see how physicists usually deal with this limitation in the following section.

6. The Extension of SR to Noninertial Frames

An accelerated observer has no inertial frame in which he is always at rest. However, there is an inertial observer that momentarily has the same velocity as the accelerated one, but a moment later is of course no longer moving with him. This inertial observer's frame is the *momentarily comoving reference frame* or *rest frame* for short [8]. It is implicitly assumed that for a small spacetime neighborhood, the accelerated observer and the comoving inertial one experience spacetime measurements equally.

The controversial part in the former explanation is the expression "it is implicitly assumed". Indeed, the assumption seems so natural that most physicists and textbooks treat it as an obvious logical inference that does not deserve further comments or clarification.

Sometimes, when applied to clocks the assumption is called the *"the clock hypothesis"*[9]. However, since we need the assumption every time we want to predict the behavior of objects that are referenced to noninertial frames, from a logical standpoint, it is necessary to state it as an independent assumption. Mashhoonn dubbed it the *"the hypothesis of locality"* [2]:

> *Which law of physics specifies what accelerated observers measure? It has been proposed that the hypothesis of locality i.e., the presumed equivalence of an accelerated observer with a momentarily comoving inertial observer underlies the standard relativistic formalism by relating the measurements of an accelerated observer to those of an inertial observer. This fundamental assumption therefore replaces the customary hypotheses concerning classical measuring devices in accelerated motion. In particular, a physical basis can be provided for the discussion of the clock hypothesis.*

Note the difference between the *"the hypothesis of locality"* and the *"the equivalence principle."* While the last one asserts that we can (locally) assimilate gravitation to acceleration, it does tell us what a noninertial observer measures. The last point is resolved with the hypothesis of locality.

7. Conclusions

For the sake of logical completeness and to avoid the student's confusion, it is commendable to implement the application of SR to noninertial frames of reference through an explicitly stated principle, namely, *" the hypothesis of locality"*[2].

The introduction of a rest frame for extending the application of SR to accelerated frames is natural and intuitive. For that reason, textbooks usually implement it without mentioning that it is, after all, an assumption. However, relativity taught us that "intuitively natural" does not mean logically correct. Indeed, through a penetrating analysis, Einstein showed us that our natural intuition about absolute simultaneity and time is not a logical imposition.

It is timely to warn the student that the failure to distinguish intuition from logical inference has produced a marginal current that denies relativity based on the belief that the rejection of absolute simultaneity and the difficulties of fully grasping its consequences is a logical contradiction. So, the problem of disentangling correct reasoning from intuition is not exclusive to novice students but affects professional scientists as well [10]. One of the most remarkable cases was Herbert Dingle [11], who sparked a controversy that reached the columns of *Nature*. Dingle's affair occurred in the 1970s, but we can still find journal articles contesting the logical and experimental basis of relativity based on incorrect inferences. Some of these papers are very recent! [12][13][14][15][16][17].

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