

On the Basic Propositions of the Special Theory of Relativity

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Abstract. The basic propositions of the special theory of relativity (STR) are meant to be Einstein's postulates, on the basis of which STR and relativistic physics in general are built. In this article the postulates and their logical relationship with each other and with the preceding classical physics are comprehensively discussed. The purpose of the work is to eliminate the seeming contradiction of the postulates and to make them as clear as possible. The questions raised frequently in the study of STR are touched upon also. Common errors in the description of some experiments are indicated.

1. Relativity of motion. The principle of relativity

The realization of the motion relativity as one of its main properties played a huge role in the development of physics and of all of natural science as well. It was the decisive factor in the transition from Aristotle's physics to Galileo-Newton's physics that is to classical physics. In the same time (it is unknown what was the first) the awareness of the fact that we live on a planet rushing at high speed in world space has led to the formation of the concept of an **inertial frame of reference** (IFR), the conclusion about the multiplicity of all possible IFR, their equality and the recognition the fact, that there is no single chosen IFR. The combination of these concepts in classical physics is briefly called the classical **principle of relativity** (PR). It can be said that with the recognition of the relativity of motion, "relativization" of the laws of physics began [1].

The explanation of the STR usually begins with the classical PR. Indeed, first Einstein's postulate, relativistic PR, is a generalization of classical PR (with the rejection of the ether at the same time) [2]. The whole drama of the struggle of ideas and searches in electrodynamics and optics in the late XIX - early XX centuries was essentially connected with the question: does classical PR extend to electrodynamics and optics, or its action is limited only by mechanics? Experiments played a decisive role finally (as it should be!). But there is a **strong logical argument in favor of generalizing classical PR**: there are no purely mechanical phenomena. "And if the Newtonian principle of relativity does not extend to all physics, it turns out to be devoid of content" [3]. The weightiness of this argument is determined by the fact that it is not associated with any particular experience, but appeals to the whole physical ideology. Therefore the generalization of classical PR does not come from "hopelessness", but consciously and purposefully. "Of course, such an assertion is a pure hypothesis, and like any hypothesis, it requires experimental verification" [3].



2. The PR and the concept of a short-range interaction

In a well-known course of theoretical physics [4] the explanation of SRT begins with the PR, which is formulated for all the laws of nature, that is, as relativistic one, although the term “relativistic” is not used. Then it is noted that, as experience shows, there are no instantaneous interactions in nature. The final velocity of propagation or transmission of interactions can in principle be measured as the ratio of the distance between bodies to a minimum period of time, after which the interaction will manifest. It further states: “From the principle of relativity it follows, in particular, that the speed of propagation of interactions is the same in all inertial frames of reference. Thus, the speed of propagation of interactions is a universal constant. ... The unification of the principle of relativity with the finiteness of the velocity of propagation of interactions is called the Einstein relativity principle (it was formulated by A. Einstein in 1905) in contrast to the Galilean principle of relativity originating from the infinite velocity of propagation of interactions” [4].

It turns out that the position on the finiteness of the speed of propagation of interactions loses its independence. Then maybe there is no need for the 2nd postulate of Einstein, the postulate of the constancy of the speed of light.

In [5], the relationship between PR and the concept of short-range interaction as two independent physical principles, well-established in physics by the end of the 19th century, is considered in more detail. The problem is being solved: how far can one advance in deriving transformations connecting the coordinates and times of different IFR moving relative to each other, without attracting the 2nd Einstein postulate, the postulate of constancy of the speed of light, and applying only the 1st postulate, PR. Transformations must be linear according to the homogeneity and isotropy of space and the homogeneity of time and must have group properties.

It turned out that the PR itself does not require the finite transmission speed of interactions. It can be performed as with long-range and so with short-range actions. However, compatibility of PR and the concept of short-range action is possible only if there is a finite invariant transfer rate of interactions. Therefore, the 2nd postulate of Einstein is necessary as an independent position.

3. The postulate of the constancy of the speed of light

Above we have already considered the role of the 2nd postulate in the system of Einstein's postulates from the point of view of the concept of short-range action. So now it is time to discuss the postulate of constancy of the speed of light directly.

3.1. Selectivity of the speed of light

In the literature there are different opinions concerning the significance of the postulate of the constancy of the speed of light and its role in the justification of the STR. Without refuting the postulate itself, some authors believe that “the theory of relativity is by no means a branch of electromagnetism, and this subject can be formulated without any references to light” and try to derive the Lorentz transformation (at least the relativistic law of velocity addition) without using the 2nd postulate [6]. Others express the opinion that “a false impression is taking shape, that relativistic effects are associated exclusively with light signals” and therefore “the teaching of the foundations of the SRT requires ... a new technique ... based on a large number of experimental results that are not related to measuring the speed of light” [7].

To answer the question of why the speed of light was in a selected position, we must recall the history of electrodynamics development and the formation of systems of units of electrical and magnetic quantities. When the system of Gauss units appeared as a result of combining the CGSE and SGSM systems, in this system the units of electrical quantities coincided with the CGSE units, and the magnetic units - with the SGSM ones. At the same time, in the formulas of magnetism a dimensional constant has appeared, the electrodynamic constant c , numerically

equal to the speed of light. Later it turned out that coincidence was not accidental and the electrodynamic constant was named simply the speed of light. But sometimes replacing the name creates an unnecessary impression.

If we take the Maxwell equations for a free electromagnetic field, that is, in the absence of charges and currents, and separate the variables, we obtain the wave equations for the electric and magnetic fields separately. Herewith the velocity of propagation of electromagnetic waves in a vacuum coincides with the electrodynamic constant c . Since electromagnetic waves in vacuum do not have dispersion, the propagation speed of any electromagnetic waves, including light, in vacuum is the same and represents the speed of propagation (transmission) of electromagnetic interaction. Therefore, the speed of light in the 2nd postulate is equivalent to the velocity of propagation of electromagnetic waves and the propagation velocity of electromagnetic interaction [8]. This is also discussed in detail in [9].

Currently, in the macroworld there are two known long-range interactions, gravitational and electromagnetic. The speed of propagation of gravitational waves is assumed to be equal to the speed of light (which does not contradict the experiments). Perhaps this is due to the fact that the STR and relativistic electrodynamics first arose, and only then the relativistic theory of gravitation. Just hypothetically, if a new long-range interaction will be opened, the transmission speed of which will exceed the speed of light, then a new version of the STR with a new fundamental constant will be needed. (If this happened, it would lead to such a revolution in science that it seems incredible).

3.2. Covariance of Maxwell's equations

From the point of view of the mathematical apparatus (analytics), the constancy of the speed of light is a consequence of the covariance of Maxwell's equations with the same value of the electrodynamic constant.

In Maxwell's equations for a free electromagnetic field, the electrodynamic constant (the speed of light) provides a connection between the spatial and temporal variations of the field vectors. Under the transition to another IFR the fields themselves change, the components of the field vectors form a second-rank tensor, an electromagnetic tensor. The constancy of the speed of light, the second postulate, ensures the invariance of the relationship between the spatial and temporal changes of the field vectors in any IFR, that is, the invariance of the laws of electrodynamics and the execution of PR for electromagnetic phenomena.

3.3. Lorentz transformations

The Lorentz transformations build the connection between the spatial and temporal coordinates of events in different IFR.

From the point of view of transformations, the answer to the question of why the speed of light remains constant seems to be obvious: we derive transformations between different IFR in a way to keep the speed of light constant, that is, as if we adjust the transformations themselves. However there is an interesting nuance here. There is no other way to establish a connection between moving IFR. For the derivation of transformations between reference frames, when all general considerations such as linearity of equations (homogeneity of space and time and isotropy of space) are used, some other specific condition is needed to establish a direct connection between two systems of reference. This condition should describe a phenomenon or process in coordinate form, the expression of which we know in each system. This condition is the requirement of the same value of the speed of light. Herewith one has to admit changing the origin of time at different points of another IFR (synchronization) and changing spatial and temporal scales (so to speak, the price that has to be paid) [8].

Usually following situation is considered. Two IFR K and K' are moving relative to each other at speed V and their axes X and X' respectively are aligned with the direction of relative

motion. At the moment when the origins of both systems, $p. O$ and $p. O'$, are matched, a light signal was emitted from that point. At some moment of time t , we have a spherical wave with a center in $p. O$ in one IFR, and one with a center in $p. O'$ in another IFR. Herewith the distance between the centers is Vt . The apparent contradiction (the wave is the same) is explained by the relativity of simultaneity: the simultaneous position of the wave front points in one IFR is not such from the point of view of another IFR [10]. This is not quite true. In addition to the relativity of simultaneity, as was noted above, there is a change in spatial and temporal scales (see also [8]).

4. The classical law of velocity addition

Another point that can significantly facilitate the perception of the second postulate, is associated with a seeming contradiction to the law of velocity addition. The classical law of addition is replaced by the relativistic law of addition which follows from the Lorentz transformations. The speed of light remains unchanged contrary to the classical law of addition, but in accordance with the relativistic law, which, as if it is “fitted” under it.

It is appropriate to recall Maxwell himself: “Now we are unable to conceive of propagation in time, except either as the flight of a material substance through space, or as the propagation of a condition of motion or stress in a medium already existing in space” [11].

The classical law of velocity addition is applied to macroscopic material objects which move as a whole and do not change from the point of view of different reference frames. Light, on contrary, electromagnetic disturbance, is a wave process that is perceived differently in different reference frames, which means that the moving object changes itself (the electrical and magnetic components change depending on the choice of IFR). Then the invariance of the speed of light means that the propagation of an electromagnetic perturbation occurs according to the same laws, with the same value of the electrodynamic constant in the Maxwell equations in any IFR [8].

5. W. de Sitter’s proof of the constancy of the speed of light

In 1913 year W. de Sitter produced the proof of the constancy of the speed of light based on many observations of spectroscopic double stars or simply spectroscopic doubles [12]. In the spectra of these stars, there is a simultaneous shift of the spectral lines to the red and violet ends of the spectrum. Since all spectroscopic doubles show the same picture of displacement of lines, de Sitter’s proof is considered the most conclusive evidence of the constancy of the speed of light. Mostly because of it Ritz’s ballistic hypothesis was rejected.

A common mistake in description of this proof is the replacement of spectroscopic doubles with visual doubles, which significantly reduces its force. In addition, which is also important, it provides the opponents of the STR by the reason (quite fair) to criticize the proof itself. Here, for example, how the idea of proof is presented in the textbook [10, p. 412], without mentioning de Sitter himself: “However, astrophysical observations of double stars strongly speak against the ballistic hypothesis. ... If the ballistic hypothesis is valid, then ... the observed motion of a star can significantly deviate from Kepler’s laws. In particular, with a very large L (the distance to a double star - M.I.), it is possible that even with $v \ll c$... the visible movement becomes quite whimsical”.

The fact of the matter is that we cannot see this, too far and too long must be observed. These are not satellites of Jupiter.

In order to clearly show how such a substitution affects the general meaning of the proof, let us turn to the review article “Double stars” by the famous specialist in star astronomy P.G. Kulikovskiy [13]. (Over the past 70 years between the works of de Sitter and Kulikovskiy, astronomy has advanced far ahead both in the number of astronomers and in the level of technology, which is make the comparison more significant.)

About visual double stars: “The number of open visual double stars ... exceeds 60 thousands. Only 10 thousands of them were measured more or less regularly. For more than 500 of them a curvature of the path already was found, sufficient to attempt to determine the shape of its relative orbits. About 150 double stars have defined orbits ... ” [13].

And about spectroscopic double stars: “Changes in the displacement or bifurcation of spectral lines of spectroscopic double stars allow one to determine the radial velocity, which is a projection of the orbital velocity onto the line of sight. ... The vast majority of spectroscopic double stars have periods of the order of several days. In total, more than 3000 spectroscopic binary stars have been discovered, orbit elements have been calculated for about 1000 of them” [13].

The whole strength of de Sitter’s proof is that the spectroscopic doubles are opened up in terms of the bifurcation and shift of spectral lines and the behavior of the lines is the same for all stars. In his conclusion de Sitter relied on the results of observations of the entire army of astronomers, in contrast to the fantastic picture presented in the textbook [14] for an in–depth (!) study of physics: “V. de Sitter in 1913 observed the movement of double stars. ... If the speed of light was dependent from the speed of stars, then due to the large distance of the double star from Earth, the difference in the speed of light from each star would lead to optical distortions of the true picture of the motion of these stars in the telescope’s field of view, which de Sitter did not detect” [14].

6. Experience with the “around- the- world” clocks

In the works [15] authors reported about the experiment with atomic clocks, which were sent to “round the world” flights in the east, and then in the west. During the flight to the east, the atomic clock lagged behind, and in the western - went ahead compared to the atomic clock that remained at rest on Earth. Based on the data obtained, it was concluded: “These results provide an unambiguous empirical resolution of the famous clock “paradox” with macroscopic clocks”.

The experiment is beautiful, effective, and, inspite of the accuracy was not high, about of 10%, it is often cited in educational literature, see, for example, [7,14].

The speed of movement of clocks relative to the Earth is the same, however the difference between the readings of the “eastern” and “western” clocks with the clocks remaining on the Earth do not coincide. Therefore, it is necessary to take into account that the Earth is non-inertial as a reference frame. The trajectory of the clock is also “non-inertial”, circular. From the point of view of the principle of equivalence, the experiment with the “round-the-world” clock confirmed only the fact that the clock was slowing down in the gravitational field [16].

Indeed, the clock, resting on the surface of the Earth and participating in its daily movement, can be considered as resting in a field with an effective potential consisting of pure gravitational and centrifugal. Then the clock, flying to the west or east, can be considered as resting on the Earth, rotating at a lower or higher speed, respectively. Thus, the difference in the readings of the clock is due to the different contributions of the centrifugal potentials to the effective gravitational potential. And the special relativistic effect of time dilation associated with the relative movement of clocks, which the authors [15] call the kinematic effect and precisely with which the paradox of clocks is associated, remained unconfirmed.

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