Is Special Relativity a Decidable Theory?

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In this paper a new principle is proposed: **The Principle of Dual Constancy of Light.** It implies the assumption that not only light itself, but also its speed c is of dual nature. That means, the speed of light c is given in a wave-like and in a particle-like form. Using this new principle the empirical undecidability of the truth of the Second Postulate of Special Relativity could be revealed.

1. Introduction

Though Quantum Mechanics is as foundational as Special Relativity is, our physical understanding of the speed of light c being a fundamental constant of Nature is almost exclusively defined and determined by the latter one. Through Special Relativity the speed of light c became f.e. the decisive link between space and time and entered in virtue of the so-called Lorentz symmetry most of the laws of physics. Hereby a specific property of light, its speed, was no longer connected with the phenomenon of light itself.

Just this disconnection between the speed of light and light itself may be the reason, that we still don't have any deeper understanding of the universal constant of c. The key to such a deeper understanding could possibly Quantum Mechanics, in particular the concept of *Wave-Particle Duality*.

Nowadays we know light is essentially a quantum phenomenon that has both particle-like and wave-like aspects. Neither of these two aspects is sufficient to describe the nature of light. Quantum mechanics posits that this dual characteristic of light is one of the most fundamental properties of light. Given this quantum theoretical view it seems to be a natural assumption that not only light itself, but also its speed c should be of dual nature. In other words: The speed of light c should exist both in a wave-like and in a particle-like way. Consequently, the corresponding Principle of the Constancy of Light should be given in two sub-versions as well – as a wave-like version and a particle-like version.

Though this assumption, which I am calling the "Principle of Dual Constancy of Light", is quite natural, at least from a quantummechanical point of view, it was never investigated. This principle could – as conveived by me – change our understanding of the universal constant of c considerably.

In order to become acquainted with this dual principle it is useful to apply it to Special Relativity (SR). We will see that in SR only the wave-like version of this principle has been taken into account. There is no particle-like version that is *explicitly* declared of being a (fundamental) principle of Nature. SR thus appears as a highly incomplete theory as far as the *Principle of Dual Constancy of Light* is concerned.

2. The wave-like face of c

Though the wave-particle duality of light is still a central concept of quantum mechanics, it was never consciously applied to light's speed. This is a strange omission, because in Special Relativity (SR) the speed of light is introduced in such a way that it can very easily be recognized as one of its two possible quantummechanical aspects.

The Second Postulate of SR states that light always propagates in empty space with a definite velocity c that is independent of the state of motion of the emitting body. This statement is nothing else than a verbal description of a key feature of light *propagating as a wave in a medium*. It is indeed a natural property of all waves, that their speed is independent of its speed source, because their propagation speed is solely determined by the properties of medium that support them. The Second Postulate of SR describes thus the speed of light in a purely wave-like way as it is demanded by the *Principle of Dual Constancy of Light*.

But at the same time one can easily see that the relativistic description of the speed of light c is highly incomplete. There is no *explicit* particle-like description of c. If Nature really satisfies the *Principle of Dual Constancy of Light* then this incompleteness of SR does not concern a little technical detail, but a physical quantity that is classified to be a further fundamental aspect of the speed of light c.

In case of such a far-reaching incompleteness of SR one would expect a multiple failure of this theory, but nothing like that has ever happened. There is no experimental data that indicates such a high degree of incompleteness of SR. From a experimental point of view Einstein's theory looks right. All the observations seem to be in perfect accord with the theory.

If we want to explain this fact thereby relating to the *Principle of Dual Constancy of Light* there are only two possible conclusions:

(i) The *Principle of the Dual Constancy of Light* is wrong. Hence, SR ist not incomplete as asserted. It describes the universal constant of c in the right way without any need to invoke the existence of a particle-like face of c.

(ii) SR does already satisfy the particle-like face of c, but the theoretical and formal elements, that are related to this face, are not yet *explicitly* identified and announced as being part of a further fundamental aspect of c.

An in-depth review of SR should reveal, that case (ii) applies.

3. The »Shadow-Principle« of SR

John Stachel is an American physicist, who is head of the Center for Einstein Studies. In his article *Einstein's Light Quantum Hypothesis, or Why Didn't Einstein propose a Quantum Gas a Decade-and-a-Half Earlier?* he expressed his surprise at the fact that in 1905 when Einstein formulated SR he does not note something that must have been obvious to him: His new kinematics, especially its addition rule of velocities, implied the possibility to explain the constancy of the speed of light in a particle-like way.[1]

$$\mathbf{c'} = \frac{c + v}{1 + \frac{cv}{c^2}} = \mathbf{c} \qquad (1)$$

Einstein mentioned this equation (1), but he didn't comment it in any way. In § 5 of his *Electrodynamics of Moving Bodies* he only stated, that the velocity of light could not be altered by composition with any subluminal velocity.

The possibility of SR to explain the constancy of c in a particle-like way is quite remarkable, because in Galilean kinematics this possibility does not exist. The classical addition rule of velocity makes the velocity of light, *if seen as a stream of particles*, different and even direction dependent in different inertial frames of reference.

$$\mathbf{c' = c + v} \qquad (2)$$

In brief, a particle-like interpretation of the constancy of the velocity of light is inconsistent with classical kinematics as formalized in equation (2). Just this inconsistency between the constancy of the velocity of light and Galilean velocity composition law was – as we know from Einstein's Kyoto talk (1922) -, the key problem that Einstein had to solve on his way to SR.

Einstein could solve this problem by formulating a new kinematical foundation. He recognized that the Galilean transformations between the coordinates of two inertial frames of reference had to be replaced by the Lorentz transformations.

This new kinematics implied a *new velocity addition rule* that included in fact the possibility to interpret the constancy of the velocity of light in a particle-like way without coming into conflict with the experimental data. If its equation (1) was applied to a particle model of light, it predicted, that *the speed of light - though being dependent on the source's motion (v) - would always be measured as being constant.*

In other words, Einstein's new kinematics allowed him to solve the original inconsistency between the constancy of the velocity of light and Galilean velocity composition law, but he completely ignored this solution.

Anyway, as these considerations are showing, SR contains *implicitly* theoretical and formal structures that can thorougly be interpreted as the reflection of a particle-like aspect of the speed of light c. As such, they represent a kind of »shadow-principle« inside SR. But this shadow-principle has never been explored in detail neither by Einstein himself nor by others. The physicist John Stachel has - as already mentioned – noticed its existence, but he did not investigate the physical consequences connected with it.

4. The Undecidability of the Second Postulate

The most important consequence caused by this shadow principle is indeed the fact that the wave-like version of c (expressed by the second postulate of SR) and the relativistic particle-like version of c (expressed in terms of relativistic kinematics) cannot be distinguished from an experimental point of view. In SR both (relativistic) sub-principles are making exactly the same empirical prediction: *The speed of light c is constant.* Hence, in the theoretical framework of SR the wave-like version of c and the particle-like version of c cannot be empirically distinguished.

According to our present understanding of SR its empirical indifference with regard to wave-like and particle-like properties of light is not considered of being a weakness of the theory but just a strength of it.

It is interpreted as a remarkable feature of Einstein's theory that its predictions, including those it makes about light, do not depend in any way on a model for light. If we apply SR to nature we have not necessarily to know whether light is a wave or particle. Whatever light is, it must conform to the principle of relativity. The physicist *Arthur Zajong* states, that much of relativity's beauty and universality stem from this remarkable feature of Einstein's theory. Actually SR offers the possibility to make predictions without knowing what light really is.[2]

The great success of SR seems to justify this unusual approach. During the last one hundred years no serious inconsistency has been found by which the relativistic approach due to light could be revealed as being insufficient or incomplete. But if we take a closer look at how SR treats the universal constant of c, then we encounter a grave inconsistency.

According to its wave-like interpretation of c the speed of light is considered of being *not-dependent* on the source's motion, whereas its particle-like interpretation of c states, that the speed of light is *dependent* on the source's motion. In other words, SR does not describe the speed of light c *consistently* - in a non-contradictory form.

As their two sub-principles of c lead to one and the same prediction, this logical inconsistency cannot be solved by SR itself: Referring to Einstein's theory we cannot decide whether the speed of light depends on the source's motion or not. *Thus the truth of its second postulate is empirically undecidable.*

References

[1] J. Stachel; *Einstein's Light-Quantum Hypothesis, or Why Didn't Einstein Propose a Quantum Gas a Decade-and-a-Half Earlier?* In: Einstein – The formative Years, 1879 – 1909, Einstein Studies 2000, p. 240.

[2] A. Zajonc, *Catching the Light*, Oxford University Press 1993, p. 279, 280