Paradigm shift in Special Relativity: From the Michelson-Morleyexperiment, Lorentz and light speed invariance, to the reciprocal linearSagnac effect and conservation of simultaneity

Gianfranco Spavieri, Prof. Espen Gaarder Haug

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Paradigm shift in Special Relativity: From the Michelson-Morley experiment, Lorentz and light speed invariance, to the reciprocal linear Sagnac effect and conservation of simultaneity.

Gianfranco Spavieri* and Espen Gaarder Haug+
*Centro de Física Fundamental, Universidad de Los Andes,
Mérida, 5101 Venezuela; gspavieri@gmail.com
+Norwegian University of Life Sciences,
Ås, Norway; espenhaug@mac.com

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Abstract

We discuss the evolution of special relativity and show that the original interpretation based on light speed and Lorentz invariance is ruled out, theoretically, by paradoxes and, experimentally, by the optical effects of the Sagnac type. This paradigm shift enables the possibility to measure the one-way speed of light.

Key Words: special relativity, paradoxes, Einstein synchronization, relative simultaneity, optical Sagnac effects, one-way light speed, paradigm shift

1 Introduction

History teaches us that scientific theories and related paradigms maintain their validity for a limited time. Questioning the foundations of theories with valid arguments has been instrumental in the progress of physics, allowing obsolete theories to be replaced by better and more complete representations of reality.

As in the case of other physical theories, relativity theory has been criticized by many physicists and epistemologists, leading to long, interesting, controversial debates. The postulate of relativity is practically unchanged from the time of Galileo. However, it is important to highlight a fundamental aspect of special relativity that has been evolving in time with the theory, even though its evolution has remained unknown to the majority of physicists. We are referring to Einstein's postulate on light speed invariance.

After decades of controversy, recent advances in optical experiments seem to justify the early criticisms of Lorentz and light speed invariance, indicating that an incipient paradigm shift has been taking place unnoticed for decades in relativity theory. Thus, in Section 2, we revise briefly the evolution of special relativity through more than a century, presenting in Section 3 the arguments and advances that, in our opinion, justify the mentioned paradigm shift that has been and is currently taking place in the theory. Some technical details are given in the Appendix.

2 The light speed paradigm shift after more than a century of special relativity: From the Michelson-Morley experiment to the reciprocal Sagnac effect. Light speed invariance and Lorentz transformations with relative simultaneity make room for noninvariant one-way light speed, and Lorentz transformations with conservation of simultaneity

2.1 Optical experiments and Einstein synchronization.

The Michelson-Morley optical experiment of 1887 was supposed to detect the famous "ether wind", the ether being the medium where light propagates according to Maxwell's laws of electromagnetism. Since no ether wind was detected, the experiment provided instead a surprising null result that gave support to Einstein's theory of special relativity of 1905, where light is assumed to propagate in empty space at the same speed c relative to any observer in motion (light speed invariance), as described by the Lorentz transformations of coordinates.

In order to measure the one-way speed of light c traveling from point A to point B, with fixed distance $\mathrm{AB} = L$, Einstein adopted a procedure for synchronizing two spatially separated clocks, one at A and the other at B, assuming that the one-way light speed coincides with the average round-trip light speed $c = 2L/T$, where T is the time interval measured by clock A in the light round-trip from A to B and back to A. However, epistemologists and physicists strongly criticized Einstein's synchronization procedure, pointing out that, since the one-way speed from A to B can be different from the return speed from B to A, Einstein synchronization leaves undetermined and arbitrary (conventional) the one-way speed c.

2.2 Conventionality of light speed and Lorentz transformations.

At this point in the evolution of special relativity, physicists Mansouri and Sexl [1], adhering to the conventionality of the light speed c, introduced, in 1977, a set of coordinate transformations equivalent to the Lorentz transformations, but with speed from A to B different from the return speed from B to A, in agreement with the requirement of Einstein synchronization that the average round-trip light speed is c. Thus, to different one-way speeds correspond different, but physically equivalent, types of Lorentz transformations.

Although well-known by few specialists, the present status of special relativity is unknown to most physicists, who still believe that the standard Lorentz transformations of special relativity are unique, and the one-way light speed is c, as originally postulated by Einstein. Actually, what has been measured with high precision and is denoted by the universal constant c, is the average round-trip light speed $c = 2L/T$, and not the one-way light speed.

As pointed out in mainstream journals such as the American Journal of Physics, the present status reflects important changes in the formulation of special relativity and may be resumed by saying that, since the one-way speed of light is conventional and can be different from c, special relativity can be described either with the standard Lorentz transformations (LT), based on relative simultaneity or any other transformations with different synchronization, e.g., the so-called LTA (Lorentz transformations based on absolute simultaneity), considered in the Appendix. The LT and LTA are physically equivalent and interchangeable, even though they adopt different, conventional values for the one-way light speed.

3 Theoretical considerations and optical experiments disprove the LT based on relative simultaneity.

3.1 The paradoxes of special relativity and the Sagnac effect.

In the evolution of special relativity, physicists have discovered and formulated many paradoxes. One of the most famous is the "Twin Paradox" based on the effect of time dilation predicted by the theory, implying that a moving clock runs slower than a clock at rest. Less known are the paradoxes of equilibrium of electromagnetism. Although there is no consensus about the solutions of paradoxes, most of them are ascribed unanimously to the nonconservation of simultaneity of the LT (see the comment of Landau-Lifshitz in the Appendix). No paradoxes arise with the LTA.

Of the many other 'paradoxes' of the theory, we mention here the important Selleri [2] paradox related to the Sagnac [3] optical effect, carried out in 1913 and shown in Fig 1-a. In his experiment, Sagnac measured the one-way speed of light with an interferometer (or clock) on the rim of a circular rotating platform (or disk) and found that the speed of light along the rotating circumference of the disk is approximately $c \pm v$, where v is the peripheral speed of the disk. Sagnac's result is in agreement with transformations based on absolute simultaneity, such as the LTA, because the measured one-way light speed is $c \pm v$ and not c, as foreseen by the LT (see expression (1) in the Appendix.

Thus, according to Sagnac, his experiment invalidates Einstein's postulate on the invariance of light speed. Nevertheless, supporters of the conventionality of light speed claim that, since light speed is conventional, we can choose equivalently either the LT or the LTA in the interpretation of the Sagnac effect. However, as shown by Selleri [2], if light speed is conventional, with the Sagnac effect we are met with the paradox that $c = c \pm v$. The polemic issue was clarified with the discovery of the linear Sagnac effect (see Fig. 1-b), performed by Wang et al. [4] in 2003. In the linear Sagnac effect the interferometer (or clock) is moving with uniform motion, and Spavieri et al. [5], [6] show that, in the

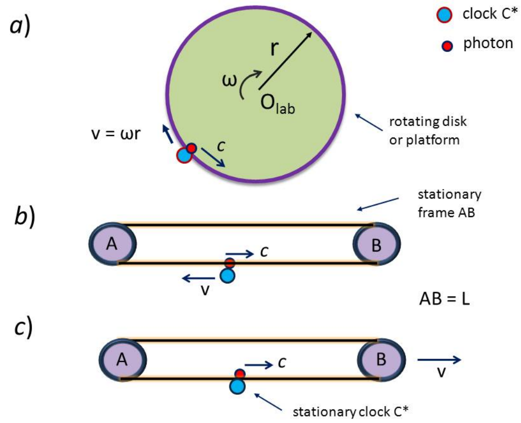

Figure 1: a) In the circular Sagnac effect, two counter-propagating photons (only a single photon is shown) are emitted from clock C* and travel on the rim of the rotating platform. C* measures the difference ΔT of the photons' arrival times after a round trip. b) In the linear Sagnac effect, device C* is moving with velocity v relative to the stationary frame AB and emits counter-propagating photons traveling in an optical fiber that slides frictionless around pulley A and B. c) In the reciprocal Sagnac effect, the frame AB moves with velocity v relative to the stationary clock C* that emits photons counter-propagating along the optical fiber.

measured round-trip time interval, the light signal cannot cover the closed contour if its local speed is c. The closed contour can be covered in the measured time interval if, and only if, the local light speed is $c \pm v$, confirming the LTA and disproving the LT.

3.2 Nonequivalence of relative and absolute simultaneity

Epistemologists claim that the basic postulates of a meaningful physical theory must be testable (i.e., falsifiable). Then, if one of its basic postulates is not falsifiable, it may be argued by physicists and epistemologists that the theory is not physically meaningful. If the LT (with relative simultaneity) are equivalent to the LTA (with absolute simultaneity) and the speed of light is conventional, the *standard* theory of special relativity has a drawback because its fundamental postulate of one-way light speed invariance cannot be tested [1], [7].

The "coup de grâce" to the thesis that the speed of light is conventional comes from our recent publications [7], [8] where we consider a new optical effect (the Spavieri-Haugh optical effect) that can be considered to be a kind of reciprocal linear Sagnac effect. In fact, in the standard linear Sagnac effect of Fig. 1-b), the emitter-receiver device is in motion relative to the contour where light propagates. Instead, in our reciprocal linear Sagnac effect of Fig. 1-c), the device is stationary, and the contour is in motion.

The unexpected result of our new optical effect is that the predictions of the LT and the LTA are strikingly different, indicating that they are by no means equivalent! Therefore, different synchronizations correspond to different nonequivalent transformations and different measurable one-way light speeds [7], [8]. The conventionalist thesis by Mansouri and Sexl, although valid in some cases, is shown to be untenable in general. The use of the LTA for "solving" the paradoxes arising with the LT, although adopted for decades by supporters of the LT, is a strategy conceptually and physically meaningless. Unfortunately, this erroneous strategy has considerably delayed the correct interpretation of the various paradoxes and the optical experiments. As recognized by Mansouri and Sexl [1], the several paradoxes arising with the LT are due to relative simultaneity. No paradoxes arise with the LTA where simultaneity is conserved. In the case of the twin paradox, for example, the LTA indicates clearly that the twin on Earth is the only one who sees moving clocks run slower [1]. Moreover, in Refs. [5]-[9], is discussed why experiments support the notion that the light speed is c in the inertial frame of the contour of the interferometers, where the electromagnetic waves propagating at the local speed c are locked along the closed interferometric light path.

4 Conclusions

The one-way speed of light is measurable in principle [9], and Lorentz invariance and standard special relativity can be tested, as required by epistemologists. Optical experiments, supporting the LT in 1905, disprove today the LT based on relative simultaneity and light speed invariance. The LTA interprets all the experiments supported by the LT, with the addition of the optical effects of the Sagnac type and without paradoxes.

Although the problems with the use of the LT are well known by detractors and supporters of special relativity, they are practically unknown to the majority of physicists. Prejudice, personal interests, fear of losing prestige, and many other factors, represent powerful forces that oppose a paradigm shift in science. Should lost rationality return in discussing controversial physical theories and the present available theoretical and experimental evidence become better known to the physics community, the likely viable alternative for special relativity is the paradigm shift from the LT to the LTA.

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5 Appendix

In the scenario of relativistic theories, the following coordinate transformations between two inertial frames of reference, S' and S, in relative motion with velocity $\mathbf{v} = \widehat{i}v$, represent the two most commonly adopted transformations:

$$\begin{array}{llll} LT & t' = \gamma(t - vx/c^2) & x' = \gamma(x - vt) & c' = c \\ LTA & t' = t/\gamma & x' = \gamma(x - vt) & c' = \gamma^2(c - v). \end{array} \tag{1}$$

In (1) the transformations $y' = y$; $z' = z$ are understood. The factor $\gamma = (1 - v^2/c^2)^{-1/2}$ depends on v and LT stands for the Lorentz transformations, based on standard synchrony and relative simultaneity. LTA stands for the Lorentz transformations based on absolute synchrony and simultaneity. The speed $c' = dx'/dt'$ is given for the special case of light speed c in the direction of $\mathbf{v}$ in frame S.

The LTA (or ALT in Ref. [11]) are known in literature also as the Tangherlini-Selleri transformations [12], [2], [13], and are formally the same as the ones used by various authors [11]-[17].

In the Sagnac effects (Figs. 1-a, 1-b), the emitter-receiver C* (clock or interferometer) is moving relative to a fixed contour where two light signals are counter-propagating and C* measures the difference $\Delta T = T_{\Leftarrow} - T_{\Rightarrow}$ of their round-trip times $T_{\Leftarrow}$ and $T_{\Rightarrow}$. For the Sagnac effects, the difference ΔT is given by,

$$\begin{aligned} \Delta T &= T_{\Leftarrow} - T_{\Rightarrow} = \frac{2\pi r}{\gamma(c-v)} - \frac{2\pi r}{\gamma(c+v)} = \frac{\gamma 2\pi r(1+v/c)}{c} - \frac{\gamma 2\pi r(1-v/c)}{c} \\ \Delta T &= T_{\Leftarrow} - T_{\Rightarrow} = \frac{2L}{\gamma(c-v)} - \frac{2L}{\gamma(c+v)} = \frac{\gamma 2L(1+v/c)}{c} - \frac{\gamma 2L(1-v/c)}{c} \end{aligned} \tag{2}$$

where $T_{\Leftarrow}$ and $T_{\Rightarrow}$ represent the round-trip time of the co- and counter-moving light signals (or photons) along the contour $2\pi r$ in the standard (or circular) Sagnac effect and $2L$ in the linear effect. Considering, for example, the counter-propagating signal, we show in Refs. [5] and [6] and in agreement with (2), that the local speed along the closed path $2L$ (or $2\pi r$) is $\simeq c + v$ for an observer instantaneously co-moving with C*, while is c for an observer stationary with the frame AB (or the centre O_{lab} of the disk), where the path covered by the signal is $\gamma 2L(1 - v/c)$ (or $\gamma 2\pi r(1 - v/c)$). Thus, observers in relative motion measure different light speeds, in agreement with the LTA and as originally claimed by Sagnac [3].

Although the use of the LT provides no difficulties with light propagation along open contours, in the case of a closed contour (as in the Sagnac effect) the root of the problem is the time discontinuity in the LT. As Landau and Lifshitz [18] put it: "... synchronization of clocks along a closed contour turns out to be impossible in general. In fact, starting out along the contour and returning to the initial point, we would obtain for dx° a value different from zero...". In agreement with the remark of Landau and Lifshitz [18] there is general agreement [2], [3], [5]-[18], that the standard procedure proposed by Einstein fails when applied to the closed contour of the Sagnac effect. even for the reciprocal linear effect.

The observable results [7], [8] related to the reciprocal Sagnac effect disprove the physical equivalence of the LT and LTA and the claim of some physicists [19], [20], [21] that the paradoxes of standard special relativity, based on the LT, can be "solved" adopting the LTA in lieu of the LT. On the contrary, the fact that the interpretation with the LT leads to paradoxes, while with the LTA no paradoxes are present, is a clear indication that the LT and LTA are not physically equivalent.

For the transformations proposed by Mansouri and Sexl [1], the equivalence between different synchronies does not hold when relative simultaneity plays a role, i.e., when the clock in the Sagnac effects changes velocity, or when in the reciprocal Sagnac effect, the contour changes velocity [7], [8].