Sagnac Effect and Special Relativity

A Thought Experiment

Ramzi Suleiman

University of Haifa

Please address all correspondence to Dr. Ramzi Suleiman, University of Haifa, Haifa 31509, Israel. Email: suleiman@psy.haifa.ac.il, Mobile: 972-(0)50-5474- 215, Fax: 972-(0)4-8240-966.

Sagnac Effect and Special Relativity

A Thought Experiment

Abstract

It is commonly claimed that the Sagnac effect does not contradict Special Relativity, because it is manifest in non-inertial radial motion and should be treated in the framework of General relativity. This claim is adhered to in justifying the implementation of both the Sagnac effect, and the Special Relativity time dilation in the GPS clocks synchronization. The present paper describes a thought experiment, called *the absent-minded assistant***,** which proves that as far as the velocity, kinetic energy, time and distance of travel, are concerned, a uniform radial motion with fixed radios *R*, and radial velocity $\omega = \frac{v}{R}$, is equivalent to a uniform linear motion with velocity *v*. With this proven on base of pure logic, the conclusions to be drawn are: (a) that the equivalence between of the linear and the radial Sagnac effects, previously detected experimentally, is also proven theoretically, and (b) That the second axiom of Special Relativity, positing that the speed of light is the same for all uniformly moving frames along a straight path, is incorrect.

I. Introduction

Sagnac effect, called after its discoverer in 1913 [1], has been replicated in many experiments (for reviews see [2-5]. It is well known that the Sagnac effect has crucial applications in navigation [2, 3, 6], and in fiber optic gyroscopes (FOGs) [7-11]. In The Sagnac effect, two light beams, sent clockwise and counterclockwise around a closed path on a rotating disk, take different time intervals to travel the path. For a circular path of radius *R*, the difference can also be represented as $\Delta t = \frac{2\,v\,l}{c^2}$, where $v = \omega R$ is the speed of the circular motion and $l=2\pi R$ is the circumference of the circle. Today, FOGs have become highly sensitive detectors measuring rotational motion in navigation [2, 6, 10, 11]. In the GPS system, the speed of light relative to a rotating frame is corrected by $\pm\, \omega r$, where ω is the radial velocity of the rotating frame and r is the rotation radios. A plus/minus signs is used depending on whether the rotating frame is approaching the light source, or departing from it, respectively.

It is widely claimed that the Sagnac effect does not contradict Special Relativity, since it *applies only to radial motion*, which is considered as to be non-inertial [12-14], and should be treated in the framework of General Relativity [15]. This position has justified the implementation in the GPS of both the Sagnac effect *and* the time dilation effect predicted by SR (In addition to GR and other corrections).

Interestingly, the findings of well-designed experiments (16-18, see also 19, 20] show, unambiguously, that an identical Sagnac effect occurs in linear uniform motion. This finding, in itself, should have raised serious questions regarding the above claim. More importantly, it should have raised serious questions about the validity of *SR*. If the Sagnac effect can be produced in linear uniform motion, then the claim, that it is characteristic of radial motion, is simply incorrect. But since the rules of Special Relativity apply to linear uniform motion, then the only conclusion, given that the experimental results are valid and reliable, is that Special Relativity is incorrect [19, 20].

Strikingly, the unrefuted detection of a linear Sagnac effect, and its diametrical contradiction with Special Relativity, has hardly been debated. In the present paper, I reconsider the issue from a theoretical point of view. I shall describe a thought experiment, called *the tail of the absent-minded assistant***,** which demonstrated that as far as time (*t*), velocity (*v*), distance (*d*) and Kinetic energy (*E*) are concerned, a given mass moving in radial motion with a fixed radios (*R*) and radial velocity $\omega = \frac{v}{R}$, is completely equivalent to a uniform linear motion is with velocity v. Following this argument - to be proven hereafter - two lemmas arise: 1. that the equivalence between of the linear and the radial Sagnac effects is also proven theoretically. 2. That the second axiom of Special Relativity, positing that the speed of light is the same for all uniformly moving frames along a straight path, is incorrect.

II. The Absent-Minded Assistant: A thought experiment

Imagine a physics professor - call her Eve - who wants to deliver a class about classical mechanics. Suppose that he wants to show, using laboratory data, that the following rules hold at low velocities: (a) the distance d traveled in time t by a body moving with constant velocity *v* equals $d = v\,t$ (b) that the Kinetic Energy E of a mass m equals: $E = \frac{1}{2}\,m\,v^2$. Assume that the professors has a lab with two adjacent rooms: A and B, where A is equipped for testing the dynamics of moving bodies in linear motion, and B is equipped

for testing the dynamics of bodies in radial motion. Suppose the professor is assisted by a young bright, but absent minded assistant, call him Adam. Suppose that the professor Eve want to give a class on linear dynamics and that she asks Adam by mail to collect data for next week class. Professor Eve's aim is to show that the experimental graphs, and match well with the corresponding classical equations. In her email to her assistant, Professor Eve wrote: "Dear Adam, please conduct the following experiment and send me the results in a table and figures. Go to lab, room A and conduct the following experiment: Put a mass of m (e.g., 50 gr) in a uniform motion for a duration of t seconds (e.g., 10 seconds); change the rate of the uniform motion and measure the velocity v, the distance travelled by the mass in t seconds (d) mass, and the mass kinetic energy at the end of its travel path. I need the results for my coming class. Thanks in advance, Eve". Now suppose that the absent minded assistance conducts the experiment in room B instead in room A and that upon conclusion of the experiment he returns all the equipment to its original places and positions.

The question of concern here is the following: would the professor succeed in convincing her students that the equations of linear motion succeed in describing his data? Or, alternatively, she would be embarrassed, and perhaps realize that something went wrong at the lab. Might she suspect that he absentminded assistant might have conducted the requested experiment in room B, on radial motion, instead of conducting it in room A, on linear motion?

The answer is obvious: She will deliver a successful demonstration of the laws above and will have no reason whatsoever, for suspecting any misconduct by her assistant. Put more formally, the above thought experiment, based on pure reason, proves that as far as the measurements of *v, t, d,* and *E* are concerned, a uniform radial motion with radial velocity $\omega = \frac{v}{r}$ (where r is a fixed radios) is completely isomorphic to a linear uniform motion with linear velocity v. Since the latter is in an inertial motion, so is the former.

III. Conclusions

From the aforementioned, is it follows that: (a) the detected identity between of the linear Sagnac effect and the radial Sagnac effect is also proven theoretically, and (b) That the second axiom of Special Relativity, positing that the speed of light is the same for all frames moving with constant linear velocity is incorrect.

References

[1] Sagnac, M. G. *C. R. Acad. Sci.* **157**, 708–710, 1913.

[2] Ashby, N. *Relativity in Rotating Frames*, Springer, 2004.

[3] Post, E. J. *Rev. Modern Phys.* **39**, 475–493 (1967).

[4] Anderson, R., Bilger, H. R., Stedman, G. E. "Sagnac" effect: A century of Earth-rotated interferometers. *American Journal of Physics*, 62, 11, 975-985, 1994.

[5] Malykin, G. B. Earlier studies of the Sagnac effect. *Phys.-Usp.*, 40 317, 1997.

[6] Ashby, N. Relativity and the Global Positioning System. *Physics Today*, 41-47, May, 2002.

[7] Chow, W.W. et al. The ring laser gyro. *Reviews of Modern Physics*, 57 (1), 61-104, 1985.

[8] Vali, V., & Shorthill, R. *Appl. Opt*. 16, 290, 1977.

[9] Leeb, W., Schiffner, G., & Scheiterer, E. *Appl. Opt*. 18, 1293, 1979.

[10] Lefevre, H. *The Fiber-Optic Gyroscope.* Artech House: Boston, 1993.

[11] Burns, W. K. *Fiber Rotation Sensing,* Academic Press, Boston, 1994.

[12]. Malykin, G. B. The Sagnac effect: correct and incorrect explanations. *Phys.-Usp.*, 43, 1229, 2000.

[13] Landau, L., Lifshitz, E. *The Classical Theory of Fields*, 4th. Ed. Pergamon: New York, 1997.

[14] Logunov, A. A., & Chugreev, Y. V. Special theory of relativity and the Sagnac effect, *Sov. Phys. Usp*., 31 861, 1988.

[15] Ashtekar, A., & Magnon, A. The Sagnac effect in general relativity. *J. Math. Phys*., 16, 341, 1975.

[16] Wang, R, Zheng, Y., Yao, A., & Langley, D. Modified Sagnac experiment for measuring travel-time difference between counter-propagating light beams in a uniformly moving fiber. *Physics Letters* A, 312 7–10, 2003.

[17] Wang, R., Zheng, Yi, & Yao, A. Generalized Sagnac effect. *Phys. Rev. Lett*., 93 (14), 143901 (3 pages), 2004.

[18] Ghosal, S. K., & Sarker, M. Cosmologically preferred frame, linear Sagnac effect and absolute synchrony,'' *Proc. Physical Interpretation of Relativity Theory Meeting* (VI) (Supplementary papers), Imperial College, London, pp. 52–64, 1998.

[19] Wang, R. First-order fiber-interferometric experiments for crucial test of light-speed Constancy. *Galilean Electrodynamics*, 16 (2), 23-30, 2005.

[20] Gezari, D. Y., Experimental basis for special relativity in the photon sector. arXiv:0912.3818, 2009.