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The Sagnac effect and its interpretation by Paul Langevin

L'effet Sagnac et son interpretation by Paul Langevin

Gianni Pascoli

Université de Picardie Jules-Verne, Faculté des sciences, Département de physique, 33, rue Saint-Leu, 80000 Amiens, France

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ABSTRACT

The French physicist Georges Sagnac is nowdays frequently cited by the engineers who work on devices such as ring-laser gyroscopes. These systems operate on the principle of the Sagnac effect. It is less known that Sagnac was a strong opponent to the theory of special relativity proposed by Albert Einstein. He set up his experiment to prove the existence of the aether discarded by the Einsteinian relativity. An accurate explanation of the phenomenon was provided by Paul Langevin in 1921.

RÉSUMÉ

Le nom de Georges Sagnac est aujourd'hui très connu des ingénieurs travaillant sur les systèmes de navigation, tant maritime qu'aérienne, qui exploitent sa découverte de 1913. Ce que l'on sait moins est que ce physicien était un farouche opposant à la relativité, théorie révolutionnaire qui avait été élaborée par Albert Einstein quelques années auparavant, en 1905. L'expérience de Sagnac a été pensée pour prouver l'existence de l'éther luminifère. Son interprétation correcte (relativiste) a été fournie par Paul Langevin en 1921.

1. Historical development

It would seem useful to recall the context of the discovery of the Sagnac effect. Around 1910, a very strong conservatism reigned concerning the paradigm of absolute space and its counterpart, the aether, the hypothetical medium of propagation of light. To this statement, we must add the presence of a very large number of skeptics, both physicists and philosophers, who opposed a non-sequitur to the new vision of space and time that was implied by the very recent Einsteinian theory of relativity. Some key points should also be highlighted.

E-mail address: pascoli@u-picardie.fr.

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1.1. *Newton and the absolute space (end of the 17th century)*

For Isaac Newton, the concept of absolute space (or pure extension) exists, regardless of the presence or not of any material. In Newton's worldview, absolute space was a pre-existing frame, empty and immutable, a fundamental background to any moving body. But its undefined nature made it a kind of metaphysical entity, close to transcendence. In the Scholium, at the beginning of the *Principia* (Definitiones), Newton expatiated on time, absolute or relative space and motion [1]. He suggested that an absolute motion can be distinguished from a relative motion. To justify his argument, he introduces a thought experiment that is still famous. A bucket filled with water is subjected to a fast rotation. There are two phases. (*i*) The bucket rotates, but the surface of the water remains flat. (*ii*) The movement is finally transmitted to the water. It is then observed that the latter leaks from the center and ascends towards the walls, the free surface taking the form of a paraboloid. During the first phase, there is indeed a relative movement water/bucket, but no centrifugal force appears. It is only in the second phase, when the movement of rotation is communicated to the water, that these forces develop. For Newton, the conclusion was that these forces are not correlated with the relative movement of the water/bucket, but are generated by the movement of water in relation to absolute space. A second thought experiment was also devised by Newton. Two spheres are connected by a rope and the assembly is rotated. The rope tightens and one can measure the tension that develops there. Newton's conclusion is the same.

1.2. *Ernst Mach and the relativity of motion (end of the 19th century)*

The concept of absolute space as introduced by Newton was strongly criticized by Ernst Mach in his book published in 1893 [2]. Mach assumed a positivist vision from the outset. He noted that Newton's experiment simply demonstrates that the shape of the water surface (a paraboloid) is not induced by the relative movement of water in relation to the immediate environment (the bucket in particular). But Newton did not extend his thought sufficiently far. It did not consider the distant masses (represented by the stars). According to Mach, it is legitimate to attribute the deformation of the surface of the water to a rotation, but not relative to an absolute space as Newton had suggested, but to a relative rotation of the water and massive distant bodies. Suppose that the bucket is fixed and that the whole Universe is put in rotation. Would the surface of the water take the form of a paraboloid? For Mach, the answer is yes.

We know that Mach's ideas had a considerable influence on the development of Albert Einstein's reasoning, especially during the first five years of the 20th century. But most physicists did not share Mach's point of view, and were very opposed to getting rid of the concepts of absolute space and aether.

1.3. *The luminiferous aether*

The idea of a medium for the propagation of light waves goes back to Christian Huygens (1690). Unfortunately, owing to Newton's great aura, Newton's corpuscular theory, exposed in his treatise Opticks (1704), completely dominated for more than 100 years and took precedence over Huygens' wave description. But Huyghens' hypothesis enjoyed a sudden revival at the very beginning of the 19th century, thanks to Augustin Fresnel and Thomas Young. Since then, the aether was considered as the absolute frame of reference, especially in relation to which Maxwell's equations (dating from 1862) had to be written and the celerity of the light was the constant c. This aether was automatically identified with the absolute space of Newton. But the Earth moves in this absolute space. Does it carry the aether with it as it moves? To answer this question considered as fundamental by the physicists at that time, a number of experiments were carried out in the first half [3,4] and at the end of the 19th century [5,6]. In spite of the fact that all these experiments, taken together, showed that the aether was an illusive medium, it must be remarked that as late as 1910, Hendrick Lorentz and Henri Poincaré had still not adopted a very clear position concerning the status of the aether [7]. For a more complete analysis of the debate on the light-bearing aether, see [8–11].

2. The experiment of Sagnac

In 1899, Georges Sagnac[1] had developed a theory of the existence of a motionless mechanical aether [12]. His aim was to explain within this theoretical framework all the optics phenomena, and especially the Fresnel–Fizeau experiment for the drag of light in a moving medium [4]. In 1910, he conceived a rotating interferometer for testing his ideas and to see the optical whirlwind effect, as he called it (Fig. 1).

The effect discovered by Sagnac, and published in the *Comptes rendus de l'Académie des sciences* in 1913 [13,14],[2] has led to many applications in positioning technologies (Global Positioning System, Galileo, etc.). The sensors (gyrolasers and gyrometers) that measure angular velocities with respect to an inertial frame of reference, exploit the physics of the Sagnac effect. Generally numbering three, these sensors form a part of the inertial stations, in particular those used to determine the orientation of all types of vehicles: aircraft, boats, submarines, space probes, etc. These devices have also been applied

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[1] This author is also known as the first in France to work on X-rays, following the German scientist W.C. Röntgen.

[2] A more extended version has also been published by Sagnac in the *Journal of Physics* the following year in 1914 [15].