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Relation between the Sagnac Effect and the Luminiferous Ether.

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Abstract: *The paper investigates the relation between two widely disputed topics in Physics: the luminiferous ether and the speed of light in rotating frames. The ether (also written sometimes as "aether") is supposed to be an invisible medium which is responsible for the constancy of the light speed. The anisotropy of the light speed is an interesting phenomenon, also called as the "Sagnac effect" after its first investigator. The article will not represent any definitive opinion on the Sagnac-effect vs ether relationship, but will show a surprising but important constraint, namely: if only one single "block-type" ether exists, as many scientists allege, then the rotational Sagnac effect can not be detected. Only Classical Physics and simple math will be used, no additional assertions will be needed.*

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I. The luminiferous ether

The conception about an invisible, space-filling substance can be traced back to the ancient Greeks. Later on, with the discovery of the finite light speed, it was usual to identify the ether as a luminiferous (light-bearing) medium.Albert Einstein was the first in his seminal paper [1] who explicitly denied the existence of ether. Or, more precisely, he surmised that the ether is unnecessary to include into his theory concerning light speed. Within few decades, Einstein's view and his Special Relativity became the official "mainstream" curriculum in the scientific community. It is interesting to note, that the Special Relativity does not follow automatically from Einstein's Postulate #2 on the constancy of the light speed. However, in many textbooks, the two concepts are used interchangeably. Despite the success of Relativity, a considerable number of scientists conserved the belief in ether. There are many modern theories on the luminiferous ether, (maybe too many). Some authors tried to reconcile the concept of the ether with the Special Relativity [2, 3], while others see an insoluble discrepancy between them (e.g. [4])Einstein himself also modified his strict anti-etherist view by introducing a limited coverage "electromagnetic" ether. Some scientists avoid the use of the word "ether", they speak about "preferred frame" instead, but with the same meaning. Most ether theories imagine the ether as a single, unitary block. However, in the last decades, some "multi-ether" or "local ether" theories have appeared, mainly in order to bring the measurement results closer to the theory [5, 6] These theories bring up some unanswered questions. (How to define therange of the local ether etc). There are many good historical reviews on the development of the ether concept, however, few of them are neutral. A good example is the retrospection of Ranzan, which reflects a definite etherist view [7]. It is interesting to see, that sometimes the same experiment can serve scientists on both side, because they make different explanations and conclusions. A typical example is the well-known Michelson-Morley measurement and its followers. [8]A very sensitive field of the debate between pro-ether and con-ether scientists is the velocity of the light in rotating frames. This phenomenon was first measured by the French physicist Georges Sagnac, very early, in 1913[9] We treat this topics in the next section.

II. The Sagnac Effect

As mentioned, G. Sagnac measured the light speed in rotating frames already in 1913.The apparatus of the Sagnac experiment consisted of a glass plate and three mirrors installed along the periphery of a disc, mounted on a platform which was rotated anticlockwise at a definite angular speed.. A beam of light from a light source was divided by a half-silvered mirror. The refracted ray traveled anticlockwise, in the direction of rotation, and the reflected ray traveled clockwise in the opposite direction of rotation. The returning rays were then recombined by the half-silvered mirror and passed into the telescope for recording of the interference fringes. Sagnac observed the following effect: as the disk was rotating, the fringes shifted aside in comparison to the still-standing state. We omit here the detailed description of the experiment and the measurement results, together with the follow-up experiments, these can be find elsewhere, e.g. in the good Wikipedia article [10], or in an easy-to-read paper [11]. However, it should be noted, that in one part of these experiments is made with help of a rotating object, while the other part uses the rotation of the Earth.The question arises: why are these results so important in the debate on the existence of ether? The answer lies in the fact, as we will see below, that in contrast to the Michelson-type interferometers, the rotating disk causes a first order effect in **v/c** (object speed in the measurement divided by the light speed). At the first sight, the result in the Sagnac-type may be disturbing for the orthodox relativist researchers, because their opponents can say: “During rotation, the mirror-to-mirror distances do not alter, or, in spirit of the Special Relativity, they suffer equal length contraction in both directions. Therefore, the light passes equal circular distances both in the clockwise and in the anti-clockwise direction. Then, why is there any fringe shift?” Therefore, no wonder that most of the textbooks on Relativity do not mention the Sagnac experiment or its modern versions. If we look around in the literature, there are several explanations. Let us list some of them, without claiming completeness:Explanation No:1. “It is nothing strange with the Sagnac effect; it fits well into the Special Relativity.” [12,13,14]. If we take a closer look to these works, we see that they use unjustified derivations or modified Postulates, which do not belong to the Standard Einsteinian theory.Explanation No 2. “Because the rim of a rotating disk represents a non-inertial reference frame, the General Relativity must be applied” [15]. This reasoning sounds believable, until we do not read the experiment of Wang et al [16]. The authors showed that the Sagnac effect occurs in translational motions, too. (So called “linear Sagnac”) This result makes any mysterious considerations about “rotational frames” superfluous and did not made he life of the orthodox believers easier.General Ether. See Sagnac’s original work. [9]Local Ether. [17, 18] According to the authors’ knowledge, this approach can correctly describe the results obtained by the Sagnac type measurement. However, this method must be developed to a more robust unified theory. For example, experience indicates that the ECI (Earth Centered Inertial) frame is a suitable reference frame for GPS equipments. [19]. However one needs a general method to find the necessary conditions for a definite location to be “preferred” or “local ether” frame.In this article we do not want to decide, which theory (Special and General Relativity, Galilean Relativity etc) is the best for describing the Sagnac effect. We only want to reduce the number of the different variations by exclude some impossible combinations with simple mathematics. We will show in the next Section that if the global ether exists, then it is impossible to detect the Sagnac effect.

III. Sagnac Effect With „Block” Ether

In this section we seemingly accept the ether theory in the original, for centuries believed form: there is one single Ether, which rules the speed of light. Because this ether is immovable, it causes anisotropy in every frames moving relative to the Ether. Because the Earth is not a privileged planet, moreover, it is rotating; consequently we must feel an “ether wind” when measuring light speed. The aim of the Michelson-Morley experiment was to detect the presence of the ether wind. We restrict ourselves to rotation type experiments with a great number of mirrors. (Investigations show that the Sagnac effect occurs with any number of mirrors.) Firstly we demonstrate the effect of the ether wind on the light speed. See Fig. 1.

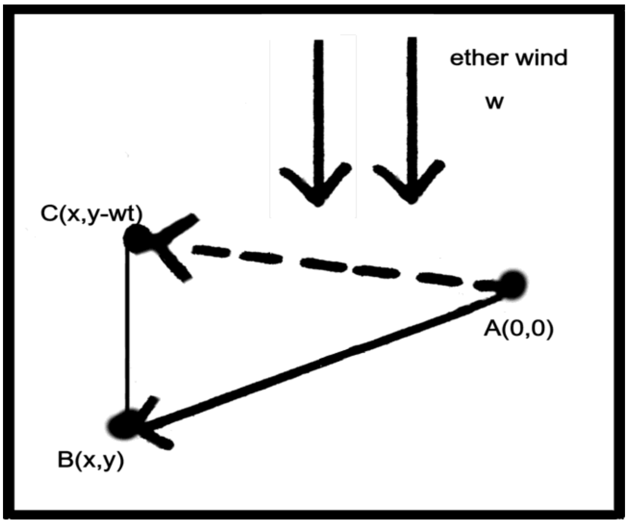

Fig.1. Effect of the ether wind on the light speed. If we want to send a light signal from A to B, we have to compensate the ether effect by directing the light to C.

Suppose we want to send a light signal from location **A** to **B**. (Coordinates are (0,0) and (x,y)). Without restricting generality, we suppose the ether wind to “blow” vertically with a velocity of **w**. If we direct the light to **B**, the ether wind “blows” away the light, therefore, we must compensate the effect by sending the light “in the eye of the wind”. The detected speed of light is: horizontally **c**, vertically **c±w**. The light needs **t** time to get from **A** to **B**.

Under these conditions we can write:

$$ct = \sqrt{x^2 + \left(x - wt\right)^2} \tag{1}$$

Let us apply the above results to the rim of a rotating disk! At the same time let us use small distances which can be approximated with deltas. See Fig. 2.

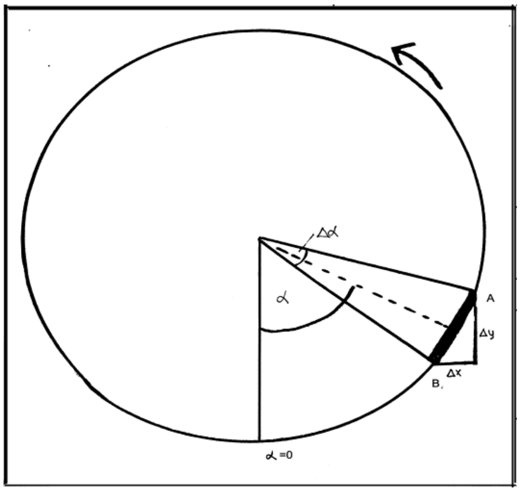

Fig.2. Light propagation on a rotating disk. The angles are measured in the lab frame, not on the rotating disk.

Eq (1) with deltas:

$$c\Delta t = \sqrt{\left(\Delta x\right)^2 + \left(\Delta y - w\Delta t\right)^2} \tag{2}$$

This is valid for both directions. As Fig.2 shows, the light advances a small angle on the rim of the disk. Eq. 2 can also be written in the following way:

$$\left[\left(\Delta t\right)^2\left(c^2 - w^2\right)\right] + \Delta t\left(2\Delta y w\right) + \left[\left(\Delta x\right)^2 - \left(\Delta y\right)^2\right] = 0 \tag{3}$$

Remark. In this calculation we only deal with the additive effect caused by the ether wind, therefore, we neglect the normal Sagnac effect. The combined effect can be calculated (in first order) by adding the two effects.
Now we apply angle variables:

$$\sqrt{\left(\Delta x\right)^2 + \left(\Delta y\right)^2} = R\left|\Delta\alpha\right| \tag{4}$$

R= radius of the disk, and

$$\Delta y = -R\sin\alpha\Delta\alpha \quad \Delta x = -R\cos\alpha\Delta\alpha \tag{5}$$

Eq. (5) is valid for one rotational direction. For the other direction opposite signs should be used.

Eq. (3) can be rewritten with these variables:

$$\left(\Delta t\right)^2 \cdot \left(c^2 - w^2\right) + \Delta t\left(2Rw\sin\alpha\Delta\alpha\right) - R^2\left(\Delta\alpha\right)^2 = 0 \tag{6}$$

The solution:

$$\Delta t_{1,2} = R\Delta\alpha \frac{-w\sin\alpha \pm \sqrt{c^2 - w^2\sin^2\alpha}}{\left(c^2 - w^2\right)} \tag{7}$$

if w=0, then $\Delta t = \frac{R}{c}\Delta\alpha$ as expected.

Now we introduce the following notation: $\beta \equiv \frac{w}{c}$

Eq. (7) can be written, omitting the negative case:

$$\Delta t=\frac{R\Delta\alpha}{c}\cdot\frac{-\beta+\sqrt{\beta^2\sin^2\alpha+\left(1-\beta^2\right)}}{1-\beta^2}=\frac{R\Delta\alpha}{c}\cdot\frac{-\beta+\sqrt{1-\beta^2\left(\cos^2\alpha\right)}}{1-\beta^2} \qquad (8)$$

The fly time for the whole circle can be achieved by integrating Eq. (8) for **Δt** between 0 and 2π. However, we are notinterested in the total time, we only want to calculate the time difference between the clockwise and anticlockwise rotation. We make a further simplification: because the Sagnac effect is a first order phenomenon, therefore we want to find first order effect in function of **w** (ether wind) too. So we neglect the second order term. (The term under the square root) . The time difference can be calculated by integrating Eq (8) not to 2π, but to 2π-Δα for one direction, and 2π+Δα for the other direction: For any expression E(α) is valid:

$$\int_{\alpha}^{\alpha+2\pi+\Delta\alpha}E\left(\alpha\right)d\alpha-\int_{\alpha}^{\alpha+2\pi-\Delta\alpha}E\left(\alpha\right)d\alpha=\int_{\varepsilon-\Delta\alpha}^{\alpha+\Delta\alpha}E\left(\alpha\right)d\alpha\approx 2E\left(\alpha\right)\Delta\alpha \qquad (9)$$

Applying the above example for Eq. (8):

$$\Delta t_{+}-\Delta t_{-}\approx\frac{R}{c}\left(\beta\sin\alpha\right)\Delta\alpha-\frac{R}{c}\left(\beta\sin\alpha\right)\Delta\alpha=\frac{2R}{c}\left(\beta\sin\alpha\right)\Delta\alpha \qquad (10)$$

Remember, we have omitted the second order expressions.
Now we have to calculate Δα with the actual parameters.

$$\frac{v}{c}\equiv\frac{R\omega}{c}=\frac{\Delta\alpha}{2\pi}\to\Delta\alpha=2\pi\frac{R\omega}{c} \qquad (11)$$

where **v** is the peripherical speed, **ω** is the angular speed at the rim of the disk. As mentioned, we have omitted the original Sagnac effect, for simplicity. We could insert it in the expression of **Δα.** Inserting **Δα** from Eq. (11) into Eq. (10) we get:

$$\Delta t_{+}-\Delta t_{-}\equiv\Delta t_{ether}\approx\frac{4\pi R^2\omega}{c^2}\left(\frac{w}{c}\sin\alpha\right) \qquad (12)$$

Let us compare the above expression with the known time shift of the Sagnac effect. (See e. g. [11])

$$\Delta t_{Sagnac}=\frac{4\pi\omega R^2}{c^2} \qquad (13)$$

Eq. (12) can be rewritten with Eq.(13)

$$\Delta t_{ether}=\Delta t_{Sagnac}\cdot\left(\frac{w}{c}\sin\alpha\right) \qquad (14)$$

Eq. (14) is our main result: the ether wind (if exists) causes an additional phase shift to the "etherless" Sagnac effect. This effect always smaller then the Sagnac effect (since **w<c**) but may be considerable if the ether wind is comparable with the speed of light. The shift is depends on the detector's angular position referred to the direction of the ether wind. Because the round trip of the light and the disk rotation are not synchronized, this angle is varying during one measurement. The varying shift causes "blurring" of the fringes, moreover, at a considerable ether wind the fringes may disappear totally.

IV. Conclusion

We have calculated the effect of the ether wind in a circular Sagnac interferometer. We found that the ether wind causes an additional phase shift, which is less than that of the Sagnac effect, but may blur or smash the fringes. Because no such effect has been reported in different measurements, it is highly probable, that the ether wind (and consequently the block ether) does not exist at all. However, the so called "local ether" may exist, but we are still lacking a uniform theory on multiple "ethers".

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