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A SECOND REVIEW OF MICHELSON-MORLEY (MM), SAGNAC AND MICHELSON-GALE-PEARSON (MGP) EXPERIMENTS

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Abstract

The velocity of light , from a source moving with velocity **u** relative to a point of reference, with respect to an observer moving with velocity **v** relative to the same point of reference, is vector **z** = **c** + (**u** – **v**), where **c** is the velocity of light, a constant relative to the source. In the MM and MGP experiments, the source and observer (interferometer) were moving with the same velocity (**u** = **v**) relative to the center of the earth. As such there should have been no time difference between rays, moving with velocity **c**, reflected off the mirrors, to give a null result. A null result was reported in the MM experiment but not so for the MGP experiment. In the Sagnac experiment, the glass plate acts as a secondary source moving at speed $u = \omega R$, with $v = 0$, relative to the center of the rotating disc. A refracted (transmitted) ray moving in a circle of radius R, at angular speed ω, travels with speed $z = (c + \omega R)$, while the reflected ray goes at speed $z = (c - \omega R)$, making a time difference between the two rays moving in opposite directions, to give a fringe shift, as observed. The fringe shifts said to have been obtained in the MGP experiment were within the experimental error of the apparatus. The Sagnac experiment should have put to rest the relativistic principle of constancy of the speed of light relative to an observer.

Keywords: *Fringe shift, light, reflection, rotation, speed, time, velocity.*

1 Introduction

This paper is a recast of an earlier one on the same topic [1]. The proposal here is that the velocity of light **z** from a source moving with velocity **u** relative to a point of reference, with respect to an observer moving with velocity **v** relative to the same point of reference, is:

$$\mathbf{z} = \mathbf{c} + (\mathbf{u} - \mathbf{v}) \quad (1)$$

where **c** is the velocity of light, a constant relative to the source, with **u** and **v** as vectors in any direction. In other words, light takes on the velocity of its source. For a stationary observer or an observer moving with the same velocity as the source (**u** = **v**), velocity of light is vector **c** of magnitude c. For velocities in the same direction, equation (1) gives speeds as:

$$z = c + (u - v) \quad (2)$$

Aberration of light, one of the most significant discoveries in physics, was discovered in 1725-1728 by the great English astronomer, James Bradley [2]. This is a direct consequence of the relative velocity of light being dependent on the motion of the observer, and it makes all the difference. Aberration of light, an important phenomenon in physics, is now relegated to the background in favor of the theory of special relativity.

In the Michelson-Morley experiment [3, 4] the time taken by a ray of light to cover the same distance along the direction of propagation and perpendicular to the direction of propagation, was compared. Any difference in the time was supposed to be indicated as a fringe shift in an interferometer. So far no fringe shift was observed despite extreme refinements and precision in various experiments.

In the Sagnac experiment [5, 6, 7, 8] the speed of rotation of the mirrors was added in the case of the refracted (transmitted) ray and subtracted for the reflected ray. This was also supposed to be the case with the Michelson-Gale-Pearson (MGP) experiment [8, 9, 10, 11], with the speed being that of rotation of the Earth at a given latitude.

The MGP experiment was conducted in 1925 in a clearing at Chicago, Illinois, USA. It was repeated with greater precision, using laser, in 1995 [7] in New Zealand, Southern Hemisphere. In this experiment, there was a positive result attributed to the difference in transit times of two different rays of light moving in opposite directions along coincidental closed paths. The two rays created a fringe shift δ observable in a telescope. The experiment took 269 separate readings and obtained values of δ ranging from –0.04 to +0.55 of a fringe with a mean of +0.26 fringes [12]. As for the MM experiment, a small persistent positive shift has been reported [12] as observed in some experiments.

The purpose of this paper is to argue that the result of the MM and MGP experiments should be a null. That the Sagnac experiment, gives rise to a fringe shift due to a time difference between a refracted ray and a reflected ray covering the same distance but in opposite direction.

2 Michelson-Morley experiment

A simplified diagram of the famous Michelson-Morley experiment is shown in Figure 1 below. The apparatus consisted of a light source *S*, a half-silvered mirror *A*, placed at an angle of 45^o, two distant mirrors *B* and *C* and a detector *D*. The whole apparatus, including the mirrors, was placed on a large turntable that could be swung around by 90^o.

Light was directed at an angle of 45^o to a half-silvered, half transparent glass plate *A*, so that half of the light went on through the glass and half of it was reflected. The transmitted light went on to mirror *B* and the reflected beam to mirror *C*, each through equal distance *L*. The reflected lights, from *B* and *C*, were returned to the half-silvered plate *A* where they were again half reflected and half transmitted. The recombined rays of light travelled behind the half-silvered plate *A* to reach the detector *D*, where interference fringes were recorded. Swinging the apparatus through 90^o should give a reading at the opposite side of the zero (center) point of the fringe pattern.

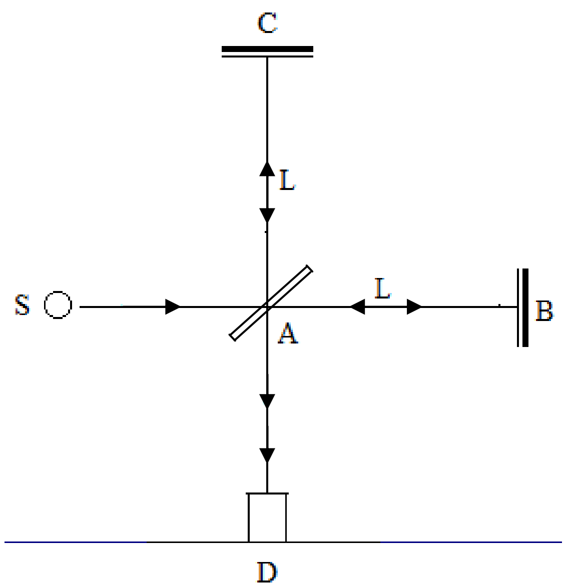

Figure 2 The apparatus of the Michelson-Morley Experiment

If there was any difference in the transit times of the two rays, going through equal distance *L*, as a result of difference in relative speeds between the rays and the mirrors, it should show as interference fringes in the interferometer *D*. The effect on speed through the luminiferous aether on one of the rays was compared by rotating the interferometer through 90^o. Then, by making measurements six months apart, one added or subtracted the speed of revolution of the Earth (30 km/s) in its orbit around the sun. The interferometer was easily sensitive enough to detect this effect if present. However, the shift obtained was 0.00 ± 0.01 fringes [11], indicating a null result within the limits of resolution of the interferometer.

In the MM experiment (Figure 1) there was no relative motion between the source of light *S*, and the detector *D*. Therefore, with the separation *L* remaining constant, the rays of light propagated at speed *c*, as given by equation (2) with ($u = v = 0$), should take the same time *2L*/c, to go to and from the respective mirrors. As such, there could be no fringe shift.

3. Sagnac experiment

The apparatus of the Sagnac experiment consisted of a glass plate *A* and three mirrors *B*, *C* and *D* installed along the periphery of a disc of radius *R* mounted on a platform which was rotated anticlockwise at angular speed ω, as shown in Figure 2 below. A beam of light from a source *S* was divided by glass plate *A* into two rays by refraction and reflection. The whole apparatus, including the source of light *S* and telescope *T*, were rotated with angular speed ω. The refracted (transmitted) ray travelled anticlockwise, in the direction of rotation, and the reflected ray travelled clockwise in the opposite direction of rotation. The returning rays were then recombined by plate *A* and passed into the telescope to record the fringes.

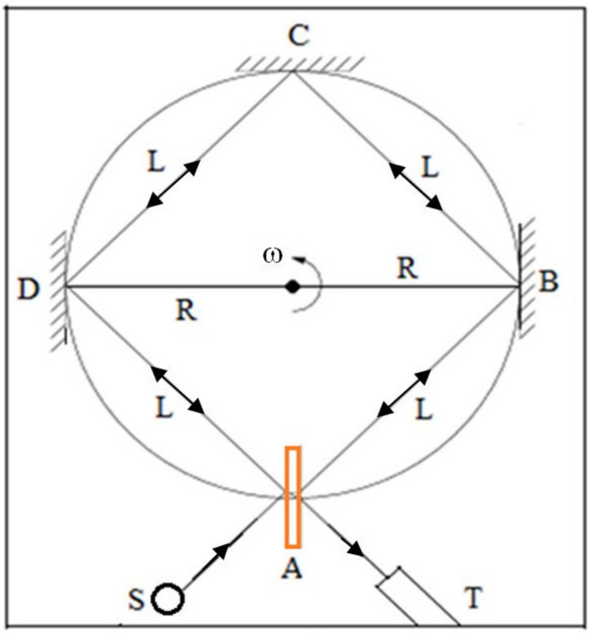

Figure 2 Apparatus of the Sagnac experiment

In Figure 2, let us first regard the system as stationary, i.e. $\omega = 0$ and $u = 0$. The time t_o taken by the two rays, for the round trips covering a distance *4L* at speed *c*, is equal to:

$$t_o = \frac{4L}{c} \tag{11}$$

Zero (central) reading was obtained with the disc stationary.

Considering the glass plate A as a secondary source, the speed of refracted (transmitted) ray of light in the direction of rotation (anticlockwise), is ($c + \omega R$), as given by equation (2) with $u = \omega R$ and $v = 0$. Time taken for light to go anticlockwise from plate *A* to mirror *B*, with speed $(c + \omega R)$ is $L/(c + \omega R)$, equal to the time taken for the ray to go from mirror *B* to mirror *C*, mirror *C* to mirror *D* and mirror *D* to plate *A*. The time t_1 taken by the ray to go anticlockwise in the round trip *ABCDA* of length 4L, is:

$$t_1 = \frac{4L}{c + \omega R} \tag{12}$$

Here, it is approximated that the light ray moves along the periphery of the disc carrying the mirrors. The accuracy of this approximation can be increased by having many more reflecting mirrors or the rays can be guided by an optic fibre cable along the periphery of the disc.

Similarly, time taken for the reflected ray to go clockwise from plate *A* to mirror *D* is $L/(c - \omega R)$, equal to the time taken for the ray to go from mirror *D* to mirror *C*, mirror *C* to mirror B and mirror *B* to plate *A*. Time taken for light to go clockwise from plate *A* to mirror *D* is $L/(c - \omega R)$, equal to the time taken for the ray to go from mirror *D* to mirror *C*, mirror *C* to mirror *B* and mirror *B* to plate *A*. The time t_2 taken by the ray to go clockwise in the round trip *ADCBA*, of length 4L, is

$$t_2 = \frac{4L}{c - \omega R} \tag{13}$$

The time difference Δt between the two rays, going round in opposite directions of the rotating disc, is:

$$t_1 - t_2 = \Delta t = 4L\left(\frac{1}{c - \omega R} - \frac{1}{c + \omega R}\right) \approx \frac{8\omega RL}{c^2} \approx \frac{4\omega\pi R^2}{c^2} \approx \frac{4\omega A}{c^2} \tag{14}$$

where *A* is the area enclosed by the rotating mirrors. The fringe shift δ, for light of wavelength λ, is given by:

$$\delta = c\frac{\Delta t}{\lambda} = \frac{8\omega RL}{c\lambda} \tag{15}$$

The *Sagnac Effect* or *Sagnac Interference* occurs in *Ring Interferometry* where two rays of light following a closed trajectory in opposite directions are made to combine and form an interference pattern. The Sagnac experiment has been performed a large number of times during the last century. Recently, using a ring laser [7] the Sagnac effect was confirmed to an extremely high degree of precision.

4 Michelson-Gale-Pearson (MGP) experiment

Figure 3 is a schematic diagram of the arrangement and apparatus of the (MGP) experiment [7, 8, 9]. The aim was to employ ring interferometry to measure the effect of speed of rotation of the Earth on the speed of propagation of light on the surface of the Earth. The experiment consisted of a very large ring (rectangular) interferometer with a perimeter of about 1.9 kilometres, large enough to detect the angular velocity of rotation of the Earth. It was a modified version of the Michelson-Morley experiment with the mirrors tilted by 45° so that the reflected rays of light were sent out to form a complete rectangle.

The rectangle consisted of 30-cm diameter water pipes *AEBCFD* about 612 metres by 339 metres, laid straight and level in a field, with the longer arms in the west-east direction and a smaller rectangle *AEFD* at one end. The pipes were evacuated using an air pump to make for clearer images. The larger rectangle carried a glass plate *A* and mirrors *B*, *C*, *D* at the corners and the smaller rectangle carried glass plates *A*, *E* and *F*. The plates were lightly coated to reflect and transmit the desired proportion of light and the mirrors were heavily silver-coated for full reflection.

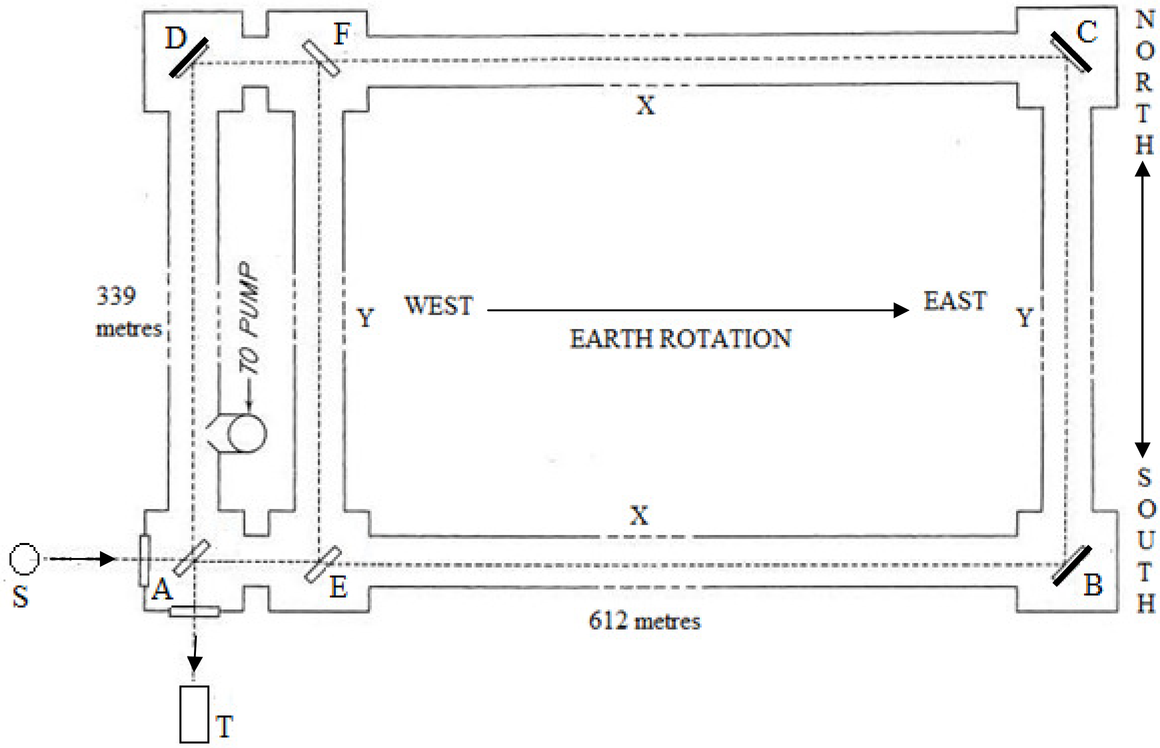

Figure 3 Apparatus of the Michelson–Gale–Pearson experiment

A light beam from a carbon arc source *S* (Fig. 3) was divided into two rays, a transmitted ray and a reflected ray, by plate *A*. The two rays of light were sent in the opposite directions into the rectangle *AEBCFD*, reflecting off the mirrors at the corners, and returned to the starting point *A*. Lights exiting the rectangle at *A* were compared in a telescope *T*. As a reading could not be taken with the Earth at a stand-still, the purpose of the smaller rectangle *AEFD*, with arms too short to provide any measurable observation, was to give a central (zero reference) point of the fringe pattern in the telescope.

In the absence of any effect due to the west-to-east rotation of the Earth, the two rays propagating in opposite directions in the rectangle *AEBCFD* of Figure 3, would go from and come back to the starting point *A* in an equal transit time. In this case the images would coincide at the centre of the screen of telescope *T*. It was thought that as a result of rotation of the Earth of radius *R*, with an angular speed, the arm *AEB* being nearer the equator, would spin faster than the arm *DFC* further north. This difference in speed of rotation, it was supposed, would cause a difference in transit times of the two rays going along the same path but in opposite directions; the ray going in the anti-clockwise direction *(AEBCFD)* taking a longer time in the round trip.

The MGP experiment conducted in 1925 at Chicago, Illinois, USA, repeated with greater precision in New Zealand, recorded a positive result. The Chicago experiment was painstaking. It took 269 readings and obtained values of fringe shifts ranging from -0.04 to +0.55 with a mean of +0.26, compared to the computed value of +0.24. These results, although positive, are not conclusive.

In this second review of the MGP experiment, it is argued that since the source of light and the observer are all moving with the same speed, relative to the centre of the Earth, the speed of transmitted and reflected lights in the tubes should be c, as given by equation (2) with $u = v$. As such, there should be no time difference between the two rays going in opposite directions with speed *c*. So the result of MGP experiment should be a null, as in the MM experiment.

5 Conclusions

1. With speed of light being *c* in the perpendicular arms of the apparatus, the null result of the MM experiment is as should be. There is no need for length contraction or time dilation, in accordance with the theory of special relativity, to explain the result.
2. The presence of fringes in the Sagnac experiment is an indication of a light ray taking on the speed of its source, contrary to the relativistic principle of constancy of speed of light.
3. The fringe shifts claimed to have been observed in the MGP experiment may be within the range of experimental error of the apparatus or within the limit of resolution of the spectrometer.

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