SIGNIFICANCE OF THE SAGNAC EFFECT

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BEYOND THE CONTEMPORARY PHYSICS

by

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2 MARKS

- \( c \) (longitudinal) speed of light
- \( c_\perp \) speed of light opposite to the velocity
- \( c_\parallel \) speed of light in the direction of velocity
- \( c_p \) speed of light perpendicularly to the velocity (transversal light speed)
- \( R \) radius
- \( v \) velocity
- \( v_o \) velocity of the earth to the ether
- \( v_R \) circumference velocity
- \( \beta \) contraction form factor
- \( \lambda \) wave-length
- \( \omega \) angular velocity
3 THE PARADIGM

3.1 Analytical Viewpoint

During the historical development, the notions of electrodynamics and theory of light have become complicated complexes of concepts [1]. And what is more, nowadays they are incomplete, or in the worst case wholly confusing. The laws of electrodynamics in present form are not valid in rotating and deforming systems in general [2]. These turbulent notion complexes— which are inadequate for the inner connections are verified by experiments, measurements results, and certain electrodynamical states and processes— have to be broken open, disintegrated, then disjoined. Henceforth, we must search those genuine, pure and simple electrodynamical ideas, which can already join in the immanent natural and well adequate manner. Consequently, progress can be achieved only by careful analysis.

Some of the unsolved problems in contemporary electrodynamics draw the attention to deeper (more profound) evidences, new ideas and new theories or equations. The aim of this historical introduction is to find the deeper evidences, and new basic concepts and connections. The guiding principle is the investigation of light propagation.

3.2 Profound Evidences and Connections

The childhood of optics was in the ancient religious Egypt. The first survived written relics of the optics originates from antique Greek science. Euclid was regarded as one of the founders of geometric optics because of his books Optics and Catoptrics (catopric light, reflected from mirror).

The geometric description of the light propagation and the kinetics description of motion were closely correlated in the history of science. Among the main evidences of the classical Newtonian mechanics is the Euclidean geometry based on the optical effects. In Newtonian physics, space has an affine structure but time is absolute. The basic idea is the inertial system, and the relations are the linear force-laws. The affine structure allows the linear transformations in space between the inertial coordinate systems, but not in time. This is the Galilean transformation:

\[ x' = x + x_0 + vt, \quad t' = t + t_0. \]  \hspace{1cm} (1)

This is a law of choice for any motion equation.

The revolution of the physics at the end of nineteenth century was determined by the new properties of light propagation and heat radiation. However, there remain many unsolved problems in these fields [2].

The laws of sound propagation in different media include the concept of ether, which is the hypothetical bearing substance of the light and electromagnetic waves.
4 HISTORICAL OVERVIEW

4.1 The Main Experiments

The first measurement for the determination of velocity of sound was made by Mersenne in 1636. In 1687 Newton gave a rough formula for the velocity of sound. It was further developed by Laplace in 1816, based on the adiabatic changes of states for gases. In 1866 Kundt constructed the so-called Kundt’s tube, which can determine the velocity of sound in liquids and solid materials. He found that the velocity of sound grows because of solidity of bearer materials. In the framework of classical mechanics, this observation inspired the notion that ether is an extremely solid substance.

The first attempt to determine the speed of light was made by Galileo in 1641. Descartes assumed an infinite speed of light based on the unsuccessful Galilean measurement.

In 1676, after 20 years observation of the motion of Jupiter’s Io moon, Römer published his result about the speed of light, which was calculated as c=220000 km/s [3].

In 1727 Bradley made a much precise experiment to determine the speed of light. His measurements were based on the aberration of stars, and the results of these measurements closely approximated today’s values.

Arago was the first who planned a light speed measurement under laboratory circumstances [4]. This measurement gave the Bradley’s value for the speed of light. In 1850 Arago’s followers Foucault [5], and Fizeau [6] proved that the speed of light is higher in the air than in liquid. These measurements closed down the old debate in the spirit of the wave nature of light. In that time this seemed to verify the concept of ether as the bearing substance of light.

The first experimental investigation for the magnitude of the change of light speed in moving media was made by Fizeau in 1851 [7]. His experiment proved that the velocity of the propagation is greater in the direction of motion of the medium than in the opposite direction, that is, the light is carried along with the moving medium. This theory was developed and confirmed by Michelson and Morley in 1886. In 1926 Michelson developed the Foucault’s rotating-mirror experiment. The result of Michelson experiment [8] is: $c=2.99769\times10^8\pm4\times10^5$ m/s.

4.2 The Turning Point: Michelson-Morley Experiment

In 1867 Maxwell published his book about the electromagnetism [9]. Maxwell’s work has a basic importance, not only in the electromagnetism but also in the optics. It also provided a common frame of reference for the propagation of electromagnetic and light waves.
The Maxwell equations are valid only in the unique inertial coordinate system, but these are not invariant for the Galilean transformation (1). This means that the Maxwell equations do not satisfy the requirements of classical equation of motion. This problem was apparently solved by the introduction of the concept of ether, the bearing substance of light. The challenge was to determine the ether as the unique inertial system or Earth's motion in this ether.

Maxwell in an other work [10] raised up the question as to whether the translation motion of the earth relative to the ether can be observed experimentally. An electromagnetic inertial system could be found by measurements, which could be used in astronomical calculations as well. Furthermore, space must be provided for formulating an equation of motion that is less rigorous than the used Galilean relativity theory.

Numerous unsuccessful measurements were made to determine the motion of Earth in the ether. These measurements were not able to give results compatible within the framework of classical Newtonian mechanics, even though that the earth has a known orbital velocity \( v_0 \sim 30000 \text{ m/s} \) (where \( v_0 \) is velocity of the Earth to the ether). In 1887 Michelson and Morley also determined the earth's orbital velocity by their precision interferometer [11]. The updated arrangement of Michelson-Morley experiment (M-M experiment) can be seen in Figure 1.

![Figure 1](image)

Here LASER means the source of light, BS means beamsplitter. M1, M2 are mirrors on the end of arms, PD is the phase detector (interferometer), and \( v \) is the earth's orbital velocity which is regarded as the inertial motion for short times.

According to the classical mechanics the travelling times of light \( T \) for the arms \( d_1 \) and \( d_2 \) can be given as follow:

\[
T_{OAO} = \frac{2d_1}{c} \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \quad T_{OOB} = \frac{2d_2}{c} \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}
\] (2)
Fitting the length of interferometer's arms -according to the zero difference of travelling times (zero interference)- it is given that $\Delta T = T_{OBO'} - T_{OAO'} = 0$. Then the lengths of two arms can be determined exactly:

$$d_1 = d_2 \sqrt{1 - \frac{v^2}{c^2}}.$$  

(3)

According to the classical physics, the difference of traveling times $\Delta T^*$ and the interference picture must be changed -turned round the instrument with $90^0$:

$$\Delta T^* = T_{OBO'}^* - T_{OAO'}^* = \frac{2}{c(1 - \frac{v^2}{c^2})}\left\{d_2 - d_1 \sqrt{1 - \frac{v^2}{c^2}}\right\}$$

(4)

Substituting Eq. (3) into Eq. (4) and arranging, the traveling time difference for $v^2 << c^2$ is

$$\Delta T^* = \frac{2d_2c}{c^2 - v^2} \frac{v^2}{c^2}.$$  

(5)

Their experiments proved that the traveling-times differences did not change along the two arms $\Delta T^* = 0$ for any turning round of instrument. In other words, there was not any change in the phase relations or interference fringes. Thus one might suppose that the solar system moved relative to the ether possessing a velocity that coincided with that of the orbital velocity of the earth, and by coincidence, the experiment was carried out during a period when the earth was moving relative to the Sun in the same direction as the ether. This experiments essentially contradict classical Newtonian mechanics. The Michelson-Morley measurements, which resulted in a negative outcome, have had one of the most remarkable influences to the development of twentieth century physics. A modern setup can be seen in Figure 2.

Figure 2  An up-to-date setting of M-M type experiment
4.3 The Sagnac-Type Experiments

The earth rotation around its axis can be seen from the apparent motion of the stars. The rotation can also be observed by mechanical experiments carried out on the surface of the earth, that is, with the help of Foucault's pendulum, or by observing the motion of a rapidly rotating gyroscope. It is important that the rotation of the earth can also be observed by closed optical experiments.

This effect was first demonstrated in 1911 by Harress and in 1913 by Sagnac, so it is now often called the Sagnac effect. Sagnac determined a rotation by a closed optical instrument [12]. Sagnac also fixed an interferometer onto a rotating disc. A flowchart of the basic arrangement of the essential features in Sagnac experiment is shown in Figure 3.

It is clear that the rotation occurs relative to the carrier of electromagnetic waves; this is, the observed rotation relative to the ether.

This measurement was improved by Michelson and Gale in 1925 using the earth instead of rotating disc [13].

In 1926 the Michelson and Gale experiment was confirmed by Pogány [14], who determined the surface velocity of the rotating Earth by a closed optical instrument: \( v_R \approx 300 \) m/s in Budapest's latitude. Because of its precision, this experiment it is used in some military application, such as in laser gyroscope techniques. It is also commonly used today in guidance and navigation systems for airlines, nautical ships, spacecraft, and in many other applications. A laser gyroscope can be seen in Figure 4.
Because of the incredible precision of interferometric techniques, this measured velocity is altogether one percent of the earth's circumference velocity derived from the orbital motion. Very Long Baseline Interferometry (VLBI) - which is an exhaustively improved Pogány experiment- can detect \( \Delta \omega \approx 10^{-9} \) in the earth's rotation.

Sagnac-type experiments are versatile and more accurate than the M-M type experiments, which cannot detect rotation. Sagnac-type experiments demonstrated that the caused phase shift is proportional to the angular velocity \( \omega \) and the measure of the enclosed surface \( S \) in a rotating system.

5. ANALYSIS OF MICHELSON-MORLEY EXPERIMENT

5.1 The Least Arbitrariness Principle: The Necessary Hidden Variables

In order to explain the negative result of the Michelson-Morley type experiments a whole series of hypotheses were proposed, all of which were eventually found to be untenable. This first explanation consists in the assumption that the ether at the earth's surface is carried along by the earth, adhering to the earth like the earth's atmosphere. This explanation became very improbable in the light of Fizeau's experiment on light propagation in media with motion. This experiment suggested that the ether is not carried along or at most only partially carried along by moving medium [7,8].

Numerous researchers tried to determine the velocity of the earth motion to the ether by electromagnetic and optical way. These experiments predicted that the earth with the experimental instruments always are standing in (or moving along with) the ether, which really is a tenacious contradiction of contemporary physics.
The physicists tried to solve this profound problem by the principle of least arbitrariness or a fortiori [2/c]. This principle means the optimum relation among the introduced hidden variables, which are necessary to description of phenomena. (This maxim is well known and accepted in the science as Occam's razor.)

5.2 The Lorentz's Interpretation of M-M Experiments

Lorentz [16] and his colleagues introduced a hidden variable: the contraction form factor $\beta = (1 - \frac{v^2}{c^2})^{1/2}$ in the Eq. (3). In the case of $d_1 = d_2$, the Eq. (3) provides a simple solution of this contradiction. In Eq (5) the difference of traveling times can be eliminated if, for example, $d$ depends on the velocity only

$$d^* = d\beta. \quad (6)$$

(where $\beta$ is a contraction form factor)

Of course in Eq. (6) the contraction form factor $\beta$ is valid only in that arm which parallel to the velocity vector. Equation (6) was interpreted by Lorentz and Fitz-Gerald as a real contraction [17]. It is important to see that in the Eq. (6) the hidden parameter $\beta$ is only one possible solution for the contradiction, but the result of Michelson-Morley experiment allows numerous other solutions based on the inner properties and features of the light. The Michelson-Morley experiment destroyed the world picture of classical physics, and it required a new physical system of paradigms. Thus, for example, the applicability of Galilean relativity principle was rendered invalid.

One of the most important requirements for an axiomatic theory is to determine the validity-round of the laws, and to verify of the self-consistency in the theory. The Michelson-Morley experiment proved that the prediction of the classical physics was not valid for the light propagation, or rather the Maxwell's theory of electromagnetism. This is an applicability limit of the Newtonian physics. Beyond this limit, the Newtonian physics becomes incomplete.

Lorentz, Fitz-Gerald and others were able to formally explain the lack of changing of interference fringes [1] using a hidden variable that is essentially the quotient of the theoretical and the measured results. This method combined with the least arbitrariness principle obtained the optimal hidden parameter which was satisfied by the experiment. The operator of the optimal hidden parameters used in the description of Michelson-Morley experiment is the generalized form factor, the so-called Lorentz transformation. Lorentz believed a fortiori that this operator is in connection with the ether's wind, and this wind is the actual cause of the assumed bodies' contractions. The merit of the Lorentz transformation is the verification for the invariance in the Maxwell equation. However, one disadvantage of the Lorentz interpretation is that the contraction is independent of the material properties of bodies.
5.3 The Einstein's Interpretation of M-M Experiments

Einstein created a tabula rasa in his 1905 paper titled "On the electrodynamics of moving bodies" [18]. He rejected the paradigm of ether as well as the classical concepts of the space and time, and founded a new physics by the exclusion of inner forces called the special relativity theory. He stated two axioms: (1) The principle of relativity and (2) the homogeneous and isotropic propagation of light in any inertial coordinate system of the vacuum. The homogeneous isotropic light propagation can be satisfied by the Lorentz-contracted space-time. Of course without concept of physical ether, the ether wind theory is meaningless. Einstein refused the material explanation of Lorentz and Fitz-Gerald, but kept the contraction form factor $\beta$ without another material interpretation. It is clear that the nonmaterial interpretation given by Einstein is high-handed, but it is still questionable that it is the least arbitrary.

It is well known that Einstein's interpretation for the Michelson-Morley type experiments self-consistent in mathematical sense, although he lost the genuine concepts and the traditional a priori and anthropic relations of the space and time forever. With this step the science left its childhood or rather it lost its innocence. In this way Einstein created the opportunity for any extravagant interpretation of strange experiments, and so any other physical concepts, for example the propagation, became illusory.

5.4 Interferometers: Standing Wave Systems

As it was confirmed that the notions of electrodynamics and the theory of light propagation have become complicated complexes of concepts and they are wholly confusing. These inadequate notion-complexes have to be broken open, disintegrated, then disjoined. Henceforth, it is necessary to search those genuine, pure and simple ideas which can already join in the immanent natural and well adequate manner.

Let us study the M-M- and the Sagnac-type experiments without any preconceptions. We can then see that the interferometers are unable to measure the traveling times; they can measure only the interference fringes of standing waves. This means that the description of M-M experiment allows the use of the wave lengths and phases, but not the traveling times and the speed of propagation. In strict sense the Michelson's type interferometers are unable to measure the velocity of propagation and traveling times in the arms. Specifically to measure traveling times it an exact optical distance measurement theory and method would be necessary. (In connection with restrictions of least arbitrariness in the geometrical optics, the principle of least action can give the way of light as the distance.)
The fine distinction between the traveling times and the shift of the interference fringes may be indifferent from the point of view of Newtonian mechanics which predicts both of changing. Finally, classical physics and the geometrical optics are refuted or restricted by the experience, notwithstanding the fact that these are self-consistent theories in their own right.

### 6. Analysis of Sagnac-type Experiments

#### 6.1 The Classical Arrangements

Consider a disc of radius $R$ rotating with an angular velocity $\omega$ around its axis [1, 12, 13, 14]. Suppose a large number of mirrors $n$ arranged on its periphery in such a way that a light signal starting say, from a point $A$ of the periphery is guided along a path very nearly coinciding with the edge of the disc. If the disc is at rest a signal starting at the time $t=0$ from a point $A$ on the periphery arrives back into $A$ at a time

$$T = 2\pi R/c. \quad (7)$$

However, if the disc is rotating with a circumference velocity $v_R = \omega R$ and the light signal is moving in the direction of rotation it will reach at the time $T = 2\pi R/c$ a point $A_0$ located in the place which $A$ had left at $t=0$. The signal has to catch up the point $A$ which is moving away; the signal will reach this location at a later time $T_*$, so that $cT_* = 2\pi R + v_A T_*$, therefore

$$T_* = \frac{2\pi R}{c - v_R} > T. \quad (8)$$

(where $v_R$ is circumference velocity)

Now suppose that the light moves relative to the edge of the disc $c_*$ according to the classical physics and Eq. (8) in the direction of velocity

$$c_* := c - v_R. \quad (9)$$

(where $c_*$ is speed of light in the direction of velocity)

Suppose that the velocity of the beam relative to the disc but that we have calculated the traveling time only and that the signal starting from $A$ must again catch up with point $A$, which moving away.

If the light signal moves in the opposite direction, it reaches $A$ sooner that at $t=T$ as point $A$ moves then towards the signal. In this case we find for the time at which the signal reaches $A$
or we may assume that the speed of light traveling in the opposite direction is velocity $c$:

$$c := c + v_R.$$  

(\(c\) is speed of light opposite the velocity)

In the boundary transition (\(n \to \infty\)) the polygon - constructed by the mirrors- becomes a circle with radius $R$, and the difference of the times needed to circle around the disc in the opposite direction is thus

$$\Delta T = T_+ - T_- = \frac{2\pi R}{c - v_R} - \frac{2\pi R}{c + v_R} = \frac{4\pi R v_R}{c^2 - v_R^2} \approx \frac{4S\omega}{c^2},$$

(12)

where $S = \pi R^2$ is the area of the disc circled round by the beams and $\omega$ is angular velocity.

Of course, according to the Section 5.4 this calculation should really be carried out the wavelengths $\lambda$-s instead of traveling times $T$-s. The Sagnac-type experiments are also standing-wave systems. Then the magnitude of shift of the interference fringes with the above $\omega$

$$\Delta\lambda = \lambda_+ - \lambda_- = 2\pi R \left( \frac{c}{c_+} - \frac{c}{c_-} \right) \approx \frac{4S\omega}{c},$$

(13)

which is confirmed by the experiments [12, 13, 14] without any doubt.

Naturally this coincidence does not mean that the geometric optics added to the classical physics could be used for the exact description of the light propagation since the Michelson-Morley experiment refuted its validity forever. It is evident that there are possible new mathematical definitions for $c_+$ and $c_-$ instead of the ordinary speed addition rule of the classical physics seen in Eqs. (9) and (11). These can be compatible with the experimental results as well.

### 6.2 The Relativistic Calculation

The major absurdity of the result of the Sagnac-type experiments is that the calculation was carried out by the geometrical optics, exclusively. Of course the calculation should carried out by the special relativity theory exhaustively. The validity of a physical theory depends on, among other things, the certainty and completeness by which the theory is ordered to the totality of experiences [2/c]. Consequently, the special relativity theory must also be confronted with observation and experiment carried out on the examined physical
system. In any given case one has to clarify the mutuality of the special relativity and the Sagnac effect. In this case, the second postulate of special relativity theory must be satisfied; that is, the speed of light must be the same in every direction

\[ c_+ = c_- = c \]  

(14)

by definition. Substituting Eq. (14) into Eq. (13) a zero shift of interference fringes we obtains: \[ \Delta \lambda = \lambda_+ - \lambda_- = 0 \] which is contrary to the experiments.

This means that the special relativity theory does not predict any shift of interference fringes opposite to the experiments. The standing wave approach of Sagnac-type experiments allow a freedom in the definition of \( c_+ \) and \( c_- \) instead of Eqs. (9) and (11), but the second postulate of Special Relativity Theory is out of this range.

Of course the Sagnac-type experiments were not made in a perfect inertial systems. The earth’s orbital motion around the Sun also is a non-inertial system. But the circumference velocity in both cases are extremely low \( v/c<<1 \), and -in the first approximation- these frames are almost inertial systems.

The Sagnac-type experiments proved that the circumference velocity can be detected by purely and closed optical instruments as well. The circumference velocity of the rotating earth \( v_R \sim 300 \text{ m/s} \) is extremely low to the earth’s orbital velocity which also is a circumference velocity with \( v_o \propto 100 \times v_R \). In both cases, Michelson-Morley and Sagnac wanted to determine the circumference velocities. The M-M experiments were unable to determine the earth’s orbital circumference velocity but the Sagnac experiment determined the rotating Earth’s circumference velocity. On the basis of the Michelson-Morley-type experiments Einstein postulated the constancy of the light speed, so the results of the Sagnac-type experiments - with different speeds of light- contradict to the special relativity theory.

In strictly sense the classical Newtonian mechanics and the Maxwell's theory of electromagnetism are not compatible. The Michelson-Morley type experiments refuted the geometrical optics completed by the classical mechanics. In the classical mechanics the inertial system was a basic concept, and the equation of motion must be invariant to the Galilean transformation Eq. (1). After the M-M experiments the Eq. (1) and so any equation of motion became invalid. Einstein realised that only the Maxwell's equations are invariant for the Lorentz transformation. Therefore he believed that they are the authentic equations of motions, and so he created new concepts for the space, time, inertia and so on. Within this framework the Lorentz transformation is the law of choice for the equation of motion. Sagnac’s result proved that the Einstein's method contradicts to the experience. Besides, on a deeper level it is proved that the Maxwell's equation are not applicable for the slowly rotating systems. So, in an authentic theory of light the Maxwell's equations must be changed, to allow for a description of rotating and deforming systems [19, 20].
6.3 The Incompleteness of the Theory of Light

The classical theory of light - consisting in the complexes of concepts such as the light propagation and interference - employs geometric optics added to classical physics and the Maxwell theory of electromagnetism. These turbulent notion-complexes were suffered from logical inconsistencies. {For example, the Maxwell equations are not invariant to the Galilean transformations (1) since those are not equation of motion in the mechanical sense.} This conceptual conglomeration was broken open by the Michelson-Morley-type experiments. In the present case, the incompleteness of classical light theory means that it cannot describe and explain the M-M-type experiments within the frame of the theory. For a complete, accurate description and explanation a new theory was needed. Einstein believed that the new theory is non-classical, and so he created the special relativity theory was needed. Einstein believed the new theory to be non-classical, and so he created the special relativity theory. The relativistic theory of light is similar in composition to the relativistic mechanics. The relativistic theory of light - beside the explanation of the M-M-type experiments - free from the logical problem of the classical light theory described above.

Eight years later Sagnac made a crucial experiment. The Sagnac-type experiments are broken open the complexes of concepts of relativistic light theory. Thus it became an incomplete theory since its prediction to the shift of interference is \( \Delta \lambda = \lambda_+ - \lambda_- = 0 \) contrary to the Sagnac-type experiments.

*We need to find a complete theory of light* based on more profound evidence, new basic concepts and authentic connections.

7 Summary

The complete theory of light should describe and explain the totality of experiences, that is, the M-M- and Sagnac-type experiments simultaneously.

In the spirit of the standing wave picture of Sagnac-type experiments, this theory needs to recalculate the result of the Michelson-Morley experiment as well. In the M-M experiment there is a new unknown hidden parameter \( c_p \) which denotes the speed of light in the direction perpendicular to the earth’s velocity. The traveled path of light in the perpendicular arm \( \lambda_p \).

\[
\Delta \lambda = \lambda_+ + \lambda_- - 2 \lambda_p = d \left( \frac{c}{c_+} + \frac{c}{c_-} \right) - 2d_1 \frac{c}{c_p} . \tag{15}
\]
It can be seen that the second postulate of special relativity theory Eq. (14) leads to the form

\[ c_+ c_- = c_p = c. \]  

(16)

Substituting the Eq. (16) into Eq. (15), we obtain a zero interference changing, corresponding to with the M-M experiment. The M-M experiments are only a limited part of the totality of experiences.

The Michelson-Morley- and the Sagnac-type experiments give only two independent equations, that is Eqs. (13) and (15) for three unknown hidden parameters \( c_+ \), \( c_- \) and \( c_p \). In the present case the incompleteness means that there are three unknown parameters for two equations. A third equation is needed in the form of a crucial experiment for the unique solutions. (Of course, this crucial experiment must be independent of the M-M- and Sagnac-type experiments.) In this manner we will be able to develop an authentic non-quantized (complete) theory of light.

After the often metaphysician optimism of a century we again return to the fundamental questions.

8 References


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