La storia della scienza, con numerosi episodi del genere, dimostra con tutta evidenza quanto sia dannoso per il progresso il formarsi di compartimenti stagni, che impediscono lo scambio delle idee e, rendendo difficile la critica, procurano lunga vita agli errori.

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# Georges Sagnac and the Discovery of the Ether[1]

by John Chappell

Most historians and philosophers of science today would probably affirm their belief that their field of study is its own justification. Without attempting to defend the extreme opposite view that all scholarship must be tied to immediate practical needs, I would like to suggest that any discipline is falling short of its true potential unless it recognizes and seeks to accomplish tasks related to the needs of the larger community of scholars, and indeed to the needs of humanity as a whole. History and philosophy of science is in a unique position to perform an extremely valuable service in this regard. It can help science revitalize its theoretical approach, by re-emphasizing the interpretation of evidence and equations from the point of view of the natural philosopher, as was carried out in the heroic era of early modern « science ».

Today, practicing scientists are very largely unconcerned with the history of their own disciplines, or at least contemptuous of opinions held in past eras; and in addition they largely ignore the careful logical analysis of the metaphysical framework which gives structure to their own working paradigm (2). They fail to realize that metaphysics plays at least as great a part as measurements and mathematical symbols, in guiding the advance of science or natural p.hilosophy.

But not only do we have, at present, a group of scientists not well informed or deeply concerned, on the whole, in history and philosophy; also, to make matters worse, most philosophers are not well-informed on the specifics of experimental evidence, so that

(1) An earlier version of this paper was delivered at the 8th Annual Meeting of the Midwest Junto of the History of Science Society, Stillwater, Oklahoma, on 2 April, 1965.

(2) The importance of the « metaphysical framework » is stressed by Joseph Agassi in his « The Nature of Scientific Problems and Their Roots in Metaphysics », in Mario Bunge (ed.), *The Critical Approach to Science and Philosophy*, 1964, p. 189-211. The « paradigm », which I take to mean a metaphysical framework plus various habitual, organizational, and instrumental appurtenances, is discussed by Thomas Kuhn in his *The Structure of Scientific Revolutions*, 1962.

their philosophizing, even when intended to be about science, remains on a remote and artificial level. Add to this the very often prejudice of many historians for accumulating fact without concern for scientific or philosophical issues *per se*, and the result is one of the most dangerous and unfortunate examples of over-fragmentation of intellectual endeavor facing twentieth-century man. It is in an attempt to bridge the gaps between history, philosophy, and science that I write this paper. A bit of geography is involved also. The novelty of the attempt can be read in the title : as the result of historical investigation and philosophical analysis, I am led to affirm the undoubted existence of a luminiferous ether, contrary to the current beliefs of the great majority of physicists.

Experimental evidence is not always what it seems, particularly to those scientists who unduly ignore rigorous logical analysis. For instance, in 1932, the report of the Kennedy-Thorndike interferometer experiment boldly announced « Experimental Establishment of the Relativity of Time » (3). In 1937, Herbert Ives unleashed a brief but devastating argument which demonstrated that the relativity of time (if such a thing exists) has nothing to do with the results of this experiment, and that the main significance they have is to disprove the Lorentz-Fitzgerald contraction hypothesis. Ives' argument fell short of a definitive solution to the problems raised by Kennedy and Thorndike, but it led him to attempt another very important experiment to try to supply the evidence which Kennedy and Thorndike did not find. When he and Stilwell had completed this experiment in 1938, they still quite properly refrained from claiming that it proved the relativity of time; but adherents to relativity theory do use those results to make such a claim (4). For reasons which are beyond the scope of this paper to expound in detail, I believe that not even Ives and Stilwell made the proper interpretation of their 1938 experiment.

(3) Roy KENNEDY and Edward THORNDIKE, « Experimental Establishment of the Relativity of Time », *Physical Review*, v. 42 no. 3 (1 Nov. 1932), p. 400-418.

(4) Herbert IVES, « Graphical Exposition of the Michelson-Morley Experiment », *Journal of the Optical Society of America*, v. 27 no. 5 (May 1937), p. 177-180; Herbert IVES and G. R. STILWELL, « Experimental Study of the Rate of a Moving Atomic Clock », *ibid.*, v. 28 no. 7 (July 1938), p. 215-226. The 1938 IVES-STILWELL results were confirmed by Hirsch MANDELBERG and Louis WITTEN, « Experimental Verification of



They did not because they were still handicapped by the Maxwell theory of light, which declares that the velocity of light is independent of the velocity of the source.

The Ritz emission theory, which adds the velocity of the source to that of the light, was introduced in 1908 but was quickly discarded. Not only did it disagree with Maxwell's theory, but it apparently was faced with an insurmountable obstacle in the form of evidence from the opposite limbs of the rotating sun and from binary stars, adduced by Tolman and by de Sitter respectively (5). But the fact that evidence is not always what it seems is again strikingly demonstrated in this case; for now in 1965, J. G. Fox makes clear that the Tolman and de Sitter evidence is no longer considered an adequate refutation of the Ritz theory (6). Fox introduces other evidence which he believes does constitute such a refutation, but admits that it makes a rather sketchy case. Once again, full discussion of all the issues involved in this problem would be beyond the scope of this paper. I have mentioned the problem of relativity of time and the problem of the Ritz emission theory because they do bear importantly on the issues raised by Georges Sagnac and other investigators of the problem of ether drift, and because I do not think a complete understanding of Sagnac's results is possible without realizing that the Ritz approach to electromagnetic theory is essentially correct and represents the main path for the future development of physics. But for those whose present beliefs are strongly at odds with these opinions of

(5) Richard TOLMAN, « The Second Postulate of Relativity », *Physical Review*, v. 31 no. 1 (July 1910), p. 26-40; Willem DE SITTER, « A Proof of the Constancy of the Velocity of Light », *Proceedings of the Section of Sciences of Koninklijke Akademie van Wetenschappen te Amsterdam*, v. 15 pt. 2 (1913), p. 1297-1298; Willem DE SITTER, « On the Constancy of the Velocity of Light », *ibid.*, v. 16 pt. 1 (1913), p. 395-396. On Ritz's theory see Alfred O'RAHILLY, *Electromagnetics*, 1938.

(6) J. G. FOX, « Evidence against Emission Theories », *American Journal of Physics*, v. 33 no. 1 (Jan. 1965), p. 1-17. The recently-found evidence which is supposed to refute emission theories consists of small-scale analogues to the binary star evidence (no more valid as a refutation than is that evidence), and the claim that meson lifetime increases with increasing velocity. As Fox does not appreciate, the latter claim depends entirely on the assumption that mass increases with velocity, which does not occur according to the Ritz theory.

Still another type of argument against the deSitter evidence has been made by Pascal RAPIER, in « A New Cosmology, Based upon the Hertzian Fundamental Principle of Mechanics », *Revista de la Real Academia de Ciencias Exactas, Fisicas y Naturales de Madrid*, v. 57 no. 4 (1963), p. 727-744.

mine, it will be sufficient to read the following discussion with an open mind, to become convinced that drastic changes of one sort or another must now be made in our accepted ideas about light velocity and the ether.

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In the case of the Sagnac interferometer experiment, we do not have evidence which needs new interpretation, so much as we have evidence which needs to shed a harmful cloak of re-interpretation which was placed over it by theoreticians who did not fully understand what the experimenter had done. We need to return to the interpretation of Sagnac, who justly claimed that he had discovered the existence of a luminiferous ether.

Ether as discovered by Sagnac need not be considered to be an imponderable elastic solid, as it was considered to be through most of the nineteenth century, after light came to be thought of as a « transverse wave ». Ether is simply a medium through which light travels, with respect to which it keeps a fixed velocity. The ether exists in, but is distinct from, any other body or medium which will transmit a light wave. The ether may be of variable density. The ether is not necessarily itself at rest, in a given coordinate system, but may move *en masse* with a given velocity. I believe that the ether consists of photons, i. e. of radiation particles, mostly of the lower frequencies. Light passing through this ether bounces off the photons it meets and thus travels in a zig-zag course. This view enables us to accept a constant point-to-point velocity for all photons, at the same time that we recognize the possibility that such photons may vary in absolute speed along their respective zig-zag paths, which may be of unequal length. The variation in absolute speed results in variation in the energy received (Doppler effect). Again, I do not wish so much to explain or to confirm this view of the ether in great detail, as to suggest to the reader that a plausible conceptualization of the ether may indeed be possible; for no doubt he has read or has heard that all attempts to posit the existence of an ether have proved to be failures.

As will be made clear below, not only Georges Sagnac but also Albert Michelson, perhaps the most skillful experimenter in the history of optics, proved by experiment that there is a luminiferous



ether. In view of the widespread misconception that Michelson is responsible for proving that there is *no* luminiferous ether (in the Michelson-Morley experiment of 1887), this is a very important point to make. But let me proceed with the historical facts.

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The famous « negative evidence » experiment conducted by Michelson and Morley proved merely this : that in the latitude of Europe and the United States, one cannot prove *translational motion* of the earth with respect to an ether, by means of a cross-type interferometer. This result led to a crisis in the minds of many physicists of the day, and later became a strong argument in favor of the special theory of relativity, even though Einstein apparently used it only indirectly in his own mental operations leading to the theory (7).

Strangely enough, Michelson himself was not particularly interested in the negative result of 1887. Although he did perform another experiment in 1897, using a vertically-arranged rectangular interferometer to test possible variation of ether drift with altitude, again with negative results (8), he left to E.W. Morley, D.C. Miller, and others the work of repeating and refining the original test with the cross-type interferometer. In fact, Michelson felt that the chief value of the 1887 work was in perfecting the interferometer for use in later experiments of a different nature (9). He was much more impressed with the positive results he and Morley obtained in their less famous collaboration of 1886, a repeat of the Fizeau experiment of 1851 on the behavior of light in moving media (10). Furthermore, Michelson reacted unfavorably to the interpretation of his negative results which was embodied in

(7) Albert MICHELSON and Edward MORLEY, « On the Relative Motion of the Earth and the Luminiferous Ether », *American Journal of Science* (ser. 3), v. 34 no. 203 (Nov. 1887), p. 333-345. See also Robert SHANKLAND, « The Michelson-Morley Experiment », *Scientific American*, v. 211 no. 5 (Dec. 1964), p. 107-114.

(8) Albert MICHELSON, « Relative Motion of the Earth and the Ether », *American Journal of Science* » (ser. 4), v. 3 no. 18 (June 1897), p. 475-479.

(9) Bernard JAFFE, *Michelson and the Speed of Light*, 1960, p. 89-90.

(10) Albert MICHELSON and Edward MORLEY, « Influence of Motion of the Medium on the Velocity of Light », *American Journal of Science* (ser. 3), v. 31 no. 185 (May 1886), p. 377-386. Hippolyte FIZEAU, « Sur les hypothèses relatives à l'Ether lumineux... », *Annales de Chimie et de Physique* (ser. 3), v. 57 (1859), p. 385-404.

Einstein's special theory; and, having limited mathematical skill anyway (11), he made no effort whatsoever to understand and interpret the general theory when it appeared later.

Perhaps this was one reason why Michelson did not insist on a non-relativistic interpretation of his 1924 experiment to test ether entrainment. Michelson had done little himself with the ether drift problem since 1897. But in the 1920's, numerous scientists urged him to make a test for *rotational* ether drift, to supplement his previous work on *translational* ether drift. This experiment, conducted in collaboration with Henry Gale, involved sending light around a large rectangle, over a mile in circumference. It supposedly tested whether or not the ether was carried along with the earth, and by obtaining first-order fringe shifts, supposedly proved that it was not (12). Michelson himself said that he had merely proved what he expected to prove : namely, that the earth rotates on its axis. This is a strangely tame response to results which, except for the substitution of rotational motion for translational motion, serve just as well to prove the existence of a luminiferous ether as the 1887 results served to prove the ether did not exist! Without the development of the theory of relativity, and particularly of general relativity (applying to rotational motion) in the meantime, Newtonian mechanics might never have been banished from its dominant position in the theoretical outlook of modern physicists.

Actually, by the time of the Michelson-Gale experiment of 1924, the existence of a luminiferous ether should not have been in doubt. For this was not in fact the first test for rotational ether drift, but merely the first test involving a rotation of the earth with respect to the sun and stars. The first rotational ether-drift experiment of any kind was performed in 1913 by Georges Sagnac.

(11) Michelson made clumsy mathematical errors in his report of his 1881 interferometer experiment (a cruder version of the 1887 experiment with Morley), and also in a 1904 paper giving the theory of the experiment he carried out with Gale in 1924. These errors were easily spotted by others and pointed out to Michelson, and they do not affect the discussion in this paper materially. See Albert MICHELSON, « The Relative Motion of the Earth and the Luminiferous Ether », *American Journal of Science* (ser. 3), v. 22 no. 128 (Aug. 1881), p. 120-129; Albert MICHELSON, « Relative Motion of the Earth and Aether », *Philosophical Magazine* (ser. 6), v. 8 (1904), p. 716-719.

(12) Albert MICHELSON and Henry GALE, « The Effect of the Earth's Rotation on the Velocity of Light », *Astrophysical Journal*, v. 61 no. 3 (Apr. 1925), p. 137-145.



Georges Sagnac, born October 14, 1869, received his doctor's degree in 1900 from the University of Paris. In the early years of his career, he worked with Pierre Curie in recording and describing the properties of the newly-discovered element radium. But his most important work was carried out during the years 1906 to 1914, on the optics of moving media. During this time he served as professor of theoretical and celestial physics at the University of Paris. His later years were marred by bad health, and he passed away on February 26, 1926 (13).

The Sagnac experiment of 1913 employed a rotating circular platform complete with mirrors, light source, and camera. The platform was about one meter in diameter, and the mirrors were so placed that they reflected light around the perimeter of the platform, inscribing a polygon. The source of light was divided by a mirror thinly silvered on one side, and was passed around the circumference of this polygon in both directions. When the platform was at rest, the two beams were exactly superimposed. The beams were then re-united and sent into an interferometer for the observation of fringe shifts. A camera took pictures of the fringes during the rotation of the apparatus. It should be emphasized that light source, mirrors, and interferometer with camera were all mounted on the moving platform. The only thing which might be expected not to move while the platform rotated was the path of the light from mirror to mirror. If the camera recorded fringe shifts, this indicated that the path of the light was fixed in the coordinate system of the room, and that this room therefore contained a luminiferous ether. While rotating the apparatus at about two revolutions per second, Sagnac obtained first-order fringe shifts, just as predicted on the hypothesis that the room contained such an ether.

This experiment has scarcely been acknowledged yet in the literature of the history of science. The only mention of it I have been able to find, by searching through numerous volumes written in several languages, is an obscure sentence in a long footnote in Whittaker's *History of the Theories of Aether and Electricity*, which reads as follows in its entirety : « An interesting experiment

(13) This brief biographical sketch summarizes the remarks by Henri BÉNARD in *Société Française de Physique, Bulletin*, no. 259 (1928), p. 45-S; bound with *Journal de Physique et le Radium* (ser. 6), v. 9-D

with a rotating interferometer was performed by G. Sagnac in 1913 ». Immediately following, references are made to the original reports (14).

Of course, physicists have taken more note of the experiment, and at least one optics text gives a careful description of it, complete with schematic diagram (15). In a review of experimental evidence dealing with the optics of moving media, in his well-known book on relativity, Wolfgang Pauli also mentions the Sagnac experiment, and evaluates it as follows : « The rotation of a reference system relative to a Galilean system can be determined by means of optical experiments within the system itself. The result of this experiment is in perfect agreement with the theory of relativity » (16).

Given comments like Pauli's, it is little wonder that even those few historians of science working on the twentieth century have paid scant attention to the Sagnac experiment. Apparently it is just another in a long and somewhat confusing string of tests which serve as confirmation for Einstein's theories, and furthermore it played no part in the line of reasoning and experiment which led up to the introduction of those theories.

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But let us now attempt, by careful analysis of the basic concepts involved, to see what Sagnac really proved. Did he prove the existence of an ether, or did he prove the validity of general relativity? Or both? It is most commonly said that his results may be interpreted by either of these two theories; and yet the theories seem to be so radically different that such a compromise is difficult to accept as representative of the true condition of the physical world.

If the ether theory is accepted, must we think of the ether as fixed or as mobile? One might follow Michelson's suggestion that his 1887 results could be explained by assuming that the ether is attached to the earth. But of course, Michelson, with Gale, disproved this himself in 1924, showing that the earth rotates

(14) Edmund WHITTAKER, *A History of the Theories of Aether and Electricity*, v. 2, 1960 (1953), p. 43.
(15) R. W. DITCHBURN, *Light*, 1953, p. 337-339.
(16) Wolfgang PAULI, *The Theory of Relativity*, 1958 (1921), p. 18-19.



relative to a luminiferous ether. This result does not affect the interpretation of Sagnac's results, however, since the earth rotates much more slowly than did Sagnac's apparatus. In other words, in interpreting Sagnac's results, we can consider that the ether is virtually at rest relative to the laboratory, or to the earth.

At any rate it appears necessary to affirm that rotational motion in the ether has been discovered, but that translational motion has not. This may appear to be a difficult dilemma. But when one considers what happens to the envelopes of water and air which surround the earth, the difficulty fades away. Air and water move along with the earth in its orbit, and yet tend not to rotate with it. Therefore they rotate *with respect to* the earth, in the same temperate latitudes in which all the ether drift experiments have been conducted. The ether, of course, behaves in the same way (17). But this rotational motion, also known as Coriolis force, is absent at the equator. There, air, water and ether alike do not move in a curved path but in a straight path, relative to the surface of the earth. This suggests, incidentally, that a repeat of the 1887 interferometer test at the equator might yield positive results (indicating rotation, not revolution). Bear in mind that the cross-type interferometer used in 1887 is equipped to detect rectilinear motion but not curvilinear motion (with respect to itself); and the rectangular or polygonal interferometer arrangements used in 1913 and 1924 are able to detect curvilinear but not rectilinear motion.

Let us examine in more detail how the fringe shifts obtained by Sagnac indicate the presence of an ether. In terms of the wave theory, the fringe shifts seen by the camera are evidence that the two superimposed light beams arrived out of phase. This means that two waves which started together, after travelling in opposite directions, arrived at different times. This difference is visible as a total difference in fringe positions, between two rotations in opposite directions, of the amount $\Delta p = 8\pi NS/v_o$, where N is frequency of rotation, S is the area of the polygon enclosed by the light path (with platform at rest, apparently), and $v_o$ is the velocity of light in the coordinate system of the room. The relationships of velocity and length to the two coordinate systems (of the platform and of the room) are especially important to keep clearly

(17) Victor ANCET, in his *Nouvelle Théorie de la Relativité et de l'Electrodynamique*, Lyon, 1964, p. 5, draws an equivalent conclusion about the ether from Sagnac's results.

in mind. In terms of the classical (Galilean) transformations : 1) in the coordinate system of the room, the *light path* is shortened in one direction and lengthened in the other; 2) in the coordinate system of the platform, the change is in *the velocity of the light*.

In terms of a purely corpuscular, additive (emission) theory of light, the fringe shifts are the result of establishing a relative velocity between the ether and the apparatus; time lag of one beam or another is not crucial. In such a corpuscular theory, the ether itself would be composed of corpuscles, as suggested earlier in this paper. It is possible that light photons would set up a subsidiary undulation in this ether, making the time difference important after all. The details of the explanation of the Sagnac experiment in terms of an additive-corpuscular-ether theory, with or without subsidiary wave motion, cannot now be elaborated, since the theory itself has scarcely yet been elaborated. But the lack of these details proves no handicap to the claim that Sagnac's fringe shifts are an excellent confirmation of the validity of *some* kind of ether hypothesis.

The interpretation offered by general relativity is much less lucid than that offered by any variant of the ether theory. Einsteinian relativity is based on logically conflicting postulates, and so I do not think it can reasonably be expected that the interpretations presented by its proponents should be clear, even in the minds of these proponents. Nevertheless I will attempt to expound the relativistic explanations which are on record.

Max von Laue wrote in 1920 that the difference between Sagnac's experiment and another experiment (that by Harress, using moving glass) lay in « the fact that in the Sagnac experiment the empty room is the carrier of the light beams. Specifically, the carrier is air of atmospheric pressure. This is optically little distinguished from an empty room, except that on this distinction the results depend » (18).

Now this sounds suspiciously like the classical explanation just outlined, with one exception. Von Laue attributes the controlling influence over the velocity of the light to the *air* of the room. Sagnac attributed this influence to an *ether*, and as a matter of fact, he had perfectly good reason for doing so. For with the plat-

(18) Max von Laue, « Zum Versuch von F. Harress », *Annalen der*



form at rest, he tested the influence of moving air on his fringes. In his own words, contained in the report of the experiment published in 1914, he says that « a turbulence of air produced over the interferometer by a fan with axis vertical and blowing downwards does not displace the center of interference... The *turbulence of air*, analogous and less intense, which the interferometer produces when turning, *does not have a sensible effect*. Therefore we have only an ether effect... » (19).

It might be wondered whether this induced turbulence of air was properly rotational in motion or not. Let us go back to earlier laboratory experiments on the optics of moving media, those of Fizeau in 1851 and of Michelson and Morley in 1886. In each case the experimenters tested the effect of moving air on the fringes, compared with the effect of moving water. In each case there was no detectable effect from moving air. Therefore Sagnac is right. *Moving air does not displace interference fringes to any appreciable extent*. Therefore it cannot be the reason for the first-order rotational effect obtained by Sagnac. Von Laue has failed in his attempt to interpret the experiment in terms of clear physical concepts.

But what of the mathematical analysis? After all, relativity won the day because of its mathematical elegance as much as because of its supposed close fit with experimental evidence. Relativistic mathematical analyses of Sagnac's results were made by von Laue in 1911 (anticipating the experiment), and by Paul Langevin in 1921. Langevin's version is of particular interest because it was made in response to an incisive challenge by Emile Picard. Picard had asked for an explanation of the Sagnac results in terms of the general theory. He reminded his listeners and readers that Descartes had once declared that the « good common sense of humanity » is the basis of truth, and the connection between our thought and reality. « Without that accord », concluded Picard, « there is nothing but skepticism; and this is an error which theoretical physicists have not always avoided. » Indeed, a more appropriate reminder could scarcely have been made. Similarly, Melbourne Evans of the University of New Mexico, who has recently demonstrated flaws in the argument for relative simultaneity, suggests that much of the trouble of modern science

(19) Georges Sagnac, « Effet tourbillonnaire optique... », *Journal de Physique* (ser. 5), v. 4 (1914), p. 177-195, esp. p. 190.

is due to a failure to heed Descartes' warning never to let the concrete physical meaning of one's mathematical symbols escape from view; in so doing one departs into subjectivism and fails to communicate adequately with other scientists (20).

At any rate, Langevin side-stepped the challenge of Picard on the issue of common sense, and presented the mathematical explanation of the Sagnac results which is given by general relativity. The results of this explanation are as follows :

The time taken by one beam to traverse the circumference of the polygon on the platform is given by

$$t_1 = k/c + 4\pi \, NS/c^2,$$

and the time taken by the other beam is given by

$$t_2 = k/c + 4\pi \, NS/c^2,$$

wehe $k$ is the length of the path on the platform, N is the frequency of rotation of the apparatus, S is the area of the polygon, and of course $c$ is the so-called « invariable » speed of light.

The difference between these two values, or $8\pi \, NS/c^2$, gives a prediction of the actual fringe shifts obtained by Sagnac. Apparently, then, the theory is a success. But we run into difficulties quickly when we ask just what the symbols in these equations mean. It turns out that we must conclude, in order to give any physical meaning to the equations, that one path must be of different length than the other (since the times are different and the velocity of light remains constant), in the coordinate system of the platform. It is not clear whether this difference in length is supposed to be that which results from differing angles of reflection form the moving mirrors. The equations themselves say nothing about this. They seem to offer no more than the virtually equivalent equations of the ether theory, while divorced from the conceptual clarity of that theory. It is possible that the relativist would seek to escape confusion by resorting to a claim that is often used in special relativity : that the two light beams do not have different lengths after all, but merely travel in different space

(20 Emile PICARD, « Quelques remarques sur la théorie de la relativité », *Comptes Rendus...*, v. 173 (1921), p. 680-682, esp. p. 682; answered by Paul LANGEVIN in his « Sur la théorie de relativité et l'expérience de M. Sagnac », *ibid.*, p. 831-834. Melbourne EVANS, « The Relativity of Simultaneity : a Critical Analysis », *Dialectica*, v. 16 no. 1 (15 Mar. 1962), p. 61-82.



systems, which do not share an objective unit of measurement. This device of different space systems serves the purpose of preserving the non-additive character of the velocity of light.

Even apart from the problem introduced by substituting a multiplicity of interpenetrating « spaces » for a single space, thus rejecting the standards of Ockham's Razor in a conceptual sense, and apart from the small matter of removing the possibility of objective agreement between relatively-moving observers (which is, incidentally, the very keystone of the relativistic world-view), the device of different space systems, along with any other dodge I can possibly imagine, fails to account for one very crucial disagreement between the general theory of relativity and the experimental results obtained by Sagnac : Sagnac has shown us *a preferred coordinate system*. He has shown us which system is at rest and which system is moving. He has shown that when a platform with light path rotates in a room, interference fringes move. He has rotated a fan over the platform, thus establishing relative motion between the light path and platform at rest in the room, and the fan, and *no* effect was observed. Only relative motion with respect to the room produces electromagnetic and gravitational effects such as the equations of general relativity describe. More accurately, of course, the motion is with respect to the coordinate system of the sun and stars; this is the preferred system for earthlings.

Now it is possible to modify the theory of general relativity so as to use its equations and yet specify that one coordinate system is to be preferred, i. e. at rest. This results in removing the notion of relativity from general relativity, and leaves it as a theory of gravitation. The equations given above provide a prediction of the effect of gravity on photons, or in the other terminology, on electromagnetic waves. Such a reinterpretation has in fact been made, in particular by V. A. Fok, and I believe I am not far from right in stating that many physicists in Western countries accept this interpretation (21).

But what are the larger implications of such a reinterpretation? It tells us, in effect, that the coordinate system of the room *controls* the velocity of the light. Now we may just as well say

(21) V. A. FOK, *The Theory of Space, Time, and Gravitation* (2nd edition), 1964 (English translation of Russian 2nd edition of 1961).

that the room contains a *luminiferous ether;* for a luminiferous ether is, in a functional sense, until we can be absolutely sure of its exact nature and composition, nothing more than a coordinate system which controls the velocity of light. This, then, strange as it may seem, is the result of applying the equations of general relativity to the results of rotational ether drift experiments : the theory becomes a gravitational theory *and also an ether theory.* But it is not so strange after all when one considers the recollection of Kapitza, that Einstein once urged him to make a test of the effect of a magnetic field on a light beam because he (Einstein) felt that the speed of light must be « dependent upon something » (22). The « disappearance » of the ether in 1887, which led to the theory of relativity, is now seen to be nothing more than a fantasy. Experiment has returned the ether to physics, confirming the suspicions of Einstein himself, and the relativity is taken out of relativity theory.

It may still be asked whether or not the *equations* of general relativity can stand the test of time. There has recently been some discussion, in the professional literature of physics, of various alternative theories of gravitation which were proposed in the early years of this century, in particular by Nordström. Although it has been concluded that none of these other theories are able to predict the advance of the perihelion of Mercury and the bending of starlight by the sun as well as does general relativity (23), the new light which has been cast on the potentialities of an additive-ether theory leads us to wonder if *some* changes in the mathematical structure of general relativity are not in order; for general relativity assumes the correctness of Maxwell's theory of light, which is imcompatible with an additive theory. Furthermore, it is supposed to represent a generalization of the two postulates of special relativity, which cannot both be true at once.

Let me now summarize the principal implication of discovering an ether, or a preferred coordinate system. By fixing the velocity of light with respect to the ether, we find that it is impossible to deny this fact : *In the ether, motion of an observer with respect to*

(22) Peter KAPITZA, « The Future of Science », *Bulletin of the Atomic Scientists*, v. 18 no. 4 (April 1962), p. 3-7, esp. p. 5.
(23) A. L. HARVEY, « Brief Review of Lorentz-Covariant Scalar Theories of Gravitation », *American Journal of Physics*, v. 33 no. 6 (June



***a photon will change the velocity of that photon with respect to the observer.*** **If a photon is coming towards me at velocity *c*, and I suddenly more through the ether towards it, the *net velocity* of the photon towards me then becomes *c* plus my own velocity. This is not true in special or general relativity; in fact it contradicts one of the postulates of special relativity. There is simply no way to have special relativity and ether at the same time. Yet the evidence demands that we recognize an ether.**

What is the source of the ether? Perhaps each body emits radiation which constitutes its own ether. (Such radiation may be stimulated by radiation received from outside the body : in the case of the earth, by radiation from the sun.) This supposition is plausible in view of the fact that the ether associated with the earth behaves essentially like air and water, as to its movement relative to the earth : like air and water, therefore, it should have its origin in the earth.

Further investigation of the origin and nature of the ether should lead to a consideration of the nature of gravity and the causes of the earth's motion. There is a strong possibility that radiation is the cause both of gravity and of the earth's rotation, if not also — in combination with some externally-imparted motion — of its revolution. There are many reasons not cited above which support this possibility. For instance, why de we now find such a phenomenon as a « gravity wave », and why do some physicists speculate on the possibility of its being « quantized »? Simply because gravity is basically associated with electromagnetic waves, which in turn are probably no more than abstractions or subsidiary phenomena associated with quanta of light, or photons. « Action at a distance » has never been more than a poor substitute for an explanation of gravity, describing a function rather than the cause of the function; we tend to forget this because we rarely look for causes any more. Newton himself did not assign the *cause* of gravity to action at a distance; he was favorable to speculation in terms of « some subtle medium » (24). Radiation, or photons, which were scarcely known as such in

(24) The most detailed discussion I have found on the possibility that gravity is caused by radiation is in the highly speculative, privately distributed writings of Hugh A. BROWN, 115 Prospect Ave., Douglaston, L. I., N. Y. — particularly in « Gravitation », dated Aug. 19, 1960; and

Newton's time, provide just such a medium. The way in which they operate, involving most probably something closely analogous to the *vortices* of Descartes, can at present only be dimly perceived; but the specific results of optical experiments involving ether drift give us solid ground upon which to build. We must not ignore promising speculation simply because it now lacks complete confirmation.

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In conclusion, I should like to mention briefly the experiment of A. Dufour and F. Prunier, reported in 1942. These experimenters used a rotating platform with mirrors, just as in the Sagnac experiment, but their light source was fixed in the laboratory, and in one variation their camera was fixed also. They claim that their results cannot at all be explained by general relativity, even using Langevin's analysis; Langevin has attempted to meet their challenge (25). Although I am not here going to attempt to judge the merits of this controversy, it is possible that the work of Dufour and Prunier will prove even more important than that of Sagnac in future work on theory of optics and of gravitation. Of course, this would still not detract from the honor due to Georges Sagnac as the first man to demonstrate the existence of a luminiferous ether.

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(25) A. DUFOUR and F. PRUNIER, « Sur un déplacement de franges enregistré sur une plate-forme en rotation uniforme », *Journal de Physique et le Radium* (ser. 8), v. 3 no. 9 (sept. 1942), p. 153-162. A brief reply by LANGEVIN is inserted at the end of the article. A previous exchange between Dufour, Prunier and Langevin over the Sagnac experiment and variations on it appeared in the *C. R. Acad. Sci.* v. 200 (1935), p. 46-51; v. 204 (1937), p. 1322-1324, 1925-1927; and v. 205 (1937), p. 304-306. The Sagnac experiment has been repeated, with the same but more refined outcome, by W. MACEK and D. DAVIS; see their « Rotation Rate Sensing with Travelling-Wave Ring Lasers », *Applied Physics Letters*, v. 2 no. 3 (1 Feb., 1963), p. 67-68.

# Aperçu biographique sur Regen, pionnier de la bioacoustique des Insectes

*« Vi dico che ho la cicala in mano, e non so come la canti... »* (1) GALILÉE.

La vie d'Ivan Regen (2) fut d'une grande simplicité. Homme solitaire et paisible, fonctionnaire modèle pendant cette calme période de l'ancienne monarchie autrichienne qui précéda les désastres de la première guerre mondiale, Regen consacra son existence à une étude infiniment patiente de la stridulation des Orthoptères. Il ne connut, semble-t-il, aucune autre véritable passion que celle d'écouter, à l'instar des anciens Chinois, le chant des Insectes.

D'origine très modeste, Ivan Regen naquit le 9 décembre 1868 dans le petit village de Lajse près de Trata dans la vallée de Polje (Poljanska dolina) en Slovénie. Alors partie de l'Autriche-Hongrie, ce territoire à la beauté sauvage appartient aujourd'hui à la Yougoslavie.

Rudolf Regen, père d'Ivan, natif de Trieste, était un enfant naturel. La grande différence sociale entre ses parents ne leur permit pas le mariage. Elevé par la famille de sa mère à Trata, en Slovénie, Rudolf devint tisserand et se maria avec une paysanne slovène, Mina Jereb, dont il eut trois fils. L'aîné, Joseph, entra en religion, tandis que le cadet, Ivan, non sans de grandes difficultés dues à la pauvreté et à l'incompréhension de ses parents, se voua à la science.

(1) G. GALILEI, *Opere*, Edizione Nazionale, t. VI, p. 137.
(2) Dans ses publications et dans la plupart des documents administratifs rédigés en allemand, Regen employait la forme germanique de son prénom : *Johann*. Nous donnons ici la préférence à la forme slave *Ivan*, car c'est ainsi qu'il se faisait appeler par ses compatriotes et qu'il signait la plupart de ses lettres.