THE EXPERIMENT OF MILLER AND THE HYPOTHESIS OF THE DRAGGING ALONG OF THE ETHER

By H. MINEUR in *L'Astronomie.**

DURING almost twenty years two new conceptions have thrown physics into confusion: the theory of relativity and the theory of quanta. The first has met with lively resistance in the world of science; perhaps the relativist revolution advanced too quickly; it upset what was believed solidly founded—the ideas regarding space and time; it demanded of the man of science to clear the board of conceptions amid which his spirit had always lived. Relativity was born of the experiment of Michelson (1887); this experiment, repeated in 1925 under new conditions by Miller, has given a result altogether different from that of Michelson. Will relativity fall? Will it surmount the obstacle?

We set forth on broad lines the debate which has arisen since the memoir of Miller appeared.

The Ether Considered as a Material Fluid.

The investigations of Huygens and of Fresnel have established the nature of luminous phenomena; light is composed of transverse vibrations; this leads us to admit the existence of a vibrating medium,—the ether; light is analogous to those waves which traverse the surface of water into which a stone is thrown. Light traverses empty space and transparent bodies,—the ether must therefore exist everywhere; the notion of ether is almost confounded with that of space: "The ether has been invented for the purpose of giving a subject to the verb, undulate".

Is this ether immovable? Is it capable of movement like a liquid or a gas? Stokes[1] offered (1845) the following hypothesis: the ether is fixed in interstellar space but the celestial bodies drag along in their movement the part of the ether which is found in their immediate neighborhood, as a train in motion carries along with it a portion of the atmosphere.

*Translated by A. F. Miller.

We must avoid confounding this hypothesis of "the partial dragging along of the ether" with a theory which bears a similar name—Fresnel's theory of the drift of the ether waves verified by many experiments. The limit of this note does not permit us to dwell on this point: we shall return to it at another time.

The Experiment of Michelson and Morley.

Michelson had the following idea: if the ether exists we might determine the velocity of the earth in relation to that medium as a mariner determines the speed of his vessel as referred to the sea. Needless to say that the experiment designed by Michelson in no way resembles towing a log with a rotating mechanism; it is based on the idea following:—

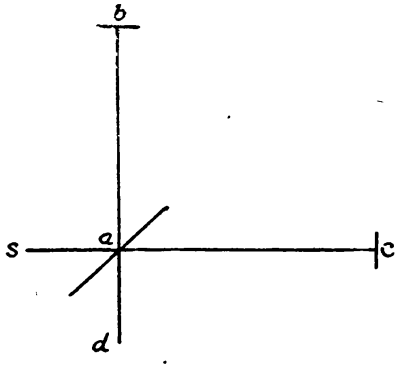

Fig. 1. Source stationary.

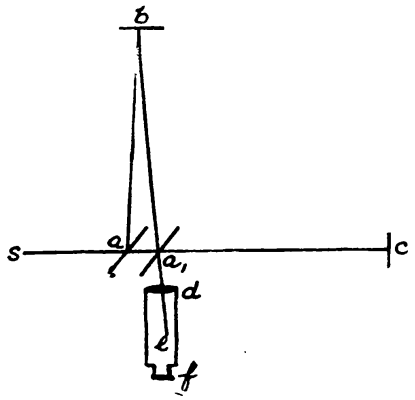

Fig. 2. Source moving.

Diagrams illustrating the path of the light.

Let *sc* (Fig. 1) be a segment of a straight line of invariable length; a ray of light goes from *s* to *c*, is reflected at *c* by a mirror and returns to *s* at the end of time *t*. The ray of light traverses the ether with the velocity *c* of light: if the apparatus is movable relative to the ether with the velocity *v*, the time *t* depends on the orientation of *sc* as regards the velocity *v*; it is not the same when *sc* has the same direction as the movement of the earth, (Fig. 2) and when *sc* is perpendicular to this motion. Michelson measured the differences between these two times by an interferential method.

The experiment was made at Cleveland[2], it gave a negative result, the time *t* was the same in all the positions of the apparatus. The precision of the experiment being granted, Michelson was in a

position to affirm that the relative movement of the earth was inferior to 7.5 km. per second.

Cleveland is in the state of Ohio on the shore of Lake Erie at 180 metres above sea level.

Admitting that the entire solar system is displaced as regards the ether; if at the moment Michelson made his experiment the velocity of this current of ether as regards the solar system had had the same magnitude and the same direction as that of the earth, his result is found to be explained; but six months later the velocity of the earth being found to have changed in direction, the experiment ought to have given a positive result and put in evidence a relative velocity double that of the earth in its orbit, that is to say, of 60 km. per second.

But the experiment of Michelson gave a negative result at all the seasons of the year.

Theory of Michelson's Experiment.

Figure 1 represents the arrangement of the apparatus. s is a luminous source; a a semi-transparent plate; c and b are mirrors; d the observer; $ac=ab$. A first ray travels the path $sabad$; a second travels $sacad$; these two paths are equal if the apparatus is at rest. Figure 2 is traced in fixed ether. Suppose the apparatus carried along with velocity v in the direction sc. The two rays depart from s at the instant t_0, reach a at the instant t_1; the first ray will reach b at the instant t_1; return to a at the instant t_3. At this moment a has arrived at a_1. The duration of this passage is $2l/(\sqrt{c^2-v^2})$, where c is the velocity of light and l is the distance ab or ac (Fig. 1). The second ray will take to traverse aca_1 the time $2lc/(\sqrt{c^2-v^2})$. It will arrive then later by $2l(v/c)^2$. If λ be the wave-length of the light used, the change in the fringes when the apparatus is turned through 90° is $2l\,(v/c)^2 \div \lambda$.

In Michelson's experiment $l = 1100$ cm., $v/c = 2 \times 10-4$, $\lambda = 5 \times 10-5$ cm., and the predicted change was 1.6 fringes.

Relativity

To explain Michelson's result three hypotheses were put forward:—

1. The contraction hypothesis of Lorentz: the length *sc* is shortened when its direction follows that of the velocity *v*; the contraction is such that the time *t* is independent of the direction *sc*.

2. The theory of restricted relativity: the classical kinematics is not to be relied upon. Minkowski and Einstein constructed a new theory which explained not only the experiment of Michelson, but many other phenomena. It suppressed the idea of the ether. It illuminated electro-dynamics with a new day. It has been verified by experiments of which we shall speak again.

3. To avoid the two preceding hypotheses Lorentz and Planck came back to the idea of Stokes: the ether is dragged along by the earth. In the interplanetary space the ether is fixed, and at the terrestrial surface this medium participates almost entirely in the movement of the earth; these two regions are separated by an intermediate zone where the ether is dragged along partially.

The physicist Lodge, a partisan of the mechanical theory of the ether, attempted to put experimentally in evidence this dragging along of the ether by a mass of lead in movement; the experiment did not show any dragging.

It could be replied that the masses with which Lodge operated were extremely small in comparison with that of the earth; it is possible that such feeble masses do not drag the ether; the mass of the earth, which is incomparably more important, might drag it. Planck attributes in effect the dragging along of the ether by our planet to the attraction exerted by this latter upon the particles of the ether; the attraction exerted by a mass of some tons is negligible in face of gravity.

The Experiment of Miller.

In 1904 Miller repeated the experiment of Michelson at Cleveland; the result was always negative; the interferometer of Miller was more accurate than that of Michelson: a relative velocity of 3.5 km./sec. would have produced an appreciable displacement of fringes.

In 1905 Miller repeated the experiment at Cleveland[3] on Mount Euclid, 100 metres higher than in the preceding year; he observed this time a slight effect corresponding to a relative velocity equal

to 1/10 of that of the earth in its orbit. The result appeared doubtful to him; he resolved to transport the interferometer to an isolated mountain.

From 1921 to 1925 the experiment was repeated at Mount Wilson at an altitude of 1700 metres; a positive result this time:[4] Miller established a relative velocity of ether equal to 1/3 of the velocity calculated if the ether were fixed.

This experiment seems to confirm the theory of the partial dragging along of the ether. The ether seems dragged along almost completely by the earth at an altitude of 200 metres; it seems to participate but to 2/3 the velocity of the earth at an altitude of 1700 metres. What is the direction of this current of ether? We are unable to say anything on this subject. Miller has so far only published the results of the observations made in April 1921 and in April 1925. Only the comparison between the results obtained at different epochs of the year would permit us to establish a conclusion.

Aberration.

Let us admit the hypothesis of Stokes and Lorentz. A ray of light coming from a star falls upon the earth; it is displaced in a straight line in the region of the ether which is not troubled by the movement of the celestial bodies. But in this intermediate zone which surrounds the earth and where the ether is partially dragged along our ray will be deviated, as a vessel which traverses a current is deviated from its course. When it arrives at our globe it will no longer have the same direction. Observation has made evident the existence of precisely such a deviation: aberration.

The hypothesis of the fixed ether has permitted us to give an explanation which was classic till our days. The theory of relativity leads to the same result. The law of aberration calculated by the one or the other of these two hypotheses is in agreement with observation.

Is it the same with the hypothesis of the dragging along of the ether? Since we do not know the law of this dragging along we cannot reply to the question. We content ourselves to seek a law of the dragging along of the ether which would account for aberration.

Mathematically, the question presents no difficulties[5]: it is necessary and it suffices,

1. That the velocity of light waves be independent of the density of fluid ether.

2. That the movement of this fluid be irrotational. Recall briefly what is meant by that.

Consider a fluid in movement; imagine that the following fictitious operation is made: we solidify suddenly the part of the fluid inside a very small sphere S and annihilate the rest of the fluid. The solidified sphere S will take a rectilineal uniform movement of translation on which is superposed a movement of uniform rotation around an axis passing through its centre. The axis of this rotation and its length define the "rotational" of the movement of the fluid. The movement is irrotational if this fictitious rotation is nil.

Such must be the case of the ether in order that aberration might have the observed value.

Notice that the classic law of aberration is verified with great exactitude; it intervenes effectively in the catalogues of fundamental stars; the observed duration differs from the calculated deviation by less than 0″.1.

The two imposed conditions do not suffice to determine the law of the dragging along of the ether; the irrotational movement of a fluid is not known unless its density is given in all points of space; we do not know this density.

Per contra, we must impose on the ether the following conditions: On the earth's surface the velocity of the ether differs very little from that of the earth. On a sphere of sufficiently great radius, (for example, double that of our globe) the velocity of the ether is almost nil.

Analysis permits us then to establish the following result: it is not possible to admit that the ether is incompressible. And further, the density of the ether must vary in very great proportions: the density of the ether at the surface of the earth must be at least seven times greater than its density in interplanetary space. There is a serious difficulty if we assume that this variation of the density of the ether must not lead to any change in the phenomena of light.

The other Data of the Problem.

Modern ideas regarding the nature of light are more and more opposed to the assimilation of the ether to a vibrating fluid. But this is but a theoretical proof against the ideas of Stokes and of Planck: that perhaps the photo-electric effect may be put in accord with the hypothesis of the existence of the ether we cannot deny *a priori*.

I have reserved for the end the principal argument against the dragging along of the ether.

The Experiment of Michelson and Gale.

Represent upon the surface of the earth in the northern hemis-

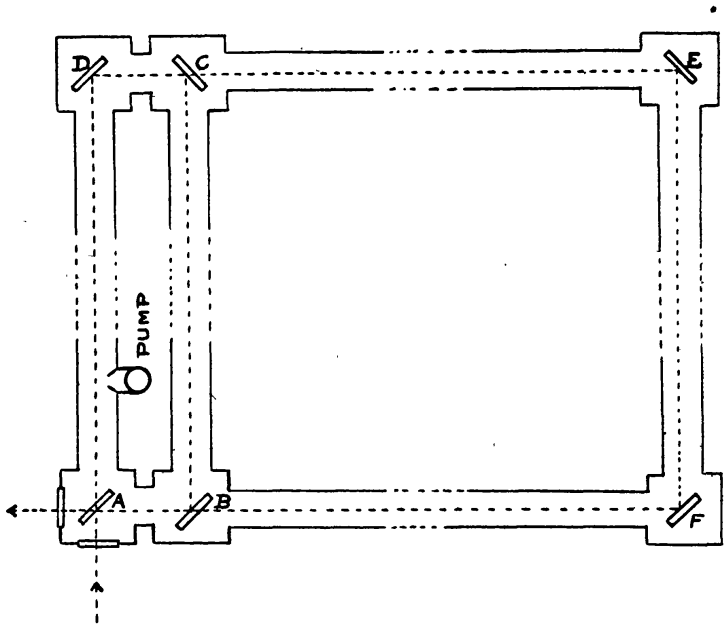

Fig. 3. Arrangement of the apparatus of Michelson and Gale.

The rays of light traverse a vacuum. The apparatus comprises two light circuits: a greater circuit *AFED* and a lesser circuit *ABCD*. The experiment consists in comparing the fringes produced by these two circuits.

phere a rectangular contour *AFED* (Fig. 3), *AF* and *ED* are two arcs of meridian, *FE* and *AD* two arcs of parallel, the latitude; *FE* is greater than that of *AD*, *DE* is west of *AF*. Suppose the ether fixed.

A ray of light follows the course *ADEFA*, a second ray traverses *AFEDA*. The two rays take the same time to traverse the arcs

of meridian AF and ED. The first ray will take less time to traverse AD than the second to traverse DA, for being carried forward by the rotation of the earth, D will seem to come to meet the first ray, while A will seem to fly from the second.

The advance of the first ray upon the second will not be exactly compensated by the analogous phenomenon which will be produced by the traversal of FE for FE is smaller than AD and the velocity of F in the rotation of the earth is inferior to that of A.

If the two rays leave A at the same time the first will come back later than the second. The retardation of this last ray is measured by an interferential method. This experiment permits putting in evidence the rotation of the earth in comparison with the ether.

For a relativist it puts in evidence the rotation of the earth with respect to the Galilean axes: the theory of restricted relativity predicted in effect for the second ray a retardation equal to that predicted by the theory of the fixed ether.

The experiment was made at Clearing, Ill., in 1925 by Michelson and Gale.[6] AF had a length of 338 metres and AD 611 metres. The theory predicted in this case a displacement of fringes of 0.236 fringe ($\pm$002). The mean of 269 observations well grouped has given a displacement of 0.230 fringe ($\pm$0.005).

The agreement is excellent.

If the ether had been partially dragged along on Mount Wilson, the displacement observed, without being nil, would have been different. If we admit the existence of the ether as a fluid medium, the experiment of Michelson and Gale proves that this fluid is not dragged along.

The three Hypotheses Compared.

Let us compute the chances of the opponents.

The theory of restricted relativity has for it:

1st—The experiments of Kaufmann and Bücherer[7] on the β rays of radio-active bodies, and those of Eug. Guye and Lavanchy upon the cathodic rays. These experiments have established the variation of the mass of an electron with its velocity according to the law predicted by relativity.

2nd—The structure of spectrum lines. Sommerfeld[8] has proved

that the dynamics of relativity account for the structure of the hydrogen lines and the spectra of X-rays.

3rd—The experimental verifications of the theory of Einstein.

It has against it: The experiment of Miller.

The theory of the fixed ether has for it: The experiment of Michelson-Gale.

Against it: Those of Michelson (1885) and of Miller (1921).

The theory of the ether dragged along has for it: the experiments of Michelson (1885) and of Miller (1921).

And against it: The experiment of Michelson and Gale.

Aberration and the "dragging" of waves remain neutral. Nevertheless relativity gives more simple explanations.

Conclusion—The opponents of relativity are hopeful. The relativists are confident; they recall what obstacles the law of Newton encountered at its beginning. We have seen that neither the theory of fixed ether, nor that of the dragging along of the ether is acceptable. The theory of Minkowski and of Einstein has nothing against it but the experiment of Miller. But the generalized relativity of Einstein has not yet given its reply.

We ought to wait; it is to be hoped that new experiments will decide the question. Perhaps from these a common explanation may be found to satisfy all the known facts.

Observatory of Meudon,
Paris.

REFERENCES

[1]Stokes, *Works. V. II.*
[2]*Philosophical Magazine*, 1887.
[3]*Philosophical Magazine*, May 1905.
[4]Proceedings of the National Academy of Sciences, June 1925.
[5]See various notes: *Comptes rendus* of the Academy of Sciences, 1925, 1926.
[6]*Astrophysical Journal*, April, 1925.
[7]*Annalen der Physik*, Vol. 19, p. 487, 1906.
[8]*Atombau und Sspectrallinien.*