Critical remarks on the repetition of the Michelson Experiment on Mount Wilson.

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With two illustrations. (Received 15 December 1925.)

1. The results of the repetition of the Michelson experiment accomplished by D.C. Miller on Mount Wilson cannot be brought in agreement with the Stokes-Planck theory of the entrained aether, because according to this theory the gradient of the relative velocity between earth and aether cannot be so large at the elevation of Mount Wilson that this speed, found by Miller, is in the amount of 9 km/seconds. 2. The aether drift accessible to an observation would have to have during one day noticeably constant amount and noticeably steady direction against the fixed starry sky. From this fact the way of the interference movement theoretically to be expected can be calculated as a function of the azimuth of the interferometers for different hours and different inclinations of the aether drift against the earth axis. A comparison with the observation data of Miller shows that one would have to accept an error of observation of the size of the whole measured effect, in order to adapt the observed curves to those computed. It is concluded from it that the effect observed on the Mount Wilson is not real, and that the earth's movement has nothing at all to do with anisotropy of the light propagation, but it is attributed to unknown disturbing effects.

According to a report of D.C. Miller[1]) the Michelson experiment, with the equipment used by Morley and Miller in the years 1904 and 1905, was recently repeated, whereby the following results were yielded: In the laboratory of the Case School in Cleveland, Ohio, where also the original attempts by Michelson and Morley had been implemented, again appeared no effect exceeding the observational error. However, comparative measurements with the same apparatus on the Mount Wilson showed a positive effect, which would correspond to an aether drift of approximately 9 km/sec. at approximately 1,800 m altitude. This result was gained from approximately 5,000 single observations, which were made in April and December 1921 as well as in April, 1925. Magnetic effects were eliminated since the summer 1921 by a re-design of the apparatus, and the influence of the temperature was eliminated perfectly by suitable measures. The attempts

[1]) D. C. Miller, *Proc. Nat. Acad. Wash.* **11**, 306, 1925; *Nature* **116**, 49, 1925.

of 1925 took place in another place on the Mount Wilson than those from 1921 and essentially showed the same result.

The positive result of Miller's experiment appears to indicate that the relativity theory was disproved, and that in its place the Stokes-Planck theory of the entrained aether was a satisfactory explanation to give all monitoring results, including the deflection of light at the edge of the sun[1]).

It will be shown below that at least the second part of this statement is incorrect. If the effect found on Mount Wilson is not due to previously unexplained sources of interference (for which in §2 of this note serious arguments are given), so it would not only contradict the special theory of relativity, but also the aether theories of Fresnel and Stokes.

§ 1. Assumption A, that the aether at the earth's surface at sea level is nearly completely carried, while with increasing altitude of the observation place an increasing relative motion between aether and earth can take place only under inclusion of a second assumption B, which maintains that the movement of the aether is a flow with a velocity potential. Assumption B goes back to Stokes and is a necessary addition of A for the following reasons: a) to the explanation of the annual aberration, b) because of the failure of the Michelson experiment in the year 1897[2]) and c), because otherwise the theory of the entrained aether would demand that spatial distribution of stars at observatories lain at different altitudes would have to differ by an amount exceeding, by far, the error of observation, which by any means is not the case[3]).

The assumptions A and B are, like Lorentz had shown[4]), incompatible with the hypothesis of the incompressibility of the aether. One could main-

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[1]) L. Silberstein, *Nature* **115**, 798, 1925; *Phil. Mag.* (6) **39**,161, 1920.

[2]) *Amer. Journ. of Science* (4) **3**, 475, 1897. With this, nearly fallen into oblivion, is the attempt where two coherent light bundles were directed along the extent of a vertically placed rectangle in opposite direction. (The analogous attempt with a horizontal lying rectangle was implemented, as well known, in an enlarged graduation and with a positive result recently done by Michelson and Gale. It delivers the influence of earth's rotation on the light propagation and is just as well probable with the Fresnel theory of the resting aether as with general relativity theory, not however being in agreement with the theory of the entrained aether. See the note of C. Runge, *Naturwissenschaften* **13**, 440, 1925.)

[3]) Eddington, *Nature* **115**, 870, 1925.

[4]) H. A. Lorentz, *Abh. über theor. Phys*. **1**, 347-349.

tain them, however, but with the additional of acceptance of Planck assumption C: the aether is compressible, subject to gravity and therefore is condensed in the surroundings of the world body. L. Silberstein has in the above-cited paper of 1920 attempted to explain the observed light deflection at the edge of the sun with the assumptions A, B and C. The numerical results by this calculation, on the basis of Boyle's Law, for the compression of the aether at the sun's limb, amounts to

$$\frac{\rho}{\rho_\infty} = 10^{13000} .$$

It highlights, most dramatically, the difficulties of a substantive aether theory, that such a substance, both because of the lack of longitudinal vibrations must be regarded as incompressible and would have to assume on the other side to explain the deflection of light in gravitational fields that the aether at the solar surface is 10^{13000} times denser than at a great distance from it.

The Stokes-Planck aether theory was calculated by H.A. Lorentz[1]), whereby for the relative velocity *v* of the aether against an observer resting on the earth's surface the following formula results:

$$v = \frac{v_\infty}{4} \frac{\sigma^3}{e^\sigma - \left(1 + \sigma + \frac{\sigma^2}{2}\right)} . \qquad (1)$$

Here v_∞ is the aether velocity at a great distance from the earth, and σ is given by

$$\sigma = \frac{\alpha M}{r} , \qquad (2)$$

where *M* is the mass of the earth times the gravitational constant, *r* the distance of the observer from the earth center and α the unknown proportionality factor between pressure and density of the aether. This unknown factor can be used in order to adapt the formula to the respective observation data.

As soon as one knows a point of that through (1) and (2) given curve $v = v(r, \alpha)$, the factor unambiguously is given, and equation (1) can be used for the calculation of *v* for other values by *r,* therefore for other elevations of the observation place. With the assumption that the effect found on Mount

[1]) Loc. cit. pages 454-460; Theory of Electrons, p. 314.

Wilson was real and really corresponded to an aether drift of 9 km/sec., one point would be given to the above-mentioned curve by the pair:

$$v = 9 \text{ km/sec.} \quad \text{for} \quad r = r_o + 1.8 \text{ km},$$

where r_o is the earth's radius at sea level for medium latitudes, approximately equal to 6370 km. Substituting this in (1), we obtain

$$v = 8{,}994 \text{ km/sec.} \quad \text{for} \quad r = r_o .$$

After the Lorentz formulas for the Stokes-Planck aether theory, a nearly immediate big aether drift would have to appear at sea level which contradicts the negative failure of the Michelson experiment in Cleveland, completely. The theory provides a smaller, by several orders of magnitude, velocity gradient of the aether as those resulting from the Michelson experiments of Cleveland and Mount Wilson, if the result of the latter is regarded as real[1]).

§ 2 By detecting the incompatibility with the Stokes-Planck aether theory route, the positive outcome of Miller's attempt on Mount Wilson is not removed from the world. There are, however, quite apart from these purely theoretical considerations, no arguments mentioned entirely different in nature, which must at least give rise to the suspicion that the effect was caused by previously unexplained local disturbances and had nothing to do with an "aether drift", as we shall call the relative motion between the observer and aether for brevity.

The portion of this drift produced by the daily movement of the earth for medium latitudes amounts to only approximately a hundredth part of the drift velocity produced by the annual movement for that place. Since now the effect is proportional to v^2/c^2, the daily movement of the earth would

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[1]) In a letter to the "*Nature*" (**116**, 132, 1925), G. Giorgi brings attention to the difficulties which oppose an interpretation of the effect found on the Mount Wilson by the Stokes-Planck aether theory. Because if one wants to interpret the positive result of the attempt of Michelson and Gale (*Nature* **115**, 566, 1925) in the sense the aether theory, then he proves that the aether is not carried forward by the rotation of the earth. One would have to assume that the earth had on the aether a "purely gravitational grip" and it from there only during the translation movement carries forward. Then it is however incomprehensible, why this effect close of the earth's surface outgoing from the gravitation center of the earth can experience a so steep a drop. - Those calculations made above supply a numeric confirmation of the argument Mr. Giorgi.

only cause a shift of approximately 1/7000 of a fringe width, which withdraws itself from the observation perfectly in the Miller apparatus. Hence, the one being considered and an observation of accessible aether drift would consist of the annual earth movement and the unknown movement of the solar system against the world aether. The latter is, in any case, of a consistent size and direction and the first changes in the course of 24 hours so little anyhow that we can make the following statement about an accessible the part observation of the hypothetical aether drift: Within one day its amount remains almost constant and its direction points toward a certain place of the fixed starry sky.

The interferometers used with the Michelson experiments float, as everybody knows, on mercury, so that the ray path remains precisely horizontal during the rotation of the apparatus. Hence, the movement of the interference fringes is generated only by the horizontal component of the aether drift. It is v the amount of this horizontal component, c the speed of light, D the length of the ray path. Then interferometers and λ, the wavelength of the light used, suffer the interference fringe movement of

$$\frac{2D}{\lambda}\frac{v^2}{c^2}$$

fractions of a fringe width if one turns the apparatus from a position where an interferometer arm aligns with the direction of the horizontal component of the aether drift and then collapses at around 90^o. Because now, as mentioned, the aether drift is directed during one day nearly consistently against a place of the fixed starry sky, the azimuth and the amount of this horizontal component will get to know in the course of one day, changes which are periodic, while the hour angle of the aether drift runs 0 to 360^o. Accordingly, the azimuth and the amount of the maximum fringe movement will also change in the course of one day, nearly periodically.

A single observation occurs with the Michelson experiment in the way that the apparatus with a period of rotation which varies between 40 sec and some minutes is moved with uniform rotation. With one observer walking while observing the crosshair of the observation telescope positioned with a micrometer always on a certain interference band, while the second observer takes down the position of the crosshair as a function of the azimuth of the apparatus. If one applies the azimuth of an interferometer arm as the abscissas and the movement of the interference fringes as ordinates,

one receives curves of the kind represented in Fig. 1. If one repeats the attempt in the same time intervals by 24 hours, one receives the curves which correspond to all hour angles of the aether drift. Then the general view of this curve series taken up during 24 hours will still only depend on the angle enclosed by the direction of the aether drift with the earth axis.

It will hereinafter be calculated theoretically expected curves for various hour angles and declinations of the aether drift. We think of the prime meridian placed at the observation place, at latitude b. The direction of the aether drift is given by its declination ϑ and the hour angle φ. In addition, we introduce a rectangular coordinate system whose Z-axis has the direction of the Earth's axis and coincides with the Z X-plane with the meridian level of the observation place. We designate the vector of the aether drift with $\mathfrak{B}$, its amount with V, its horizontal component with v, furthermore the unit vector in the horizontal east direction of the observation place with $\mathfrak{e}$ and the unit vector in the horizontal north direction with $\mathfrak{n}$. This gives the following analysis of the components:

	X	Y	Z
$\mathfrak{B}$	$V \sin\vartheta \cos\varphi$	$V \sin\vartheta \sin\varphi$	$V \cos\vartheta$
$\mathfrak{e}$	0	1	0
$\mathfrak{n}$	$\sin b$	0	$\cos b$

Furthermore it is the azimuth of the horizontal component of the aether drift δ; its projection on the west-east direction is v_e; its projection in the south-north direction v_n. Then this is valid:

$$\left.\begin{aligned} v_n &= (\mathfrak{B}\mathfrak{n}) = V(\cos\vartheta\cos b - \sin\vartheta\cos\varphi\sin b),\\ v_e &= (\mathfrak{B}\mathfrak{e}) = V\sin\varphi\sin\varphi. \end{aligned}\right\} \quad (3)$$

$$\left.\begin{aligned} v^2 &= V^2\{(\cos\vartheta\cos b - \sin\vartheta\cos\varphi\sin b)^2 + \sin^2\vartheta\sin^2\varphi\},\\ \delta &= \pi + \operatorname{arctg} v_e/v_n. \end{aligned}\right\} \quad (4)$$

By means of these formulas for the geographical latitude of the Mount Wilson, $b = 34°$, computed values of v^2 and δ are indicated in Table 1 as function of ϑ and φ. Since we are concerned only on the shape of the observation curves and not on the amount of the fringe shift, in the table $V = 1$ has been set, while in the following curves the ordinate yardstick was selected in such a way that the best possible adaptation to the amplitudes of the Miller observation curves is achieved.

Fig. 1 shows the theoretical curve family for different hour angles and declinations of the aether drift, resulting from these computations, in the first five columns. Each individual curve represents the shift of the interference fringes as function of the azimuth ψ of an interferometer arm. The curves in a column belong to a certain inclination of the aether drift against the Earth's axis and give that overall view of a series of twelve observations, which can be expected, theoretically, which are shown in two-hour intervals. Then in

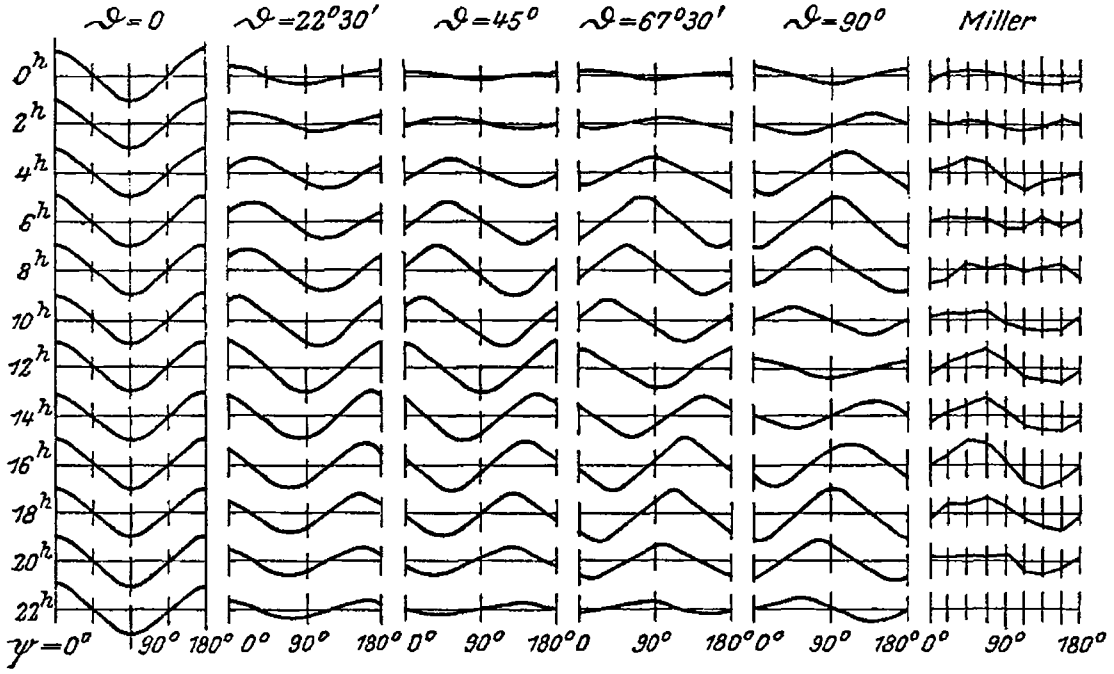

Fig. 1.

the last column are reproduced the curves of what Miller actually observed during one day in the appropriate scale.

If the observation curves are to represent a real effect, which is produced by an aether drift oriented somehow, then they must be able to be set in their whole with one of the drawn theoretical curve columns or coincide with one of their intermediate forms. On this occasion, may, according to the arbitrariness in the choice of the initial hour angle, the single curves standing in a column still cyclically are exchanged, may be shifted and, in addition, all curves of a column together 90° in the phase, because neither of the two interferometer arms is distinguished more than the other. Finally, still another certain tolerance would be to be permitted because of the errors of observation. A more detailed analysis of Fig. 1 now

shows that these tolerance errors in individual curves would have to almost accept the full amount of the observed effect with individual curves, so that the overall view on one day of the observations can be adapted to that picture which can be expected theoretically. Those observation curves, which were taken up over equal long times before and after the passage of the aether drift by the Meridian of the observation place, must correspond with each other as mirror-image, which with the Miller curves is not at all the case. One could, e.g., identify with $\varphi = 4^h$ drawn observation curve of Miller with some tolerance with the theoretical curve $\vartheta = 45^o$, $\varphi = 4^h$. Then however curves would have to arise between 14^h and 22^h, whose maxima lay between $\psi = 90$ and $\psi = 180^o$. The curves observed by Miller between 14h and 22h differ however from the appropriate computed nearly around the double amount of the observed effect. For small values of ϑ becomes however the difference between equivalent for a long time before and/or after the meridian passage observed curves weaker. For such ϑ-values would have however the curve amplitudes for all hour angles to remain noticeably alike, and in addition would have then the maxima and minima of the curves with the NS- and/or EW-position of the apparatus ($\psi = 0$ and/or $\psi = 90^o$) to be almost achieved. Both are with the actually observed curves not at all the case.

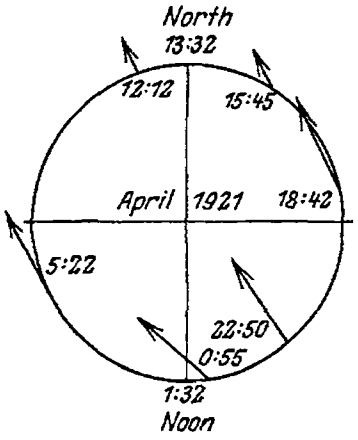

Fig. 2.

One recognizes the discrepancy between theory and observation also quite clearly from the view of Fig. 2, which is taken from the paper by Miller. It represents the directions of the alleged aether drift projected on the horizon of the observation place to different observation hours. It is noticeable that the arrows are directed after size for all observation hours. From the equations (3) and (4) and from into the table 1 indicated values for δ one recognizes however immediately that the horizontal component of any space-fixed direction must make symmetrical excursions during one day to the east and to the west.

It should be emphasized that no further assumption is at the basis put to the computation of the theoretical curves, that the observable aether drift changes during one day its amount and its direction against the fixed star sky

for only very little. The fact that the Miller's observation curves cannot be brought into line with the theory, without in each of them an error of observation must be assumed that at least reaches the full extent of the observed effect, probably justifies the assumption that the found effect had nothing to do with an influence do to the earth's motion on the propagation of light, but is caused by unresolved local disturbances. It would be from large interest to accomplish the attempt also in Pasadena in order to decide whether the effect in the environment of the Mount Wilson arises not even at lower altitude.

Tabelle 1.

$\vartheta =$	0^0		$22^0\,30'$		45^0		$67^0\,30'$		90^0	
q	v^2	δ	v^2	δ	v^2	δ	v^2	δ	v^2	δ
0^h	0,688	0^0	0,304	0^0	0,036	0^0	0,040	180^0	0,313	180^0
2^h	0,688	0^0	0,374	$18^0\,15'$	0,184	$55^0\,25'$	0,229	$105^0\,45'$	0,484	$134^0\,10'$
4^h	0,688	0^0	0,544	$26^0\,40'$	0,526	$58^0\,40'$	0,644	$85^0\,50'$	0,827	$107^0\,50'$
6^h	0,688	0^0	0,739	$26^0\,30'$	0,843	$50^0\,20'$	0,955	$70^0\,05'$	1,000	90^0
8^h	0,688	0^0	0,870	$20^0\,50'$	0,987	$38^0\ 0'$	0,971	$54^0\,25'$	0,827	$72^0\,10'$
10^h	0,688	0^0	0,940	$10^0\,25'$	0,987	$21^0\,10'$	0,797	$31^0\,10'$	0,484	$45^0\,50'$
12^h	0,688	0^0	0,980	0^0	0,982	0^0	0,695	0^0	0,313	0^0
14^h	0,688	0^0	0,940	$-10^0\,25'$	0,987	$-21^0\,10'$	0,797	$-31^0\,10'$	0,484	$-45^0\,50'$
16^h	0,688	0^0	0,870	$-20^0\,50'$	0,987	$-38^0\ 0'$	0,971	$-54^0\,25'$	0,827	$-72^0\,10'$
18^h	0,688	0^0	9,734	$-26^0\,30'$	0,843	$-50^0\,20'$	0,955	$-70^0\,05'$	1,000	90^0
20^h	0,688	0^0	0,544	$-26^0\,40'$	0,526	$-58^0\,40'$	0,644	$-85^0\,50'$	0,827	$-107^0\,50'$
22^h	0,688	0^0	0,374	$-18^0\,15'$	0,184	$-55^0\,25'$	0,229	$105^0\,45'$	0,484	$-134^0\,10'$

Addendum in proof. Mr. F. Zerner had the kindness to make me aware that according to the Stokes-Planck theory the aether current at the earth's surface had only a tangential component. It is not maintained from there (contrary to the wording of the condition used above) their direction against the fixed star sky during one day, but change rather in such a way like the horizontal component of a space-fixed vector. There now into the computation in Fig. 1 represented curves straight just only the horizontal component as space-fixed accepted aether drift is received, by this statement in the numeric information and in the conclusions of present work, nothing is changed.