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WITH SEVEN PLATES.

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ART. LI.—*The relative Motion of the Earth and the Ether;* by ALBERT A. MICHELSON.

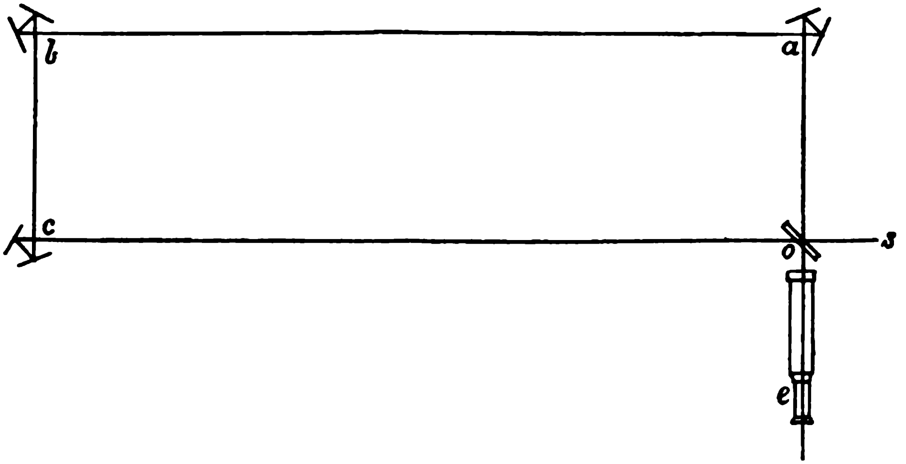
To account for the phenomenon of aberration Fresnel supposes the luminiferous ether at rest, the earth moving through this medium without communicating any perceptible part of its motion. On this theory it has been shown* that it should be possible to detect a difference of the velocity of light in two directions at right angles. As no such difference was observed, it would seem to follow that Fresnel's hypothesis is incorrect.

Another theory is that of Stokes, in which the aberration is accounted for if the relative velocity of the earth and the ether have a potential. This requirement, however, is inconsistent with the results of the experiment just cited, which indicates that at the earth's surface the relative motion is zero.

In the hope of detecting a relative motion corresponding to a difference of level, the following experiment was undertaken.

I take this opportunity of gratefully acknowledging the faithful and efficient services rendered in the execution of this work by Professor S. W. Stratton and Mr. C. R. Mann.

1.

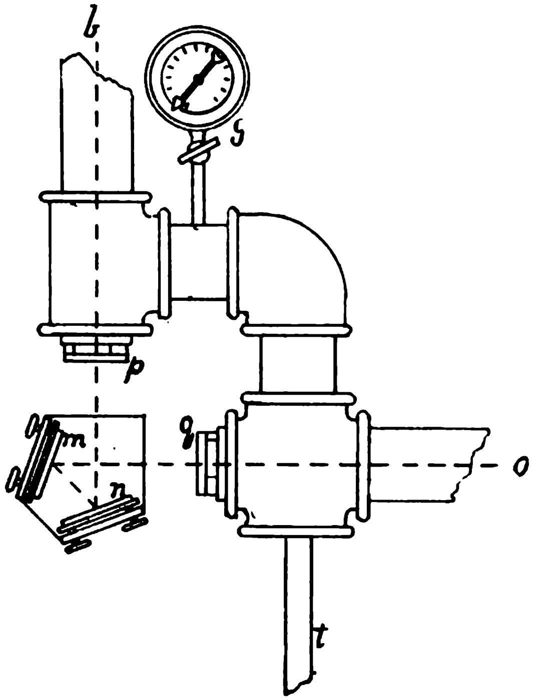


Light from the source *s*, a calcium light or an electric arc lamp, separated into two pencils at a plane-parallel glass plate, *o*, lightly silvered. The two pencils were reflected by double mirrors along the paths *oabcoe*, and *ocbaoe*, respectively. The two paths being equal, interference fringes could be observed with the aid of the telescope at *e*. Fig. 2 shows details of the corner at *c*: *pq* are plane-parallel glass disks, cemented to the

* This Journal, November, 1887.

ends of the iron pipes; *mn*, plane glass plates silvered on front surface, and provided with adjustments in two planes; *omnb*, the path of the pencil of light. The apparatus was set up in the vertical east and west plane, the light traversing the entire circuit of the Ryerson Laboratory, a path about 200 feet long and 50 feet high.

2.



It was found that under ordinary conditions the temperature disturbances in this length of air made it impossible to measure the position of the fringes; and the difficulty was only slightly remedied by enclosing the whole path of the light in a wooden box. By making this enclosure an iron pipe and exhausting the air to within a hundredth of an atmosphere, it was found possible to measure the position of the central bright fringe to within something like a twentieth of the fringe-width.

A difficulty is encountered in the selection of a fiducial mark. The double image of the source does not remain on the cross hairs of the observing telescope for any great length of time, notwithstanding the precaution of the double reflections at the corners, but by using this double image itself as the fiducial mark, any possible errors due to daily temperature changes, etc., are eliminated. This double image and the interference fringes are not in focus at the same time, but by sacrificing a very little in the definition of each, the measurements may be made with very considerable precision.*

The observations were taken in the morning, at noon, evening and night; no special care being taken as to the exact hour. The results are summed up in the table containing the observations taken and reduced by Mr. Mann, as follows:—

The micrometer was set on one spot, then on the central fringe, then on the other spot, giving three readings of the micrometer. The first reading was subtracted from the third, giving the distance between the spots in divisions of the micrometer head. The second reading was subtracted from the third, giving the distance of the central fringe from the lower in divisions of the micrometer head. This last remainder was divided by the first, giving the distance n of the central fringe from the lower spot in fractions of the distance between the spots regarded as unity.

Each reading was reduced this way and the mean of ten taken as the result for any given time. The weights p were calculated as usual from the formula: $p = c/e^2$.

Date.	6 A.M.			12 Noon.			6 P.M.			11 P.M.		
	n	p	pn	n	p	pn	n	p	pn	n	p	pn
March 11	·500	67	33·50	·515	40	20·60	·503	12	6·03	·480	20	9·60
	·513	38	19·49				·506	10	5·06	·490	32	15·68
March 13	·495	11	5·44	·530	33	17·49						
March 16	·507	55	27·88	·499	50	24·95	·492	13	6·40	·479	60	28·74
	·509	120	61·08	·491	45	22·09	·488	40	19·52	·487	22	10·71
March 17	·490	40	19·60	·504	80	40·32	·500	35	17·50	·488	105	51·24
	·488	50	24·40	·502	60	30·12	·498	30	14·94	·496	100	49·60
March 18	·501	80	40·08	·492	80	39·36	·493	40	19·72	·498	25	12·45
				·507	50	25·35	·488	25	12·20	·498	35	17·43
Sums.		461	231·47		438	220·28		205	101·37		399	195·45
Means.	·502 ± ·002			·503 ± ·003			·494 ± ·002			·490 ± ·002		

12 Noon − 11 P.M. = ·013
1 fringe = ·250 $\therefore$ maximum displacement $\frac{13}{250} = \frac{1}{20}$ fringe.

The conclusion from these results is that if there is any displacement of the fringes it is less than one-twentieth of a fringe.

If we consider the times occupied by the two pencils in com-

* On account of the inequality of the angles of incidence and reflection there will be a slight difference between the real and apparent positions of the double image. This difference will be altogether too minute to produce any appreciable error. Again, this difference in direction produces a difference in the length of the two paths—which is however of the second order and can also be neglected.

pleting their paths at noon and at midnight (when the horizontal parts of the path are parallel with the earth's motion in its orbit), we find the difference is $4s\frac{v}{V^2}$ where s is the length of the horizontal part of the path, v, the *difference* of relative velocities above and below, and V the velocity of light. This corresponds to a *displacement* $\Delta = 4\frac{s}{\lambda}\frac{v}{V}$ fringes.

If the relative motion be assumed to follow an exponential law it may be represented by

$$v = v_0(1 - e^{-kh})$$

where v_0 is the velocity of the earth and h, the height above the surface.

Suppose $\frac{v_0 - v}{v}$ falls to $\frac{1}{e}$ of its surface value in one hundred kilometers. Then in fifteen meters, which is the difference of level of the two horizontal pipes

$$v_0 - v_1 = \cdot 00015\ v_0.$$

Substituting this for v in the equation for Δ we have

$$\Delta = \cdot 0006\ \frac{s}{\lambda}\ \frac{v_0}{V}.$$

Putting $\frac{s}{\lambda} = 12 \times 10^7$ and $\frac{v_0}{V} = 10^{-4}$ we find $\Delta = 7 \cdot 2$ fringes.

As the actual displacement was certainly less than a twentieth of a fringe, it would follow that the earth's influence upon the ether extended to distances of the order of the earth's diameter.*

Such a conclusion seems so improbable that one is inclined to return to the hypothesis of Fresnel and to try to reconcile in some other way the negative results obtained in the experiment cited in the first paragraph.

The only attempt of this character is due to H. A. Lorentz.† It involves the hypothesis that the length of bodies is altered by their motion through the ether.

In any case we are driven to extraordinary conclusions, and the choice lies between these three :—

1. The earth passes through the ether (or rather allows the ether to pass through its entire mass) without appreciable influence.

2. The length of all bodies is altered (equally ?) by their motion through the ether.

3. The earth in its motion drags with it the ether even at distances of many thousand kilometers from its surface.

* Of course this will depend on the law assumed for the rate of diminution of relative velocity with distance from the earth's surface; and possibly an exponential law is far from the truth. It may be desirable to repeat the experiment with a much greater difference of level, and perhaps to bury the lower tube some distance underground.

† "Versuch einer Theorie der El. u. Op. Erscheinungen in bewegten Körpern," H. A. Lorentz.