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A REPETITION OF THE MICHELSON-MORLEY EXPERIMENT USING KENNEDY'S REFINEMENT

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Abstract

The ether drift experiment as performed by Kennedy with a reduced optical system in helium has been repeated with the same apparatus somewhat modified and the same results obtained. The interferometer has been improved by resilvering the mirrors so that 1/1500 of a fringe shift could be detected by an observer with good eyes, and 1/500 by an observer with poorer eyes. Additional readings, which eliminate steady thermal shifts of the fringes, have been made and these show no ether drift to an accuracy of about one kilometer per second.

In a recent paper[1] Dr. R. J. Kennedy, National Research Fellow at the California Institute of Technology, has described a modification of the Michelson interferometer and its application to the ether drift experiment. This modification consisted of a small step one-twentieth of a wave-length thick in one of the total reflecting mirrors of the interferometer. The purpose of the present investigation is to make a study of the sensitivity obtainable by Kennedy's method and to make further investigations as to the presence of an ether drift using Kennedy's apparatus. This work has been done in a sub-basement constant temperature room in the Norman Bridge Laboratory of Physics.

The float, mirrors and light source and also methods of adjusting are the same as used by Kennedy. The mirrors are mounted in steel and brass supports attached to a marble slab which is four feet square. A brass case encloses the mirrors and light paths, so that the paths may be filled with helium, or exhausted as desired. Helium was used, as it has such a low index of refraction that variations due to temperature changes are reduced to a negligible quantity. Because of tarnishing, three of the mirrors previously used had to be resilvered, but two which had platinum surfaces were not resurfaced.

One of the platinum mirrors has a step in it of approximately one-twentieth of the wave-length of green light. Light from the source was focused on this step mirror, the fringes were formed there and the observing telescope was focused accordingly. Because of the small difference in path to the two halves of the step mirror a slight discontinuity exists between the fringe systems on either side of the step, the two systems being out of phase by one-tenth of a fringe. In general this produces a sharp change in intensity at the step A as seen in Fig. 1a, which represents the distribution of energy in the fringe systems in the neighborhood of the step at A. If, however, the fringes are shifted to the position relative to the step as shown in Fig. 1b,

[1] Kennedy, Nat. Acad. Sci. Proc. **12,** 621–629 (1926).

there will be no discontinuity in the intensity at A. Consequently, when a telescope is focused on a small region in the immediate neighborhood of the step, one observes for the two cases the fields of view as shown in the small circles just below A in each diagram. In case 1a the two halves of the field are unequally illuminated with a sharp line of demarcation, while in case 1b the two halves of the field are equally illuminated. This equality of the two halves of the field constituted a very delicate test as to the exact position of the fringes as a movement of one-twentieth of a fringe would change the field from equal intensity on the two sides to zero on one side and several times the original intensity on the other. The quantitative theory of the intensity changes caused by small shifts has been worked out in detail by Kennedy.[1]

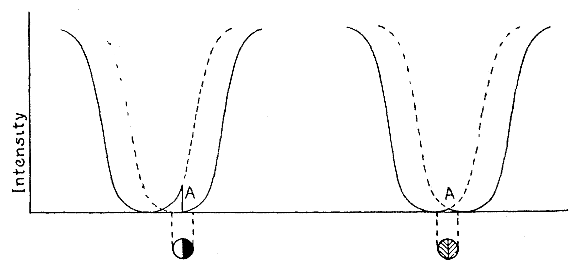

Fig. 1a. Fig. 1b.

Illustrating the half-shade method of locating the position of interference fringes.

For determining experimentally the sensitivity of such an arrangement, Kennedy's method of distorting the marble slab by placing small weights on one corner was used. A direct movement of the compensator mirror caused a too rapid movement of the fringes and could not be set with precision. By observing the weight required to distort the marble slab sufficiently to change the fringe pattern a measurable fraction of a fringe, the weight for a whole fringe could be computed by simple proportion. This was done on the assumption that Hooke's law holds for the small forces employed. In this manner it was determined that 7,500 g. placed at a fixed point on the slab would change the pattern by one fringe. The apparatus is then adjusted so that the intensity across the step is uniform and no line of demarcation is visible. In other words the two systems are as in Fig. 1b. The part of the fringe actually observed was so small that the two halves of the field were evenly matched. By observing the smallest weight which when put on the marble at the fixed point produces a noticeable change in the intensity of the two halves a measure of the sensitiveness or least fringe shift which can be detected is obtained.

As the sensitivity of this method depends on the minimum difference of intensity the observer can detect, the sensitivity was determined by five men from the laboratory staff. While making the tests the observer could not see what weights were added or removed. The observed sensitivity was defined as the minimum weight the removal or addition of which the observer could name correctly in nine cases out of ten. Table I gives values of the sensitivity for the five observers in terms of grams added and corresponding fringe shift. In the last column the ether drift velocity corresponding to these shifts is given.

TABLE I

Sensitivity of the interferometer system as determined by five observers.

Observer	Least weight observed	Fraction of fringe	Velocity of ether drift this would detect
A	15 grams	.002	5.0 km/sec
B	15	.002	
C	5	.0007	3.0
D	5	.0007	
E	25	.0035	6.6

During the latter part of June the original Kennedy method of observing ether drift was used; namely, to await temperature conditions so stable that the apparatus could be rotated through a right angle and back to the original position without a noticeable change in intensity of the two halves of the field of view. In all cases the observer started looking North, rotated the apparatus to look West, and then back to North. On thirteen occasions during the ten days it was possible to fulfill the above conditions. In no case when the conditions were fulfilled was it possible to observe a shift as the apparatus was rotated from the north to the west position of as much as .002 fringe, which would detect an ether drift above 5.0 kilometers per second.

As it was difficult to obtain stable temperature conditions, it was thought best to use a method which would eliminate the effect of a steady displacement due to thermal changes. Therefore a large number of 14 gram weights were arranged on a vertical rack fastened to the marble slab where the previous sensitivity checks had been made. Starting with the field of view exactly balanced it was noted how many weights were removed or added to balance again after a rotation of 90°. It was therefore possible to get numerical readings for the shift of the fringes as the rotation progressed, and to average these readings so that even smaller ether drifts could be detected and greater precision obtained. This method has the further advantage that it was impossible for the observer to be influenced by prejudice.

During the first ten days of July a set of observations was made on the following program. Each day at 11 A.M., 5 P.M., and either 5 A.M. or 11 P.M. the apparatus was rotated twenty revolutions and readings taken every 90°. During the first ten, the observer stopped the apparatus and took a reading when he was looking north, west, south, east and north, the readings being taken every 30 seconds. During the last ten the directions were changed to north-east, north-west, south-west, south-east and north-east.

Table II gives the readings that were taken at 11 A.M. July 9 for the N, S, E, W and N positions and is typical of all readings taken. The number represents the total number of weights removed and hence fringe displacement after leaving the north position. One weight equals 1/500 fringe.

TABLE II

Readings taken for the N, S, E, W and N positions at 11 A.M. July 9, 1927.

The numbers represent the total number of weights removed in order to balance the system. One weight equals 1/500 fringe.

N	E	S	W	N
0	−3	− 7	−12	−17
0	−5	−10	−15	−19
0	−4	− 9	−14	−19
0	−4	− 9	−14	−19
0	−4	− 8	−13	−20
0	−8	−14	−19	−23
0	−5	−10	−14	−17
0	−5	− 8	−12	−17
0	−4	− 9	−14	−18
0	−4	− 9	−13	−18
Average 0	−4.6	−9.3	−14.0	−18.7

Average N S N = −9.33
Average E W = −9.30

−0.03 Average displacement, due to orientation, in terms of weight.

It will be noted that this method of averaging eliminates the effect of steady thermal shifts. The results of the displacements for the ten days are tabulated in Table III. Each value in the table represents the displacement due to orientation as determined from a set of readings for ten revolutions similar to those shown in Table II.

TABLE III

Summary of results

	5 A.M.		11 A.M.		5 P.M.		11 P.M.	
	N,S,−E,W	NW,SE−SW,NE	N,S−E,W	NW,SE−SW,NE	N,S−E,W	NW,SE−SW,NE	N,S−E,W	NW,SE−SW,NE
	+.12	−.33	+.35	−.11	+.12	+.22	−.05	+.12
	+.57	+.12	−.21	−.18	−.28	−.23	+.09	+.09
	.00	.00	−.03	−.26	−.72	−.40	−.63	−.03
	+.10	−.22	−.15	+.06	−.08	+.02	−.22	−.13
	+.32	.00	−.11	+.19	+.09	+.08	.00	+.12
	−.01	−.05	+.24	+.10	+.15	+.15	−.20	−.02
			−.07	−.03	+.15	+.07		
			−.03	+.02	+.18	−.18		
			−.03	+.08	+.03	−.03		
			.00	+.12	−.05	+.05		
Average displacement in terms of weights.	+.18	−.08	−.004	−.001	−.041	−.025	−.17	+.025
Fringe displacement	+.00036	−.00016	−.000008	−.000002	−.000082	−.000050	−.00034	+.000050
Probable error	.00012	.000090	.000073	.000060	.00012	.000082	.00014	.000056
Ether velocity in kilometers per second.	+2.1	−1.41	−.32	−.16	−1.0	−.79	−2.1	+.79
Fringe displacement for Miller's results	.003	.005	.008	000	.003	.005	.002	000

In Table III the ether velocity is computed from the well known formula which, for the dimensions of the interferometer here used, simplifies to $V = 112D^{1/2}$ where D is the fringe displacement caused by a rotation through a right angle. The probable errors have been computed for the deviations of the values in Table III from the mean value. The values of the fringe displacement one would have to observe on the equipment here used in order to get an ether velocity such as reported by Miller were computed from data in Miller's paper[2] and Kennedy's[1] paper. The ether drift as reported by Miller reaches a maximum 5.5 hours after sidereal noon. This makes the maximum occur at approximately 11:00 A.M. for the time of year the above readings were taken.

For 11:00 A.M. and 5:00 P.M. when the largest number of readings were taken and the temperature control was most satisfactory the probable error as indicated in Table III corresponds to an ether drift velocity of about one kilometer per second. For 11:00 P.M. and 5:00 A.M. when fewer readings were taken and when temperature conditions were erratic the probable error corresponds to a slightly larger velocity. Since in over one half the cases the observed shift is less than the probable error the present work cannot be interpreted as indicating an ether drift to an accuracy of one kilometer per second. This is but little more than one-tenth of the velocity found by Miller. In terms of fringe shift which is the quantity directly observed the present work shows that for the more reliable 11:00 A.M. and 5:00 P.M. averages the shift was in no case more than 1/100 of the maximum value of 0.008 calculated from Miller's observations. Even the large reading at 5:00 A.M. yields only 1/22 of this value.

NORMAN BRIDGE LABORATORY OF PHYSICS,
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[2] Miller, Science April 30, 1926.