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PRELIMINARY EXPERIMENTS ON THE VELOCITY OF LIGHT

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ABSTRACT

Description of the method employed.—A beam of light from a Sperry arc at a station on Mount Wilson is reflected from one face of a rotating octagonal mirror to a mirror located on Mount San Antonio, about 22 miles away, whence it is reflected back to the originating station, where it is reflected by the next succeeding face of the rotating mirror into the micrometer eyepiece. The velocity of the light is ascertained from the rate of rotation of the mirror. The details and the formulae of the method together with a diagram are given. The advantages of the method are (*a*) greater distance between the stations, (*b*) sufficient light for accurate measurement, (*c*) elimination of the measurement of angles.

Preliminary results of experiments.—The distance between the stations as measured by the Coast and Geodetic Survey is estimated to be accurate to within one part in two million. The velocity of light as determined by these preliminary experiments is 299,820 km per sec., and this result is probably correct to one part in ten thousand. It is hoped that next summer the accuracy can be extended to one part in one hundred thousand.

The following investigation, by invitation of Dr. George E. Hale, then director of the Mount Wilson Observatory under the auspices of the Carnegie Institution of Washington, was begun in 1921. The following summers of 1922 and 1923 were spent at Mount Wilson in the endeavor to obtain the best conditions for a more accurate determination of the velocity of light.

These conditions are (1) a greater distance between the stations, with a maximum visibility of the return image; (2) sufficient light for accurate measurement of the position of the image; (3) elimination of the measurement of angle, thus reducing the actual observations to measurement of the distance between stations and the measurement of the speed of rotation of the revolving mirror.

The former measurement was undertaken by the United States Coast and Geodetic Survey under the direction of Major William Bowie, and it is estimated that the result is accurate to within one part in two million.

The stations selected were, for the home station, Mount Wilson, and for the distant station, Mount San Antonio, about 22 miles away, requiring about 0.00023 seconds for light to go and return.

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During this time the octagonal revolving mirror making 530 turns per second will rotate through one-eighth of a turn, thus presenting the succeeding face to the return light at the same angle as though it were at rest.

The observation will then consist in obtaining this speed, in the present case by stroboscopic comparison with an electric fork making 132.25 vibrations per second, the latter being controlled by comparison with a free seconds pendulum, which last is compared with an invar gravity pendulum furnished and rated by the Coast and Geodetic Survey. When the reflections of the revolving mirror in the mirror attached to the fork are stationary, the observer measures the very small[1] angle α_1 to the zero.

The direction of rotation is then reversed and a similar measurement α_2 is made, thus eliminating the measure of the zero, and giving for the double "deflection" of the return image

$$2\phi=\pi-(\alpha_1-\alpha_2)=16\pi nD/V ,$$

whence

$$V=\frac{16nD}{1-\beta} ,$$

where

$$\beta=\frac{(\alpha_1-\alpha_2)}{\pi} ,$$

n = number of rotations per second, and D = length of light-path.

The figure represents the arrangement of the apparatus at the home station. Many other modifications were tried before the final adoption of this arrangement (or with a slight alteration which permits the final reflection from the octagon at nearly normal incidence), the chief merit of which is to eliminate direct reflections as well as diffuse light. These were tried during the summer of 1923, including the arrangement just described, but haze and smoke from forest fires prevented even such preliminary observations as would indicate the feasibility of the method—which would be determined by the intensity of the return image while the mirror is revolving.

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[1] The angle $\alpha_1-\alpha_2$ was of the order of 0.002, so that an accurate knowledge of the "radius" was unnecessary.

This uncertainty was eliminated by the observations in June and July of this year, which showed an abundance of light, even on days which were unpromising. Another important point which was satisfactorily settled in these observations was the steadiness and sharpness of the return image. During the hour after sunset this was at times so small and distinct that its position could be measured to the hundredth of a millimeter. This, with a "radius" of 250 mm[1] giving a total "displacement" of 392 mm, would correspond to an order of accuracy of nearly one in forty thousand.

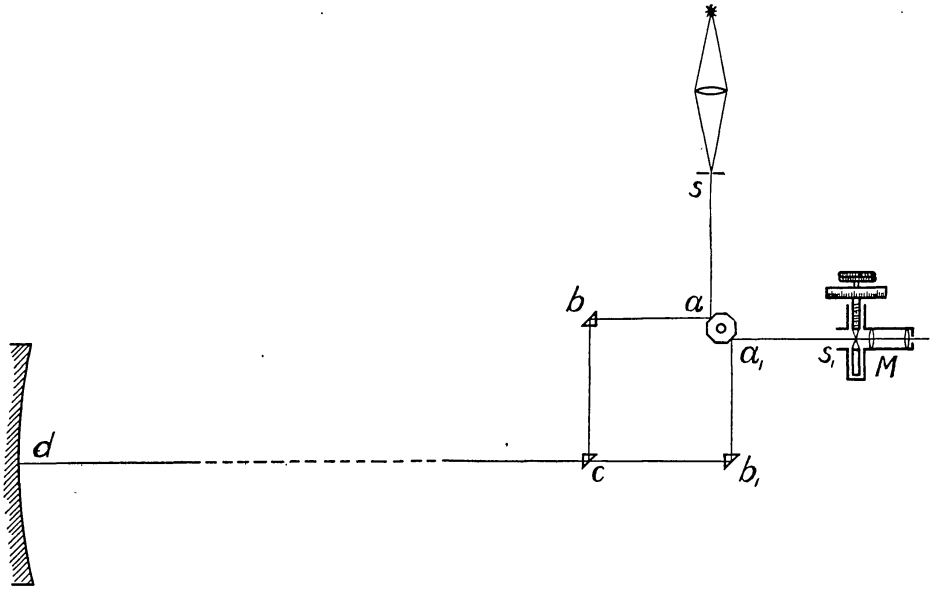

Fig. 1

Even on ordinary occasions when the "seeing" was less perfect the position could still be measured to 0.03 mm.

The light-source is a Sperry arc, which is focused on the slit *s*. Falling on the face *a* of the octagon, the light is reflected to a right-angle prism *b* to another at *c*, whence it proceeds to the concave mirror *d*, of 24-inch aperture and 30-foot focus. This reflects the pencil as a parallel beam to the distant mirror (also a 24-inch, 30-foot concave), proceeding thence to a small concave reflector at its focus. An image of the slit is formed at the face of this small

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[1] The intensity of the image varies inversely as the cube of the "radius," which accounts for the rather small value actually used.

reflector, which necessitates the return of the light to the concave at d,[1] whence it passes over the prism at c to b_1, whence it is reflected to the face a_1 of the octagon, forming an image at s_1 where it is observed by the micrometer eyepiece M.

The program in the observations from August 4 to August 10 was as follows:

The rate of the electric fork in terms of the free auxiliary pendulum is measured shortly after sunset by counting the number of seconds required for a complete cycle. If P_1 is the period of the auxiliary pendulum and C the number of seconds in the cycle, then the number of vibrations of the fork per second will be

$$N=\frac{N_1}{P_1}+\frac{1}{C},$$

in which N_1 is the nearest whole number (in the present instance 133) of vibrations in one swing of the pendulum.

The auxiliary pendulum makes and breaks (by the passage of a platinum point through a mercury globule) the primary circuit of an induction coil, thus giving a spark reinforced by a condenser in the secondary, which is observed in a mirror attached to the fork. The Sperry arc is then put in action and focused on the slit (width varying from 0.5 to 0.1 mm). With proper adjustment[2] the return light is observed in the eyepiece as a brilliant starlike image. The valve for the air blast is then opened until the pressure near the nozzle is about 40 cm of mercury, when the image reappears in the field. The speed is regulated by a valve controlling a counter-blast, until the stroboscopic images (four slowly moving images of one polished facet on the check nut of the revolving mirror) are just

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[1] This is the arrangement also used in the method of Fizeau and Cornu, but so far as I know it was not supposed to be applicable to the method of the revolving mirror. It has given complete satisfaction, involving no other precautions but the careful focusing of the image on the face of the small reflector. It is true that this focus changes with temperature and causes a diminution in the intensity of the return beam, in the present instance of 1:8 for a change in focus of 3 mm.

[2] The adjustment is made shortly before sunset when the station at Mount San Antonio is well illuminated, by turning the revolving mirror until the image of the distant mirror is exactly in the middle of the slit. With this adjustment, as soon as the arc is focused at this point of the slit the light always returns; but slight adjustments of the slit or the arc may be necessary to obtain the maximum intensity.

stationary. At this instant the crosshair of the micrometer is made to bisect the image. The observations are repeated five to ten times, the direction of rotation of the mirror is then reversed and a similar series of observations is taken. The difference between the means of the two sets divided by the distance r (from crosshair to face of mirror) gives the angle $\alpha_1-\alpha_2$ of the formula. On completion of these observations the fork is again compared with the auxiliary pendulum, the mean between this and the previous determination being taken as the true rate of the fork in terms of the pendulum.

The true rate in seconds is found by comparing the auxiliary pendulum with an invar pendulum furnished and rated by the United States Coast and Geodetic Survey[1] by counting the number of seconds in one cycle of the image of the spark given by the auxiliary pendulum as viewed in the mirror attached to the invar pendulum.

Following is a summary of results:

TABLE I

Date	P_1	N/P_1	$1/C$	$\alpha_1-\alpha_2/\pi$	K
August 4........	1.00630	132.16	+0.07	+0.00020	132.20
August 5........	1.00630	132.16	−0.03	−0.00060	132.21
August 7........	1.00622	132.17	.04	.00054	132.20
August 8........	1.00628	132.16	.01	.00070	132.24
August 9........	1.00633	132.16	.01	.00040	132.20
August 9........	1.00633	132.16	.01	.00050	132.22
August 10........	1.00635	132.16	00	.00020	132.19
August 10........	1.00635	132.16	−0.05	−0.00030	132.15
Mean........	....	....	....	....	132.20±.006

$V=64KD$

$D=35385.5+40.8$[2]$=35426.3$ m

Final result:

$V_1=299735$ km per sec. in air

$V=299820$ km per sec. *in vacuo*

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[1] This measurement was carried out by Lieutenant Donal Pheley, of the United States Coast and Geodetic Survey.

[2] 35385.50 = distance between C.G.S. marks
30 ft. = focal length of mirrors
12 ft. (provisional) = distance from C.G.S. marks to focus of mirrors
$4\times30+2\times12=144$ ft. $=44$ m
Correction 3.2
40.8m

These results, though provisional and to be supplemented by a more careful and more extended series of measurements contemplated for the summer of 1925, are probably correct to within one part in ten thousand.

The principal source of error was found to be in the maintenance of sufficiently constant speed of the revolving mirror. This was doubtless due to lack of proper provision for a constant pressure of the air blast and not to any lack of precision in the measurements of the displacement of the image. This difficulty will be eliminated in the work for next summer, when, it is hoped, the uncertainty of the result will be reduced to one in one hundred thousand.

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