EXPERIMENTAL DETERMINATION OF THE VELOCITY OF LIGHT[1]

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CONSIDERING the importance of this physical constant as one of the simplest and most accurate means of ascertaining the distance of the sun from the earth, it seems surprising that but three scientists have sought to obtain it experimentally.

These were Foucault, Fizeau and more recently Cornu.

Foucault used the method known as that of "Wheatstone's revolving mirror," the application of which was first suggested by Arago.

Fizeau and Cornu both used another method, known as that of the "toothed wheel."

In Foucault's experiments the distance traversed by the light was 20 meters. The result obtained was 185,200 miles per second. Cornu's stations were about 14 miles apart. The result obtained by him was 186,600 miles, which exceeds the former one by 1,400 miles.

The objection to Foucault's method is that the displacement, a quantity which enters directly in the formula, is very small, and therefore difficult to measure accurately. The objection to Fizeau's is that the time of total disappearance of the light was necessarily uncertain.

The object of the experiments which I have undertaken is to increase the displacement in the first method. This can be done in several ways: 1st, by increasing the speed of the mirror; 2nd, by increasing the distance between the two mirrors; 3rd, by increasing the radius of measurement, *i.e.*, the distance from the revolving mirror to the scale.

In Foucault's experiments the speed of the mirror was 400 turns per second: the radius of measurement was about one mètre, and the distance between the mirrors was about ten (10) mètres. The displacement obtained was about 0·8 milimètre.

In my experiments, the speed of the mirror was but 130 turns per second—but the radius of measurement was from fifteen to thirty feet—and the distance between the mirrors was about 500 feet.

The displacement obtained varied from 0·3 inch, to 0·63 inch, or about twenty times that obtained by Foucault.

With a greater distance between the mirrors, and better apparatus, I expect to obtain a displacement of two or three inches and to measure it to within one thousandth part of an inch.

The following is a description of the apparatus employed in these preliminary experiments.

Fig. 1 represents the plan. The sun's rays are reflected by a heliostat through a slit *S*, and upon a mirror *R*, which revolves about a vertical diameter. They are thence reflected to a fixed plane mirror *M*, upon the surface of which an image of the slit is formed by means of the lens *L*. The light now retraces its path, and finally forms an image of the slit, which, when the mirror, *R*, is at rest, coincides exactly with the slit itself. When the mirror revolves slowly, this coincidence is still maintained, but the

[1] Reproduced on the occasion of the fiftieth anniversary of the presentation of this historical paper before the American Association for the Advancement of Science. It was printed in 1878 in the *Proceedings* of the Association. The Michelson Meeting of the Optical Society which convened during the first week of November celebrated this event. An account of this meeting—together with a picture of Dr. Michelson—may be found at the end of this number.

image is perceived by flashes of light at each revolution till they follow each other in such rapid succession as to form a continuous impression. This image is displaced more and more as the revolution becomes more rapid, the displacement being twice as great as the displacement of the mirror, during the time required for the light to travel from *R* to *M* and back again.

It will be observed that the difference between this arrangement and that of Foucault is that the concave mirror is dispensed with, its office being accomplished by the lens and plane mirror; and that this arrangement permits the use of *any* distance between the mirrors.

When the revolving mirror is in the astronomical focus of the lens, the light, reflected from it in directions continually changing as the mirror revolves,

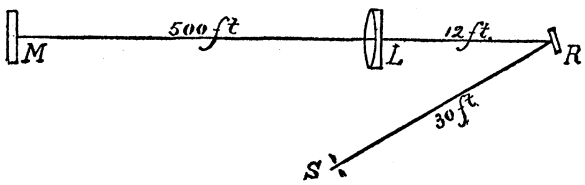

FIG. 1

is, after passing through the lens, always rendered parallel to the axis. Thus, all the light which comes during the part of a revolution represented by the angle subtended by the lens, is collected into a succession of pencils whose axes remain parallel to the axis of the lens; hence the distance between the mirrors may be as great as we please.

It is to be remarked, however, that as this distance is increased, the radius (or distance *R S*, Fig. 1) must be decreased, if we wish to preserve the maximum of light. In practice, it was found unnecessary to place the revolving mirror at the astronomical focus of the lens, and, in fact, this distance was in some cases only one fourth the focal length of the lens.

Other things equal, the greater the diameter and the focal length of the lens, the brighter will be the image.

In these experiments the lens and the fixed mirror were those used in one of the expeditions for observing the transit of Venus. The lens was five inches in diameter and thirty-nine feet focal length. The mirror was tested and found to be almost exactly plane. For these experiments it had to be silvered on the front surface.

The lens being in position, the mirror, which had a slow motion in two planes, was adjusted perpendicular to the line passing through their centres, as follows:

A rough adjustment was made by sighting along a square applied to the mirror, and then an observer, with a telescope placed behind the centre of the lens, saw, reflected in the distant mirror, the image of some adjacent object. By signals the mirror was moved till the observer saw the reflection of his telescope exactly in the centre of the mirror, when the adjustment was complete. This adjustment had to be repeated from day to day.

The revolving mirror was next brought into position, and then the slit placed so as to allow the beam of light passing through it to fall on the revolving mirror, and at such a distance that the image of the slit was superposed upon the slit itself.

The revolving mirror was a disc of plane glass about one inch in diameter—silvered on one side, and supported by two screws, terminating in needle points, which fitted into two small conical holes in the edge of the disc.

It was driven round by a blast of air from a bellows, which impinged upon one half of the mirror. *t, t, t,* Fig. 2, represents a section of the tube supplying the air. *R, R,* is a section of the glass disc; and *O,* is the axis about which it turns.

This crude piece of apparatus is now supplanted by a turbine wheel, which insures a steadier and more uniform motion.

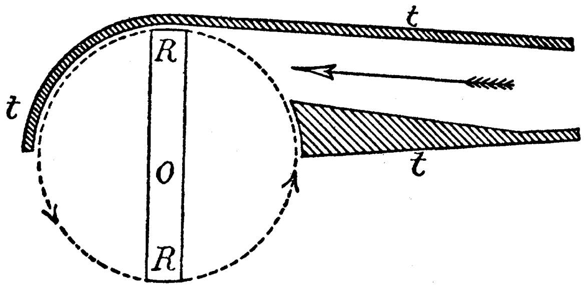

FIG. 2

For keeping the speed constant and for measuring it accurately two devices were used. In the first the light reflected from the revolving mirror fell upon the toothed wheel of a chronograph, which itself was accurately timed after each experiment.

When the time between the passage of two adjacent teeth was the same as the time of one revolution of the mirror, then the wheel appeared stationary, turning slowly forwards or backwards as the mirror revolved too slowly or too rapidly.

In the latter part of the experiments, a tuning-fork, bearing a mirror on one prong, was used. This was kept in vibration by a current of electricity. The fork was placed so that an observer, about to measure the displacement, could also see, in the mirror attached to the fork, an image of the revolving mirror. When both mirrors are at rest, this image is of course similar to the object; but when the fork is set in vibration the image is drawn out into a band.

When, however, the revolving mirror is started and attains the proper speed, the image again assumes its original shape. The fork is afterwards compared with one of König's standards.

The slit and micrometer were connected so as to form but one piece. This piece of apparatus is represented in Fig. 3. *S,* is the slit; *ab,* a piece of plane glass partly silvered. The light, proceeding in the direction *SM,* is re-

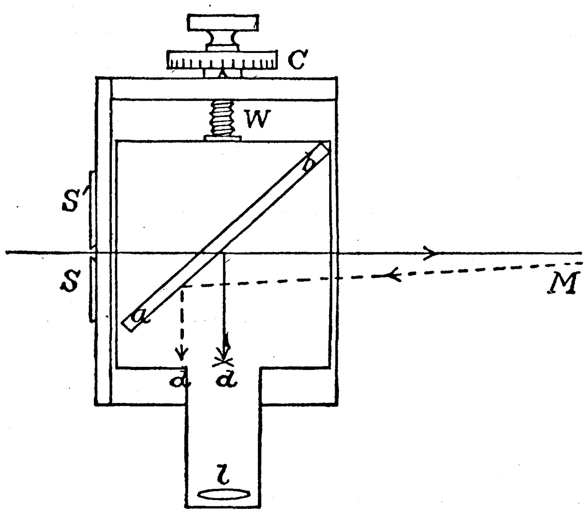

FIG. 3

turned in the contrary direction, and part of it is reflected from the glass *ab,* forming an image of the slit which is made to coincide with the cross-hairs at *d.* When the mirror revolves this image is displaced to *d′.* The slit *S* may then be moved in the direction *SS′* till the *displaced* image coincides with the cross-hairs, and the distance *SS′* accurately read by a screw bearing a divided circle. This method of observing does away with any error which might arise from ''parallax'' due to inexact focusing.

In these experiments the displacement was so great that the slit moved entirely outside the field of light. To avoid this difficulty, the other parts of the apparatus, viz.: *ab,* the glass mirror, *d,* the cross-hairs, and *l,* the lens for viewing the image—were moved by the screw *w* in the opposite direction past the slit; the distance moved, which is exactly equal to the displacement, is accurately read on the divided circle *c.*

The piece of glass *ab* was partly silvered in order that when the mirror was at rest, the image of the slit would be seen from the unsilvered portion, while the *displaced* image, which is very much fainter, would be seen by reflection from the silvered part.

The annexed table gives the results of ten independent observations, made under difficulties and with apparatus adapted from the material found in the Laboratory of the Naval School:

Their accordance with each other and with the generally accepted result justifies the expectation of obtaining, with proper appliances and under more favorable conditions, the correct result within a few miles; and, I trust, justifies the demand I have made on your time and attention.

In conclusion, I take this opportunity of tendering thanks to Mr. A. G. Heminway, of New York, for contributing $2,000 for the purpose of carrying out these experiments.

RESULTS OF OBSERVATIONS

VELOCITY OF LIGHT IN AIR IN MILES PER SECOND

	186,730
	188,820
	186,330
	185,330
	187,900
	184,500
	185,000
	186,770
	185,800
	187,900
Mean –	186,508

Formula, $V = \frac{4 \pi r \ n \ D}{\delta}$

V = velocity of light.
r = radius of measurement.
n = number turns per sec.
D = twice dist. bet. mirrors.
δ = displacement.