

Measurement of the speed of light with rotating mirrors

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Abstract

An eight-sided rotating mirror is used to measure the speed of light. Fashioned after the famous Albert Michelson experiments, the rotating mirror reflects a returning beam of light from one face of the mirror onto an eyepiece with a micrometer where a shift of the incident light can be observed. This shift along with the frequency of the rotating mirror can be used to calculate the speed of light.

Introduction

A number of techniques have been used to measure the speed of light. Galileo attempted to measure the speed of light by trying to measure the time required for light to travel a known distance between two hilltops. However, his experiments were dependent upon human reaction time and he concluded that the speed of light must be extremely high.

The first successful determination that the speed of light is finite was made by the Danish astronomer Ole Roemer (1644-1710)¹. Roemer had noted that the carefully measured period of one of Jupiter's moons varied slightly longer, and when Earth was moving toward Jupiter, the period was slightly shorter. Roemer concluded that the speed of light-though great-is finite.

Since then a number of techniques have been used to measure the speed of light. Among the most important were those carried out by the American Albert Michelson (1852-1931). Michelson used a rotating mirror in a series of high-precision experiments as diagrammed in figure 1. Light from a source was directed at one face of a rotating eight-sided mirror. The reflected light traveled to a stationary mirror a large distance away and back again as shown. Light from a source was directed at one face of the mirror into a small telescope through which the observer looked. At a different speed of rotation, the beam would be deflected to one side and would not be seen by the observer. From the required speed of the rotating mirror and the known distance to the stationary mirror, the speed of light could be calculated. He later measured the speed of light in vacuum using a long evacuated tube. The accepted value today for the speed of light, c , in vacuum is as follows:

$$c = 2.99792458 \times 10^8 \text{ m/s.}$$

We usually round this off to 3.00×10^8 m/s when extremely precise results are not required. In air, the speed is only slightly less.

Setup and Methodology

This setup was based on the principles of the Michelson experiment with the exception that more stationary mirrors were used to give a long beam path length of 192.2 meters. The light source was a red laser of characteristic wavelength 670 nanometers. The apparatus is as shown in figure 2. A focusing lens of 1.5 m focal length is placed in front of the beam before it returns to the other face of the rotating mirror. The focusing lens was used to provide a sharper beam to reflect off the other face of the rotating mirror. It was needed since the beam diffracts off the edges of the stationary mirrors and also becomes more diffuse the farther it travels. A photometer, placed outside of the return beam path but not too far away from the rotating mirror, hooked up to an oscilloscope was employed to measure the frequency of rotation. The oscilloscope displays a repeated pattern eight times that can be used to figure out the period that is used in the calculation of the speed of light (figure 3). The period was on the order of milliseconds. A shift of the light on the scale in the eyepiece can be observed once the mirror starts rotating. Before the mirror starts rotating, the beam appears as a sharp point on the scale. Once rotation has begun, the point shifts on the scale and becomes a diffuse chromatic aberration. The time the light takes to traverse the setup is given by

$$t = \frac{\text{optical length}}{c} \quad (1)$$

In this time, the mirror rotates by an amount

$$\theta = \omega t \quad (2)$$

where ω is the angular frequency of the rotating mirror. Since the light is reflected,

$$\phi = 2\theta \quad (3)$$

where ϕ is the shift angle in the measurement. If we multiply (3) by the distance from the second face of the mirror to the point of observation, we get the amount of shift on the scale. It is hard to get a clear reading of the amount of shift since the mark has changed

from a sharp circular point to a diffuse rectangular blur as can be seen from figure 4. The amount of shift was measured at the point where the blur appeared to be the most intense and brightest, which was usually in the center of the rectangular blob. The shifts ranged from 0.5-6 millimeters. Several measurements were taken and the calculated values of c were plotted as a function of frequency.

Analysis

Idealistically, a horizontal line would result from such a plot. Our results (figure 5) show a fairly linear plot that approximates c to within standard error. Most of the deviation came from the difficulty in trying to precisely measure the light shift. There was a little loss of intensity as the laser beam became spread out over long distances and diffracted off the stationary mirrors of area one inch squared. More focusing lens placed in the beam's path would help to provide a more uniform beam. Also a longer path length would show a larger, more defined shift which was why the initial Michelson experiment was done between two mountain tops.

Conclusions

Our calculated value for the speed of light is, $c = (3.23 \pm 0.11) \times 10^8$ m/s. This result has a relative error of 7.6% which is very good for this type of apparatus setup. Nevertheless, the experiment gives a closely approximated value for the speed of light compared to the standard accepted value. It is definitely a convenient modern day version of the Michelson light experiment.

Acknowledgements

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References

1 D. Giancoli, Physics for Scientists and Engineers, (Prentice Hall, New Jersey, 1988).

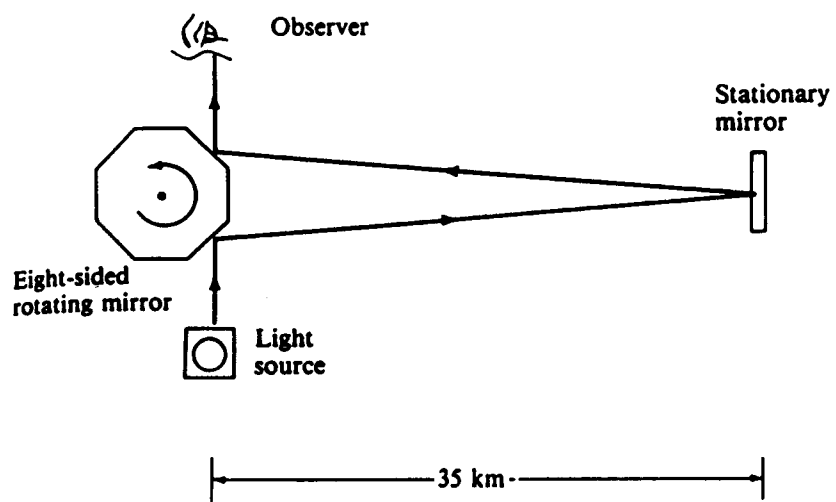
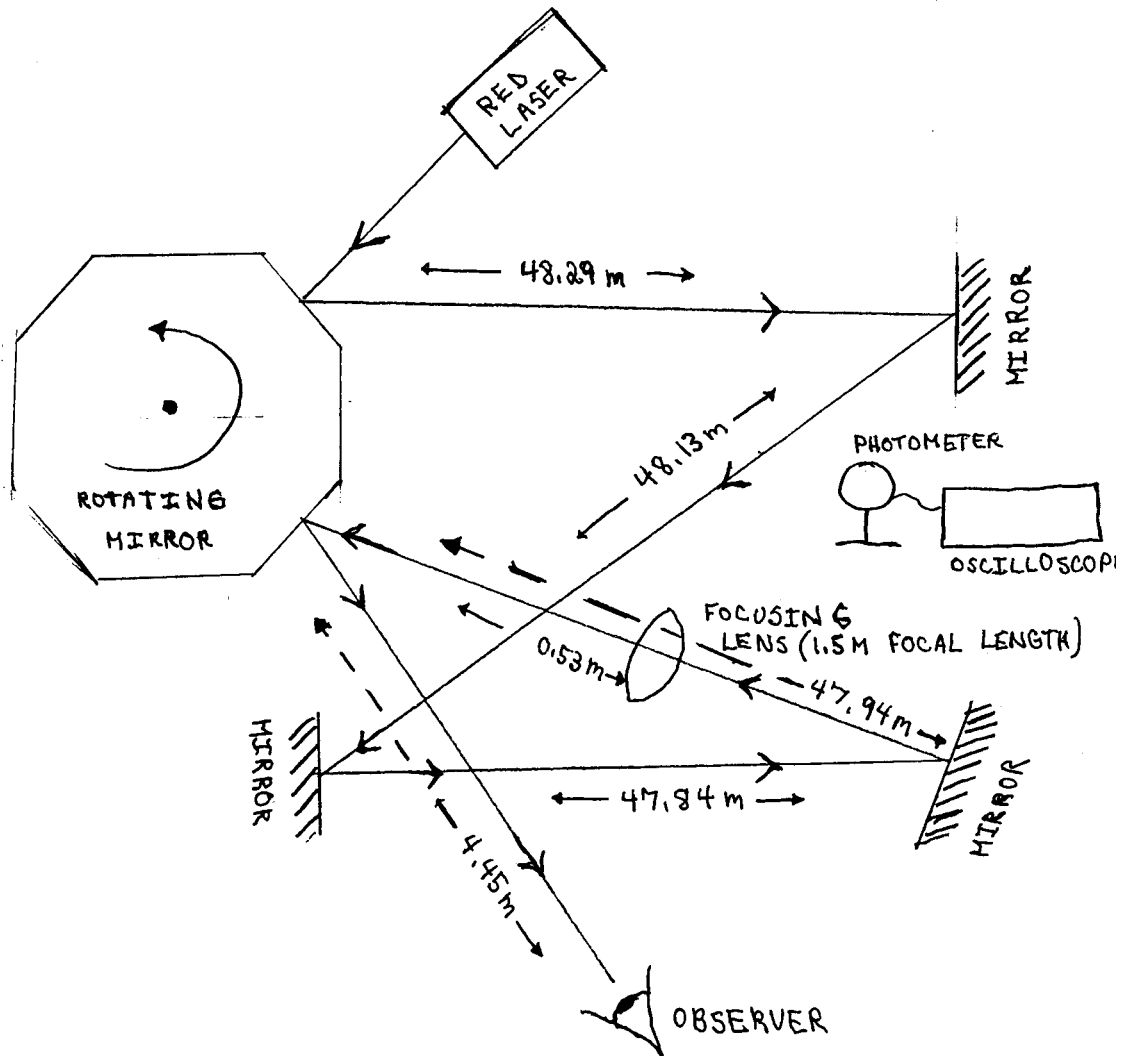


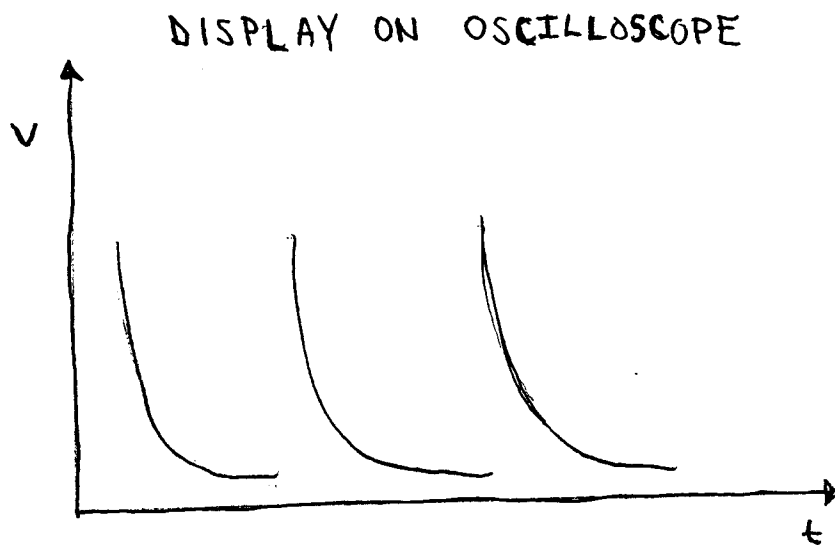
Figure 1

Figure 2



NOTE: FIGURE NOT DRAWN TO SCALE

Figure 3



NOTE: PATTERN REPEATS EIGHT
TIMES SINCE MIRROR
IS 8 SIDED

LIGHT SHIFT

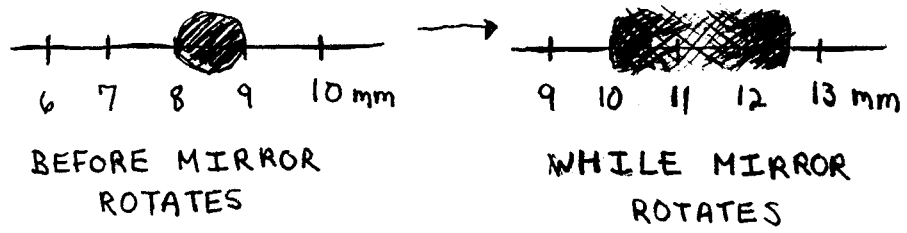


Figure 4

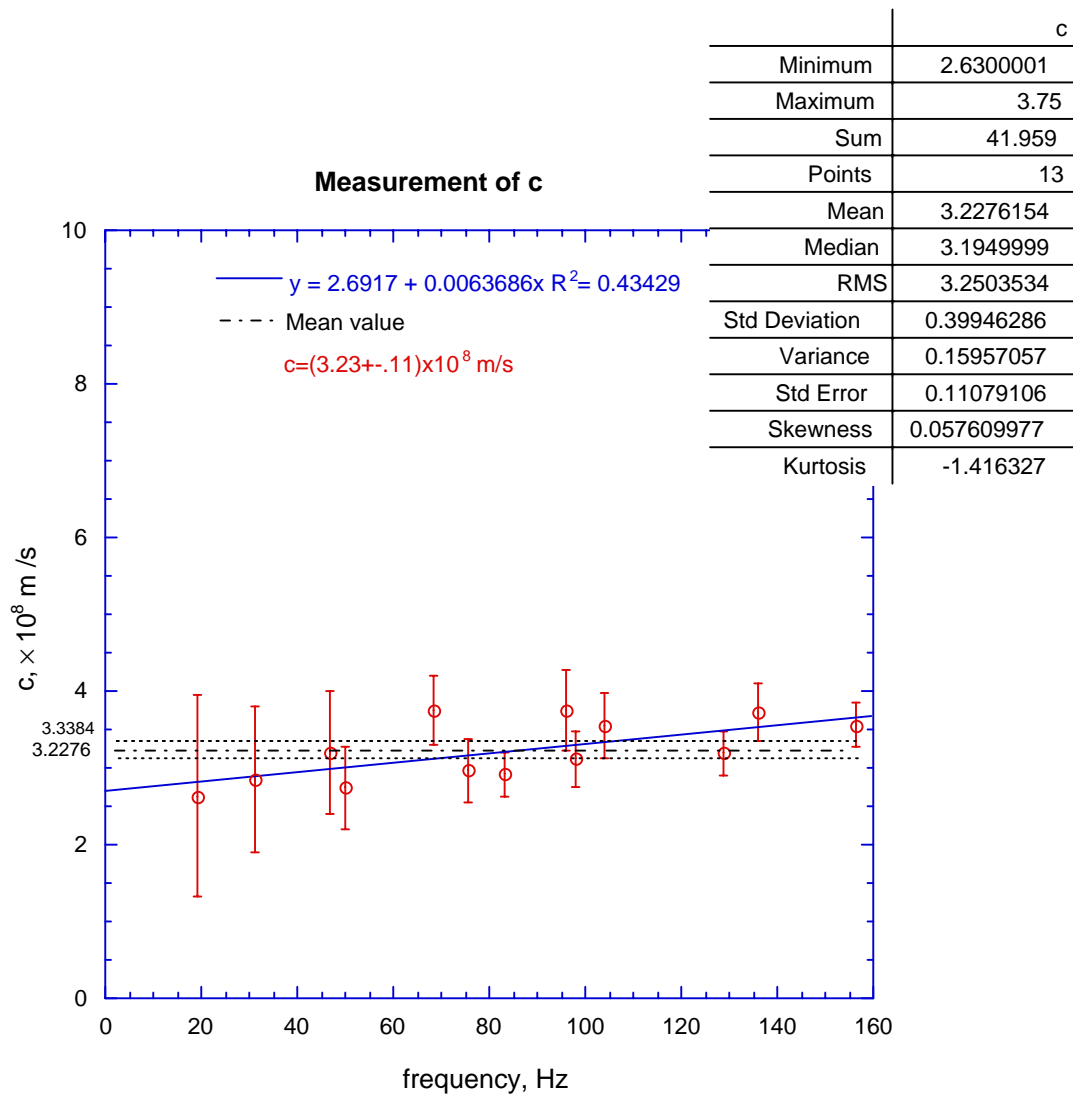


Figure 5