Speed of Light Measurement Utilizing Octagonal Rotating a Mirror

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Abstract. The layout of a speed of light experiment is discussed, which makes use of the time required by light to travel through a long optical arm. This layout utilizes a rotating mirror to cause rotation frequency dependent deflections in beams of light. Experimental results are then presented, having an average result of $(2.8 \pm 1.7)10^8$ m/s.

I. Introduction

Studies of the velocity of light have a long and important history in physics. Römer first demonstrated light's finite speed in 1676, and Fizeau made the first earth-based measurements of the speed of light in 1849 [1]. Since then there has been considerable interest and effort spent in obtaining accurate values of the speed of light. This particular procedure makes use of the time necessary for light to traverse a long optical path length.

II. Apparatus

The experimental design employed by the author (Fig. 1) makes use of an eight sided rotating mirror and a laser to measure the speed of light. The laser was a Spectral Physics 155 laser, and we made use of a Copal Electronics PD60FRB rotating mirror. Light was reflected off the face labeled number one in Fig. 1, and passed through a series of mirrors to create an optical path length of (38 ± .5) m. The light then passed through a lens of focal length 1.21m, labeled "a" in the figure. The light was then deflected off the

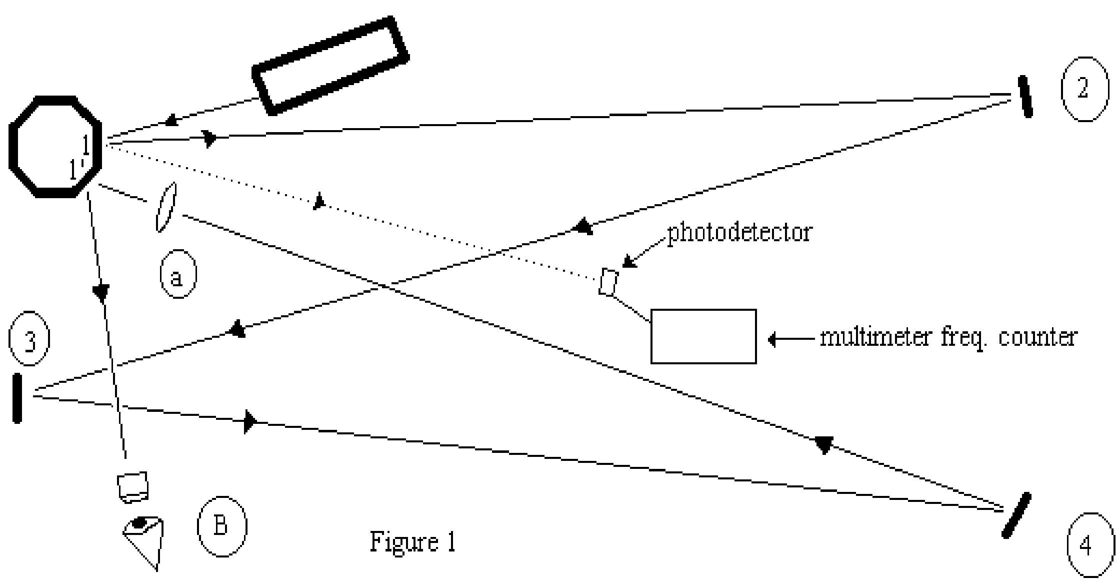


Figure 1

1' face of the rotating mirror into the eyepiece labeled "B." The location of the rotating lens “a” was the most important factor in the entire experiment. If the lens was placed after the rotating mirror no shifts will ever be seen. This is because the shifts are so small that they are well within the paraxial approximation. The lens therefore sends all of the “parallel” rays to the same point, defeating the purpose of the entire experiment.

As the mirror rotates the laser beam sweeps out an arc from the mirror. By placing a photodetector in the plane swept out by the beam, we were able to measure the frequency of rotation (multiplied by eight). We used the frequency counter on a Fluke multimeter because it was spatially compact. The measured multimeter frequencies matched those obtained with an oscilloscope.

Due to the finite speed of light, as the light reflected from the mirrors 2, 3, and 4 and back, the rotating mirror turned through an angle $\Delta\theta=\omega\bullet\Delta t$. The Δt equals the optical path length divided by the speed of light. As the frequency ω is changed, the angle of beam deflection changes by an angle α, which is equal to twice the change in θ (Fig. 2).

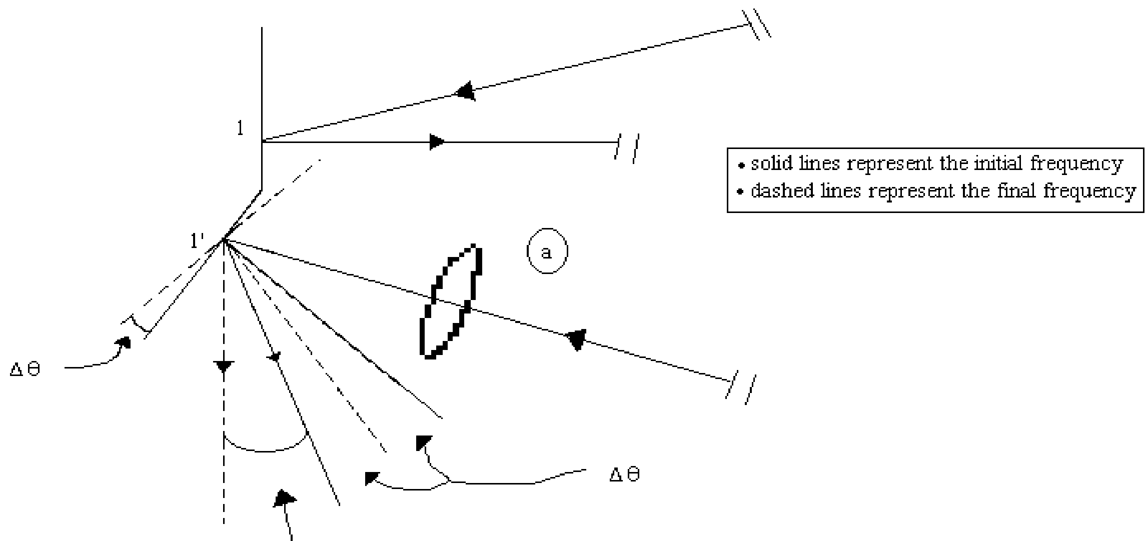


Figure 2

The distance from the rotating mirror to the eyepiece was (1.1 ± .1) m. The eyepiece possessed .1mm markings. Once the mirror started rotating, only a small percentage of the energy was captured by the mirror system. As a consequence the intensity of the light low enough to allow for direct observation with no filtering.

III. Results

By looking through the eyepiece spatial changes in the position of the beam were measured. There was a reasonable amount of difficulty obtaining the correct amount for the shift in the beam because even when focused the beam had a wide width. While the movement was apparent, numerical values were difficult to read. No successful way was developed to make the measurements precise, and as a consequence, the uncertainties in the values of Table 1 are substantial.

The relationship between the change in position x and change in frequency ν is given by:

$$\Delta x = (\alpha r)2\pi = 2(\Delta\varpi)rt2\pi = 2\left(\frac{\Delta\nu}{8}\right)\left(\frac{Opl}{c}\right)r2\pi = \frac{\Delta\nu r(Opl)\pi}{2c}$$

(where r is the distance from the rotating mirror to the eyepiece)

By using linear regression to determine the slope of the best fit line through the data, we obtain c equaling $(2.1 \pm 1.7)10^8$ m/s for observer one and $(3.4 \pm 1.7)10^8$ m/s for observer two. The uncertainty in c is given by:

$$\delta c = \frac{\Delta\nu r(Opl)\pi}{2\Delta x}\left[\frac{2\delta\nu}{\Delta\nu} + \frac{2\delta x}{\Delta x} + \frac{\delta r}{r} + \frac{\delta(Opl)}{Opl}\right]$$

In the expression for the uncertainty in the speed of light the Δx term in the second factor contributes 86% of the uncertainty. Clearly the key to improvements is to reduce this term. It has been shown that Δx is proportional to r, optical path length, and Δν, so doubling any of these would reduce the uncertainty to 60% of the current value.

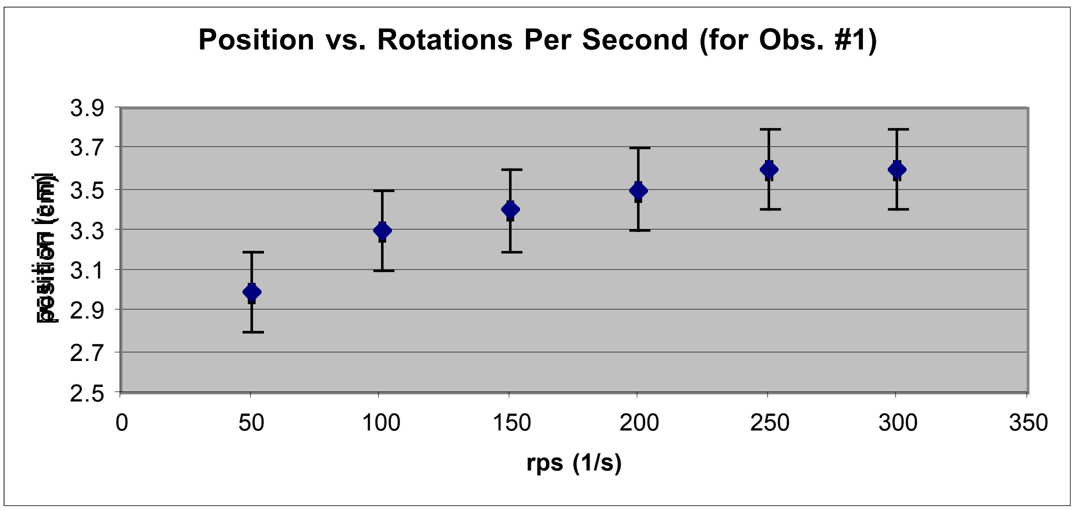
IV. Future Experiments

The most obvious of future examinations is simple error reduction n the uncertainty in the speed of light. One should be able to obtain very precise results from simply lengthening the optical path length, the focal length of the lens, and increasing the rotational frequency. The main obstacle in these measurements will be to have a beam intense enough to view. Because our optical path length, lens' focal length, and rotational frequencies were low intensity was not a problem. However, increasing any of these will result in energy losses, which may effect visibility.

A more challenging endeavor would be to examine the possibility of designing an apparatus that used multiple bounces off of the mirror for a compounding change in the deflection angle.

Two observers looked at the image of the laser at various frequencies (Table 1).

Frequency registered by photodiode and focus position.			
Observer One			
ν		x	
400 +/-	5	3 +/-	0.2
806 +/-	5	3.3 +/-	0.2
1200 +/-	5	3.4 +/-	0.2
1600 +/-	5	3.5 +/-	0.2
2000 +/-	5	3.6 +/-	0.2
2400 +/-	5	3.6 +/-	0.2
400 +/-	5	3 +/-	0.2
Observer Two			
397 +/-	5	7 +/-	0.2
2470 +/-	5	6.6 +/-	0.2



Acknowledgments

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4. Cornell Document, Unpublished, Physics 410/510, "The Velocity of Light."