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 \((2.8 \pm 1.7) \times 10^8\) 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 \((38 \pm .5)\) 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 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 \( \Delta \theta = \omega \cdot \Delta t \). The \( \Delta t \) equals the optical path length divided by the speed of light. As the frequency \( \omega \) is changed, the angle of beam deflection changes by an angle \( \alpha \), which is equal to twice the change in \( \theta \) (Fig. 2).

![Figure 2](image)

The distance from the rotating mirror to the eyepiece was \((1.1 \pm .1) \text{ m}\). The eyepiece possessed \(.1\text{mm} \) 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 \( \nu \) is given by:

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

(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 \((2.1 \pm 1.7) \times 10^8 \) m/s for observer one and \((3.4 \pm 1.7) \times 10^8 \) 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 \( \Delta x \) 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 \( \Delta x \) is proportional to \( r \), optical path length, and \( \Delta \nu \), 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 in 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).

<table>
<thead>
<tr>
<th>Observer One</th>
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<tbody>
<tr>
<td>( \nu )</td>
</tr>
<tr>
<td>400 +/- 5</td>
</tr>
<tr>
<td>806 +/- 5</td>
</tr>
<tr>
<td>1200 +/- 5</td>
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<tr>
<td>2000 +/- 5</td>
</tr>
<tr>
<td>2400 +/- 5</td>
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<tr>
<td>400 +/- 5</td>
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<table>
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<tr>
<th>Observer Two</th>
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<tr>
<td>397 +/- 5</td>
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<td>2470 +/- 5</td>
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Acknowledgments

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References