Measuring the Speed of Light using the Foucault Method

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Abstract

1 Introduction

1.1 Objective

1.2 Background

1.3 Theory

2 Methods and Procedures

2.1 Method Description

2.2 Derivation of the Speed of Light Equation

3 Results

3.1 Data

Three sets of data were taken spread across three measurement sessions on different dates. The first two measurement sessions used the same experimental setup on different days. Session three occurred after the experiment was broken down and rebuilt so as to try and exonerate the experimental setup as a source of error in the measurements. As a result, the first two sets of data can be analyzed together, while the third set of data must be analyzed separately at first, since the process of rebuilding the experimental setup introduced systematic differences to the measurements made during the third session. Since the calculated speed of light value is dependent on relative measurements and not absolute measurements, this systematic difference between the first two sets of data and the third will be shown to be negligible in the overall calculation of the speed of light.

	A(m) (+/-0.005m)	B(m) (+/-0.005m)	D (m) (+/-0.01m)
Set 1	0.26	0.481	6.65
Set 2	0.26	0.481	6.65
Set 3	0.326	0.45	6.63

Table 2: Measurements of the lengths A, B, and D.

Table 1 shows the measurements taken in each of the three sessions. The data is indexed by a trial ID. The session each measurement belongs to is indicated by the leading digit of the Trial ID. For example, measurement 23 is the third measurement taken during the second set of data.

For the first two sessions, data was only taken for the +/-1500 rev/s rotating mirror speeds. In the third set, additional measurements were made at mirror speeds +/-1000 rev/s in order to characterize backlash in the micrometer knob.

Other values necessary for the calculation of the speed of light included the distance A between L_1 and L_2, the distance B between L_2 and the rotating mirror, and the baseline distance D between the rotating mirror and the fixed mirror. Measurements of each of these distances were taken for each set and are reported in Table 2.

3.2 Calculations

The equation for calculating the speed of light is dependent on the deflection difference between measurements at the maximum rotation speeds clockwise

Trial ID	CW Measurement (mm) ($\pm$0.01)	CW Speed (rev/s) ($\pm$5)	CCW Measurement (mm) ($\pm$0.01)	CCW Speed (rev/s) ($\pm$5)
11	10.17	1503	9.27	-1460
12	10.19	1505	9.27	-1464
13	10.18	1510	9.28	-1461
21	10.16	1506	9.28	-1462
22	10.18	1503	9.33	-1463
23	10.22	1507	9.36	-1460
31	12.00	1508	11.12	-1465
32	12.00	1505	11.08	-1456
33	12.00	1507	11.12	-1468
34	12.10	1510	11.12	-1466

Table 1: Laser deflection data taken during three separate sessions. Positive rotation speeds correspond to clockwise rotation of the rotating mirror, and negative speeds correspond to counterclockwise speeds.

Trial ID	Deflection (mm)
11	0.90
12	0.92
13	0.90
21	0.88
22	0.85
23	0.86
31	0.88
32	0.92
33	0.88
34	0.98

Table 3: Deflection measurements of the laser between the maximum rotation speeds in the clockwise and counterclockwise directions, in mm and m.

and counter-clockwise. Table 3 shows the deflections for each measurement in mm.

Comparing the measurements in sets 1 and 2 to those in set 3, we can see that the absolute value of these measurements are different, yet the relative deflections are still roughly the same. This indicates that our experimental setup was consistent and did not affect the outcome of the measurements. This will be further supported in the section on error analysis.

To calculate a value for the speed of light, each set of measurements was averaged with respect to mirror rotation speed and direction. The average measurement values for each set are shown in table 4. The mean deflection for each set was calculated from the difference of the mean measurements at +1500 rev/s and -1500 rev/s.

The rotation frequencies for each measurement were recorded as well and averaged for each set. The total rotation frequency $f_{CW} + f_{CCW}$ is just the sum of the mean rotation frequencies for each set, and is used in the calculation of the speed of light. These values are reported in table 5.

The speed of light c for each set was calculated using the mean deflections $s'_{cw} - s'_{ccw}$, the rotation speed difference $f_{cw} + f_{ccw}$, the distances A, B, and D, and the equation described in Methods and Procedures and restated in below as Equation 1.

$$c = \frac{8\pi A D^2 (f_{cw} + f_{ccw})}{(D + B)(s'_{cw} - s'_{ccw})} \tag{1}$$

The calculated speed of light c for each set of data is shown in Table 6.

Data Set	Measurement Mean, CW (mm)	Measurement Mean, CCW (mm)	Mean Deflection (mm)
Set 1	10.18	9.27	0.91
Set 2	10.18	9.32	0.86
Set 3	12.02	11.11	0.92

Table 4: Mean measurements for each set of data averaged with respect to mirror rotation speed and direction.

Data Set	Mean CW Rotation Speed (Rev/s)(+/-5)	Mean CCW Rotation Speed (Rev/s)(+/- 5)	Mean Deflection Frequency (Rev/s)(+/-10)
Set 1	1506	-1461	2967
Set 2	1505	-1462	2967
Set 3	1508	-1464	2971

Table 5: Mean measurement rotation speeds for each set of data.

Data Set	c (m/s)	Random Uncertainty $(\pm m/s)$	Systematic Uncertainty $(\pm m/s)$
Set 1	$1.33 * 10^8$	TODO	TODO
Set 2	$1.39 * 10^8$	TODO	TODO
Set 3	$1.65 * 10^8$	TODO	TODO

Table 6: Calculated values of the speed of light

3.3 Error Analysis

We first consider the uncertainty associated with each of our measured values.

3.4 Discussion

4 Conclusion