Practice makes perfect speed of light measurement using the Foucault Method

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Introduction

The speed of light was measured using a method Leon Foucault developed in 1862.

The Foucault method allowed Albert Michelson to measure some of the most accurate values for the speed of light between 1926 and 1929. Michelson was able to measure a value of 2.99712×10^8 m/s compared to the current accepted value of 2.99796×10^8 m/s.

By performing this experiment it is found that modifications of experimental setting show significant progress in the accuracy of the measurement.

A laser is focused through a beam splitter onto a rotating mirror that directs the beam onto a fixed mirror which reflects it back toward the rotating mirror and through the beam splitter. By rotating the mirror at a known angular velocity in both the counter-clockwise and clockwise directions and measuring the displacement of the image produced by the reflected beam the speed of light can be determined.

Theory

The laser is focused through L_1 at s and then focused through L_2 on to the fixed mirror M_F after being reflected off the rotating mirror M_R as seen in figure 1. This causes the beam to be reflected back toward the mirror and, if the mirror were fixed, focused through L_2 again at s. A beam splitter is placed in front of the image at s so that a second image may be produced at s' and viewed through a measuring microscope. When the mirror rotates, the reflected image is shifted slightly so that the displacement in the image can be measured through the measuring microscope.

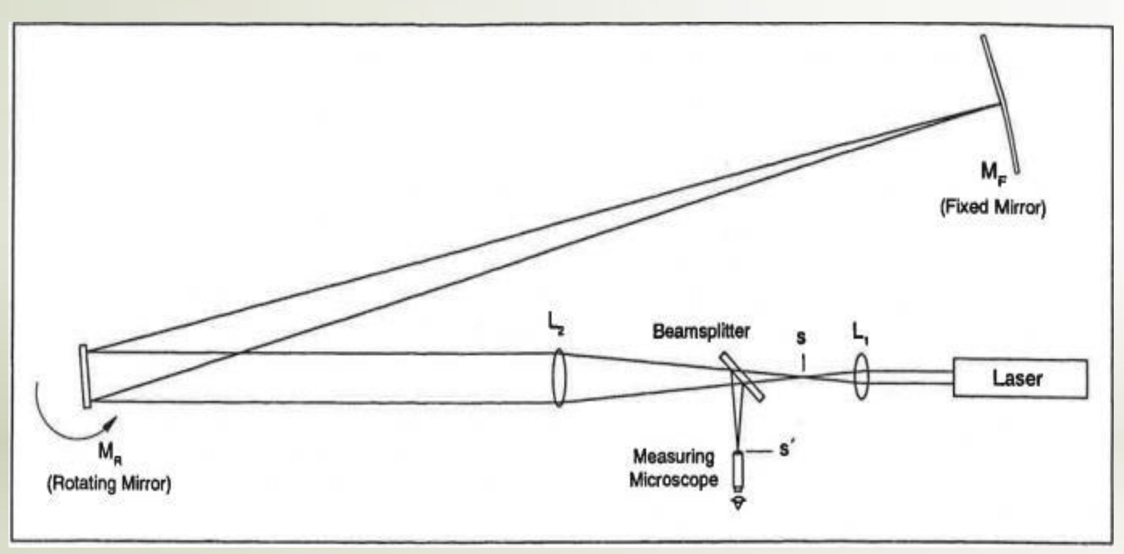


Figure 1

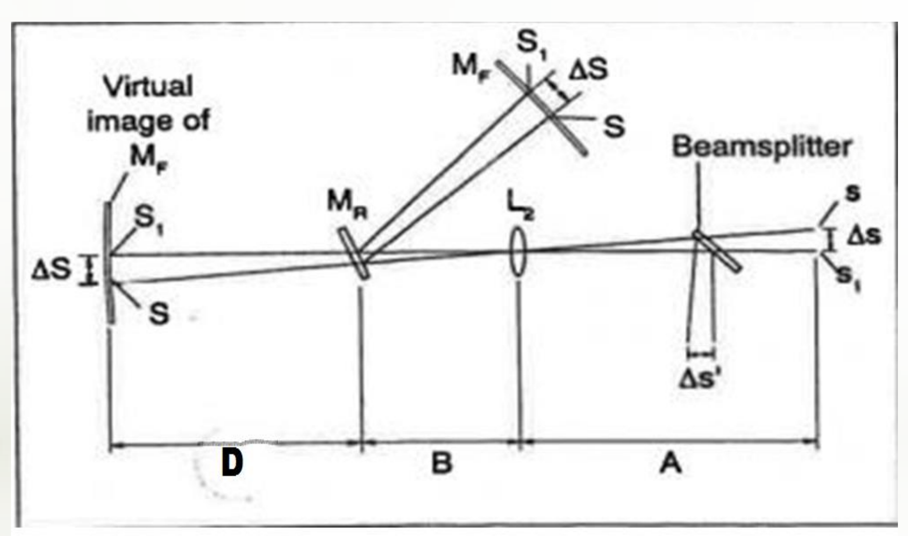


Figure 2

If the rotating mirror is at some angle θ then the beam will hit the fixed mirror at some position S. If the rotating mirror is at an angle $\theta + \Delta\theta$ then the beam will be reflected to a new point S_1 as seen in figure 2. This allows the distance, Δs, to be calculated between the images focused in front of L_2 at s_1 and s:

$$\Delta s' = \Delta s = \frac{A}{D+B}\Delta S.$$

An equation for the speed of light can be created by determining the angle Δθ rotated during the time the light travels between the rotating mirror and the fixed mirror by using the known rotational velocity of the mirror ω:

$$c = \frac{4AD^2\omega}{(D+B)\Delta s\prime} = \frac{8\pi AD^2(w_{cw}+w_{ccw})}{(D+B)(s'_{cw}-s'_{ccw})}.$$

The variables w_{cw} and w_{ccw} are the clockwise and counterclockwise rotational velocities of the mirror, and s'_{cw} and s'_{ccw} are their respective displacements of the image. The variables D, B, and A are the distances between components as depicted in figure 2.

Experimental Setup

Three iterations of the experiment were performed consisting of two distances for the position of the fixed mirror M_F. An average value for the speed of light was found for each iteration after performing five trials.

A distance of 5.899m to the fixed mirror was used for the first and second iteration while a distance of 14.135m was used for the third iteration.

Attempts for further precision were attempted at each iteration (e.g., tuning and securing components, sacrificing time for accuracy), until accuracy of results exceeded expected experimental component accuracy rating.

Figure 3 – Setup for iterations 1 & 2 with reflecting mirror in the background

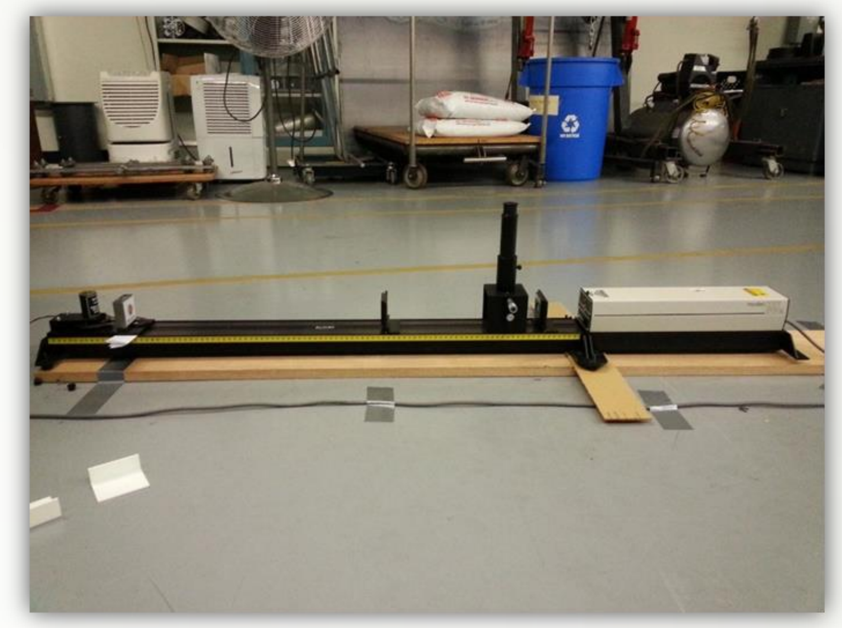


Figure 4 – Setup for iteration 3 with all components secured

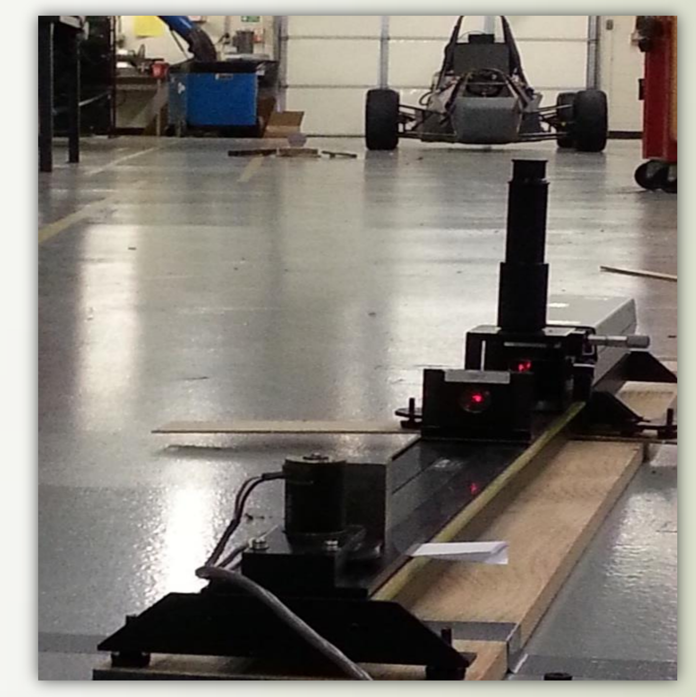


Figure 5 – Setup for iteration 3 with reflecting mirror in background

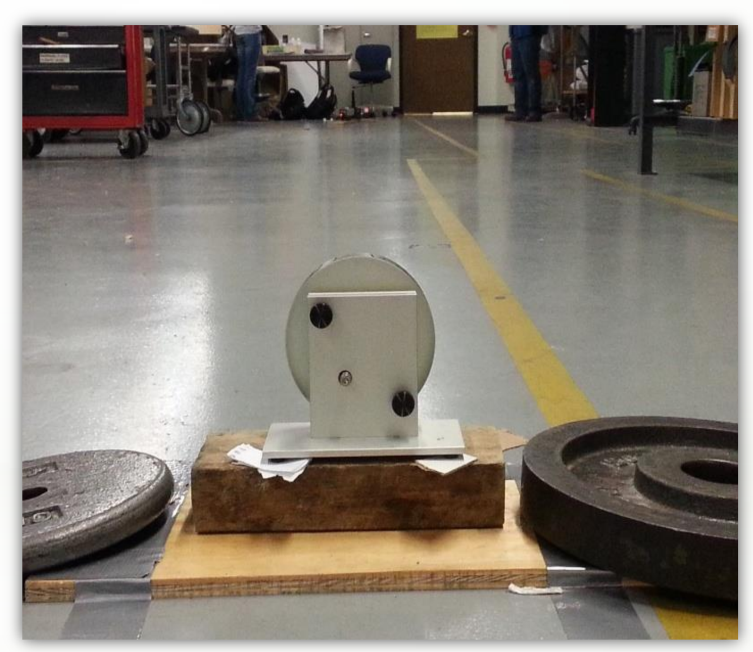
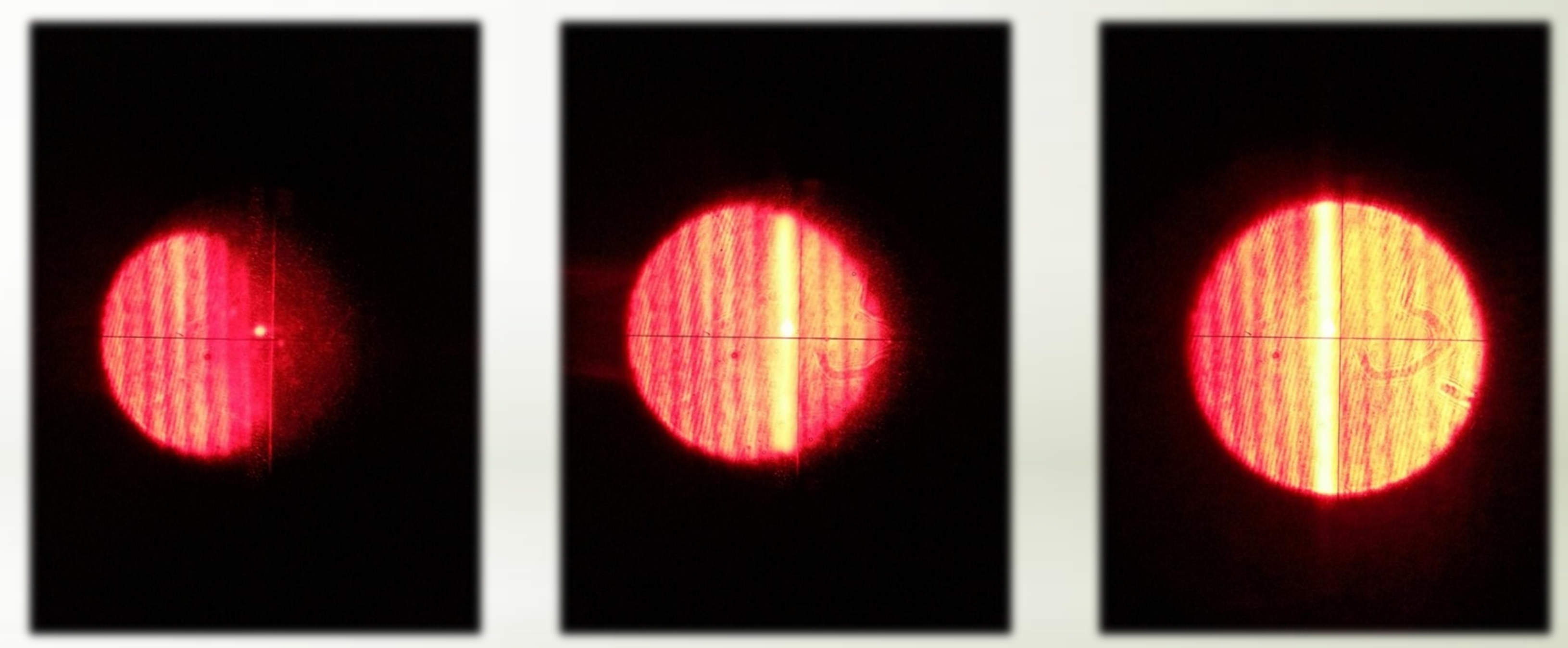


Figure 6 – Rear of the reflecting mirror for iteration 3



Figures 7 -9 – Image of laser point in microscope showcasing background patterning and vertical band of light directly over laser point indicating excellent setup precision

Results

The result of the first iteration yielded an error of ~32%, the second iteration yielded an error of ~5%, and the third iteration yielded results with an error of approximately 0.7% for the speed of light—or 3.02×10^8 m/s.

Conclusion

The significant progress in the accuracy of the measurements demonstrates the drastic range of results which this experiment can produce; several factors played key roles in the improvements. Increased familiarity with the equipment through practice, tightening the microscope shaft which was loose, and securing all the components in the final iteration all contributed to better results. The suspected most significant factor was increasing the distance of the fixed mirror.