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The Speed of Light

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1 Introduction

The speed of light, c, is a fundamental constant that is built upon by much of today's physics. It was first calculated in an experiment by Ole Roemer in 1676, and later confirmed by Maxwell's equations in 1865. Following this, Einstein published his theory of special relativity in 1905, asserting that the speed of light is constant to any observer. Einstein also concluded that space and time were not as separate as they seem, and proposed that they were linked, spacetime

Since Einstein, more research has been done measuring the speed of light, time dilation, and parallel concepts. In the late 1970s, the most accurate speed of light experiments were conducted using interferometry, which yielded the accepted speed of light we use today;

$$c = 299,752,458\ \frac{m}{s} \tag{1}$$

This value is considered so precise that the International System of Units (SI) now defines the meter as the distance that light travels in a vacuum in 1 / 299,752,458 of a second.

This lab report discusses another experiment on the speed of light using rotating mirrors to displace the light, and then calculate a time value based on the displacement. The tolerance for this experiment is not as high as the interferometry tests in the 1970s, but an accurate value for the velocity can be achieved.

2 Experimental

The velocity testing experiment was set up in such a way to create a sufficient distance for the light to travel. As shown in the diagram, a one millimeter diameter laser is reflected off of a rotating mirror attached to a motor. The light then reflects through a series of lenses and mirrors, and then back towards the laser.

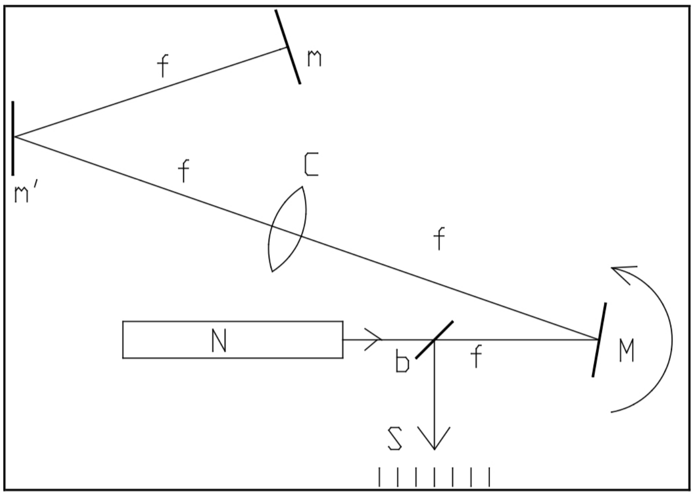

Figure 1: Diagram of Experimental Setup

Once the stream of photons returns to the initial position, it is reflected downward onto a piece of paper by a prism. As the revolutions per minute of the motor increase, the beam deflects further from the initial mark on the paper. The difference in position of the laser on the paper is inversely proportional to the velocity of the light.

The reason that the beam deflects further on the paper with more RPMs is because the mirror rotates a certain amount between the initial contact from the laser and when it returns. We know from the change in position of the laser the amount the mirror rotates, and since we know the angular velocity, we also know the time duration. Since we know the distance travelled and the time duration, we can calculate the velocity of the light.

Our procedure is as follows:

1. Align all mirrors and lenses such that the laser is clearly visible and not blurry on the paper.
2. Measure distances between each mirror and lens.
3. Turn on motor at desired RPM.
4. Mark position of center of laser with sharp mechanical pencil.
5. Repeat previous step until data collection is complete.
6. Once complete, turn off laser and motor,
7. Measure distances between marks using vernier caliper.

3 Results

After aligning our laser with each mirror and lens, we measured the distance between the laser and the rotating mirror D, and the distance the light travels after the rotating mirror L.

$$D = 4.64 \text{ m}$$

$$L = 15.11 \text{ m}$$

3 trials were conducted, one low (<100 Hz), one medium (600-800 Hz), and one high (1,000 Hz). We measured a fairly linear relationship between the displacement of the laser on the paper and the RPM. The data table for these trials is shown below.

Motor Speed	Hz	n (Hz)	Δn (Hz)	x (mm)	Δx (mm)
High	998	499	467.5	32.4	3.2
Medium	702	351	319.5	33.9	1.7
Low	63	31.5		35.6	

Table 1: Frequency and Displacement Data across Motor Speeds

4 Calculations

In order to calculate the speed of light from the collected data, the following equation will be used:

$$c = \frac{8\pi DL\Delta n}{\Delta x} \tag{2}$$

Since we took frequency and displacement data on 3 trials, we can use this equation between data points 1 and 3, as well as 2 and 3. In other words, the high and medium frequency trials will be compared to the low.

Comparing the high and low frequency data, we have a change in frequency of 467.5 Hz and a displacement of 3.2 mm. This yields a value of:

$$c = 2.574 * 10^8 \ \frac{m}{s} \tag{3}$$

Repeating the same process between the low and medium frequency data with a change in frequency of 319.5 Hz and displacement of 1.7 mm:

$$c = 3.312 * 10^8 \ \frac{m}{s} \tag{4}$$

Averaging these values gives a speed of:

$$c = 2.943 * 10^8 \ \frac{m}{s} \tag{5}$$

This averaged value has a percent error of 1.9%.

5 Discussions and Conclusions

The averaged value of c = $2.943 * 10^8 \frac{m}{s}$ falls within the generally accepted tolerance of 5% error. This is evidence that the experiment was conducted in such a way that both accuracy and precision were attainable.

With that being said, there are sources of error originating from the procedure that should be addressed in the future. The greatest source of error was likely the marking and measuring of the light beam on the paper. Since the displacement was only 3.2 mm at the greatest, marking these positions with a pencil with a 3 mm tip was problematic. If the experiment was repeated, the light position should be marked with a sharp marking knife instead of a pencil so that a greater level of precision can be reached.

One other source of error was marking the center of the light beam. Determining the center of the beam was up to the observer's judgement, and there was no perfect way to measure to the center since the sides of the beam were faded.

The experiment was successful in measuring the speed of light. Although measures can be taken in the future to improve precision, a measured value very close to the actual speed of light was recorded, supporting the findings of many previous scientists and physicists.

References

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