Foucault's Method of Light Speed Measurement & Light Speed Invariance

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ABSTRACT

This experiment is subdivided into two major portions, where we will replicate two very well known light speed measurement experiments. In the first portion we attempt to measure the speed of light with a fairly high degree of accuracy and precision using Foucault's method of measuring the speed of light. Foucault's Method is perhaps the most common in university settings and most notably consists of a monochromatic light source and a positive vertically oriented spinning mirror. In the second portion, we will test the invariance of the speed of light under variations in wavelength (or frequency) of light sources, using the light speed invariance postulate of the special theory of relativity as a basis. The final objective (or conclusion) of the aforementioned experiments, following calculation, is to measure the well known constant of the speed of light as well as verifying light speed invariance.

1 Introduction

We seek to calculate the speed of light c by method of a rotating mirror. The speed of light is accepted to be about 2.998×10^8 m/s. The physics community postulated this from Maxwell's Equations by way of the magnetic permeability constant and electric permittivity constant but did not conclude the speed to an exact value until 1983 when it was defined in terms of cesium-133 hyperfine frequency. Our primary method of measurement was first conducted by Leon Foucault in 1862. Foucault was only able to calculate the speed light to an error of about 0.6%, using his method. This was later improved upon in 1926 by Albert A. Michelson by increasing the distance for the light to travel and using more accurate lenses. Michelson was able to determine the speed of light within the error of about 12 parts per million (ppm). The theory is the same for our experiment, however we will be using smaller distances more akin to the Foucault's experiment.

2 Research Purpose

The primary objective of our experiments is to test and study two major statutes of the speed of light: 1.) the measurement the speed of light by using Foucault's method with light sources of varying frequencies and 2.) testing the invariance of the speed of light with said light sources of differing wavelength.

Foucault's method theoretically demonstrates a light source bounces between a spinning mirror and stationary mirror, which are separated at a distance d. As the light beam bounces back from the stationary mirror, the position of the spinning mirror will change by a fairly minute but appreciable distance. This differential distance is associated with a fairly small deflection angle from the light's original path. This will let us determine an effect that is inversely proportional to the speed of light[2].

To measure the speed of light with a high degree of accuracy our equipment setup must be able to account for the small and large fluctuations from human error, surrounding electrical equipment and other unavoidable inefficiencies. Given the reality of the experimental setup, we are attempting to reach the official value of the speed of light that was established in 1983 to the highest degree of accuracy possible with our equipment. Taking into account the deficiencies of the real world, we should be able to determine the speed of light with our equipment to a reasonably high degree of accuracy.

We will measure the separation between the original light path and the reflected light and later calculate c to compare our measured result to the known value. In addition to measuring the well-known constant of the speed of light, we will also attempt to test the hypothesis of the isotropy of speed of light of differing wavelengths. Our hypothesis is that the speed of light will be invariant under changes in wavelength. The source of our hypothesis stems from the theoretical predictions of Albert Einstein and is primarily reliant upon the Second Postulate of the Special Theory of Relativity, Einstein's Light Speed Invariance Postulate. In which he stated that "At all events we know with great exactness that this velocity is the same for all colours, because if this were not the case, the minimum of emission would not be observed simultaneously for different colours during the eclipse of a fixed star by its dark neighbour[1]."

3 Experimental Setup

Foucault's method of measuring the speed of light is the very widely used by university laboratories because of the simplicity of the setup and fairly high accuracy of the results. Figure 1 represents a general schematic of the experimental setup that we will recreate. For this experiment to be successful, there are quite few parameters restrictions to be addressed in the experimental setup. For instance, the rotating mirror must be sufficiently stable so that the reflected light beam from the stationary mirror will bounce back on the same path as the incident beam. The spinning mirror is fixed upon a modified centrifuge and spins around the positive vertical axis. It is quite possible that in the event that the light source undergoes divergence over a distance, we will need to use a lens with a finite focal length to focus the laser to a converging point, so as not to lose the intensity of the Gaussian distribution of the laser. We have a variety of lasers at out disposal in the laboratory to test and observe to compare results of light sources of varying wavelengths.

To perform this experiment, we will place the spinning mirror at a distance D apart from the stationary mirror. We will have a screen near the laser source to detect the reflected beam. Start the spinning mirror at our determined angular velocity, and allow the laser beam strikes this mirror from a distance R away. When the beam is reflected back near the light source, measure the separation distance between the original and reflected beams. We would recommend to perform this step for at least 5 data points. Next, we adjust the separation between the spinning mirror and the stationary mirror, or the angular frequency of the rotating mirror. For example, We can increase the separation distance between the two mirrors, and keep the angular velocity of the spinning mirror the same, or vice versa. Similarly to the previous steps, we want to measure the deflected distance at least 5 times. In addition, we will also repeat these steps above with different light sources, such as green and blue lasers.

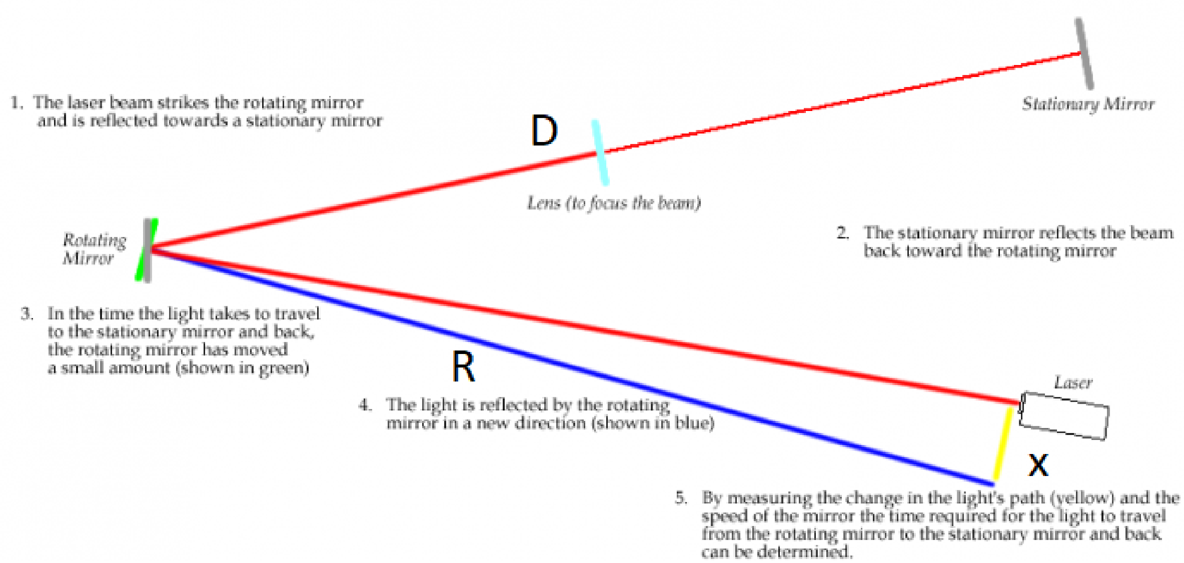

Figure 1. Setup for Foucault's method showing the deflected angle between original light beam and reflected light beam.

The theory is that by measuring the angle of deflection at point 5 in Figure 1 and knowing the rate of rotation of the mirror, we can calculate the time it takes for the light to travel the entire path, as shown in Equation 1 below

$$\omega_{mirror} = \frac{\Delta\theta}{t} \tag{1}$$

where ω is the angular velocity of the rotating mirror, t is the time of rotation, and $\Delta\theta$ is the change in angle of the spinning mirror. Figure 1 shows that there is only one angle θ_i of the rotating mirror at which the red beam will travel to the stationary mirror and straight back while all other angles are not considered. When the light has come back the mirror will have rotated an angle $\Delta\theta$, making a right triangle with the blue beam at the hypotenuse. By geometrical relationship and sine small angle approximation, we can say

$$\Delta\theta \approx \frac{x}{R} \tag{2}$$

where x is the distance we will measure (yellow line in Figure 1), R is the distance between the spinning mirror and the point of measurement. We can relate t to our measured values and the speed of light c_0 we seek to calculate, hence

$$t = \frac{x}{R\omega_{mirror}} = \frac{2D}{c_0} \tag{3}$$

4 Justification

Physics is a very dynamic discipline and universal constants like the speed of light can be defined but can only be confirmed by experimentation, measurement and constant refinement of theory and practice. There can always be improvements on how we understand the speed of light and this experiment is a part of a bigger picture of how we can define it. Our experiment will test how different wavelengths correspond to different measurements of their speed of propagation and will also test how different distances and angular speeds of a spinning mirror affect results.

We already have all of the tools we need accessible to us in the lab and all of the calculations necessary to understand our future measurements. The last task is to set it up and measure to prove our calculations. We have more than enough time in the next two months to collect measurements and report our results.

References

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