Measuring the Speed of Light in Air, Glass, and Water

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Abstract

In this experiment, the speed of light and index of refraction in air, glass, and water was analyzed by studying the time lag and distance travelled by a split laser beam. The index of refraction of air was measured to be 1.019 ± 0.009, which was 1.57 % and 1.64 σ above the typical value of 1.000293. For glass, the measured index of refraction was 1.502 ± 0.007, only 0.03 % and 6.34 σ larger than the typical value, 1.456. The typical index of refraction in water was 1.333, while measured index of refraction in water was 1.274 ± 0.009. The measured value was 4.44 % or 6.31 σ larger than the typical value.

Introduction

The goal of this experiment was to measure the speed of light in air, glass, and water by measuring the distance travelled by a laser beam through two paths and the respective time lag between the paths.

The speed of light in a vacuum has a known measured value of 299792458 m/s, referred to as *c* [1]. The speed of light through a medium is often less than this value. Photons must navigate through the particles of the medium to travel through it, and therefore a denser, more solid medium will slow down the speed of light. Mediums are classified by their index of refraction, a value that denotes the ratio of the speed of light in a vacuum divided by the speed of light in the medium, as described by Equation 1:

$$n = \frac{c}{v} \qquad \text{Eq. (1)}$$

Where *n* is the index of refraction, *c* is the speed of light in vacuum, and *v* is the speed of light through the medium [2]. The index of refraction for air, glass, and water are well-studied. Using an optical setup with two laser beams traversing different distances and one passing through glass or water, it was possible to calculate the speed of light through the material and its respective index of refraction.

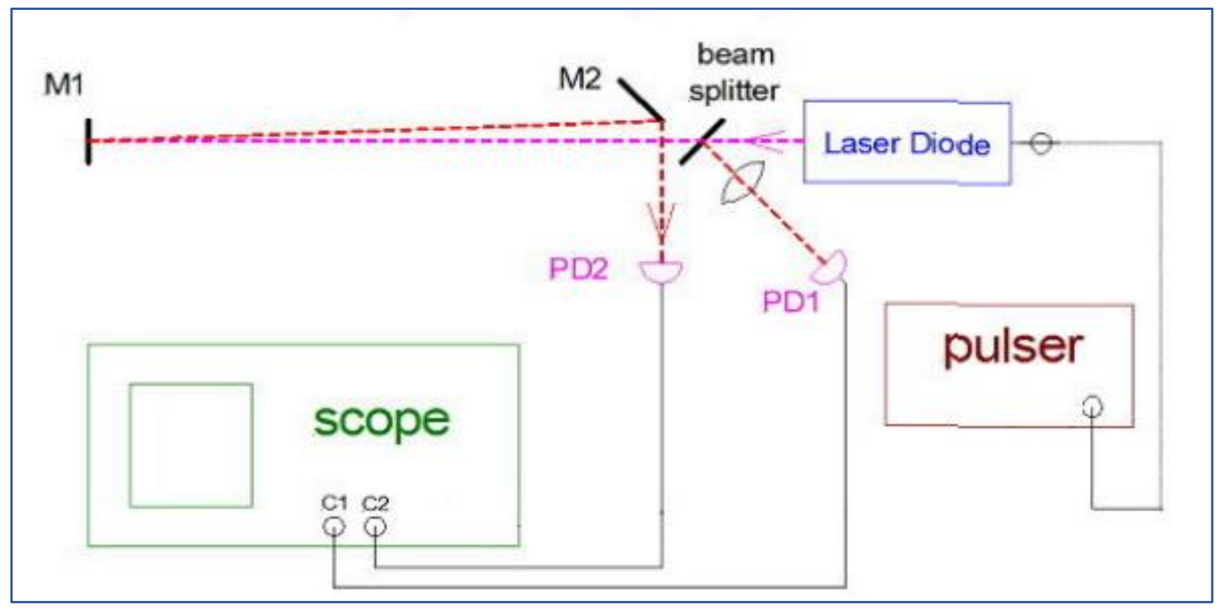

Figure 1. Optical Setup used to measure speed of light in air, glass, and water .

Methods

Optical components (*one red laser diode, 2 photodiodes (PD1, PD2), two mirrors (M1, M2), beam splitter*) were arranged as in Figure 1. PD1 and PD2 were connected to an oscilloscope, allowed laser waveforms to be measured.

Air: Using cables of equal lengths between each photodiode and the oscilloscope, the peak-to-peak time lag between PD1 and PD2 was recorded. The difference in laser path to PD1 and PD2 was measured. (*Figure 2*)

Glass: The waveform to PD2 was recorded. A fiber optic cable was added between PD2 and the oscilloscope. The time lag between the waveforms with and without the fiber optic cable was recorded as well as the length of the fiber optic cable. (*Figure 3*)

Water: A long cylinder of water was added between the beam splitter and M1, such that the laser passed twice through the water cell before reaching PD2. The time lag between PD1 and PD2 was recorded. The difference in laser path to PD1 and PD2 was measured. (*Figure 4*)

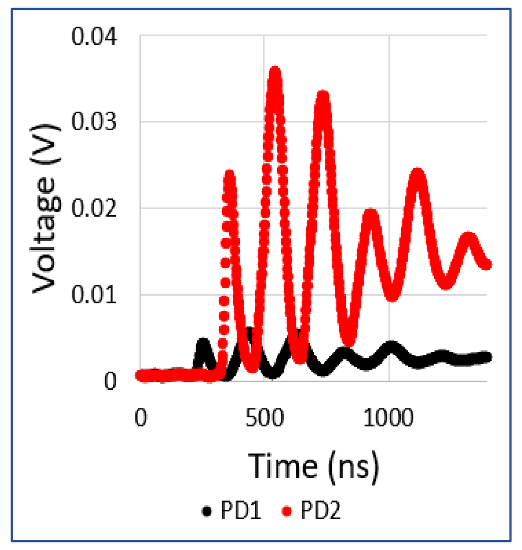

Figure 2. Waveform of incident laser beam in from PD1 (Channel 1) and PD2 (Channel 2).

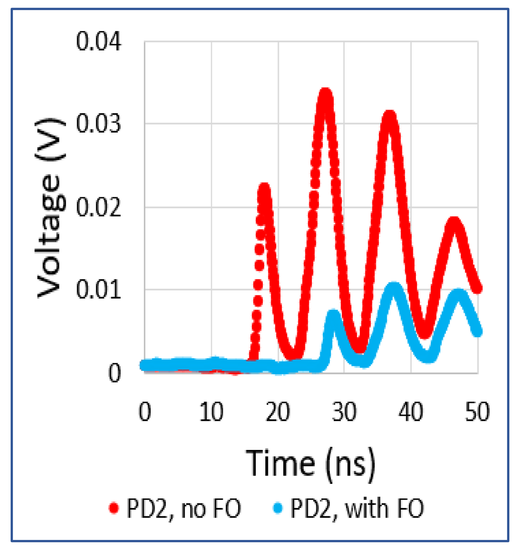

Figure 3. Waveform of laser beam to PD2 with and without a fiber optic cable (FO).

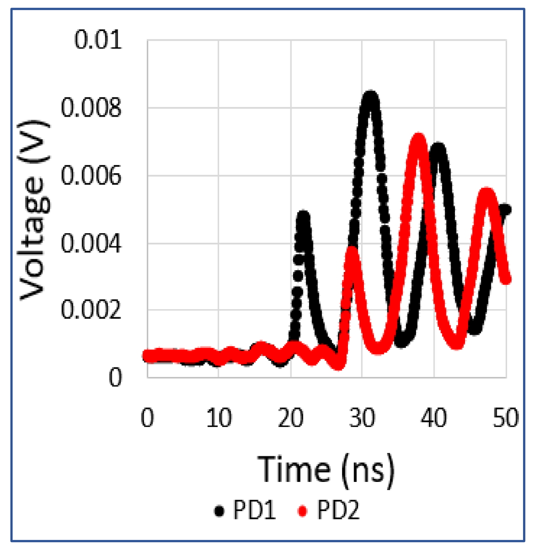

Figure 4. Waveform of laser beam to PD1 (Channel 1) and PD2 (Channel 2) with water cell before PD2.

Table 1. Measured and Accepted Value for Index of Refraction for Air, Glass, and Water.

	Air	Glass	Water
Measured $n \pm \sigma$	**1.016 ± 0.009**	**1.502 ± 0.007**	**1.274 ± 0.009**
Accepted n Values	1.000293	1.456	1.333
% Deviation	1.57 %	0.03 %	-4.44 %
σ Deviation	1.64 σ	6.34 σ	-6.31 σ
Reference	[4], [3]	[5]	[3]

Results

By measuring the distance traversed by a laser and the time lag between two signals from the beam, it was possible to calculate the speed of light through various materials as well as their index of refraction. The first material studied was **air**. Using a peak-to-peak method to measure the time lag of waveforms shown in Figure 2, the speed of light in air was calculated to be $2.95 \cdot 10^8 \pm 0.03 \cdot 10^8$ m/s. The expected speed of visible light in air is $2.997 \cdot 10^8$ [4]. The measured value for air was 1.55 % and 1.66 deviations below the typical value. The accepted index of refraction for air is 1.000293 [3]. The measured value was 1.019 ± 0.009, which was 1.57 % and 1.64 deviations above the expected. The peak-to-peak measurements were used for this comparison as they were closest to the typical values.

The optical properties of **glass** were also measured, as shown in Figure 3. The measurements when using the half-max to half-max method of determining time lag were closest to the typical values, and so were used in this comparison. The measured speed of light in glass was $1.965 \pm 0.009 \cdot 10^8$ m/s, which was 0.03 % and 6.54 deviations below the typical value of $2.997 \cdot 10^8$ m/s. The measured index of refraction for glass was 1.502 ± 0.007, which was 0.03 % and 6.34 deviations above the typical value of 1.456 [5]. The typical value was for SiO_2 at a wavelength of 654 nm.

Finally, the optical properties of **water** were analyzed. Figure 4 shows the laser waveforms from PD1 and PD2 with a water tube before PD2. The measured speed of light in water was $2.35 \pm 0.01 \cdot 10^8$ m/s. With an accepted value of $2.249 \cdot 10^8$ m/s, the measured value was 4.64 % and 6.03 deviations larger. The typical index of refraction for water is 1.333 [3]. The measured index of refraction from this experiment was 1.274 ± 0.009, which was 4.44 % or 6.31 deviations below the typical value.

Conclusions

Table 1 summarizes the index of refraction values determined through this experiment and their respective accepted values.

It should be noted that the index of refraction for any material varies slightly depending on the wavelength of incident light. For this experiment, the laser was measured to have a wavelength of 652 nm. As light wavelength increases, the index of refraction decreases [5]. The typical values used to compare to measured for air and water were for visible light around 590 nm [3]. The wavelength used to determine a typical value for glass was 652 nm [5]. According to the data, the speed of light and index of refraction for glass matched the typical value most closely compared to the other two mediums. This increased precision could in part be a result of a more accurate typical value that corresponds directly to the wavelength of light used in this experiment.

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References

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