Lab Report

EXPERIMENT 3: Velocity of Light

Group 10
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We hereby declare that we are the sole authors of this Lab Report and that we have not used any sources other than those listed in the bibliography and identified as references. We further declare that We have not submitted this thesis at any other institution in order to obtain a degree.

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1 Abstract

In this experiment, we attempted to measure the velocity of light in air and in a different medium (resin) by comparing a detected signal to a modulated reference signal.

The value we obtained for the velocity of light in air was $v_{air} = (2.991 \pm 0.0048) \cdot 10^8 \text{ms}^{-1}$, With the accepted theoretical value of the velocity of light in air being $v_{Standard-air} = 299,792,458 ms^{-1}$ [5], our result agrees with it within its uncertainty range.

In addition, the value obtained for the velocity of light in the resin block was $v_{resin} = (1.913 \pm 0.059) \cdot 10^8 \text{ms}^{-1}$, and the refractive index obtained this value was found to be $n_{resin} = (1.5664 \pm 0.0020)$, while the valuye obtained by using snell's law was $n_{snell} = 1.521 \pm 0.022$ Since there is no standard value, an averaged value from standard sources was used and found to be around $n_{standard} = 1.52 - 1.57$ [1][6]. Therefore, our results agree with this averaged accepted value within their respective uncertainty ranges.

2 Introduction

Our focus in this experiment will be using a set of lab equipment to measure and calculate the velocity of light in air. But first, one must understand the grounds upon which we will build up and gather information to reach a successful and reasonable conclusion based on empirical evidences.

The simplest question that one might ask is: What is light?. Throughout the early stages of the development of modern physics, it was hypothesized by James Clerk Maxwell that light is an electromagnetic wave; consisting of perpendicularly oscillating magnetic and electric fields, this hypothesis was later proven by Heinrich Hertz. Through Maxwell's mathematical work, he showed that a changing electric field generates a magnetic field, and vice versa, forming a self sustaining electromagnetic wave.

Maxwell's equations predicted that all electromagnetic waves travel at the same speed in a vacuum, The velocity of light, denoted as c, is given by equation (2.1):

$$c = \frac{1}{\sqrt{\mu_0 \cdot \epsilon_0}} \tag{2.1}$$

where μ_0 is the permeability of free space and ϵ_0 is the permittivity of free space. This equation defines the speed of light as 299,792,458 m/s [3], a value now used as a fundamental constant in physics.

The velocity of light in any medium other than vacuum is lower, and depends on the medium's permittivity ϵ_r and permeability μ_r. This relationship is given by equation (2.2):

$$v = \frac{1}{\sqrt{\mu_r \mu_0 \cdot \epsilon_r \epsilon_0}} \tag{2.2}$$

Since most transparent materials have a relative permeability of $\mu_r \approx 1$, the velocity of light primarily depends on the relative electric permittivity of the material ϵ_r. This results in the concept of the refractive index n, defined as the ratio of the speed of light in vacuum to its speed in a given medium as demonstrated in (2.3):

$$n = \frac{c}{v} = \sqrt{\epsilon_r \cdot \mu_r} \tag{2.3}$$

For air, $\epsilon_r \approx 1.0005$ and $\mu_r = 1$, making the velocity of light in air nearly identical to that in a vacuum.

The experiment to measure the speed of light relies on modulated light signals. A light-emitting diode (LED) produces a sinusoidally modulated light beam, which travels a known distance before being detected by a photodiode (PD). A wave with frequency $f_\circ$ can be expressed in Equation (2.4) as:

$$E(t) = E_0 \cos(2\pi f_\circ t) \tag{2.4}$$

where E_0 is the amplitude of the wave, and t represents time that the wave has traversed. When the wave encounters a delay, such as when light travels a longer path before reaching the detector, the received signal at the photodiode will experience a shift in phase. The delayed wave can be written as:

$$E'(t) = E_0 \cos(2\pi f_\circ (t - \Delta t)) \tag{2.5}$$

where Δt is the time delay introduced by the additional distance traveled by the light wave. Expanding the argument of cosine, we obtain:

$$E'(t) = E_0 \cos(2\pi f_\circ t - 2\pi f_\circ \Delta t) \tag{2.6}$$

Which demonstrates that the wave undergoes a phase shift δ, given by Equation (2.7):

$$\delta = 2\pi f_\circ \Delta t \tag{2.7}$$

This equation demonstrates that the phase shift is directly proportional to both the frequency of the wave and the time delay it experiences due to propagation effects. To connect this relationship to the experimental setup, we consider how the time delay is related to the distance traveled by the light. Since light moves at velocity v_{air}, the time required for the wave to travel an additional distance Δx, considering that the light travels to the mirror and back, is given by Equation (2.8):

$$\Delta t = \frac{2\Delta x}{v_{\text{air}}} \tag{2.8}$$

Substituting this into the phase shift equation results in (2.9):

$$\delta = 2\pi f_\circ \frac{2\Delta x}{v_{\text{air}}}$$

which simplifies to:

$$\delta = \frac{4\pi f_\circ \Delta x}{v_{\text{air}}} \tag{2.9}$$

By rearranging for v_{air}, we obtain the final expression Equation (2.10):

$$v_{\text{air}} = \frac{4\pi f_\circ \Delta x}{\delta} \tag{2.10}$$

Furthermore, given that the experiment aims to find the corresponding Δx_π for which $\delta = \pi$ the equation simplifies even more to:

$$v_{\text{air}} = 4 f_{\circ} \Delta x_{\pi} \tag{2.11}$$

This equation is crucial in determining the speed of light from measuring the displacement Δx_{π} of the mirror that produces a phase shift of π. A phase shift of π radians corresponds to the light traveling an additional half-wavelength.

To measure the velocity of light in a transparent medium, such as a resin. The velocity of light inside the medium is calculated using using Equation (2.8) [3]:

$$\frac{v_{\text{air}}}{v_{\text{medium}}} = \frac{2\Delta x}{l_{\text{medium}}} + 1$$

$$v_{\text{medium}} = \frac{v_{\text{air}}}{\frac{2\Delta x}{l_{\text{medium}}} + 1} \tag{2.8}$$

where l_{medium} is the length of the resin block (or the length of the part through which light passes). Since $v_{\text{air}} \approx c$, this equation allows for the calculation of the medium's refractive index, providing insight into how light propagates through different materials. The refractive index of the resin is given in Equation (2.12):

$$\frac{v_{\text{air}}}{v_m} \approx \frac{c}{v_m} = n_m \tag{2.12}$$

The experiment uses Lissajous figures on an oscilloscope to visualize phase shifts. These figures appear when two sinusoidal signals are plotted against each other, with different shapes indicating varying phase relationships. A straight line corresponds to signals perfectly in phase, while a circle suggests a $\frac{\pi}{2}$ phase shift, and an ellipse suggests some other arbitrary phase shift. This is demonstrated in Figure 2.1:

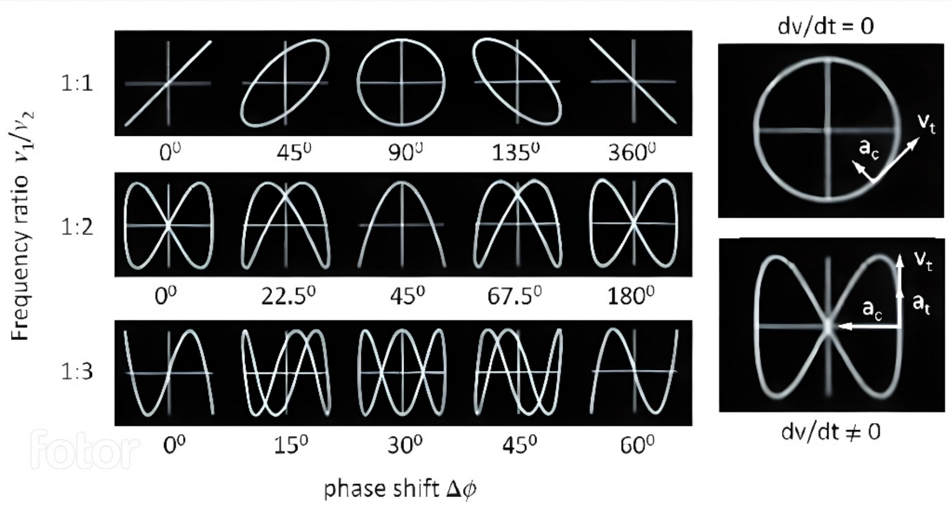


Figure 2.1: Lissajou Figures
[4]

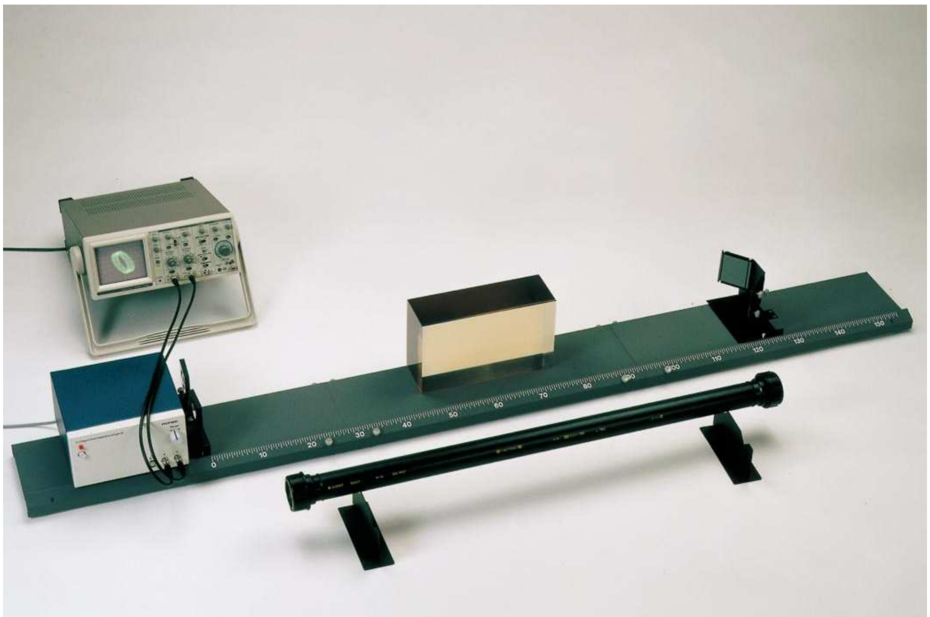
3 Method and Procedure:

The methodology allows for high precision measurements of light speed and refractive indices. However, uncertainties arise from systematic errors, environmental factors, and imperfections in the equipment and/or the procedure. These limitations highlight the need for careful alignment, signal optimization, and statistical analysis to achieve accurate results; the following section will concern such method and procedure.

Equipment List:

- Electronics box with light emitting diode, photodetector, and signal outputs
- Two Lenses to focus Light beam,
- Bench with scale and adjustable mirror
- Oscilloscope with two channels
- Block of synthetic Resin.

Figure 3.1: Experimental setup



The setup consisted of an Electronics Box positioned at the far end of the bench which produced a light beam from a Light Emitting Diode used for all findings of the experiment. From the box, a lens was used to focus the beam into the mirror at parallel height to the bench to create no shift when adjusting the displacement of the mirrors from the source. From the mirror, the beam is reflected into another mirror to make a turn directed to the recieving end of the electronic box and it is focused once again into the opening, as seen in Figure 3.1. The block of resin seen is utilized for calculations regarding refractive index and velocity of light within the block. The light is recieved by the photo detector and both the reference signal and the output signal are recieved by an oscilloscope to be able to compare their phase difference as well as try to minimize the noise created by the output signal. The procedure for positioning the lenses is as follows.

Positioning of Lenses

The mirror was positioned at the far end of the bench, at 160cm from the LED. This was to establish the alignment for the lenses, as the intensity of the light signal at this distance was lower and required precise adjustment. For shorter distances, the intensity was naturally higher, ensuring a strong signal and minimum noise. The first lens was placed 2 cm from the LED to focus the light onto the first mirror; it was adjusted to be perpendicular to the light beam, and a sheet of white paper was used to trace the path of the beam; it was centered on the first mirror, ensuring that the entire mirror surface was targeted. The lens position and height were fine-tuned to produce a sharp, well-defined beam at the location of the mirror. The beam was reflected from the first mirror to the second mirror and then directed back toward the photodiode. Minor adjustments to the the height of the first lens were made to ensure the beam accurately hit the photodiode. The second lens was positioned 1.5cm in front of the photodiode to focus the reflected beam onto the box. The lens position was adjusted horizontally and vertically until a bright red spot was observed on the hole of the photodiode. This ensured maximum light intensity and signal definition. This step required repeated adjustments to optimize the alignment. Once the beam was properly aligned, the setup was ready, and data collection could begin however, this process will then be repeated to ensure reproducibility of values.

Oscilloscope Adjustment

The oscilloscope was then used to further refine the signal quality and analyze the phase relationship between the reference and recorded signals. The oscilloscope was connected to the electronic box, with the X and Y outputs linked to its two input channels, as depicted in Figure 3-2. The gain (Volts/Div) and vertical offset were adjusted to clearly distinguish the two sinusoidal waveforms. The reference signal was stable and was easily identified, while the recorded signal appeared with noise which lead to further readjustments in the setup for the lenses. The phase knob on the electronic box was used to manipulate the phase difference between the reference and recorded signals. The oscilloscope provided a simple visual interface to compare the signals as well as an XY display mode, generating Lissajous figure to find the distance which produced a phase shift of π which resulted in the diagram to appearing as a line with equation of $y = -x$. This provided a visual confirmation of the phase difference and served as a complementary method to the Y(T) mode for phase analysis.

As the mirror was moved along the bench, the phase shift between the signals was monitored in both display modes. When the mirror is positioned away from the photodiode, the recorded signal amplitude decreased; this meant adjustments to the oscilloscope's gain settings to maintain visibility were needed when doing measurements.

The amplitude (in mV) of the recorded signal was recorded at two key positions: when the mirror was closest to the electronic box and when it was at the far end of the bench. The following measurements were taken for both values of displacement to calculate the uncertainty, noise and value for the amplitude: Minimum voltage captured, Maximum Voltage Captured, Lower and Upper bounds generated by noise for both Min and Max. It is expected to find a much higher absolute uncertainty on the minimum distance due to a much higher amplitude value recorded, but a much higher fractional uncertainty in the distance due to lower intensity of light and loss of definition from the beam of light, creating more noise. The value for both amplitudes is calculated from the Equation:

$$A = \frac{S_M - S_m}{2} \tag{3.1}$$

and S_M, S_m are the maximum and minimum for the signal, respectively. To find the uncertainty in the amplitude δA , it is only required to find the uncertainties for S_m, S_M which are $\delta S_m, \delta S_M$ respectively and use the addition of uncertainties, namely:

$$\delta A = \delta S_m + \delta S_M$$

To calculate $\delta S_m, \delta S_M$, find the upper and lower bound values for S_m, S_M

$$\delta S_m = \frac{uS_m - lS_m}{2} \qquad \delta S_M = \frac{uS_M - lS_M}{2}$$

$$\implies \delta A = \frac{uS_m - lS_m}{2} + \frac{uS_M - lS_M}{2} \tag{3.2}$$

The experimental setup proved consistent enough to utilize a phase shift of π for calculations, simplifying the calculation and avoiding the need for Equation (2.10).

Calculating Velocity of Light in Air

To determine the speed of light in air v_{air} , the mirror was placed as close to the electronic box as possible without contact with the lens, defining the starting position $\Delta x_0 = 0$ of the displacement, Use Figure 3.2 as reference. This position was aligned with the zero point of the optical bench scale. At this specific position, the Lissajous figure on the oscilloscope was adjusted to form a positive gradient straight line by turning the "Phase" knob on the electronic box. This straight line indicates that the reference and recorded signals were in phase, serving as the starting point for the measurement.

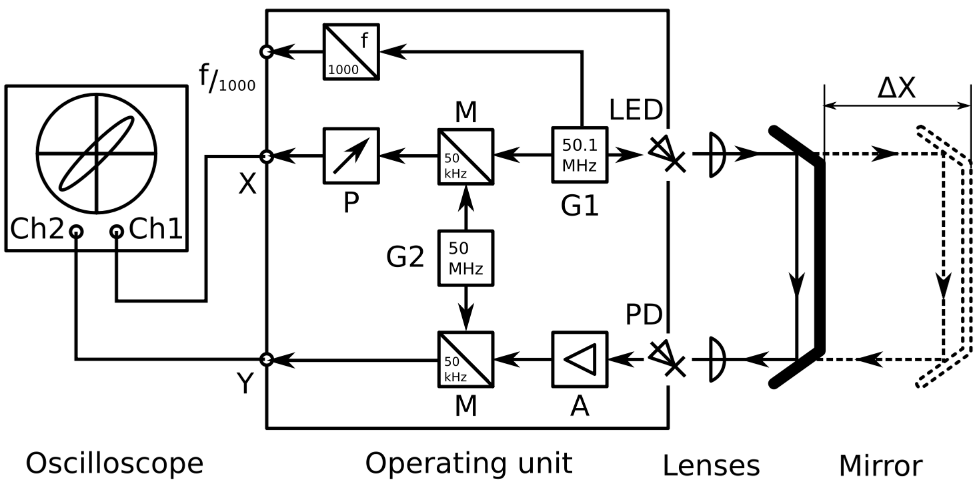


Figure 3.2: Displacement Δx Diagram

The mirror was moved along the optical bench until the phase difference between the reference and recorded signals was π. This phase shift was confirmed by observing a straight line with a negative slope on the oscilloscopes XY-display. The second position of the mirror was recorded, and the displacement $\Delta x_\pi - \Delta x_0$ was calculated. Using

Equation (2.11) and taking a value for $f_\circ = (50.10 \pm 0.01)$ MHz [3], the calculation of v_{air} is done.

The procedure was done $n' = 5$ times to reduce inaccuracy and minimize random error and then after completed, the setup was removed and placed all over again to ensure reproducibility for a total of $n = 10$ times. For each measurement, initial displacement Δx_0 was increased to $\Delta x'_0$ by 1cm (a new position) and the "Phase" knob on the electronic box was adjusted to modulate the signal such that the signals are in phase again. The new position $\Delta x'_\pi$ for phase difference π is found and the value for Δx_π is calculated from $\Delta x'_\pi - \Delta x'_0$. With all 5 values, the mean $\overline{\Delta x_\pi}$ is calculated from Equation (3.3) [2] with error $\delta\overline{\Delta x_\pi}$ (Note: In these formulas Δx^i is an indexing and does not refer to Δx to the power of i):

$$\overline{\Delta x_\pi} = \frac{\sum_{i=1}^{n} \Delta x^i_\pi}{n} \qquad \delta\overline{\Delta x_\pi} = \frac{\sigma_{\Delta x_\pi}}{\sqrt{n}} \tag{3.3}$$

Where $\sigma_{\Delta x_\pi}$ represents the standard deviation of the set of averaged values Δx^i_π, given by [2]:

$$\sigma_{\Delta x_\pi} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\Delta x^i_\pi - \overline{\Delta x_\pi})^2} \tag{3.4}$$

Finally, the value of v_{air} is calculated from Equation (2.11) and the Averaged Error is calculated from Equation (3.5) [2], Assuming that variable v_{air} is a simple function of independent variables $f_\circ, \Delta x_\pi$, the formula for the averaged error δv_{air} is given in (3.5) as:

$$\delta v_{\text{air}} = \sqrt{\delta\overline{\Delta x_\pi}^2 + \delta f_\circ{}^2} \tag{3.5}$$

Where $\delta f_\circ$ denotes the uncertainty in $f_\circ$.

Refractive Index and Light Velocity in Resin

Furthermore, to determine the velocity of light in a synthetic resin block, the setup is modified to include the resin block in the path of the beam. The block was positioned such that the light passed through its entire length and entered and exited perpendicularly to its surfaces, minimizing refraction effects. The mirror was placed directly behind the block to reflect the light back to the photodiode. The oscilloscope signal was adjusted using the "phase" knob until a straight line was displayed on the XY-display, indicating that the reference and recorded signals were in phase. The corresponding mirror position was recorded as the "zero point" P_1.

Afterwards, the resin block was removed from the light path, and the mirror was moved away from the electronic box until the Lissajous figure on the oscilloscope displayed a straight line with the same slope as in the previous measurement. This ensured that the phase difference was identical to that observed with the resin block in place. The new mirror position P_1 was recorded, and the displacement Δx between P_1 and P_2 is calculated. This displacement corresponds to the additional path length introduced by the resin block, allowing for the calculation of the refractive index and the velocity of light in the resin according to Equation (2.8).

The experimental procedure began with measuring the length of the resin block l_{resin}, including its absolute uncertainty, using a ruler. The mirror is then placed at position P_1 was recorded for five different measurements similar to the procedure for v_{air}. After removing the resin block, the mirror was moved to P_2, until the phase shift matched that of P_1. This process was repeated five times. To ensure consistency, the entire setup was readjusted for reproducibility, and another set of five measurements for P_1, P_2 was taken, resulting in a total of ten measurements. Throughout the experiment, the typical amplitudes of the sinusoidal signals at positions P_1, P_2 were recorded similar to before, including their uncertainties and noise levels, to assess the quality of the data.

Using Equation (3.3), the Mean and Error of Mean are calculated for Δx. Given Equation (2.8), the propagated error for v_{resin} can also be calculated using Equation (3.6) [2]:

$$\delta v_{\text{resin}} = \sqrt{\left[\left(\frac{\partial y}{\partial x_1}\right)_{x_j \neq x_1} \delta x_1\right]^2 + \left[\left(\frac{\partial y}{\partial x_2}\right)_{x_j \neq x_2} \delta x_2\right]^2 + \cdots + \left[\left(\frac{\partial y}{\partial x_p}\right)_{x_j \neq x_p} \delta x_p\right]^2} \tag{3.6}$$

and each δx_p is the error of variables in v_{resin} ie: Δx and l_{medium}. Since c has a theoretical value, it is taken to have no uncertainty.

To further validate the results, the refractive index of the resin block was estimated using Snell's law. The angles of incidence $\theta_i$and refraction θ_r were measured as light is shined and passes through the resin block, and the refractive index was calculated using the relationship:

$$n_{\text{resin}} = \frac{\sin\theta_i}{\sin\theta_i} \tag{3.7}$$

This value is compared to the refractive index obtained from the phase shift measurements. This additional method provided a verification of the results and highlighted the consistency (or potential inconsistencies) in the experimental data.

4 Results and error analysis

The recordings for the Amplitude A of the light beam (in mV) for both values of $\Delta x = 0cm, 153cm$ denoted A_0 and A_{153} are seen in Figure 4.1.

With the given values from Table 4.1, use Equation (3.1) for the Amplitude A_0 and Equation (3.2) for the error, we obtained:

$$A_0 = \frac{214 - (-214)}{2} = 214\text{mV} \qquad \delta A_0 = \frac{214 - 208}{2} + \frac{-214 - -206}{2} = 7$$

Similarly for maximum distance:

$$A_{153} = \frac{20.4 - (-20.2)}{2} = 20.3\text{mV} \qquad \delta A_0 = \frac{20.4 - 19.0}{2} + \frac{-20.2 - -18.6}{2} = 1.5$$

The final values for Ampltitude are:

$$A_0 = (214 \pm 7)\text{mV} \qquad A_{153} = (20 \pm 1.5)\text{mV} \tag{4.1}$$

Measurement	**0 cm**	**153 cm**
Min of Signal S_m (mV)	-214	-20.2
Max of Signal S_M (mV)	214	20.4
Amplitude A (mV)	214	20.3
Lower Bound of Max of Signal lS_M(mV)	208	19
Upper Bound of Max of Signal uS_M(mV)	214	20.4
Error for Max (mV)	3	0.7
Lower Bound of Min of Signal lS_m (mV)	-214	-20.2
Upper Bound of Min of Signal uS_m(mV)	-206	-18.6
Error for Min (mV)	4	0.8
Total Absolute Uncertainty for Amplitude (mV)	7	1.5

Figure 4.1: Signal measurements at minimum (0 cm) and maximum (153 cm) distances.

Measurements concerning the calculation of V_{air}

:

The measurements of positions P_1 and P_2 were recorded to determine the displacement Δx_π, which corresponds to a phase shift of π. The results are given in Figure 4.2. Additionally, the results of the second set of 5 measurements, intended to check for the reproducibility of the experiment is presented in Figure 4.3: averagif

Figure 4.2: First set of measurements

$\Delta x'_0$ /cm	$\Delta x'_\pi$ /cm	Δx_π /cm
0	148.5	148.5
1	150	149
2	150.5	148.5
3	152	149
4	154	150

Figure 4.3: Second set of measurements (checking reproducabillity)

$\Delta x'_0$ /cm	$\Delta x'_\pi$ /cm	Δx_π /cm
0	149	149
1	150	149
2	151	149
3	152.5	149.5
4	155	151

Using all the values, the mean is calculated from Equation (3.3) and its error from the Standard deviation Equation (3.4) and converting from cm to m the value for the mean is:

$$\delta\Delta x_\pi = \frac{148.5 + 149 + \cdots + 151}{10} = 1.4925m \qquad \delta\Delta x_\pi = 0.002386m$$

$$\Delta x_\pi = (1.4925 \pm 0.0024)m \tag{4.2}$$

Taken the value for $f_\circ$ mentioned before and Δx_π the velocity of light in air v_{air} is calculated from Equation (2.11):

$$v_{air} = 4(50.1 \cdot 10^6)(1.493) = 299097000\text{ms}^{-1} \tag{4.3}$$

For the error δv_{air}, Equation (3.6) is utilized as follows:

$$\sqrt{(4f_\circ \cdot \delta\Delta x_\pi)^2 + (4 \cdot \delta f_\circ \cdot \Delta x_\pi)^2} = 504544.4381\text{ms}^{-1}$$

Substitute the values and get final value:

$$v_{air} = (2.991 \pm 0.0051) \cdot 108\text{ms}^{-1} \tag{4.4}$$

Calculating V_{Resin}

As described in the Procedure, the results in Figure are the values recorded for the distances P_1, P_2 by placing the Resin and finding the phase difference created by the resin by adjusting the distance to remove the Phase difference. The measurements for the Amplitude at distance $P_1 = 34cm$ and distance $P_2 = 43cm$ are in Figure 4.4.

Measurement	P_1	P_2
Min of Signal S_m (mV)	-50.1	-136
Max of Signal S_M (mV)	51.8	138
Amplitude A (mV)	50.95	137
Lower Bound of Max of Signal lS_M(mV)	45.5	126
Upper Bound of Max of Signal uS_M(mV)	51.8	138
Error for Max (mV)	3.15	6
Lower Bound of Min of Signal lS_m (mV)	-50.1	-136
Upper Bound of Min of Signal uS_m(mV)	-45.5	-127
Error for Min (mV)	2.3	4.5
Total Absolute Uncertainty for Amplitude (mV)	5.45	10.5

Figure 4.4: Signal measurements P_1 and P_2 distances.

Take the values from Table 4.4, use Equation (3.1) for the Amplitudes A_{P_1} and $A_{P_2} and$Equation (3.2) for the error, to obtain:

$$A_{P_1} = \frac{51.8 - (-50.1)}{2} = 50.95\text{mV} \qquad \delta A_{P_1} = \frac{51.8 - 45.5}{2} + \frac{45.5 - -50.1}{2} = 5.45$$

Similarly for maximum distance:

$$A_{P_2} = \frac{138 - -136)}{2} = 137\text{mV} \qquad \delta A_{P_2} = \frac{138 - 126}{2} + \frac{127 - -136}{2} = 10.5$$

The final values for Resin Amplitude are:

$$A_{P_1} = (51.0 \pm 5.5)\text{mV} \qquad A_{P_2} = (137 \pm 11)\text{mV} \tag{4.5}$$

For the 10 measurements of P_1, P_2

Figure 4.5: First set of measurements

P_1 /**cm**	P_2 /**cm**	Δx /**cm**
34	42	8
35	43	8
36	44.5	8.5
37	45	8
38	46.5	8.5

Figure 4.6: Second set of measurements (checking reproducabillity)

P_1 /**cm**	P_2 /**cm**	Δx /**cm**
34	41.5	7.5
35	42.5	7.5
36	44.5	8.5
37	45	8
38	46.5	8.5

The measurement for the length of the resin l_{resin} was done using a ruler and the error was considered since the ruler is incremented in units of centimeters (cm). The smallest scale division is a tenth of a centimeter or 1 mm. Therefore, the uncertainty is the smallest increment divided by 2: 0.5mm.

$$l_{resin} = (0.286 \pm 0.0005)m$$

Taking all 10 values for Δx, the mean was found using Equation (3.3) and its error from the Standard deviation Equation (3.4) and converting from cm to m the value for the mean is:

$$\delta\Delta x = \frac{8+8+\cdots+8.5}{10} = 0.081m \qquad \delta\Delta x_\pi = 0.0027889m$$

$$\Delta x = (0.0810 \pm 0.0028)m \tag{4.6}$$

Taken the value for $f_\circ$ mentioned before and Δx the velocity of light in the resin v_{resin} is calculated from Equation (2.8):

$$v_{\text{resin}} = \frac{299,792,458}{\frac{2\cdot 0.081}{l_{0.286}+1}}\ \text{ms}^{-1} = 191327965\ \text{ms}^{-1} \tag{4.7}$$

For the error δv_{resin}, Equation is utilized as follows:

$$\sqrt{(4f_\circ \cdot \delta\Delta x_\pi)^2 + (4\cdot\delta f_\circ \cdot \Delta x_\pi)^2} = 504544.4381\text{ms}^{-1}$$

Substitute the values and get final value:

$$v_{resin} = (1.913 \pm 0.059)\cdot 10^8 ms^{-1} \tag{4.8}$$

The calculation of the refractive index of the resin n_{resin} is done from Equation (2.3) as follows:

$$n_{resin} = \frac{2.997\cdot 10^8}{1.912\cdot 10^8} = 1.5664 \tag{4.9}$$

The error is also calculated from Equation (3.6), since the error in n_{resin} only depends on the error $\delta\Delta x$, this resolves nicely to:

reach final value that is then given as:

$$n_{resin} = 1.521 \pm 0.022 \tag{4.10}$$

4.1 Snell's Law

The corroboration of our value from Equation (4.10) using Snell's Law is done with the values from Figure 4.7:

The mean for $\frac{sin(i)}{sin(r)}$ is done from Equation (3.3) and for the Error of mean to get :

$$n_{resin} = (1.521 \pm 0.022)$$

Which deviates within the uncertainty range of our original value gotten from our previous method.

Figure 4.7: Snell's Law Data

Incidence Angle (i) [rad]	sin(i)	Refraction Angle (r) [rad]	sin(r)	sin(i)/sin(r)
1.0472	0.8660	0.57596	0.54464	1.5909
0.87266	0.7660	0.52360	0.50000	1.5321
0.69813	0.6428	0.43633	0.42262	1.5210
0.52360	0.5000	0.33161	0.32557	1.5358
0.34907	0.3420	0.22689	0.22495	1.5204
0.17453	0.1736	0.12217	0.12187	1.4249

5 Discussion and Conclusion

The results obtained in this experiment demonstrate a reasonable agreement with theoretical expectations. The measured velocity of light in air, $v_{air} = (2.991 \pm 0.0048) \cdot 10^8$m/s, is consistent with the accepted standard value of $v_{\text{Standard-air}} = 299,792,458$m/s [5], as the experimental uncertainty encompasses the theoretical value. This confirms the reliability of the method used to measure the speed of light in air, indicating that systematic errors were minimal in this part of the experiment.

For the velocity of light in the resin block, the measured value of $v_{\text{resin}} = (1.913 \pm 0.059) \cdot 10^8$m/s resulted in a refractive index of $n_{\text{resin}} = (1.5664 \pm 0.0020)$. This value was compared to the refractive index obtained using Snell's law, which was found to be $n_{\text{snell}} = 1.521 \pm 0.022$. The reference range for the refractive index of resin from various sources is approximately $n_{\text{standard}} = 1.52 - 1.57$ [1, 6]. Both experimentally obtained values for n_{resin} and n_{snell} fall within this expected range, confirming that they are consistent with standard values within their respective uncertainties.

Despite this agreement, the discrepancy between the refractive indices calculated using the two methods suggests that each approach introduces distinct sources of error. The time-delay method, used to determine v_{resin}, is highly sensitive to systematic uncertainties such as alignment precision, signal processing delays, and material inhomogeneities within the resin block. Additionally, minor imperfections in the optical setup, such as beam divergence and reflections, could contribute to measurement deviations.

On the other hand, the refractive index derived from Snell's law depends on precise angle measurements. Errors in determining the incident and refracted angles, as well as slight imperfections in the shape and surface quality of the resin block, could significantly impact the calculated value. Additionally, Snell's law assumes an ideal boundary between the two media, whereas real experimental conditions may involve slight variations in surface quality and internal scattering effects.

Ultimately, while both methods yield values that align with the expected theoretical range, the variation between them highlights the influence of different error sources. The time-delay method is more dependent on precise timing measurements and electronic response factors, whereas the Snell's law method is more sensitive to angular resolution and boundary conditions. Future improvements in alignment accuracy, signal processing, and optical component quality could reduce these discrepancies and further refine the precision of the measured values.

References

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