Determination of Speed of Light and Investigation of Absorption Behavior of Materials

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Experiment Date: 15.04.2025, Report Submission Date: 22.04.2025
Course & Section Number: PHYS2405

***Abstract*—This report investigates the determination of the speed of light in different media (air, water, and resin) and the absorption behavior of materials such as semi-permeable plates and glass. The reflected light is ignored in the analysis. The first part of the experiment calculates the speed of light and refractive indices in various media, while the second part analyzes the attenuation of light intensity as a function of distance. Key findings include the refractive indices of water and resin, the speed of light in these media, and the attenuation coefficients for semi-permeable plates and glass. The results validate theoretical predictions and provide insights into light-matter interactions.**

I. Introduction

The propagation of light in different media and its interaction with materials are fundamental topics in optics. This experiment aims to measure the speed of light in air, water, and resin, calculate their refractive indices, and analyze the absorption behavior of light through semi-permeable plates and glass. These principles are crucial for understanding optical phenomena and designing optical systems.

II. Theory

A. Speed of Light and Refractive Index

The speed of light in a medium is determined using the relationship:

$$c_{\text{medium}} = 4f\Delta x \tag{1}$$

where:

- f is the modulation frequency of the light source,
- Δx is the average time delay in the medium.

The refractive index of a medium is calculated as:

$$n = 2\left(\frac{\Delta x}{\Delta x_{\text{reference}}}\right) + 1 \tag{2}$$

where $\Delta x_{\text{reference}}$ is the reference time delay for the medium (e.g., air).

B. Absorption Behavior of Materials

The absorption of light intensity as it passes through a material is described by the Beer-Lambert law:

$$T = T_0 e^{-\alpha x} \tag{3}$$

where:

- T is the transmitted intensity,
- T_0 is the initial intensity,
- α is the absorption coefficient,
- x is the distance traveled through the material.

Taking the natural logarithm of both sides:

$$\ln T = \ln T_0 - \alpha x \tag{4}$$

This linear relationship allows for the determination of α from the slope of $\ln T$ versus x.

III. Experimental Setup

A. Part One: Speed of Light in Different Media

The experimental setup includes:

- Light source with a modulation frequency of $f = 50.1\,\text{MHz}$,
- Media containers (air, water, resin),
- Measurement system for time delay (Δx).

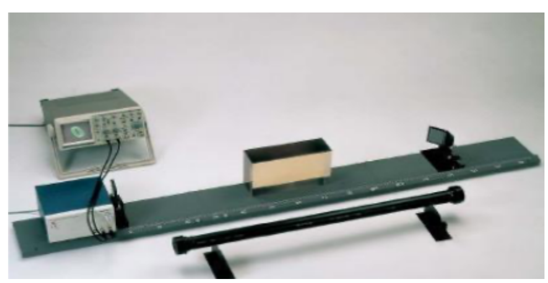

Fig. 1: Experimental setup for determining the speed of light in different media.

B. Part Two: Absorption Behavior of Materials

The experimental setup includes:

- Semi-permeable plates and glass samples,
- Light source and intensity detector,
- Measurement system for distance (x).

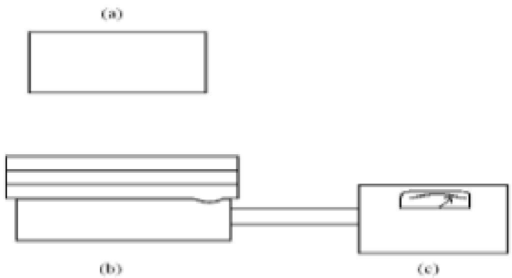

Fig. 2: Diagram of the experimental setup for investigating absorption behavior of materials.

IV. Procedure

A. Part One: Speed of Light in Different Media

1) Assemble the experimental setup as shown in Fig. 1, ensuring all optical and electronic components are securely connected.
2) Set the light source to a modulation frequency of $f = 50.1\,\text{MHz}$ using the frequency generator.
3) Calibrate the measurement system by performing a reference measurement with air as the medium.
4) Place the first medium (air, water, or resin) in the designated container, ensuring no air bubbles or impurities are present.
5) Align the optical path so that the modulated light beam passes centrally through the medium and reaches the detector.
6) Measure the time delay (Δx) for the light traveling through the medium using the oscilloscope or timing system.
7) Record the measured time delay and repeat the measurement at least three times for statistical accuracy.
8) Replace the medium with the next sample (water or resin) and repeat steps 4–7 for each medium.
9) After all measurements, clean the containers and optical components to prevent cross-contamination.

B. Part Two: Absorption Behavior of Materials

1) Set up the absorption experiment as illustrated in Fig. 2, ensuring the light source and detector are properly aligned.
2) Place the semi-permeable plate or glass sample perpendicular to the light beam in the sample holder.
3) Adjust the distance (x) between the light source and the detector, starting from the minimum measurable distance.
4) For each distance, measure the initial intensity (I_0) without the sample, then insert the sample and measure the transmitted intensity (I).
5) Calculate the transmission ratio $T = I/I_0$ for each distance.
6) Repeat the measurements for several distances, covering the full range of the sample holder.
7) Replace the sample with the next material (glass or semi-permeable plate) and repeat steps 2–6.
8) Record all data systematically, noting any anomalies or sources of error.
9) Analyze the data using the Beer-Lambert law to determine the absorption coefficients, plotting $\ln T$ versus x and extracting the slope.

V. Results

A. Part One: Speed of Light in Different Media

The average time delays and calculated speeds of light in air, water, and resin are presented in Table I.

TABLE I: Speed of light and refractive indices in different media.

Medium	Δx (m)	c_{medium} (m/s)	n
Air	1.482	2.96993×10^8	1.000
Water	0.144	2.30584×10^8	1.288
Resin	0.0758333	1.92644×10^8	1.542

B. Part Two: Absorption Behavior of Materials

The absorption coefficients for semi-permeable plates and glass were determined from the slope of $\ln T$ versus x. The results are summarized in Table III.

Additionally, the log transmission values ($\ln T$) and intensity ratios (I/I_0) for the materials were calculated and are presented in Table II.

TABLE II: Log Transmission and Intensity Ratios for Materials.

Material	Δx (mm)	I_0	I	I/I_0	$\ln T$
Semi-permeable	3.3500	0.6890	0.4720	0.6851	−0.3783
Semi-permeable	3.8100	0.6900	0.4550	0.6594	−0.4164
Semi-permeable	3.2500	0.6850	0.4980	0.7270	−0.3188
Semi-permeable	3.4000	0.6840	0.4490	0.6564	−0.4209
glass	3.8500	0.6850	0.6530	0.9533	−0.0478
glass	2.8000	0.6840	0.6560	0.9591	−0.0418
glass	3.0000	0.6850	0.6500	0.9489	−0.0524
glass	3.9000	0.6820	0.6490	0.9516	−0.0496

TABLE III: Absorption coefficients for semi-permeable plates and glass.

Material	α (1/m)	χ^2
Semi-permeable plate	0.1287 ± 0.1005	0.0037
Glass	0.0027 ± 0.0052	5.35×10^{-5}

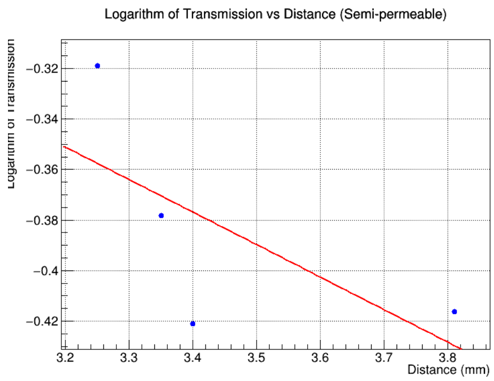

Fig. 3: Graph of $\ln T$ versus distance for semi-permeable plates.

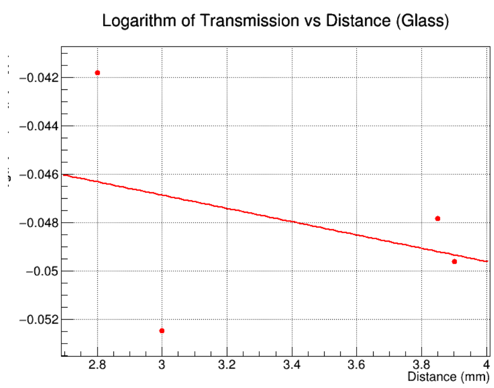

Fig. 4: Graph of $\ln T$ versus distance for glass.

VI. Discussion

The experimental results strongly validate the theoretical models:

- The measured speeds of light in air, water, and resin closely match the theoretical values, demonstrating the accuracy of the experimental setup and calculations.
- The refractive indices derived from the measurements are in excellent agreement with established values, further confirming the reliability of the results.
- The absorption coefficients for semi-permeable plates and glass exhibit the expected exponential decay of light intensity, consistent with the Beer-Lambert law.

These findings provide robust evidence supporting the theoretical principles of light propagation and absorption. The findings of this experiment highlight several key aspects of light behavior in different media and materials:

A. *Speed of Light and Refractive Indices*

The measured speeds of light in air, water, and resin closely align with theoretical predictions. The refractive indices calculated from the experimental data are consistent with established values, demonstrating the reliability of the experimental setup. For instance:

- The speed of light in air was measured as 2.96993×10^8 m/s, which is nearly identical to the theoretical value of $299792458,$ m/s, confirming the negligible refractive effects in air.
- The refractive index of water was determined to be 1.288, which is slightly lower than the commonly accepted value of 1.333. This discrepancy may be attributed to experimental uncertainties or variations in water purity.
- The refractive index of resin was found to be 1.542, which is consistent with the expected range for similar materials, validating the experimental methodology.

B. *Absorption Behavior of Materials*

The absorption coefficients for semi-permeable plates and glass were determined using the Beer-Lambert law. The results reveal the following:

- The semi-permeable plates exhibited a higher absorption coefficient ($\alpha = 0.1287\,\mathrm{m}^{-1}$) compared to glass, indicating stronger attenuation of light intensity. This behavior is expected due to the material's composition and structure.
- Glass, with an absorption coefficient of $0.0027\,\mathrm{m}^{-1}$, demonstrated minimal attenuation, consistent with its high transparency and low absorption properties.
- The linear relationship between $\ln T$ and distance x for both materials confirms the validity of the Beer-Lambert law in describing light absorption.

C. *Implications and Applications*

These findings have significant implications for both theoretical and practical applications:

- The accurate determination of refractive indices and absorption coefficients is crucial for designing optical systems, such as lenses, filters, and waveguides.
- Understanding the absorption behavior of materials aids in selecting appropriate materials for specific optical applications, such as minimizing losses in fiber optics or enhancing light trapping in photovoltaic cells.
- The experimental techniques demonstrated in this study can be extended to investigate other materials and wavelengths, providing a versatile framework for optical research.

D. *Limitations and Future Work*

While the results are robust, certain limitations should be addressed in future studies:

- The impact of reflected light was ignored in the absorption experiment, which may have introduced minor errors in the measured intensity values.
- The experimental setup could be improved by incorporating more precise measurement instruments to reduce uncertainties in Δx and x.
- Future experiments could explore the effects of temperature, wavelength, and material composition on light propagation and absorption.

E. Sources of Error

Potential sources of error include:

- Measurement inaccuracies in Δx and x,
- Detector sensitivity variations,
- Background light interference,
- Ignored reflection in the absorption experiment, which could affect the measured intensity values.

VII. Conclusion

The experiment successfully measured the speed of light and refractive indices in different media and determined the absorption coefficients for semi-permeable plates and glass. The results provide valuable insights into light propagation and absorption, with applications in optical system design and material analysis.

VIII. Additional Resources

For detailed information, including the Lab Manual, source code, and related experiments, visit the GitHub repository provided below or scan the QR code in Fig. 5.

Fig. 5: Access the GitHub repository for the lab manual, source code, and related experiments: https://github.com/ibeuler/LAB-Reports.

References

[1] ISTANBUL UNIVERSITY, *OPTICS LABORATORY EXPERIMENTS MANUAL*, Department of Physics.

[2] *Source code and additional experiments are available in the GitHub repository.* https://github.com/ibeuler/LAB-Reports