Optical index of refraction

J. Kade Minton '25, Brown T.W. Riggins '26, Oscar A. Servellon '26, and Hugh O. Thurman III

Department of Physics and Astronomy, Hampden-Sydney College, Hampden-Sydney, VA 23943

Abstract

Indices of refraction were measured through different-length fiber optics cables to evaluate the cable composition. A Time-of-Flight technique, which used a short pulse wave from a red LED, determined the speed of light through the respective material. Indices of 1.774 ± 0.0662, 1.6300 ± 0.0720, 1.7062 ± 0.0245, 1.7776 ± 0.0290 were observed. Then, observed values were compared to common polymers of the following indices: Plexiglass: n=1.489 | Polycarbonate: n=1.585 | Teflon: n=1.29. It was concluded that the composition of the optics cable must be polycarbonate because this was the nearest value to what was observed experimentally.

Background Information

Time-of-Flight (TOF) experiments are used in projects that utilize light (photons or lasers) to provide data on a separate variable that is of interest to the researcher. For instance, Terra and Hussein (2015) used this technique to find an accurate measurement of fiber optic (optical plastic) cables of various lengths with a known index of refraction for the material and using the C constant (speed of light).[1] From modern times [2] to as far back as 1675, scientists have been able to generate numerical data from experiments such as Ole Roemer's estimation of 200,000 km/s, or Hippolyte Louis Fizea's estimate in 1849 of 313,000 km/s.[3] For the variety of TOF experiment covered in this project, an oscilloscope is utilized to provide data for the time variable (in nano seconds). A speed of light apparatus (circuit) is calibrated to have a standard output voltage curve that is compared to an input voltage curve that is a generated signal that travels through the optical plastic. The start of the signal rises of the two curves are compared, and the discrepancy between them is the observed delay of the input signal through the optical plastic. This time delay, when placed against the C constant and the observed cable length, gives the index of refraction for the optical plastic in question. The calculated values of the indices are then compared to a list of known manufactures' indices for certain optical plastics. This allows for the rough identification of the material composing the fiber optic cables.

Materials and Methods

First, the length of all four cables (L1, L2, L3, L4) were measured five times each. The cable was moved to an open space and stretched taunt. While the cable was taunt, a measuring tape was stretched out beside the cable to get a value in meters. The average length for each cable was the lengths used for the index of refraction calculation. After the lengths were measured, an oscilloscope and a speed of light apparatus (circuit) were used to measure the time it takes for the short pulse red LED to go from one node to the other while traveling through an optical cable. To ensure that the data would be accurate, the speed of light apparatus had to be calibrated. To do this, a calibration cable that was a "0s delay" was attached and the knob on the speed of light apparatus was adjusted until the graph on the oscilloscope was zeroed. The graph was zeroed with the signal rise. Next, cables L1-L4 were each attached to the speed of light apparatus and 10 measurements of delay were taken, also from the signal rise. These delays were averaged for each cable and then used in the index of refraction calculations. With both lengths and time delays measured, all data acquisition was completed.

Analysis

Analysis began with the cable lengths for L1-L4. The resolution for these measurements was 0.001m, relative to the measuring tape. This means that the bias was 0.005m. For each cable, five measurements of length were made and then each had an average, standard deviation, random bias, systematic bias (0.005m), and finally a delta L or uncertainty. Observe Table 1. The average and standard deviation were calculated by definition. Then, the Del L Ran (random bias) was calculated using the 95% confidence interval multiplied by the

Trial	L1
1	4.482
2	4.482
3	4.476
4	4.484
5	4.482
Average	4.4812
Std	0.003033
Del L Ran	0.003766
Del L Bias	0.0005
Del L	0.003799

Table 1. Uncertainty for L1 lengths

standard deviation over the square root of the sample size: (2.776*Std.)/Sqrt(5). The Del L Bias (systematic bias) is 0.005m. Finally, the Del L or uncertainty was calculated by doing the square root of the sums for Del L Ran and Del L Bias: Sqrt((Del L Ran)^2 + (Del L Bias)^2). The same calculations were made for L1-L4.

Next, analysis of time delay measurements began. The time delay was noted by using an oscilloscope with a resolution of 1ns and a systematic bias of 0.5ns. Exact data was pulled from the oscilloscope by first calibrating the system which meant aligning the rise of the “reference” pulse and the rise of the “0s delay pulse.” Then, a cable would be connected to the system, and a pulse would appear on the oscilloscope. The rise of the newly inserted pulse would appear some horizontal distance away from the rise of the reference pulse. That horizontal distance, which appeared in the form of nanoseconds, was measured using the trigger on the oscilloscope. Note in Figure 1 the 57ns on the right side of the image.

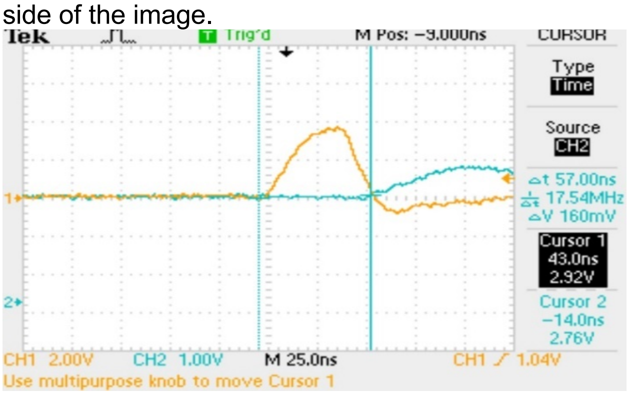

Fig 1. Oscilloscope Graph for L2

In this case, 57ns is the delay for that cable. For each cable, 10 measurements were made and had an average, standard deviation, random bias, systematic bias (0.5ns), and finally a delta T or uncertainty. The average and standard deviation were calculated by definition. Then, the Del T Ran (random bias) was calculated using the 95% confidence interval multiplied by the standard deviation over the square root of the sample size: (2.776*Std.)/Sqrt(10). The Del T Bias (systematic bias) is 0.5ns. Finally, the Del T or uncertainty was calculated by doing the square root of the sums for Del T Ran and Del T Bias: Sqrt((Del L Ran)^2 + (Del L Bias)^2). The same calculations were made for L1-L4.

Lastly, indices of refraction were calculated for L1-L4. The calculation used the speed of light (3.0*10^8 m/s) multiplied by the average time delay of that cable and then that quantity divided by the average length of that cable: ((c*average time delay of cable)/(average length of cable)). Take for instance the averages calculated in for L1. These values produced an index of refraction of 1.77 which can be seen in Table 2. Table 2 also shows the uncertainty associated with each index of refraction represented as Del N. These uncertainties were calculated using Del L and Del T across L1-L4.

Column1	L1	L2	L3	L4
IOR	1.77	1.63	1.71	1.78
Del N	0.0662	0.072	0.025	0.029

Table 2. Indices of Refraction and their respective uncertainties.

Results

The indices of refraction were 1.774 ± 0.0662, 1.6300 ± 0.0720, 1.7062 ± 0.0245, 1.7776 ± 0.0290 for L1-L4 respectively. These results were graphed in a scatter plot as can be seen in Fig 2. Also, because the average index was closest to the known index of polycarbonate (1.59), a percent error was calculated for each cable length with reference to polycarbonate which can be seen in Table 3.

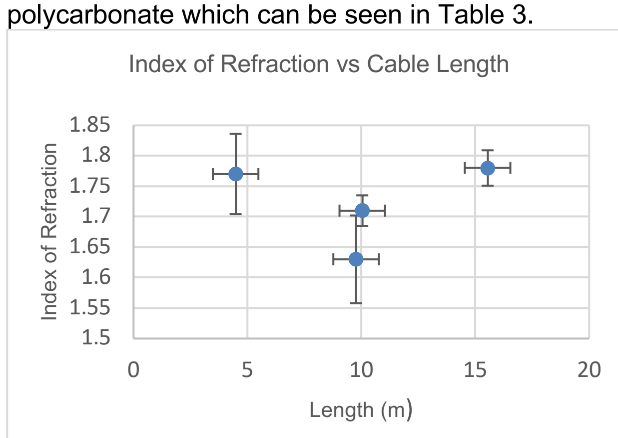

Fig 2. The four data point for cables L1-L4. The error bars come from the calculated Del N

Cable	L1	L2	L3	L4
% Error	10.16949	2.453988	7.017544	10.67416

Table 3. Percent Error of respective indices when compared to polycarbonate (n=1.59)

Discussion

The objective of this experiment concerned deducing the index of refraction of an unknown optical plastic found in several fiber optic cables of various lengths. A TOF experimentational method was chosen to generate data that could be used in indices calculations that additionally contained variables of cable length and the speed of light constant (C). Accurate index measurements of four (4) fiber optic cables were measured using a TOF technique. A setup consisting of an oscilloscope and a speed of light apparatus (circuit) connected to each of the four fiber cables was utilized to produce time values used in refractive index calculations for the optical plastic(s) in question. The generated calculations fall within an acceptable range of index values for the determination of the optical plastic to be made that the cable composition is most likely a polycarbonate plastic.

This experimentation setup could be improved by increasing the lengths of the optical cables to give a longer TOF delay, utilizing more accurately measured cables, and use of a higher definition oscilloscope, if available. Future work for this experiment could utilize the previously mentioned improvements as well as broadening the scope of the research to include different optical plastics covered in the study.

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