Lab 4: Reflection, Refraction and Polarization of Light

PH-2712 Section C1

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Introduction:

The purpose of this lab is to take advantage of multiple behavioral properties of light in order to determine the index of refraction in a piece of Plexiglass.

In Part A, the angles of reflection and refraction were measured in Plexiglass and then used to find the index of refraction. This took advantage of Snell's law and very directly calculated the index of refraction, having measured both the angles of incidence and refraction.

In Part B, Brewster's angle was determined experimentally and then used to determine the index of refraction. Reflection and Brewster's angle can be used to polarize light. By measuring the intensity of light and determining the point at which it is least intense, Brewster's angle can be found, as polarizing light results in it having lower intensity.

Analysis:

Part A:

Initial Data:

Table 1: Raw Data

Arrow, deg	Reflected beam, deg	Refracted beam, deg
15	30	185
20	40	188
25	50	189
30	60	190
35	70	193
40	80	195
45	90	197
50	100	199
55	110	201
60	120	204

Table 2: Adjusted Angles

Angle of Incidence, deg	Angle of Reflection, deg	Angle of Refraction, deg
15	15	10
20	20	12
25	25	16
30	30	20
35	35	22
40	40	25
45	45	28
50	50	31
55	55	34
60	60	36

Angular Uncertainty: 1 Degree

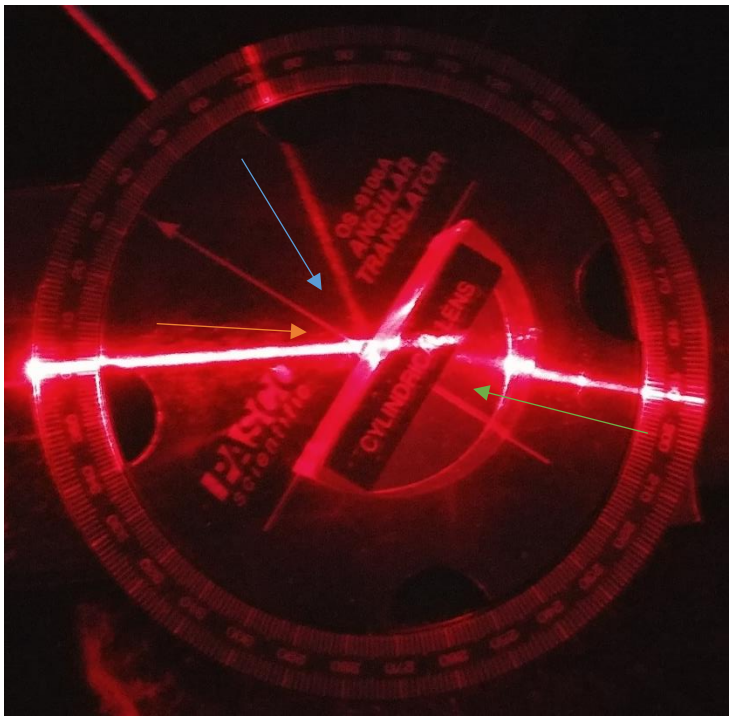

Figure 1: Image of Ray Table

Here, the blue line points at the angle of reflection, the orange line points at the angle of incidence, and the green line points at the angle of refraction.

$$Angle\ of\ Incidence = Angle\ of\ Arrow$$

$$Angle\ of\ Incidence = 15°$$

Figure 2: Equation for Angle of Incidence

$$Angle\ of\ Reflection = Angle\ of\ Reflected\ Beam - Angle\ of\ Arrow$$

$$Angle\ of\ Reflection = 30° - 15° = 15°$$

Figure 3: Equation for Angle of Reflection

$$Angle\ of\ Refraction = (180° + Angle\ of\ Arrow) - Angle\ of\ Refracted\ Beam$$

$$Angle\ of\ Refraction = (180° + 15°) - 185° = 10°$$

Figure 4: Equation for Angle of Refraction

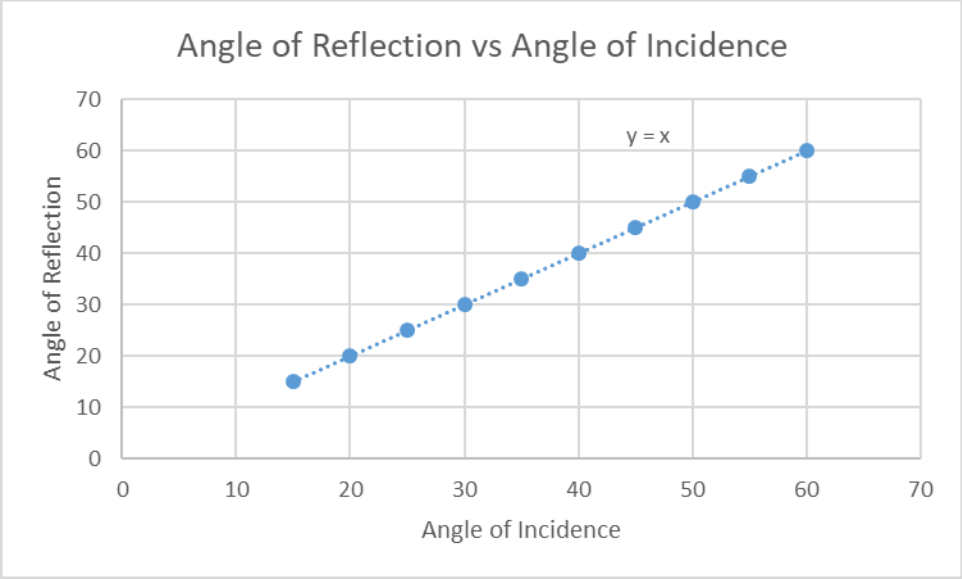

Figure 5: Angle of Reflection vs Angle of Incidence

Table 3: LINEST Results for Angle of Reflection vs Angle of Incidence

1	0
0	#N/A

Plotting the angle of reflection against the angle of incidence leads to a line with a slope of 1, indicating that the laser setup was correctly calibrated.

Best Estimate:

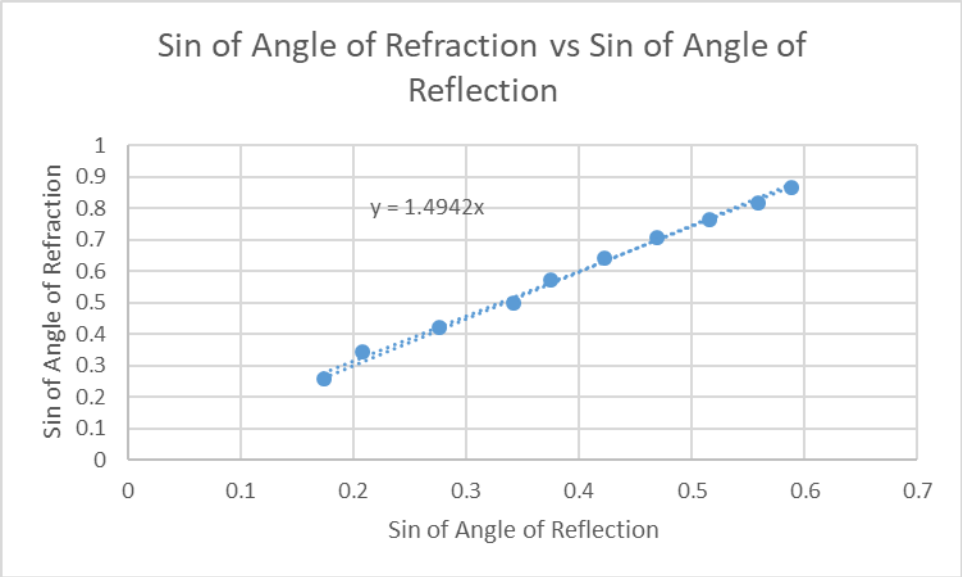

Figure 6: Plot of Sine of Angle of Refraction vs Sine of Angle of Reflection

Table 4: Angle of Reflection, Refraction, and their Sine Values

θ1, deg	θ2, deg	sin(θ1)	sin(θ2)
15	10	0.258819045	0.173648178
20	12	0.342020143	0.207911691
25	16	0.422618262	0.275637356
30	20	0.5	0.342020143
35	22	0.573576436	0.374606593
40	25	0.64278761	0.422618262
45	28	0.707106781	0.469471563
50	31	0.766044443	0.515038075
55	34	0.819152044	0.559192903
60	36	0.866025404	0.587785252

Table 5: LINEST Results of Sine of Angle of Reflection vs Sine of Angle of Refraction

1.494211705	0
0.011347213	#N/A

Error Evaluation:

According to LINEST, deltan = 0.011347213.

Part B:

Initial Data:

Table 6: Part B Intensities and Angle

Arrow, deg.	Intensity (light blocked), nA	Intensity (light unblocked), nA	Iθ, nA
46	0.00193	0.00619	0.00426
48	0.00192	0.00487	0.00295
50	0.00191	0.00383	0.00192
52	0.00193	0.00289	0.00096
54	0.001925	0.00259	0.000665
56	0.001925	0.00211	0.000185
58	0.001935	0.002187	0.000252
60	0.001905	0.002625	0.00072
62	0.00192	0.00417	0.00225
64	0.00192	0.005917	0.003997
66	0.00193	0.00855	0.00662

Table 7: Uncertainties in Part B Initial Data

Uncertainty (light blocked), nA	Uncertainty (light unblocked), nA	Δiθ, nA	Δθ, deg
2.75E-05	2.00E-05	3.40037E-05	1
3.00E-05	3.00E-05	4.24264E-05	1
2.70E-05	4.20E-05	4.993E-05	1
2.50E-05	3.80E-05	4.54863E-05	1
2.14E-05	3.60E-05	4.18803E-05	1
1.20E-05	1.80E-05	2.16333E-05	1
3.00E-05	1.90E-05	3.55106E-05	1
2.00E-05	2.50E-05	3.20156E-05	1
3.00E-05	6.50E-05	7.15891E-05	1
2.15E-05	2.20E-05	3.07612E-05	1
2.50E-05	3.10E-05	3.98246E-05	1

$$I_\theta = I_{unblocked} - I_{blocked}$$

$$I_\theta = 0.00619\,nA - 0.00193\,nA = 0.00426\,nA$$

Figure 7: Formula for Itheta

$$\Delta I_\theta = \sqrt{\Delta I_{unblocked}{}^2 + \Delta I_{blocked}{}^2}$$

$$\Delta I_\theta = \sqrt{2.00E-5\,nA^2 + 2.75E-5\,nA^2} = 3.40037E-5\,nA$$

Figure 8: Formula for Uncertainty in I Theta

Best Estimate:

Table 8: Light Intensity and Angle

Arrow, deg.	Iθ, nA
46	0.00426
48	0.00295
50	0.00192
52	0.00096
54	0.000665
56	0.000185
58	0.000252
60	0.00072
62	0.00225
64	0.003997
66	0.00662

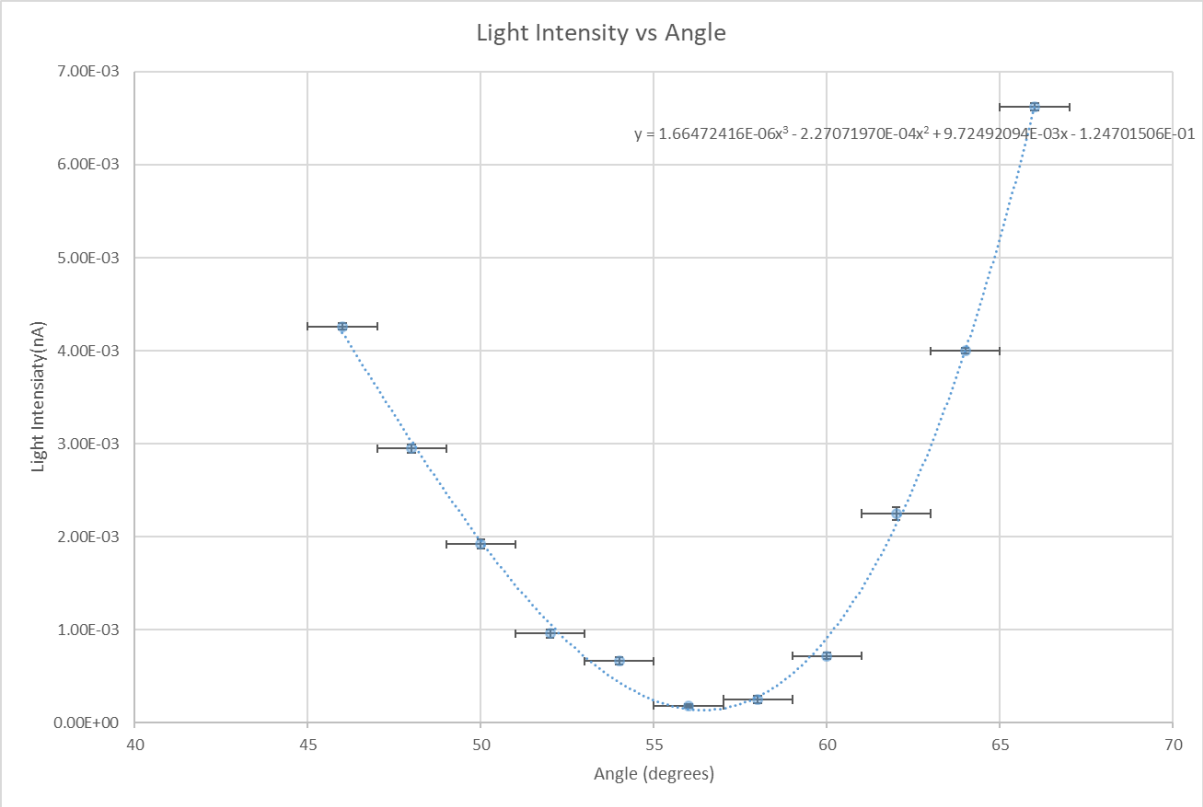

Figure 9: Plot of Net Light Intensity vs Angle

The minimum appears to be at approximately 56 degrees.

A third order polynomial was found to provide the best equation for a line of best fit, as it had an apparent minimum in line with the estimated minimum. The equation of that line is shown below in Figure 10: Equation for Best Fit Line.

$$y = 1.66472416 * 10^{-6}x^3 - 2.27071970 * 10^{-4}x^2 + 9.72492094 * 10^{-3}x - 1.24701506 * 10^{-1}$$

Figure 10: Equation for Best Fit Line

The minimum of the equation was found by calculating the zeros of the derivative of the equation. The derivative of the equation is shown below in Figure 11: Derivative of Best Fit Line, and its zeros were found to be 34.515 and 56.4233. The first zero was disregarded as it fell outside of the range of the data, meaning that the minimum of the graph was located at 56.4233 degrees, Brewster's Angle for this substance.

$$y = 4.99417 * 10^{-6}x^2 - 0.000454144\,x + 0.00972492$$

Figure 11: Derivative of Best Fit Line

$$n = \tan(\theta_B)$$

$$n = \tan(56.4233°) = 1.50644972$$

Figure 12: Calculations for Index of Refraction

Error Evaluation:

The error in Brewster's Angle was found by multiplying the value of the second derivative of the best fit line with the uncertainty in angle for the entire experiment.

$$\Delta\theta_B = 9.98834 * 10^{-6}\,\theta_B - 0.000454144\Delta\theta$$

$$\Delta\theta_B = 9.98834 * 10^{-6}\,(56.4233°) - 0.000454144(1°) = 0.00010943°$$

Figure 13: Formula for Uncertainty in Brewster's Angle

$$\Delta n = sec^2(\theta_B)\Delta\theta_B$$

$$\Delta n = sec^2(56.4233°)(0.00010943°) = 0.000357773$$

Figure 14:Formula for Uncertainty in Index of Refraction

Results:

Part A:

The index of refraction is 1.494 ± 0.011. $\frac{\Delta n}{n}$ = 0.0076 , 0.76%.

Part B:

Brewster's Angle is 56.42330 ± 0.00011°. $\frac{\Delta\theta_B}{\theta_B}$ = 1.9E-6, 0.00019%

The index of refraction is 1.50645 ± 0.00036. $\frac{\Delta n}{n}$ = 2.4E-4, 0.024%.

Conclusion:

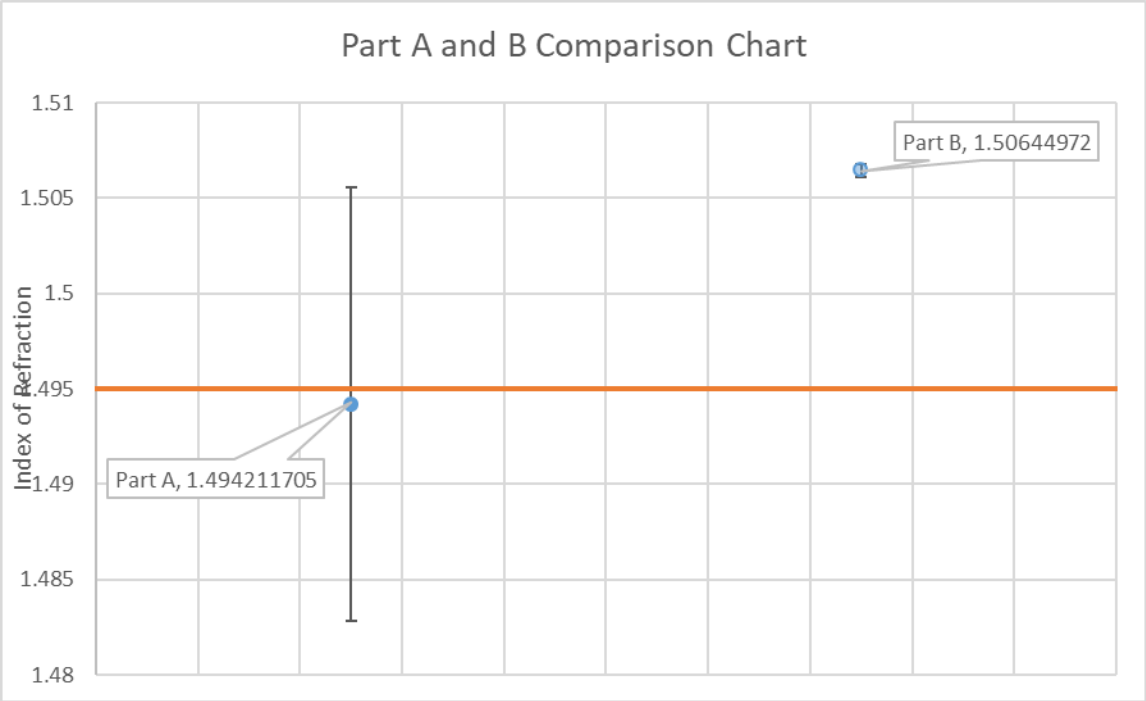

Figure 15: Comparison Chart

Research indicated an expected value of the refractive index for Plexiglass to be 1.495. The results from Part A of the experiment agree with this value, as the expected value is well inside the error bars for the value found in Part A. However, Part B does not agree with Part A or the expected value. This may be due to a miscalculation in uncertainty for Part B, as a larger value for uncertainty would potentially include the value from Part A and the expected value.

That said, the uncertainty for Brewster's Angle was very small, far smaller than the uncertainty of individual angles, suggesting that even a very small deviation in angle would have a large impact on results as uncertainty would not allow for results to overlap.

The equation for the best fit line was chosen because it was of odd order and appeared to have a minimum closest to the apparent minimum suggested by the data.