Experiment 10: Polarization

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Abstract

A laser, polarizer, and analyzer were used to test the law of Malus. Quarter and half-wave retardance were made using a LC cell. The refractive index of glass was found by finding the Brewster angle. The Law of Malus produced a cosine curve, the quarter-wave polar plot produced an elliptical plot of aspect ratio 2.15, the half-wave polar plot showed a plane of vibration to be at -45 degrees, and the Brewster angle was found to be 56.5 degrees, which helped calculate the refractive index of a prism glass to be 1.51.

1 Introduction

Light can be split and described by the electric, $\boldsymbol{E}$, and magnetic field, B, vectors. In this experiment, the magnetic field will be neglected. $\boldsymbol{E}$ is split into two perpendicular components of magnitude E_y and E_z, from this is known that the wave is travelling along the x direction. While the instantaneous electric field is difficult to measure, the intensity, I, is not, so this experiment will measure this quantity. A film polarizer can be used to plane-polarize the light from an initial random polarization to a transmission of $\boldsymbol{E}$ in any given plane and the absorption of the vibrations that are not in the plane. Adding another polarizer, called an analyzer, the absorption or reduction in the amplitude of $\boldsymbol{E}$ varies with the angle, α, between $\boldsymbol{E}$ and the analyzer axis. The intensity at $\alpha = 0$ is the law of Malus, which would produce the maximum intensity, I_0. It is possible to retard component of a wave using materials which have some unique direction in their structure. This creates a fast and slow axis in the polarizer, which causes light to experience different indices of refraction. It's possible then to make plates that retard the phase of the wave by different degrees such as $\pi/2$ or π, as well as a variable shifts using a liquid crystal. As unpolarized light is reflected from an interface, it becomes partially or completely polarized with the amplitude parallel to the plane of incidence being smaller than normal. At a certain angle, Brewster's angle ϕ_b, the reflected light is completely polarized normal to the incident plane as the components parallel to it are completely refracted.

1.1 equations

$$\boldsymbol{E} = E_0 sin(\omega t - kx) \cdot \hat{\boldsymbol{r}} \tag{1}$$

$$E_y = E_0 sin(\theta) sin(\omega t - kx) \tag{2}$$

$$E_z = E_0 cos(\theta) sin(\omega t - kx) \tag{3}$$

$$I = \frac{\epsilon v E^2}{2} cos^2(\alpha); I_0 = \frac{\epsilon v E^2}{2} \tag{4}$$

$$R_P = \frac{E_{PR}}{E_{PI}} = \frac{tan(\phi - \phi')}{tan(\phi + \phi')} \tag{5}$$

$$R_N = \frac{E_{NR}}{E_{NI}} = \frac{sin(\phi - \phi')}{sin(\phi + \phi')} \tag{6}$$

$$tan(\gamma) = \frac{E_{PR}}{E_{NR}} = -\frac{cos(\phi - \phi')}{cos(\phi + \phi')} \tag{7}$$

$$sin(\phi_B) = nsin(90 - \phi_B) = ncos(\phi_B) \tag{8}$$

$$tan(\phi_B) = n \tag{9}$$

$$tan(\phi_B) = tan(56.5^o \pm 1^o) = 1.51 \tag{10}$$

2 Experimental Procedure and Design

For the data collection parts of the experiment, LoggerPro was used with light sensors to detect each event as a point, instead of a time-based collection.

The steps taken were in parts below

1. For the first part of the experiment, the law of Malus was to be tested. The setup will consist of a polarizer and an analyzer between a laser and the light probe.

2. The measurements to be taken would be in steps consisting of different degrees of the analyzer angle. The intensity was recorded for a full analyzer rotation in increments of 10 degrees. The intensity was normalized and a graph was plotted with it and $cos(\alpha)$.

3. For the second part of the experiment a liquid crystal (LC) cell was placed between the polarizer and analyzer and an oscilloscope and LCC25 control unit connected to the cell. The cell has a "slow" axis and the polarizer and analyzers were set to zero degrees so that the estimated voltage could be set to 2.41V.

4. The polarizer was set to 45 degrees with respect to the LC cell, and the intensity was recorded by varying the analyzer fully in increments of 10 degrees. If the values did not vary, with rotation, then circular polarization was achieved and a phase shift of 90 degrees produced it. A polar graph of the intensity and analyzer angle was plotted to see what shape the graph forms.

5. Next, a half-wave retarder was created by setting both the polarizer and analyzer angles to 45 degrees with respect to the LC cell axis. The voltage from the control unit was adjusted until the intensity was minimized. Then again, a full analyzer rotation was made to collect the data and polar graph was plotted.

6. Finally, its time to determine the Brewster angle by reflecting a laser using a prism on an angular scale. A laser producing unpolarized light was used. The laser was aligned with the scale such that it was parallel with zero degrees. The prism was also parallel to the laser pointer, which makes the prism rotate with the angle of incidence, ϕ. As the scale is rotated the light is reflected and refracted, until at some angle the light disappears from the screen, which is the Brewster angle. The analyzer was placed between the screen and the prism, and was adjusted continuously with rotation to check the angle at which the light fades to zero. The scale was moved $\pm 10^o$ along with using a second polarizer in front of the laser to determine at what analyzer angle the light disappears off the screen.

3 Graphs

4 Results

Here you want to go through all of the finding of the lab. Present plots, show data tables, note any unexpected features of your data. The final results for the law of Malus produced a graph of cosine as seen in figure 1, which is consistent with the graph produced by equation 4. The resulting polar plot for the quarter-wave retarder can be seen in figure 2. The general shape of the graph is elliptical, with the aspect ratio of approximately 2.15, which is not the expected result of a circular plot with aspect ratio of 1. Next, the polar plot for the half-wave retarder was found to have a figure-8 pattern as seen on figure 3. The plot is consistent with what the theoretical plot should look like. The optimal voltage for the second part of the experiment was found to be 17.614V. From the plot, the final orientation of the plane of vibration is -45 degrees. Finally, the Brewster angle, ϕ_B, was measured to be 56.5 degrees, which resulted in an index of refraction of 1.51 for the glass prism using equation 9. The analyzer angle was determined to be 273 degrees at which the

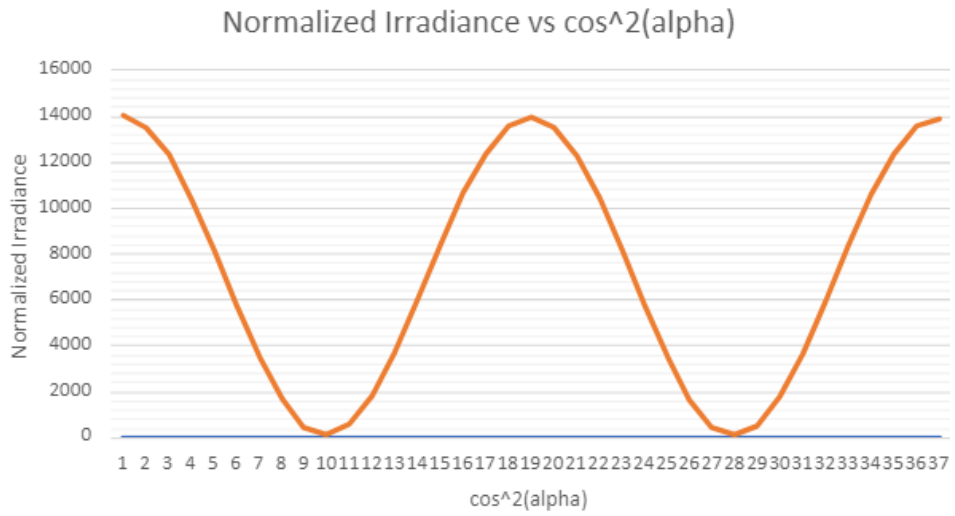

Figure 1: cosine curve resulting from the law of Malus

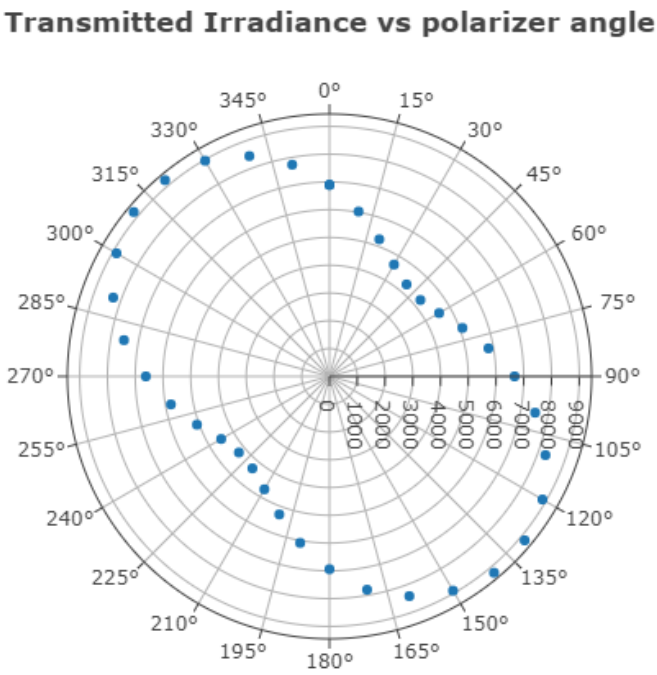

Figure 2: quarter-wave polar plot, aspect ratio = 2.15

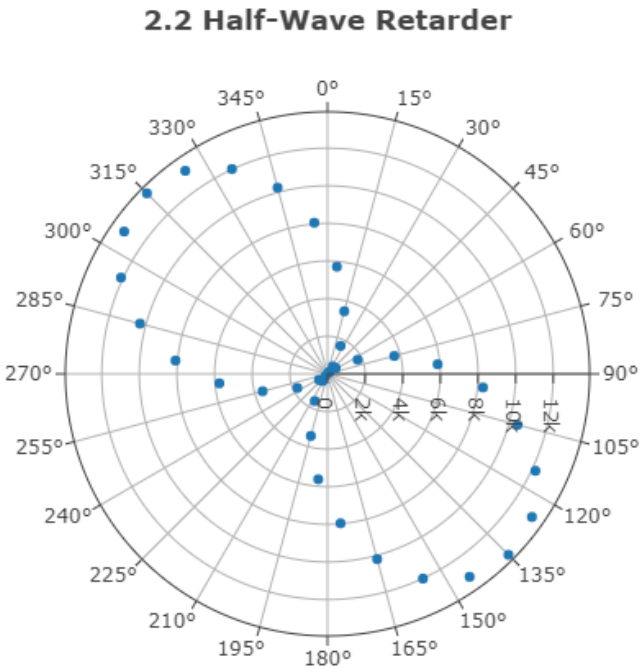

Figure 3: Half-wave polar plot, figure-8 shape

light vanished. The light disappeared at an analyzer angle of 286 and 284 degrees for -10 and +10 scale adjustments respectively.

5 Discussion

Aside from the quarter-wave retarder which was elliptical and not circular, the results for the other parts of this experiment matched what was expected. The half-wave retarder produced the figure-8 polar plot, which had the transmitted plane of vibration to be at -45 degrees. The the Brewster angle was found to produce a refractive index of 1.51 for the prism glass, which is consistent with the actual index that is typical for glass, 1.5. The elliptical graph for the quarter-wave retarder could potentially be explained by the experiment having an inaccurate value for the "optimal" voltage, of 2.41V. In another attempt at this part of the experiment, this voltage should be adjusted and checked to minimize the variance in intensity with the angle. If this is done then I predict the aspect ratio of the polar plot would be much closer to 1.

6 Conclusion

The results for most of the experiment matched expectations expect for the quarter-wave polar plot having an elliptical shape. As mentioned, this is likely to be fixed with varying the voltage to minimize variance in the intensity.

References

[1] D. Rosa. Physics 325, Laboratory Manual. University of Victoria, 2021.