Polarization and Interference
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I. Introduction

Polarization and interference are two fundamental concepts of wave mechanics that have been used to advance our understanding of the world in various ways. Among the different types of waves there are two essential types being longitudinal and traverse waves. Longitudinal waves have vibrations parallel to the direction of the wave, like sound waves, whereas transverse waves have vibrations perpendicular to the direction of the wave, like light waves.

Transverse waves exhibit polarization which refers to the axis of wave oscillation perpendicular to wave propagation. Most light we experience is unpolarized since it oscillates and propagates in random directions. For the polarization part of this experiment though we will use laser light to observe light waves undergoing to successive polarizations. We will observe the changes to the intensity of light as it passes through an analyzer which will demonstrate the relationship between intensity and angular orientation described by Malu's Law. We will also use Thomas Young's experimental set up on double and single slits to observe wave interference and destructive and constructive interference. The wavelength and slit width will be calculated and compared to the actual values. Our calculated values may be skewed due to background light in the experimental environment causing noise in the measuring device.

II. Method

For the first part of the experiment, we examined transverse light waves coming from a laser to observe the polarization of a wave. A laser was placed on a track near a light sensor with rotary motion sensor (RMS) at one end of the track between, and between the two were a polarizer and RMS. The light from the laser is passed through the polarizer made of polymer film.

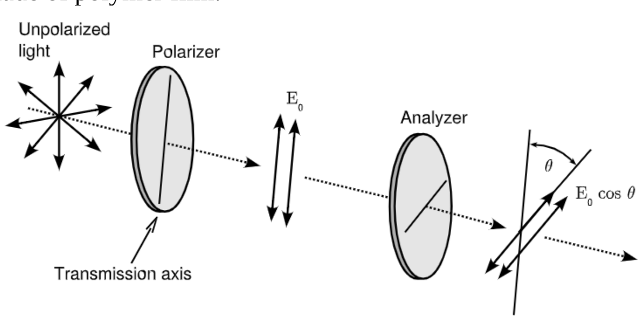


Figure 1: Creation and detection of polarized light

The oscillating parallel component of the electric field of the light is absorbed by the molecular chains of the polymer film allowing for only the perpendicular component to get transmitted. The intensity of the light prior to passing through the polarizer is proportional to $|E^2|$ which means we can describe the intensity of the transmitted light using Equation 1.

$$I = I_0 \cos^2\theta, \tag{1}$$

We first measured the intensity of the unpolarized light, I_o, with corresponding angular position, θ_o, using the data collection software on the computer. We then rotated the polarizer one full revolution while the intensity was measured for corresponding points. We recorded 20 of the measured data points from the revolution. We recorded angle θ as being the difference between the polarization directions of the laser and polarizer.

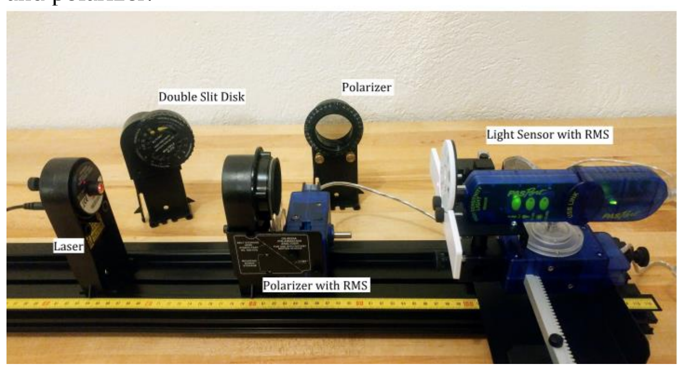


Figure 2: Equipment apparatus for Polarization observation

For the second part of the experiment where we observed interference the laser was placed all the way at the end of the track with the light sensor with RMS at the opposite end. A cardboard piece was placed between the laser and double slit as shown in Figure 3. The laser light was set up opposing the linear translator such that it went through the hole in the translator. The double slit disk was set to the position where a=0.04mm and d=0.25mm, and the distance, D, between the slits and the light sensor was 92.7cm. The wavelength of the laser was recorded as 650nm. The position of the laser beam was adjusted until it was as bright as possible on the light sensor.

Figure 3: Cardboard piece between laser and double slit

Wave interference can be totally destructive, totally constructive, or a mix of the two. Destructive interference decreases light intensity while constructive increases intensity. Using Thomas Young's double slit apparatus shown in Figure 4.

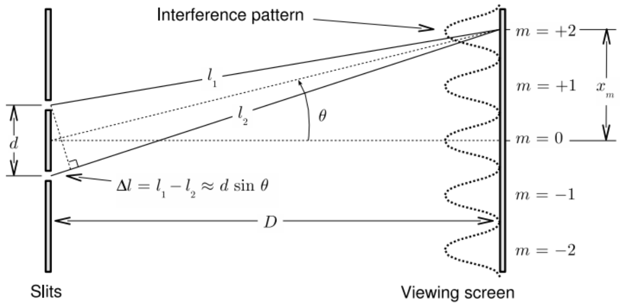


Figure 4: Thomas Young's double slit apparatus

Two slits are separated by a distance, *d*, along a screen where the incoming light hits. The outgoing light then travels along lines l_1 and l_2 as they approach the second screen distance D away from the first. As the light waves move along the two lines, they propagate at angle θ, so that Δl can be described using Equation 2.

$$\Delta l = d \sin\theta \tag{2}$$

Δl is what determines the locations of intensity maxima and minima. Intensity minima exist due to destructive interference where Δl is a half-integer multiple of the wavelength of light as described by Equation 3.

$$\Delta l = (m + \frac{1}{2})\lambda, \qquad m = 0, \ \pm 1, \ \pm 2 \ \ldots \tag{3}$$

Intensity maxima exist due to constructive interference where Δl is an integer multiple of the wavelength.

$$\Delta l = m\lambda, \qquad m = 0, \ \pm 1, \ \pm 2 \ \ldots \tag{4}$$

We can derive Equation 5 using Equations 2 and 4 to find the *m*th maxima such that *sin* θ and tan θ are equal.

$$x_m = \left(\frac{\lambda D}{d}\right) m \tag{5}$$

The double slit modulated by a single slit envelope results in intensittes that can be described by Equation 6, where *a* is the width of the slit, and Figure 5 where the intesnity is a funciton of angle θ.

$$I = I_0 \left(\frac{\sin\left(\pi a \sin\theta/\lambda\right)}{\pi a \sin\theta/\lambda}\right)^2 \tag{6}$$

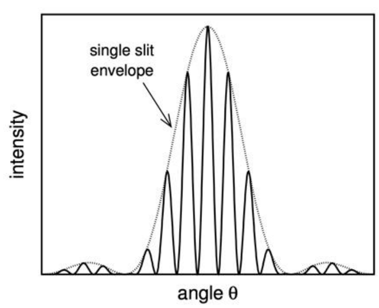


Figure 5: A graph of Intensity vs θ shows a double slit pattern modulated by a single slit envelope

Using this data, we can use Equations 7 and 8 to see the conditions met for there to be single slit minima at a particular position.

$$\frac{\pi a \sin\theta}{\lambda} = n\pi, \qquad n = \pm 1, \ \pm 2, \ \ldots \tag{7}$$

$$\sin\theta_n = n\frac{\lambda}{a} \tag{8}$$

And Equation 9 uses Equations 7 and 8 to show the position of single slit minima.

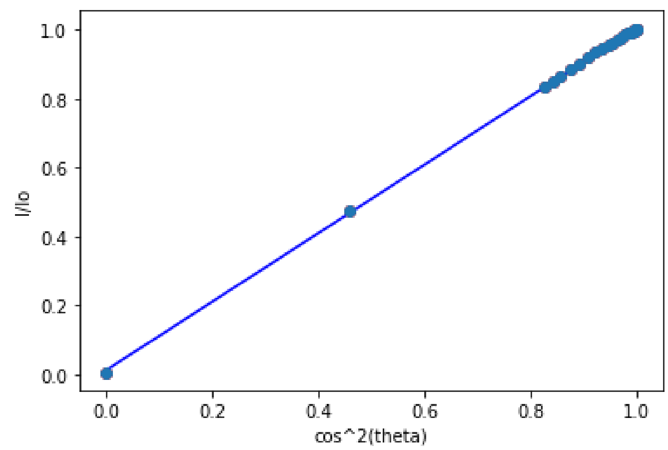
$$x_n = \left(\frac{\lambda D}{a}\right) n \tag{9}$$

The light sensor was moved from left to right when measuring data for the double slit and single slit envelope parts.

For the single slit envelope part, the set up was maintained, but the double slit was replaced with the single slit disk set at a *a=0.04*mm position. The minima positions were recorded a we took a screenshot of the overlapping graphs.

III. Results & Analysis

For the first part of the experiment when we observed polarization, we recorded one revolution's worth of data on the intensity and angle. Our maximum intensity I_o was 959.89 ± 0.01 W/m^2 with corresponding angle 190.40 ± 0.01^o. We subtracted the angle corresponding max intensity from each of our measured angles to get the angular difference between the polarization directions. We graphed variation in intensity, I/I_o, against $cos^2(\theta - \theta_o)$ using the 20 data points that we recorded to get the plotted data in Figure 6 with associated linear regression.



The slope of our graph was 0.993 ± 0.004 with a y-intercept of 0.0124 ± 0.004. The error bars on the graph are there but very small indicating that the relationship appears to be linear. This relationship agrees with Malu's Law which states that intensity is linearly proportional with $cos^2(\theta - \theta_o)$.

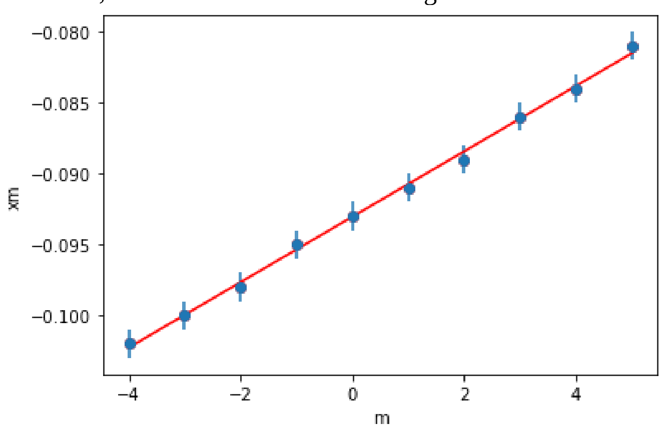
When the polarizer is at a 90^o angle relative to the maximum intensity the measured intensity, or noise of our measuring device, is 0.007 ± 0.004. If there was a reading of noise the expected intensity should be 0 since it would likely mean that two polarizers were placed at a right angle from each other not allowing for any transmitted light. Using our maximum intensity, we can find our signal to noise ratio of 137127.14. This means that the noise is insignificant to the maximum intensity.

The room was dimmed in order to reduce background light which could induce noise in the measuring device. In order to reduce background light further all lights in the room would have to be shut off to allow only the laser light to enter the polarizer. Noise cannot be eliminated completely though since experimenters would need to see the apparatus. Black lights can be used in order to allow for experimenters to visualize the apparatus under darker conditions. Beyond precautions taken to minimize black light in our experimental environment, we could account for noise in our data analysis by normalizing each intensity value to the determined noise measurement.

The y-intercept was not zero but zero was very close to zero especially given the standard error range. This supports the analysis that the plotted data represents a linear relationship between I/I_o and $cos\ (\theta - \theta_o)$ which supports Malu's Law.

If the same experiment was performed using an incandescent bulb instead of the laser there would be significantly different results in the data. The light from the incandescent bulb would be unpolarized and would undergo only one polarization.

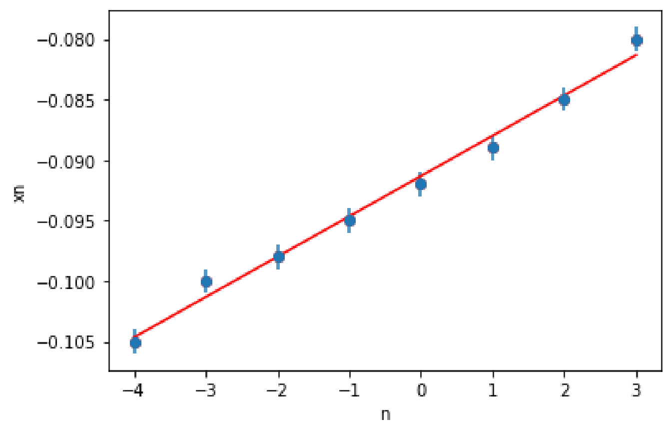
In the double slit part of the lab the positions of the maxima x_m and order number m were recorded and then plotted with a least squares analysis that had a slope of $2.31x10^{-3} \pm 0.04x10^{-3}$ and y-intercept of -0.093 ± 0.001. Using this value, we can calculate the wavelength to be 623 ± 10 nm.



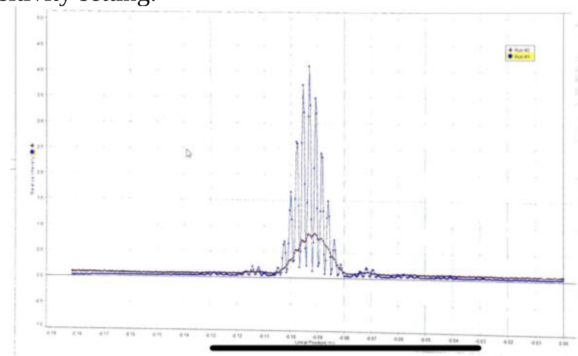
The known wavelength, 650 nm is not within the standard error, but is very close and could be slightly off due to background noise of the device caused by background light.

Some limitations of our measurement for wavelength could be that we couldn't variate our variables like increasing the slit width, d, or manipulating the wavelength of the laser. Being able to do this would increase the number of fringes shown in the central inference pattern. Decreasing the distance from the slits to the light sensor, D, could make the fringes shown be more frequent because they would be less spread out due to the increased maxima position x_m. Changing the distance between the laser and the slits on the other hand would not have a great effect on the results since the light would still travel the same distance to the two slits.

In the single slit envelope part of the experiment the positions of the diffraction minima x_n and order number n were recorded and plotted with a least squares analysis yielding a slope of $3.33x10^{-3}$ and y-intercept of -0.0913 which is very close to the measured -0.092 ± 0.001. We calculated our slit distance, a, using Equation 5 to be $1.73x10^{-4} \pm 0.08x10^{-4}$ with the actual value being 2.5x1.



Our error for both linear regressions is large which is likely due to the measuring device error having a high sensitivity setting.



As one can see by looking at the overlapped graphs shown in Figure 9 the envelopes have the same width but the double slit has much greater intensity values which is likely due to the greater degree of constructive interference stemming from the double slit.

IV. Conclusion

In this experiment we tested the changes to the intensity of light after passing through an analyzer utilizing Malu's Law to observe the data. The linear results from the polarization part confirmed Malu's law on the relationship between intensity and angular orientation. In the second part of the lab, we used Thomas Young's apparatus on double and single slits to observe interference. Our calculated wavelength value and slit width value did not agree with actual values in the diffraction and interference part of the lab. Our error likely stemmed from noise in the measuring device caused by background light which can be reduced in future iterations of the experiment by removing more light from the experimental environment and compensating for noise in data analysis.

References

[1] Department of Physics, "Experiments in Physics," Columbia University. New York, pp. 1 5 -22.