Polarization Experiment

Serdar Ali Andırınlıoğlu

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1 Introduction

Malus law gives the relationship between the intensity of light transmitted from the polarizer and the incoming light. In this experiment, the validity of this law is questioned.

2 Theory

According to the theory of electrodynamics, light is a wave formed by the distortion of the electric and magnetic fields. Maxwell's equation gives us the relationship between the propagating magnetic and electric fields. Traveling electric and magnetic waves can be represented as the following equation

$$\vec{E}(x,y) = E_{max}cos(kx - \omega t + \phi)$$
$$\vec{B}(x,y) = B_{max}cos(kx - \omega t + \phi)$$
$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$$

Where $\vec{S}$ is the poynting vector, represents the total intensity. Notice $\vec{E}$ is proportional to $cos(\theta)$. The time average for the intensity gives the following equation[1]

$$I\langle t\rangle = \langle S\langle t\rangle\rangle = \frac{1}{2c\mu_0}{E_0}^2 \tag{1}$$

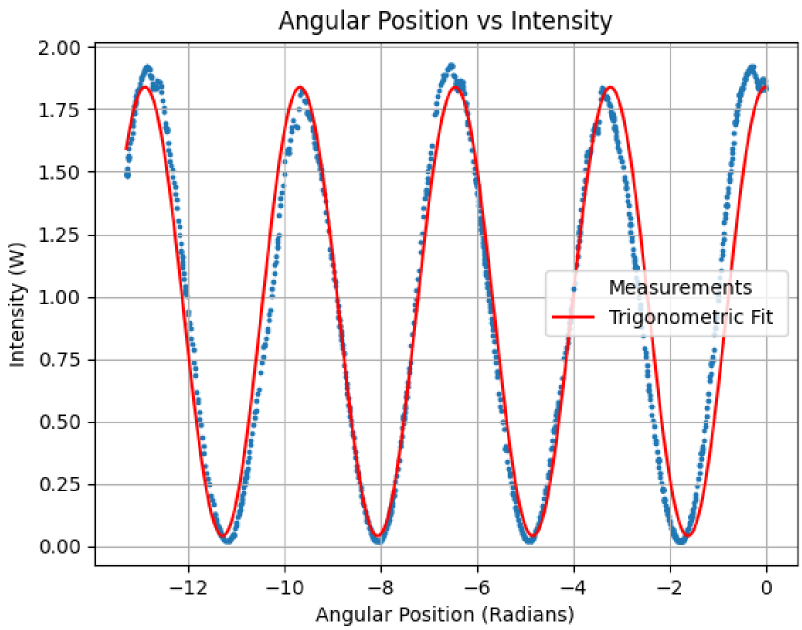
The polarization direction of the electromagnetic wave is the propagation plane of the electric field. A polarizer only passes the unpolarized lights propagation direction parallel to its transmission axis. Thus when unpolarized light is passing through the polarizer, the maximum amplitude of the electric field is simply the projection of the electric field vector to the transmission axis, i.e $E = E_0 cos(\theta)$. And by (1) we get the following result called Maulus Law:

$$I = I_0 cos^2(\theta) \tag{2}$$

Where θ is the angle between the transmission axis and the polarization direction of the light. In the experiment, an unpolarized light source was directed to the first polarizer to make the light polarized in the direction of the first polarizer's transmission axis. Then analyzer is rotated slowly counterclockwise. At the end of the analyzer, a power meter is placed. With the 20 measurements per second rate, the detector recorded the data of the radial position of the analyzer and the power input. According to the eq.2, a sinusoidal relationship between the rotation angle and light intensity must be observed.

In the second part of the experiment, the velocity of the wave in a dielectric medium is being measured.

3 Results



For the calculation of the trigonometric fit, candidate function was $asin^2(bx)+c$ and the coefficients a,b,c was approximated using a non-linear least squares method, namely curve-fit[2], in the *scipy* library (see appendix A). The result of the candidate function is as following:

$$a = -1.797$$
$$b = 0.974$$
$$c = 1.838$$

4 Discussion

Since the rate of collecting data was chosen to be 20 per second there is an uncertainty due to the measurement device. By looking at the graph it can be seen that the intensity is never zero. But according to Maulus law (2) when the angle is a multiple of $\frac{\pi}{2}$ the cosine term in the equation must be zero since $cos(\theta) = 0$ when $\theta = n\frac{\pi}{2}$ where $n \in N$. From this result, it can be concluded that the polarizers that have been used in the experiment were not ideal polarizers. Also, it should be pointed out that this result might also be caused by the fact that in the laboratory there is ambient light which causes a driving current in the power detector. Other than this, the sinusoidal relationship between the angle θ and intensity has been observed as Maulus law (2) suggested. So it can be said that the light is polarized linearly after passing through the first polarizer.

5 References

1) Hecht, Eugene (2002). Optics. Addison-Wesley. ISBN 978-0-321-18878-6.
2) https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.curve$_fit.html$

A Python Code

```
import matplotlib.pyplot as plt
import numpy as np
import csv
import pylab
from scipy.optimize import curve_fit

x = []
y = []
# .txt file first turned to .csv. I erased the first unnecessary column.
with open('New OpenDocument Spreadsheet.csv', 'r') as csvfile:
    plots = csv.reader(csvfile, delimiter=',')
    for row in plots:       # using for loop i put the values is the empty arrays x,y
        y.append(float(row[0]))
        x.append(float(row[1]))

plt.scatter(x, y, s=3, label='Measurements')
plt.xlabel('Angular Position (Radians)')
plt.ylabel('Intensity (W)')
plt.grid()
plt.title('Angular Position vs Intensity')
plt.legend()


# candidate function asin^2(bx) + c
def objective(x, a, b, c):
    return a * (np.sin(b * x) * np.sin(b * x)) + c


popt, lak, = curve_fit(objective, x, y)  # non-linear least squares method in scipy library
# summarize the parameter values
a, b, c = popt
print(popt)

x_line = np.arange(min(x), max(x), 0.01)
y_line = objective(x_line, a, b, c)

plt.plot(x_line, y_line, color='red', label='Trigonometric Fit ')
plt.legend()
plt.show()
```