

Analyzing Malus' Law and the Polarization of Light

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Malus' Law, which relates light intensity to polarization, was analyzed and confirmed in this experiment. This was accomplished in the lab by using a series of polarizing filters to measure light intensity at various polarizing angles.

I. Introduction

A. Polarization of Light

The classic wave theory of light models light as a transverse electromagnetic wave. This means the direction of oscillation is always perpendicular to the direction of propagation for the light wave. Due to the nature of transverse waves, light can be *polarized*. Linear polarization, the phenomena of study in this experiment, is said to occur when the direction of oscillation of light waves are confined to only one direction.

While most light sources, such as lamps and sunlight, emit unpolarized light – that is, the directions of oscillation are random – light waves can be polarized using a special filter known commercially as a *Polaroid*. A Polaroid filter blocks out light oscillating in all directions except for one, known as the direction of polarization.

B. Malus' Law

When two pieces of Polaroid are placed in succession along the path of a light wave, the intensity of light received behind the two Polaroids is described by Malus' Law. The law expresses light intensity, I , as a function of the angle θ which is the angle between the direction of polarization of the two filters. The law can be expressed as follows:

$$I(\theta) = I_{max} \cos^2 \theta \quad [1]$$

where I_{max} is the light intensity between the two sheets of Polaroid.

II. Apparatus

To measure the effects of polarization on light intensity, an optical bench was arranged such that a tungsten light source at one end shone a beam of light towards a photodiode at the other end. The

photodiode was connected to an ammeter, from which measurements were read. A diaphragm and lens placed in front of the light source was used to focus the light onto the photodiode. Polaroid sheets mounted on rotating dials marked with angles of rotation were placed in between the lens and photodiode as needed in the experiment.

III. Results

A. Two Successive Polarizers

In the first of two experiments, two Polaroid sheets – the first labeled “*polarizer*” and the second “*analyzer*” – were placed in succession. The polarizer was set at an angle designated 0° . The analyzer was then set at angles relative to the polarizer between 0° and 90° at 5° intervals. The light intensity measured for these trials is graphed in Fig. 1, along with the function given by the theoretical predictions of Malus' Law.

It was observed that the experimental results agreed with the theoretical values to a significant degree. The data points from the experimental data followed the same general trend as the theory predicted. However, the data did not completely fit the theory given the error values assigned during the experiment. In hindsight, it is possible that the error values used were too optimistic for the laboratory conditions. The error values used to obtain the error bars in Fig. 1 were from the precision of the measuring equipment. It is likely, however, that other error factors were more significant than the precision error of the equipment.

Sources of error in this experiment included human error in setting the polarization angle by hand, light lost through the photodiode, as well as

slight variations in ambient lighting that may have skewed the light intensity measurements.

Given greater error values to account for some of the above factors, the experimental data would indeed agree with predictions from Malus' Law.

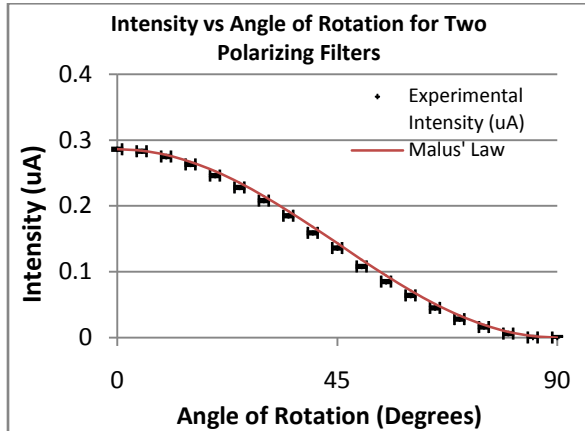


Fig. 1: Light intensity as a function of angle of rotation for two polarizing filters. I_{max} for Malus' Law was measured at 0.286 uA during the experiment.

B. Three Successive Polarizers

In a second experiment to confirm Malus' Law for systems involving more than two successive polarizing filters, a third Polaroid – labeled “insert” – was placed between the polarizer and analyzer.

In the first part of this experiment, the polarizer and insert were set at an angle 45° relative to each other. The analyzer was then rotated at 15° intervals from –90° to 90° relative to the polarizer. Light intensity measurements from this experiment were plotted in Fig. 2.

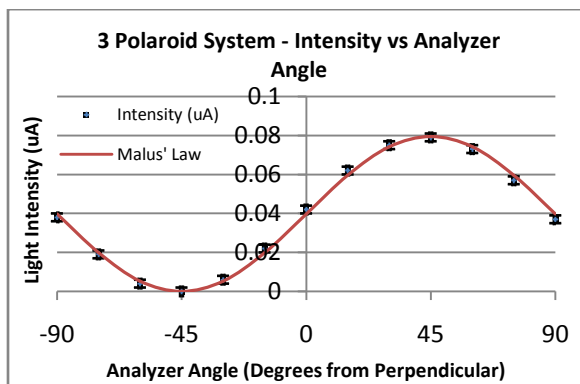


Fig 2: Light Intensity as a function of angle of analyzer relative to polarizer. $I_0 = 0.159$ uA for fitted Malus' Law curve (see equation [2]).

The resulting plot shows a sinusoidal wave that appears similar, but not exactly, like the relationship described by Malus' Law. In this case, Malus' Law cannot directly be applied to the angle between the polarizer and analyzer, since a third Polaroid was inserted between them. Instead, Malus' Law must be applied twice – once for the first pair of Polaroids, and again for the second pair.

Applying the equation twice, an expression can be derived for the system of three Polaroids, as follows:

$$I(\theta_2) = I_0 \cos^2 \theta_1 \cos^2 \theta_2 [2]$$

where θ_2 is the angle between the analyzer and insert, θ_1 is the angle between the polarizer and insert, and I_0 is the light intensity after the first polarizer. In this particular experiment, θ_1 was set at a constant 45°.

Given this relation, Malus' Law can then be applied to the three polarizer system. Equation [2] was fitted to the data, plotted in Fig. 2. The plot shows a good match with the equation, fitting within the error of the experiment. Some errors such as ambient lighting, human error, and systematic errors were still present as in part A – but did not affect the results greatly.

A second part of this experiment was conducted. In this part, the insert was rotated instead of the analyzer. It was noted that equation [2] succeeded in describing this modified experiment as well as it did in the first part.

This result suggests that Malus' Law can be applied to any system of successive linear polarizers, so long as the system can be broken down into pairs of polarizers which follow the more general form of Malus' Law described in equation [1].

IV. Conclusion

This experiment has experimentally confirmed Malus' Law for light intensity passing through two polarizers within reasonable errors. Further, it has been shown that Malus' Law can be applied to systems of three polarizers by applying the general law on the system twice (one for each pair of polarizing filters), and it is likely that this trend can be extended to systems with greater than three polarizers.