Malus's law of light polarization using a Computer-Based Laboratory

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Abstract

An experimental arrangement based on computer-controlled data acquisition system was used to measure the light intensity transmitted through two polarizers and the angle, θ, of the axes of the polarizers. The setup was proposed to physics undergraduate students to do real hands-on experiment where real-time display of the experimental data facilitates the analysis and interpretation of the results. The excellent quantitative and qualitative results are reported and compared with the exact theory of Malus's law. The slope of the plotted data of light intensity versus $\cos^2\theta$ has an uncertainty within 0.8% of unity.

Keywords: Light polarization, Malus's law, Computer-based laboratory.

Resumen

Se utilizó un arreglo experimental basado en un sistema de adquisición de datos controlados por computadora para medir la intensidad de la luz transmitida a través de dos polarizadores y el ángulo, θ, de los ejes de los polarizadores. La instalación se propuso a estudiantes de física para hacer prácticas reales en donde se muestra la adquisición de datos experimentales en tiempo real que facilitan el análisis y la interpretación de resultados. Los excelentes resultados cuantitativos y cualitativos son reportados y se comparan con la teoría exacta de la ley de Malus. La pendiente de la traza de datos de la intensidad de la luz contra el $\cos^2\theta$ posee una incertidumbre en el 0,8% de la unidad.

Palabras clave: Polarización de la luz, ley de Malus, Laboratorio basado en computadora.

I. INTRODUCTION

Sensors attached to a computer are being used in most experimental physics and chemistry research laboratories. These sensors create a very powerful system for the collection, analysis and display of experimental data. In this paper, hands-on experiment combined with a computer-based acquisition system was used to investigate the Malus' law of polarization.

In this activity, we worked with different experimental arrangement relative to the one described in literature [1]. A diode laser instead of a basic optic light source and a collimating lens divergent of 10 cm focal length [2] were introduced to the experimental setup in order to obtain qualitative and quantitative measurements of Malus' law of polarization of light.

A light from diode laser source was passed through two polarizers. As the second polarizer, analyzer, is rotated by hand, the relative light intensity is recorded as a function of the angle between the axes of polarization of the two polarizers. The angle was measured using rotary motion sensor coupled to the polarizer with a drive belt. The plots of light intensity versus angle, the intensity versus cosine angle and the intensity as a function of cosine^2 angle were fitted. The experimentally result was matching the predicted relationship between the polarization direction of the light and the intensity of that light transmitted through a second polarizer. The plotted data of the intensity versus the $\cos^2\theta$ was representing a linear regression having a slope within an uncertainty of 0.8 % of unity.

We believe that the experimental setup, employing polarization analyzer system coupled with a computer using Datastudio software and *Science workshop 750 interface* supplied by PASCO [3], could be very useful and practical to physics students undertaking this kind of laboratory experiment to get satisfactory results.

II. THEORY

When unpolarized light is incident on an ideal polarizer, the intensity of the transmitted light is one-half of the incident light. A diode laser was used as the light source for this experiment. This light is already polarized, so most of the light will pass through a polarizer oriented with its axis of polarization parallel to that of the laser. If the light is transmitted through the second analyzer, polarizer, which is rotated by an angle of 90° of polarization from that of the first, in this case no light will be transmitted. In the case, where the second polarizer is placed parallel to the first polarizer, the angle of polarization is 0° with respect to the first, essentially all of the light will be transmitted.

If θ is the angle difference between the direction of polarization of the light incident out the analyzer and the direction transmitted by the analyzer, the component of the electric field transmitted will be proportional to cosθ, as shown in Fig.1. Since the intensity of the light is proportional to magnitude of the electric field squared, the intensity of light transmitted by the analyzer is given by.

$$I(\theta) = I_0 \cos^2(\theta).$$

Where I_0 is the maximum intensity transmitted when $\theta = 0$. This is known as Malus' Law.
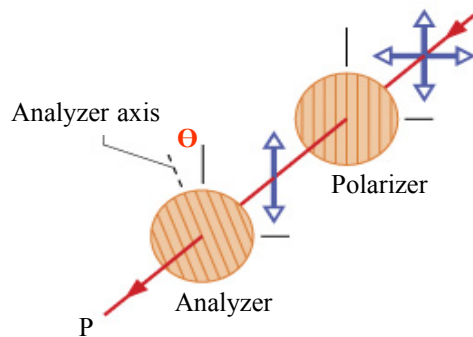

FIGURE 1. Schematic diagram of the setup used to study Malus's law. An unpolarized light beam passes through a polariser and then through an analyzer. The axis of the two Polaroid sheets are at an angle Θ. After Halliday, Resnick and Walker Fundamentals of Physics.

III. EXPERIMENTAND PROCEDURE

The components of the experimental arrangement were supplied by PASCO Scientific and mounted on an optical bench, as shown in figure 2. The apparatus of the setup are: a light source diode laser, collimating lens divergent, two polarization analyzers, rotary motion sensor, aperture bracket and light sensor.

A collimating lens divergent was inserted between the light source and the first polarizer in order to produce a narrow beam of parallel light ray. The optimum positions of collimating lens divergent, polarizer, analyzer, aperture bracket with light sensor, relative to the light source, were 40, 55, 60 and 100 cm, respectively.

In the Experiment Setup window, the rotary motion sensor and the light sensor were selected and connected to Digital Channel 1 and 2 and Analog Channel A of the *750 interface*, respectively. A high resolution, 1440 divisions per rotation, was setup for the rotary motion sensor and a *Large Pulley (Groove)* was selected for the linear calibration. The sample rate was set to 20 Hz.

The relative intensity of light beam that passes through two polarizers was measured by the light sensor. The rotary motion sensor measures the angle that was obtained from rotating the second analyzer relative to the first polarizer. The light sensor and the rotary motion sensor were connected to the computer via *Science Workshop* 750 *interface*.

The Datastudio software of PASCO Scientific records and displays in the computer the light intensity and the angle between the axes of polarizers. By using the *built-in experiment calculator* we can achieve the functions of the light intensity with respect to the *angle*, the *cosine of the angle*, and the *cosine² of the angle*.
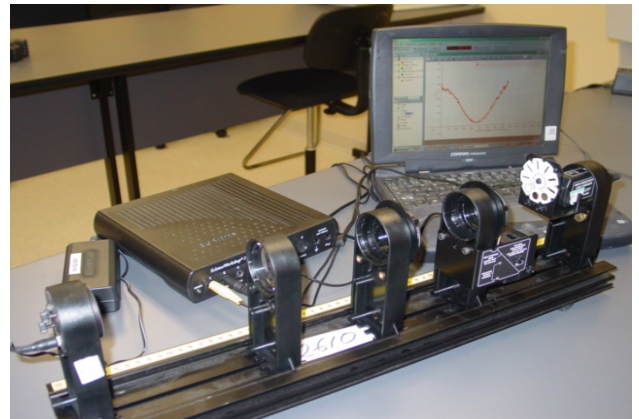

FIGURE 2. Photograph of the experiment setup. The apparatus are, from left to right, Basic optic diode laser, Collimating lens divergent, first polarizer, second polarizer (Analyzer) with rotary motion sensor and aperture bracket with light senor.

IV. RESULTS AND DISCUSSION

Experimental results representing the light intensity versus the angle (θ), the cosθ and the cos² θ are shown in figure 3, 4 and 5, respectively. The shape of the graph of the intensity versus the angle is sinusoidal, as seen in figure 3. This was obtained by positioning both polarizers at the same angle, zero degree, and then one polarizer is rotated from 0° to 360°. The maximum and minimum light intensity corresponds to 0° and 180°, 90° and 270°, respectively.

The experiment calculator in *Datastudio software* was used to create a calculation of *cosine* of the angle and the *cosine²* of the angle between the polarizers. A Graph display was used to examine the plot of light intensity versus the *cosine* and the *cosine²* of the angle. The shape of the graph, fig. 4, representing the intensity of light as a function of cosine of the angle between the polarizer and the analyzer is a curve.

As can be seen from this graph, the intensity of polarized light was maximum at (-1) and (+1) corresponding to cos (180°) and cos (0°), respectively. The minimum of polarized light intensity was at zero which corresponds to cos (90°). The *best-fit* of this curve was a polynomial function of the form: $Y = A + Bx + Cx^2 + Dx^3$. The values of the parameters A, B, C and D are given in the graph.

The plot of the intensity of light versus the cosine² of the angle between the two polarizers, fig.5, demonstrated perfectly the predicted relationship of Malus' law. The plotted data was representing a linear regression having of a slope, m = 53.9.0±0.37 and a correlation coefficient of 0.992. The uncertainty in the slope was within 0.8% of unity.

The curve fit for the polynomial function indicated that the light intensity varied as the square of the cosθ. This is confirmed by the curve fit for the linear function when light intensity is compared to the square of cosθ.

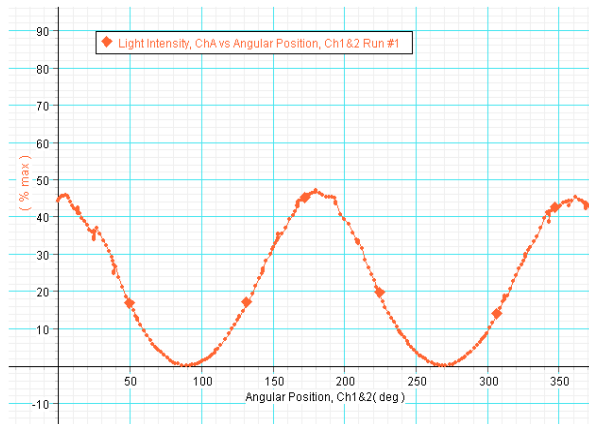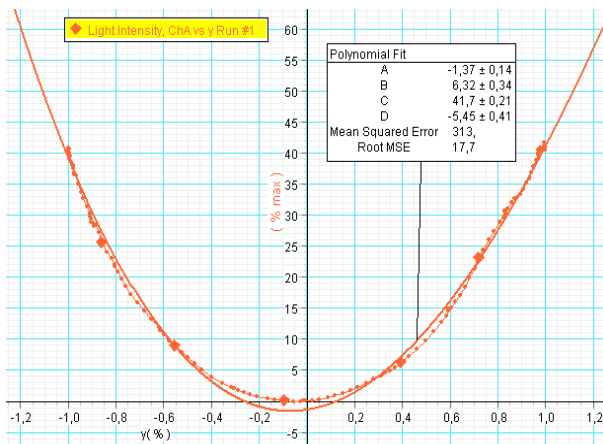**FIGURE 3.** Light intensity I as a function of the angle, θ.

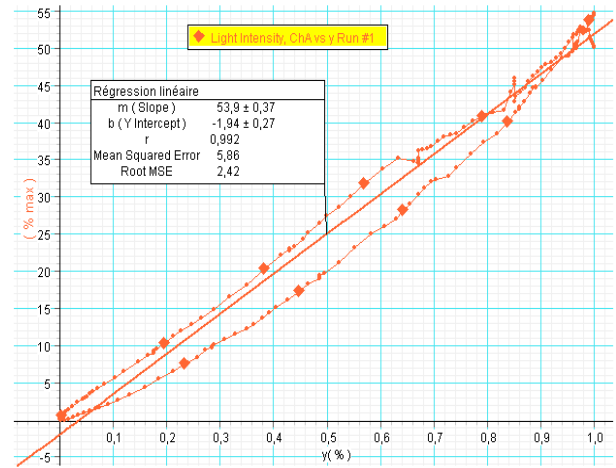

FIGURE 4. Light intensity as a function of cos θ.

FIGURE 5. Light intensity as a function of cos² θ.

V. CONCLUSION

We have demonstrated the Malus' law of polarization of light by means of computer-based acquisition data system using *Datastudio* software, *Science workshop* interface and accessories supplied by PASCO Scientific. The experimental results agreed well with the predicted relationship between the polarization direction of light and the intensity of that light transmitted through a second polarizer. This experimental setup is appropriate for undergraduate physics laboratory to investigate the light transmission through two polarizers. We believe that this laboratory experiment could be achieved using software programs and apparatus which are made by other companies.

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