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DESIGN OF AN OPTICAL ROTATION VALUE MEASUREMENT TOOL USING AN ARDUINO DEVICE

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Abstract: Malus' law asserts that the square of the cosine of the angle formed between two polarizers is directly proportional to the light intensity after passing through them. In this study, we demonstrate this law using a straightforward configuration. Our method of measuring the polarizer's rotational angle while keeping the other polarizer stationary is innovative. It involves manually attaching a multi-turn potentiometer to one of the polarizers. The Arduino board is connected to the potentiometer and light sensor used to detect the intensity of transmitted light, allowing for the measurement of light intensity as a function of rotational angle. Additionally, we think that the configuration as it is now can be helpful in physics laboratory classes. It can also be demonstrated by using it during lectures.

Keywords: *Malus' Law, Arduino, Polarizer, Physics Laboratory*.

INTRODUCTION

One way to measure optical rotation is with a polarimeter [1]. Polarimeters were introduced in 1840 [2]. Polarimeters work on the principle of the polarization of light [3]. The natural light beam is passed through a polarizer to become linearly polarized light [4]. Then, this light is passed to the analyzer. When the analyzer is rotated, the intensity of light coming out of the analyzer changes [5]. This change depends on the axis position of the polarizing analyzer [6]. When the polarization axis of the analyzer is parallel to the polarization axis of the polarizer, the intensity of light that comes out of the analyzer is maximum [7]. Conversely, if the polarization axis of the polarizer is perpendicular to the polarization axis of the analyzer, the intensity of light that comes out of the analyzer is minimal [8]. Therefore, the direction of light polarization is determined by rotating the analyzer until the maximum light intensity is found [9].

Based on how the polarimeter works, the polarimeter can be used to determine the angle of optical rotation [10]. To determine the angle of optical rotation, the polarization direction of light must be determined first as a reference [11]. After the reference is determined, an optically active solution is placed between the polarizer and the analyzer [12]. The intensity of light from the analyzer is observed to decrease [13]. This event indicates that the direction of polarization of light is changing [14]. The polarization direction of this light changes because it is rotated by an optically active solution [15]. This rotation of the direction of polarization of light is called optical rotation [16]. In order to ascertain the amount of the optical rotation angle, the analyzer is then adjusted until the point of maximum light intensity is achieved [17]. The analyzer's rotation angle to the reference is the optical rotation angle [18]. Measurement of the angle of optical rotation using a polarimeter is done visually so it is difficult to do because of the limited ability of the eye [19].

In their experiment, the sensor can automatically collect data on the light intensity, but the polarizer's angle must be manually measured [20]. Alternatively, a smartphone can show how the transmitted intensity and angle are related [21]. Other methods include electronically controlling the angle with a step motor [22], albeit this is a more difficult technical solution [23]. Here, we propose a method for employing sensors and an Arduino board to gather the inputs' angle and strength. It is only one of the several physics experiments that can be carried out using an Arduino in conjunction with sensors and electronic components.

RESEARCH METHOD

The essential tools for observing Malus's law are a light source, two polarizers, and a detector. Our system uses a lux meter (model BH1750) as the detector and a laser pointer as the light source. The polarizers came from an old LCD. One is fastened to a support, and the other is circle-cut and fastened to a handcrafted wooden pulley. A drive belt mechanically connects the pulley to a potentiometer with many turns (a rubber band) [24]. A

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potentiometer may be calibrated to measure the polarizer angle. Figure 1 depicts the fundamental configuration.

The used circuit diagram is shown in Figure 2. An Arduino Nano board is coupled with a push button, a multi-turn potentiometer, and a lux meter. There are five electrical connectors on the BH1750 lux meter, but we only use four: VCC (3.3 V), GROUND, SCL, and SDA. The Arduino's analog ports, A5 and A4, are connected to the SCL and SDA terminals, which are utilized for communication [25]. The push button is connected to the D2 digital port in series with a 10-k resistor, while the potentiometer is attached to the A7 analog port.

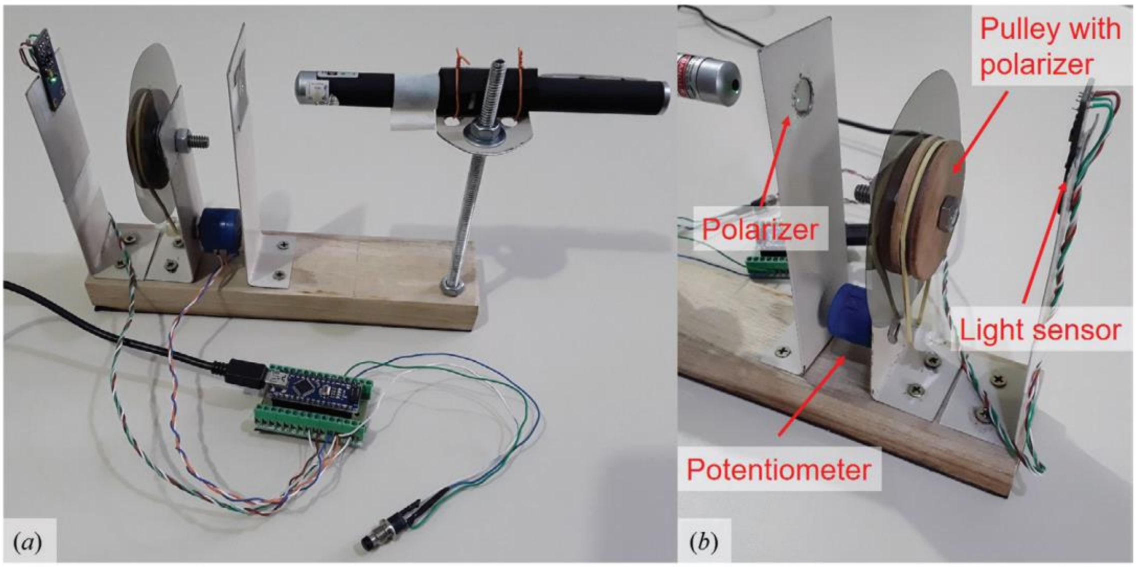

Figure 1. (a). An illustration of the testing equipment. (b). A close-up of the polarizer, pulley, and potentiometer.

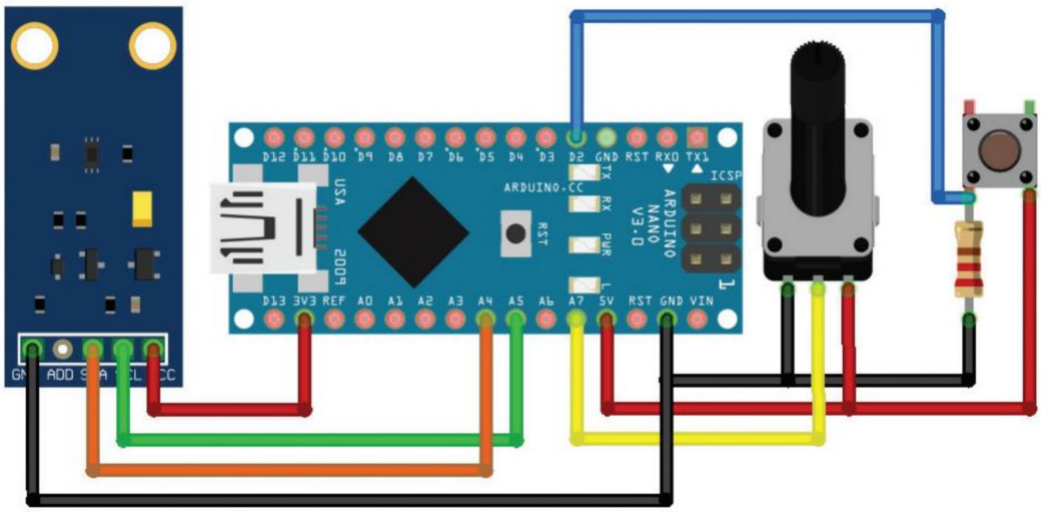

Figure 2. A circuit sketch using an Arduino.

RESULTS AND DISCUSSION

The optical rotation angle can be determined if the reference is determined beforehand. Previous studies determined the reference and the light beam passing through the optically active solution separately, even though the light source can produce a different light intensity change. Therefore, in this study, the reference and the light beam passing through the optically active solution were measured simultaneously [26]. A beam splitter is used as a laser beam breaker to simultaneously measure the reference and the light beam passing through an optically active solution [27]. The reference light beam is then called the first beam, and the light beam that passes through an optically active solution is called the second beam.

Figure 3 shows the source code. The Arduino measures the light intensity and the potentiometer signal when the push button is pressed; when it is pressed again, the measurement is stopped. A digital representation of the potentiometer signal is an integer number between 0 and 1023. We fully turn the polarizer to calibrate the angle. Then, we note the corresponding change in the analog input signal

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[28]. This method yielded a calibration factor of 0.604 cnts deg^{-1}. The routine resets the potentiometer's reading to 0 before each measurement.

Fitting the data using Malus's law and relationship graphs the intensity of one light beam against the intensity of two light beams is used to determine the optical rotation angle for one solution concentration. The specific optical rotation value is determined from the optical rotation angle graph to the solution concentration [29]. The greater the concentration of the solution, the greater the optical rotation angle [30]. The higher the concentration of the solution indicates that the material that can rotate the vibrating plane of polarized light in the solvent increases so that the rotation is further away [31]. The gradient of this graph is the value of the specific optical rotation of the solution under study.

We modify the angle of the second polarizer while measuring the amount of laser pointer light transmitted through our experimental setup. We get more than 1.5 turns on the polarizer from the 10 turns of the potentiometer. The data was immediately gathered from the Arduino IDE's Serial Monitor and then evaluated with graphical tools [32]. The data on gathered intensity as a function of angle is shown in Figure 4.

```
#include <wire.h>
#include <BH1750.h>
BH1750 lightMeter;
int pot_value_zero, pot_value, button;
float theta; uint16_t lux;
void setup() {
  Serial.begin(9600);
  Wire.begin();
  lightMeter.begin();
  button = Low;
}
void loop() {
  Serial.println ("Angle(degree) Intensity(lux)");
  do {
    button = digitalRead(2);
    delay(300);
  } while (button != HIGH);
  pot_value_zero = analogRead(A7);
  do {
    lux = lightMeter.readLightLevel();
    pot_value = analogRead(A7) - pot_value_zero;
    theta = 0.604 * pot_value;
    Serial.print(theta);
    Serial.print(" ");
    Serial.println(lux);
    button = digitalRead(2);
    delay(300);
  } while (button != HIGH);
}
```

Figure 3. Arduino source code

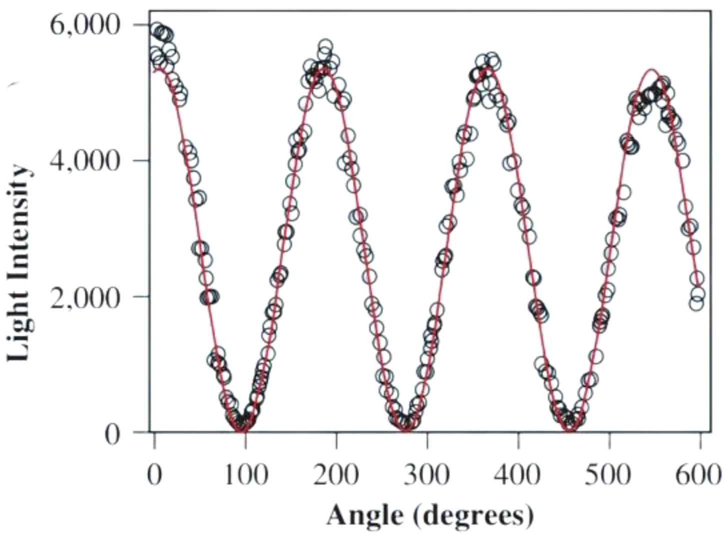

Figure 4. A graph of light intensity as a function of the angle

The red line fits the equation for Malus's law. Due to the polarizer's random alignment at the experiment's beginning, the maximum intensity does not happen at = 0. The behavior of the intensity concerning the angle between the two polarizers is consistent, as shown in Figure 4. The red line represents a fit [15]. The intensity does not peak at zero because we did not align the two polaroids before measuring [33]. The fit in Figure 4 revealed that θ_0 = 6.32 and I_0 = 5358 lux. In Figure 5, we plotted the normalized intensity (intensity divided by I_0) as a function of $\cos^2(\theta - \theta_0)$. As expected from Malus's law, the plot of Figure 5 is linear with the slope B = 0.978 ± 0.007.

Analysis with Malus's Law suits situations experiments with constant analyzer rotation. If the analyzer rotation is constant, the graph of light intensity against the angle of the analyzer rotation can be formed properly [34]. Even though the analyzer does not rotate constantly, this method can still be used because the data fitting facility in the LoggerPro software can display fitting results closest to the exact graph equation [35]. This data fitting uses all the resulting data points to determine the graph equation. Meanwhile, the analysis using a graph of the relationship between the intensity of one light beam and the intensity of two light beams does not require time calculation to obtain the relationship between intensity and angle [36]. The analyzer does not have to be rotated constantly because how to rotate the analyzer does not affect the shape of the graph.

Finally, we believe that the arrangement, in its current form, can be useful in physics lab sessions. It might also be demonstrated during the lectures. The educator can investigate the rule more quantitatively by displaying a live graph of the intensity as a function of the angle instead of only demonstrating the qualitative relationship using two polarizers. Software like Excel, Labview, Matlab, and Makerplot can be used to accomplish it.

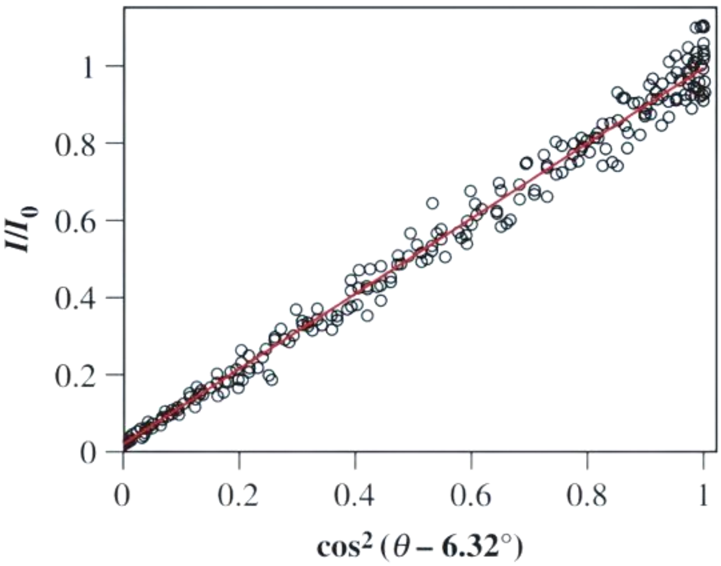

Figure 5. Graph of normalized intensity versus $\cos^2(\theta - \theta_0)$. The red line is the linear fit.

CONCLUSION

We have demonstrated using an Arduino Board coupled with a light sensor and potentiometer to learn Malus's law. The latter is used to gauge the rotatable polarizer's angle. The results are in line with what was anticipated. Arduino-assisted observation of polarized light intensity is also relatively easy to use. Computers are media that are already familiar. This experimental method can also be used in wave and optics practicum learning. Computers can help students to observe the intensity of polarized light passing through the analyzer. With the help of computers, students do not need to observe visually. So, learning becomes more interesting.

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