Design of an Optical Rotation Value Measurement Tool Using an Arduino Device

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Abstact: In this work, we design equipment to study the phenomenon of Malus' Law about the square of the cosine angle formed between two polarizers in direct proportion to the intensity of light after passing through it. The method we use is a direct experiment to measure the angle of rotation of a certain polarizer in accordance with the theory so that the other stationary polarizer remains stable. The Arduino board is connected to a potentiometer and a light sensor that is used to detect the intensity of the transmitted light, allowing measurement of the light intensity as a function of the angle of rotation. Our results show that analysis by Malus' Law is suitable for experimental situations with constant analyzer rotation. If the rotation of the analyzer is constant, the graph of light intensity against the angle of rotation of the analyzer can be formed properly. In addition, we think that experiments like this can also help students understand the phenomenon of Malus' Law by demonstrating.

Keywords: Malus' law, Arduino, Polarizer, Physics Laboratory.

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I. 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 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 be able 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, between the polarizer and the analyzer is placed an optically active solution [12]. The intensity of light coming out of 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]. To determine the magnitude of the optical rotation angle, the analyzer is then rotated until the maximum light intensity is found [17]. The angle of rotation of the analyzer to the reference is the angle of optical rotation [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]. As an alternative, 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 to use sensors and an Arduino board to collect input angle and power. because it requires simple equipment, besides that the costs involved in designing this equipment require low costs. However, the analysis resulting from this design has high accuracy.

II. METHOD

The essential tools for observing Malus' law are a light source, two polarizers, and a detector. Our system makes use of a lux meter (model BH1750) as the detector and a laser pointer as the light source. The polarizers came from an old LCD display. One of them 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]. To measure the polarizer angle, a potentiometer can be calibrated. Fig. 1 shows the basic setup.

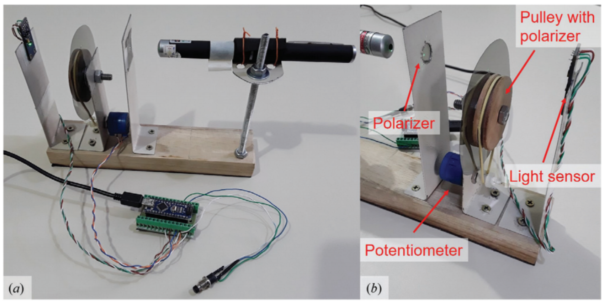

FIG. 1: (a) An illustration of the testing equipment, (b) A close-up of the polarizer, pulley, and potentiometer.

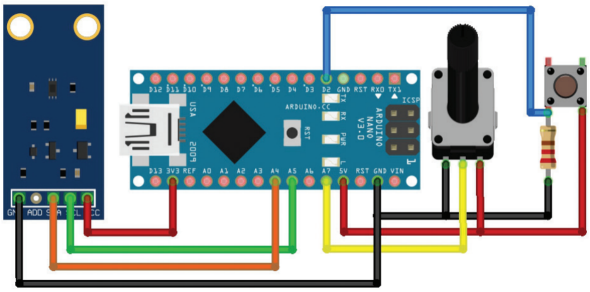

FIG. 2: Illustrates a circuit sketch using an Arduino.

The used circuit diagram is shown in Fig. 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.

III. RESULTS AND DISCUSSION

The angle of optical rotation can be determined if the reference is determined beforehand. In previous studies, the reference and the light beam passing through the optically active solution were determined separately, even though the light source used 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. To be able to measure the reference and the light beam passing through an optically active solution simultaneously, a beam splitter is used as a laser beam breaker [26]. 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.

Fig. 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

```
#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);
}
```

FIG. 3: Arduino source code.

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 [27]. 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' law and relationship graphs the intensity of one light beam against the intensity of two light beams is used to determine the angle of optical rotation for one concentration of the solution. The specific optical rotation value is determined from the graph of the optical rotation angle to the concentration of the solution. The greater the concentration of the solution, the greater the optical rotation angle [28]. 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. 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 that is transmitted through our experimental setup. We get somewhat 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 [29]. The data on gathered intensity as a function of angle is shown in Fig. 4.

The equation for Malus' law is fit by the red line. Due to the polarizer's random alignment at the beginning of the experiment, the intensity maximum does not happen at = 0. The behavior of the intensity with respect to the angle between the two polarizers is consistent, as shown in Fig. 4. The red line represents a fit. Because we didn't align the two polaroids before measuring, the intensity doesn't peak at zero [30]. The

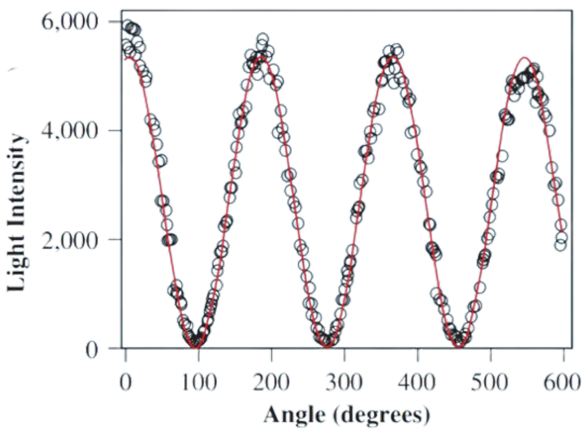

FIG. 4: A graph of light intensity as a function of the angle.

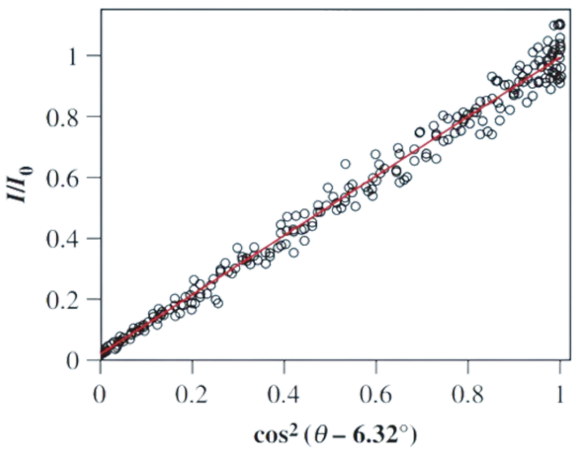

FIG. 5: Graph of normalized intensity versus $\cos^2(\theta - \theta_0)$. The red line is the linear fit.

fit in Fig. 4 revealed that θ_0 = 6.32 and I_0 = 5358 lux. In Fig. 5 we have plotted the normalized intensity (intensity divided by I_0) as a function of $\cos^2(\theta - \theta_0)$. As expected from Malus law, the plot of Fig. 5 is linear with the slope B = 0.978 $\pm$ 0.007.

Analysis with Malus' Law is suitable for 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. 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 that are closest to the exact graph equation [31]. 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 the calculation of time to obtain the relationship between intensity and angle [32]. 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 think that the arrangement, in the form that it is currently offered, can be helpful in physics lab classes. It may also be demonstrated as part of the lectures. The educator can investigate the rule more quantitatively by displaying a live graph of the intensity as a function of the angle, as opposed to only demonstrating the qualitative relationship using two polarizers. Software like Excel, Labview, Matlab, and Makerplot can be used to accomplish it.

IV. CONCLUSION

In summary, we have successfully designed a tool to understand Maulus' Law by demonstrating how to use an Arduino Board combined with a light sensor and a potentiometer to learn Malus' law. Arduino-assisted observation of polarized light intensity is also relatively easy to use. Our results show that analysis by Malus' Law is suitable for experimental situations with constant analyzer rotation. If the rotation of the analyzer is constant, the graph of light intensity against the angle of rotation of the analyzer can be formed properly.

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