Polarization of a Quasi-Monochromatic Light Wave with a Honey Solution

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(Dated: May 5, 2025)

This study investigates the optical rotation of a polarized red laser beam (λ = 630–670 nm) as it propagates through aqueous solutions prepared by adding 8.5 mL "scoops" of honey into 71.7 mL distilled water (concentrations 0–0.702 g mL^{-1}). The analyzer angle was swept over 0–180° in 1° steps and transmitted intensity was recorded by a photoresistor. Voltages were converted to normalized intensities and fitted to an attenuated Malus's-law model from which the rotation angle $\theta_0 = -\frac{c}{b}\frac{180}{\pi}$ was extracted. Across nine concentrations, a linear regression of θ_0 suggested $[\alpha] \approx 12.52$ and results validate the described polarimetric setup for quantitative analysis of optically active multi-component solutions.
Keywords: Optical rotation, polarization, polarimetry, honey-bee, Malus' Law.

I. INTRODUCTION

Accurate characterization of optical activity in chiral media is essential for understanding and exploiting the interaction between polarized light and asymmetric molecular structures. This phenomenon, known as optical rotation, plays a central role in analytical chemistry, pharmaceutical quality control, and the study of biomolecular systems. When linearly polarized light passes through a chiral substance, the plane of polarization is rotated by an angle that depends on the concentration and nature of the chiral molecules.

Optical rotation arises from the difference in refractive indices experienced by the left- and right-circularly polarized components of the incident beam. As these components propagate at slightly different speeds through the medium, a phase shift accumulates, resulting in a net rotation of the polarization plane. This rotation can be quantified indirectly by analyzing changes in transmitted intensity through a second polarizing filter, commonly referred to as an analyzer. According to Malus' Law, the transmitted intensity $I(\theta) = I_0 \cos^2(\theta)$ varies with the angle θ between the analyzer and the polarization direction of the incoming light.

In this study, we explore the optical rotation induced by aqueous solutions of honey at increasing concentrations, leveraging their high content of optically active chiral compounds. A linearly polarized red laser beam (λ = 630–670 nm) is directed through solutions with varying honey concentrations. This experiment isolates the effect of chiral concentration on optical rotation, providing a clear demonstration of the molecular basis of this classical optical phenomenon.

II. EXPERIMENTAL DETAILS

A. Experimental Procedure

The experimental arrangement, shown in Figure 1, was designed to measure the angular intensity distribution of a linearly polarized red laser beam (λ = 630–670 nm) as it propagated through aqueous solutions of honey at varying concentrations. The setup functions as a polarimeter, in which the angular position of a photoresistor is adjusted to detect changes in light intensity after transmission through a chiral medium and a rotating analyzer.

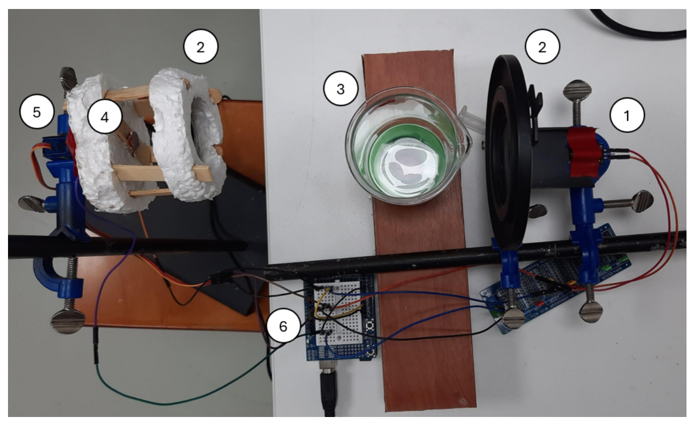

FIG. 1. The photograph of the polarimeter used to measure intensity distributions. ① Laser; ② Polarizers; ③ Volumetric container; ④ Photoresistor; ⑤ Servomotor; ⑥ Arduino UNO

Initially, the red laser beam was directed through the first polarizer to produce linearly polarized light. This beam then passed through a cylindrical container filled with an aqueous honey solution, which introduced optical rotation due to its content of chiral molecules such as glucose and fructose. In fact, for the sample of honey used in the experiment, approximately 85.70% of it's content corresponds to optically active chiral compounds such as fructose, glucose, proteins, vitamin D and vitamin B2. The rotated beam subsequently reached the analyzer (second polarizer), whose orientation was varied systematically by a servomotor.

The analyzer's angular position was controlled via an Arduino UNO microcontroller and a precision servomotor. The servomotor was programmed to rotate in small increments (typically $\sim 1^\circ$ per step), sweeping across a 180° range. For each angular position, the transmitted light intensity was detected by a photoresistor placed behind the analyzer. The voltage signal from the photoresistor was read by the Arduino's analog-to-digital converter, providing a voltage resolution of approximately ~ 4.9 mV.

The intensity data were recorded for each concentration of honey, ranging from one to nine injections of 8.5 mL of pure honey into an initial volume of 71.7 mL of distilled water. This allowed for a comparative analysis of the angular shift in the intensity maxima, governed by Malus' Law, as a function of the chiral concentration of the solution.

B. Mathemathical Model

The photodiode produces a voltage $V(\theta)$ that decreases as transmitted light intensity increases. We convert these voltages into a normalized intensity

$$I(\theta) = \frac{V_{\max} - V(\theta)}{V_{\max} - V_{\min}} \in [0, 1],$$

where $V_{\max}$ and $V_{\min}$ are the maximum and minimum voltages recorded over the 0–180° analyzer sweep.

The transmitted intensity through the honey solution is modeled as a modified Malus's law with an amplitude attenuation factor. Denoting by θ the analyzer angle in degrees, by a an amplitude factor ($0 < a \leq 1$), by b the angular frequency parameter in radians per degree, and by c the phase offset in radians, we write

$$I(\theta) = a\big|\cos\big(b\,\theta + c\big)\big|.$$

Here $I(\theta)$ is normalized so that its maximum is unity. Once the parameters b and c have been determined by fitting this expression to the measured intensity-versus-angle data, the net polarization rotation introduced by the honey sample is obtained from

$$\theta_0 = -\frac{c}{b}\,\frac{180}{\pi} \quad \text{(in degrees)}.$$

In the dilute regime the rotation angle θ_0 is expected to scale linearly with the solute concentration C (in g mL^{-1}) and the optical path length ℓ (in dm):

$$\theta_0 = [\alpha]\,\ell\,C + \theta_{\text{blank}},$$

where $[\alpha]$ is the specific rotation in units of deg dm^{-1}(g mL^{-1})$^{-1}$ and θ_{blank} accounts for any residual offset measured in pure solvent. A linear regression of θ_0 versus $C\,\ell$ then yields $[\alpha]$ as the slope.

Each data set is prepared by adding n "scoops" of honey (each of volume V_{scoop}) into a total solution volume V_{tot}. To convert to a mass concentration C (in g mL^{-1}), we use the honey density ρ_{honey}:

$$C = \frac{m_{\text{honey}}}{V_{\text{tot}}} = \frac{n\,V_{\text{scoop}}\,\rho_{\text{honey}}}{V_{\text{tot}}} \quad \big[\text{g}\,\text{mL}^{-1}\big].$$

In our experiments $V_{\text{scoop}} = 8.5$ mL and $\rho_{\text{honey}} \approx 1.36$ g mL^{-1}.

III. RESULTS AND DISCUSSION

The normalized intensity profiles for all nine honey concentrations were fitted to the function

$$I(\theta) = a\big|\cos(b\,\theta + c)\big|,$$

yielding amplitude factors a between 0.994 and 1.041, angular-frequency parameters b in the range 1.230–1.298 rad/deg, and phase offsets c between -0.264 and -0.080 rad. These fits translate into rotation angles $\theta_0 = -\frac{c}{b}\,(180/\pi)$ ranging from 3.74° up to 12.01°. Table I summarizes the best-fit parameters and derived offsets for each dilution step.

Concentration (g/mL)	a	b (rad/deg)	c (rad)	θ_0 (deg)
0.000	1.013	1.260	–0.264	12.01
0.144	0.994	1.247	–0.227	10.42
0.261	1.013	1.277	–0.254	11.41
0.357	1.041	1.298	–0.246	10.87
0.437	1.021	1.263	–0.202	9.15
0.506	1.032	1.266	–0.154	6.97
0.565	1.034	1.230	–0.080	3.74
0.617	1.025	1.237	–0.100	4.62
0.662	1.017	1.234	–0.085	3.96
0.702	1.022	1.241	–0.119	5.51

TABLE I. Fit parameters for the modified Malus's-law model and resulting rotation offsets θ_0 as a function of honey concentration.

Figure 3 displays the measured intensity data and their fits, confirming that the attenuated Malus's-law model accurately describes the polarization behavior of the honey solutions. The amplitude factor a remains close to unity, indicating that absorption and scattering in the viscous medium do not significantly distort the cos-dependence of the analyzer transmission.

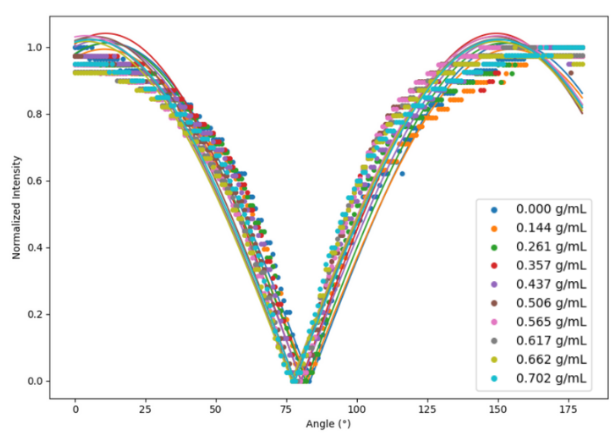

FIG. 2. Overlay of normalized intensity measurements (dots) and corresponding fits (solid curves) for all nine concentrations.

A linear regression of the rotation offsets θ_0 versus honey concentration C (g mL^{-1}) yields

$$\theta_0 = (-12.517)\, C + 13.188,$$

with a coefficient of determination $R^2 = 0.79$. This moderate linear trend suggests that, in our dilute regime, optical rotation may not scale perfectly proportionally with concentration at higher levels. From this fit one extracts the specific rotation

$$[\alpha] \approx 12.517 \text{ deg}\, \text{dm}^{-1} (\text{g/mL})^{-1}$$

using $\ell = 1$dm.

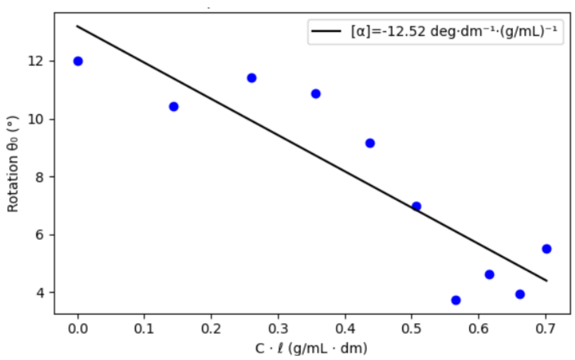

FIG. 3. Correlation between angular displacement and honey concentration in 71.7 mL of distilled water

Figure 2 demonstrates that each data set adheres to a common trend, exhibiting only a rightward shift of the inverted peaks without appreciable vertical offset for most concentrations. This behavior confirms that the degree of polarization rotation grows with the number of chiral molecules in the light path. The pronounced vertical shift observed in the two highest-concentration curves, however, likely arises from a systematic measurement error.

Additionally, the downward drift at the extreme low- and high-angle ends suggests increased energy loss along the optical path as honey concentration rises; the largest deviations again coincide with the systematic error region.

Finally, the angular displacement in figure 3 and the determination coefficient of the fit show a moderate linear correlation with the honey concentration in the solution. However, because of the small overall displacement, it is unclear whether the relation will remain linear for higher concentration values.

IV. CONCLUSION

We have demonstrated that aqueous honey solutions exhibit a clear optical rotation of a linearly polarized red laser beam, and that this rotation can be quantified by fitting the normalized transmitted intensity

$$I(\theta) = \frac{V_{\text{max}} - V(\theta)}{V_{\text{max}} - V_{\text{min}}}$$

to an attenuated Malus's-law model

$$I(\theta) = a \big|\cos(b\, \theta + c)\big|.$$

Across nine concentrations (0–0.702 g mL^{-1}), the fit parameters remained physically reasonable ($0.994 \leq a \leq 1.041$, $1.230 \leq b \leq 1.298$ rad deg^{-1}), and the derived rotation angles $\theta_0 = -c/b\,(180/\pi)$ ranged from 3.74° to 12.01°. A calibration plot of θ_0 versus concentration yielded a specific rotation of

$$[\alpha] \approx 12.52 \text{ deg}\, \text{dm}^{-1} (\text{g}\, \text{mL}^{-1})^{-1}$$

with $R^2 = 0.79$. While the overall linear trend confirms that optical rotation increases with chiral solute concentration, deviations at higher concentrations indicate onset of systematic effects such as increased scattering, absorption, and non ideal mixing that limit quantitative accuracy. Possible improvements including thermostatted flow cells, lock-in detection, and direct path-length verification will reduce these errors.

Future work should focus on exploring shorter optical path lengths or alternative wavelengths to mitigate absorption induced attenuation, and expanding the concentration range to test the limits of linearity and to extract higher-order concentration terms.

In sum, this paper validates a low-cost, servo-automated polarimeter for measuring the specific rotation of complex, multi-component solutions like honey.

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