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Examining the Optical Properties of Monosodium Urate for the Detection of Gout Using a Magneto-Optical Device (MOD)

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Abstract

The purpose of this research was to quantify the magneto-optical properties of monosodium urate (MSU) crystals that would allow for an easy diagnosis using a magneto-optical device (MOD). Characterization of these magnetic and optical properties was achieved by measuring the transmitted light intensity of a laser shining through a sample of monosodium urate with or without an applied (static) magnetic field. Using our theoretical model under the simplifying assumption that absorption is dominant, we determined that the extinction cross-section is $\sigma_x = 0.0127\ \text{cm}^3/\mu\text{g}$ and we determined σ_z using two different relationships which gave two distinctly different values. Due to this 78.8% difference in our calculations of σ_z, we determined that the extinction cross section for MSU crystals relies on both scattering and absorption interactions.

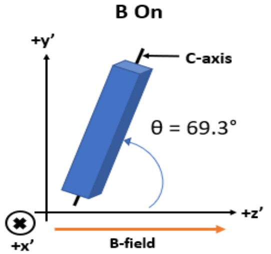

Figure 1 shows the orientation of an MSU crystal and its c-axis relative to an applied magnetic field.

Background

In the United States alone as of 2019, around 9.2 million people are currently living with gout.[1]

Often, patients begin seeking a diagnosis from their primary care physicians after the onset of acute symptoms like pain and joint swelling.[2] However, gout causes a wide range of nonspecific symptoms, making it difficult to diagnose in a primary care setting.

This difficulty in receiving a diagnosis is due to lack of access to gold standard diagnostic techniques in a primary care setting and the high cost of gout diagnosis with these techniques.

Theory

Beer's Law[3]

- $\langle\sigma_\epsilon\rangle$ = the average extinction cross-section in the direction of the polarized light
- $\frac{I}{I_0}$ intensity of the transmitted light to the incident light shone through the solution

$$\frac{I}{I_0} = e^{-\langle\sigma_\epsilon\rangle \ell c}$$

- The MSU crystals have magnetic anisotropy and align with the applied magnetic field along an angle relative to their c-axes (Fig. 1). With this property, we can manipulate the crystals in solution and affect the absorbed light intensity.

Then, we used a basis transformation using Euler angles to relate the average value of the cross-sections in the lab frame to the crystal frame cross-sections assuming absorption is dominant:[4]

$$\sigma_x = \langle\sigma_{z'}\rangle_{B\,on}$$

$$\sigma_z = 2\langle\sigma_{x'}\rangle_{B\,on} - \langle\sigma_{z'}\rangle_{B\,on} = 3\langle\sigma\rangle_{B\,off} - 2\langle\sigma_{z'}\rangle_{B\,on}$$

Methods

1. The laser emits a beam that is polarized and split. One of the beams goes to the initial photodiode to measure the initial light intensity and the other goes through the sample in the cuvette holder.
2. The second photodiode measures the intensity of the light transmitted through the sample.
3. Moveable magnets are pushed over the sample to induce a static magnetic field.
4. Data is collected using LabVIEW and the experiment is repeated with differing concentrations of MSU crystals.

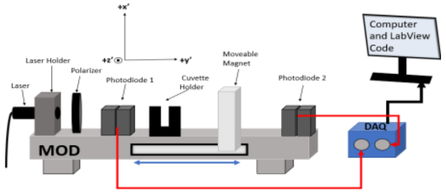

Figure 2 shows a schematic of the Kara Lab Prototype of the MOD used for research.

Results

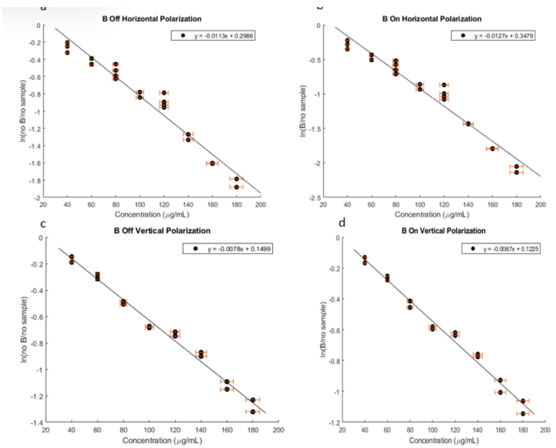

Figure 3 shows plots of the natural log of transmitted light intensity vs. concentration of MSU crystals

Table I shows the calculated extinction cross sections in the crystal basis found experimentally using the average values of the average absorption cross sections of x' and z' from the laboratory frame.

Absorption Cross Section	Calculation from Average Values in Lab Frame	Experimental Result ($\text{cm}^3/\mu\text{g}$)
σ_x	$\sigma_x = \langle\sigma_z\rangle_{B\,on}$	0.0127
σ_z	$2\langle\sigma_x\rangle_{B\,on} - \langle\sigma_z\rangle_{B\,on}$	7.00×10^{-4}
σ_z	$3\langle\sigma\rangle_{B\,off} - 2\langle\sigma_{z'}\rangle_{B\,on}$	0.0033

Discussion

From the experimental data, our calculated values for σ_z were distinctly different from each other by 78.8%. Because these overdetermined equations assume that absorption interactions dominate the extinction of light, we now believe that scattering is non-negligible in the overdetermined equations used. Other studies have hypothesized that scattering does play a role in the extinction interaction of MSU.[5] The scattering found in the study was consistent with Mie scattering which is dependent on the angle of the incident light upon the sample. Our results assumed that scattering was negligible, so the effects of non-negligible Mie scattering may explain the discrepancy in our calculated σ_z values.

Conclusion

In conclusion, the average extinction cross-sections for horizontally and vertically incident polarized light for MSU samples in the presence of a magnetic field were found to be distinctly different. Due to the disagreement between our theoretical model and experimental results in the lab frame, it must be concluded that proper analysis of extinction cross-section for MSU crystals relies on understanding both absorption and scattering interactions. Even with a disconnect between our theoretical model and our results, we are still confident that the MOD can be used for MSU detection. Going forward, the scattering of light by MSU crystals must be studied in detail and a theoretical model that includes data will need to be created. With a new theoretical model and equation, experiments can then be run to test the sensitivity of the MOD in detecting crystal samples at various concentrations.

References

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