Physics 3100/3101
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Painting in Polarization: Optics Final Project

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Studying Polages: Background and Motivation

Light is an electromagnetic wave where the electric field oscillates perpendicular to the direction of travel. Most light sources are **unpolarized.**

Polages visually demonstrate core concepts of polarization and birefringence.

The phenomenon illustrates fundamental ideas in polarization optics and has applications in various technologies, including **Liquid Crystal Displays (LCDs)**.

Project Goal: To verify the wavelength variation when light passes through a birefringent film within a polarization gate.

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[1]

Birefringence and Retardance

Birefringence

An optical property where a material's **index of refraction** depends on the polarization direction of incident light.

- Certain materials (like clear tape) are birefringent, having two distinct perpendicular optical axes (n1 and n2).

Retardance

Thickness of film

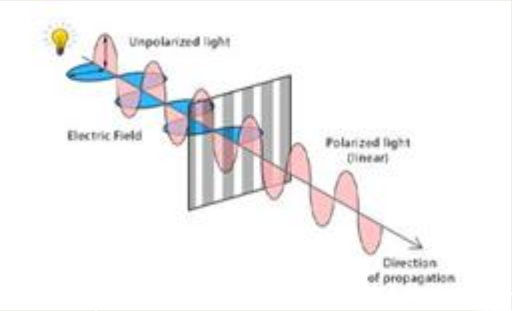
Phase Retardance

$$\delta = \frac{2\pi \, d\Delta n}{\lambda}$$

Birefringence

Color from Polarization Filtering

Because retardance (δ) is wavelength (λ) dependent, the material alters the polarization state differently for each color. This differential transmission of wavelengths produces color when filtered by a second polarizer.



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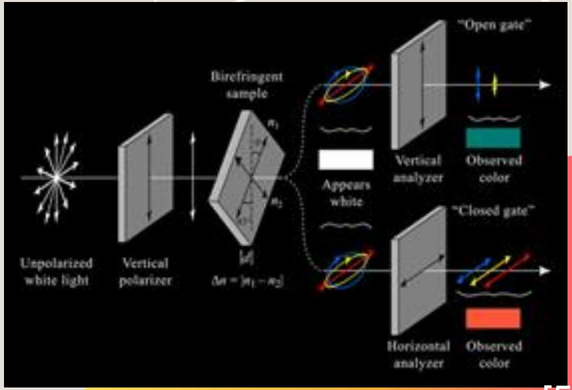

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Subtractive Filtering and Complementary Colors

The Polarization Gate:

The Analyzer is the mechanism that converts the wavelength dependent phase retardance into a visible, wavelength dependent intensity.

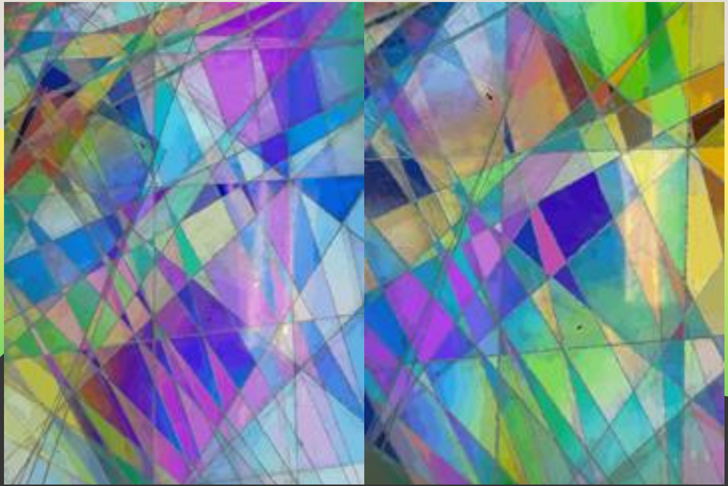
The resulting color is produced by subtractive filtering.

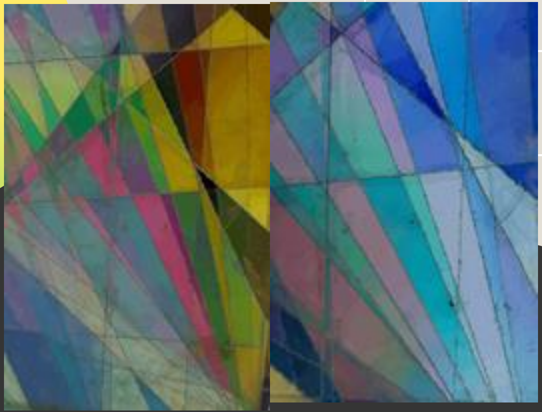
The Complementary Relationship:

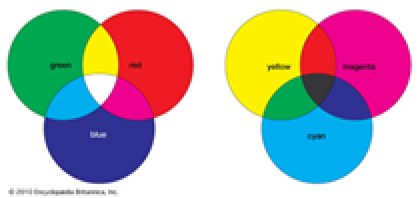
Open Gate - Parallel Polarizers, Closed Gate - Perpendicular Polarizers.

The spectral intensity for the two positions are complementary, they sum back to the original white light intensity.

$$I_{Closed} + I_{Open} = I_{Max}$$







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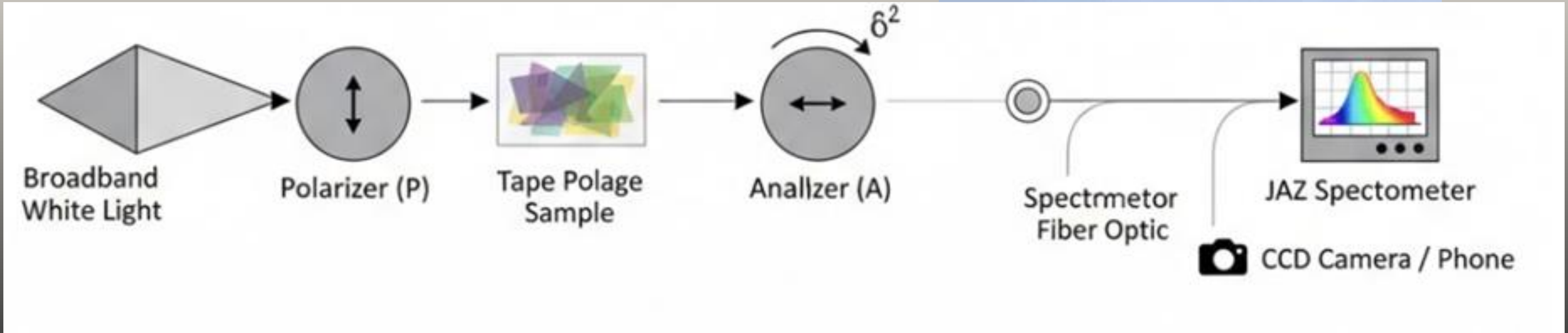
Experimental Setup

The sample is sandwiched between a **Polarizer** and an **Analyzer**.
The Polarizer creates the initial linearly polarized light.
The Birefringent Sample alters the polarization state in a wavelength-dependent manner.
The Analyzer converts polarization state changes into **intensity** changes.
Spectral data with a JAZ Spectrometer and visual data using a phone camera are recorded.
Visual data acts as a benchmark for comparison against the computed sRGB colors.



R: 255
G: 59
B: 214

Measurements

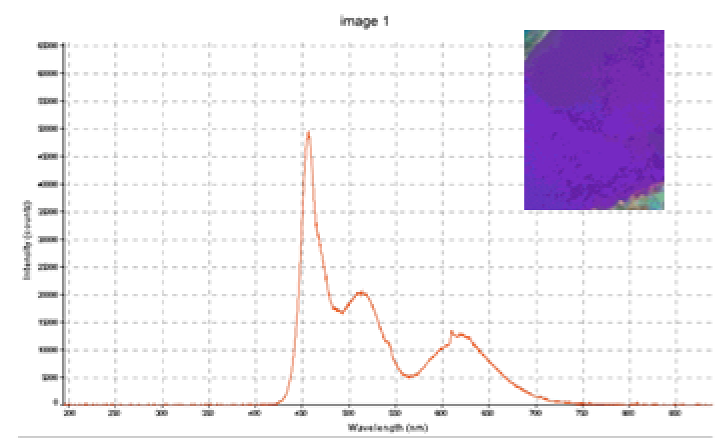
Shape 1 - Purple?

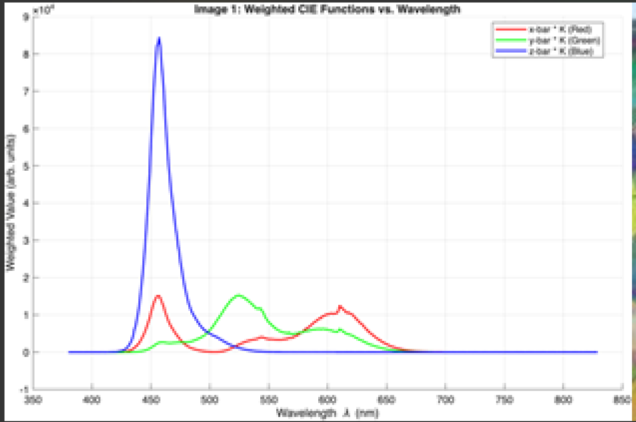
Key Plots:

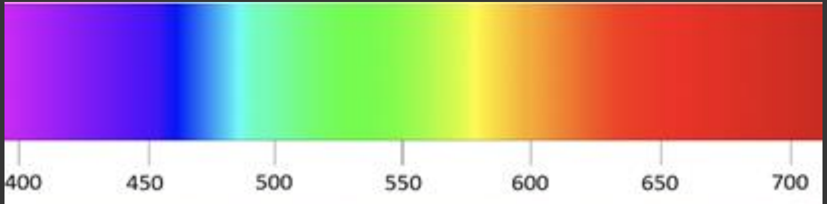
1. Top: Shows the initial plot formed by the JAZ Spectrometer.
2. Bottom Right: Shows the calculated color matching functions ($\bar{x}K$, $\bar{y}K$, $\bar{z}K$) where K is the interpolated intensity.

Key Features:

- The blue ($\bar{z}K$) function shows the highest peak.
- The red ($\bar{x}K$) function and green ($\bar{y}K$) function contribute less.



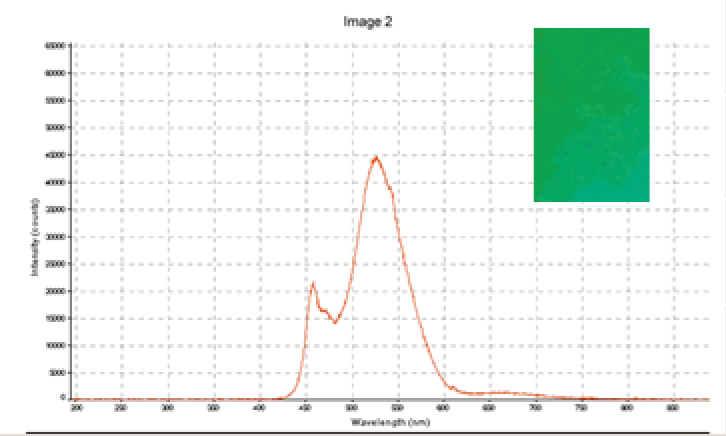




R: 184
G: 255
B: 139

Measurements

Shape 2 - Green

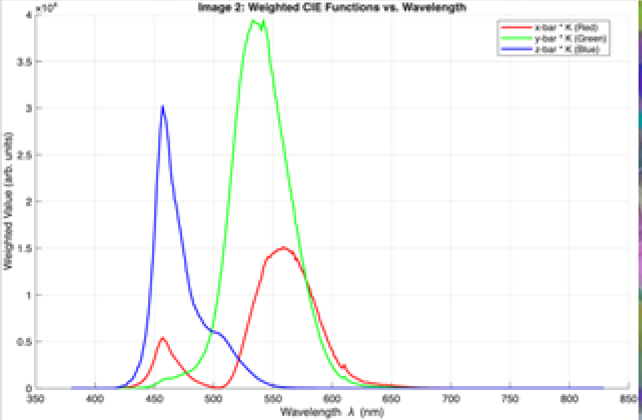


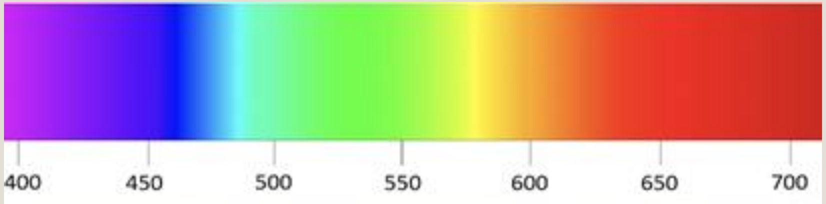
Key Plots:

1. Top: Shows the initial plot formed by the JAZ Spectrometer.
2. Bottom Right: Shows the calculated color matching functions.

Key Features:

- The green (y¯K) function shows the highest and broadest peak (centered around 550 nm).
- The blue (z¯K) function shows a strong, narrow peak.
- The red (x¯K) function shows a significant contribution, but remains below the green and blue peaks.





Measurements

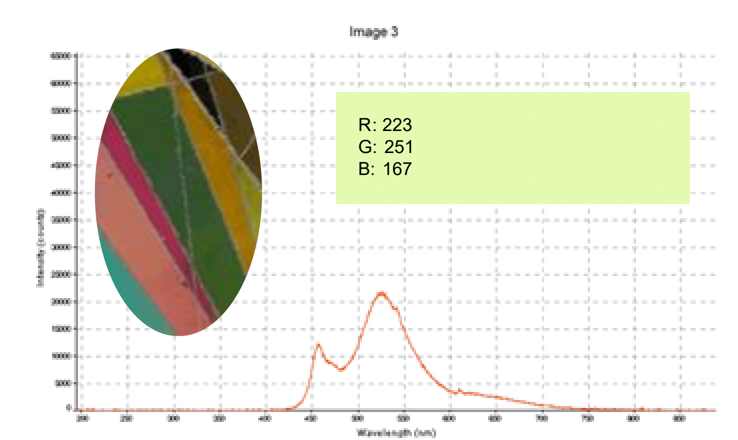
Shape 3 - Green Again

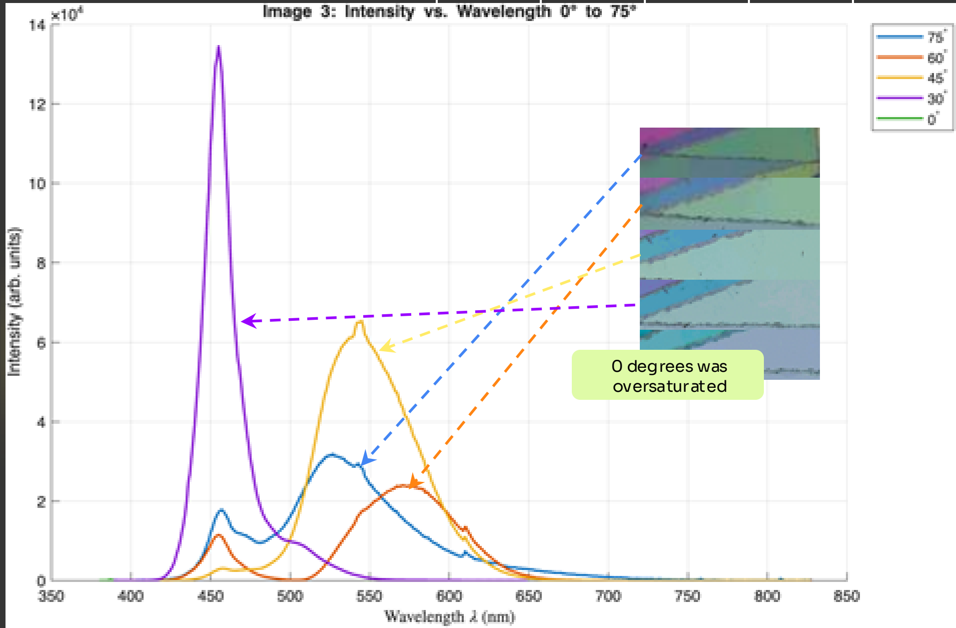
Key Plots:

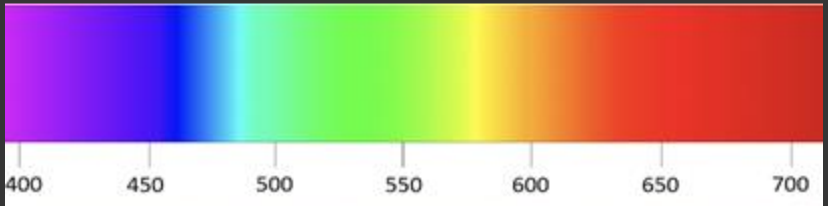
1. Top: Shows the initial plot formed by the JAZ Spectrometer.
2. Bottom-Right: The main plot showing the intensity of each wavelength at the various angle increments.

Key Trends:

- As the angle increases, the overall transmitted intensity decreases
- Peak intensity shifts from cyan towards yellow-green (wavelength-dependent filtering).







R: 255
G: 132
B: 18

Measurements

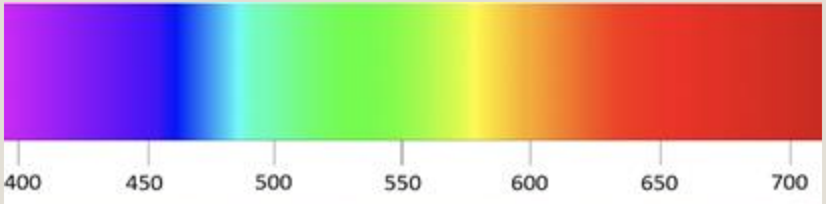
Shape 4 - Orange

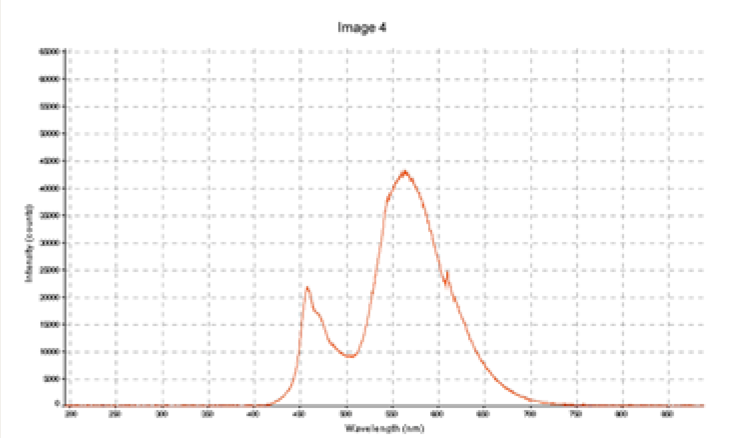
Key Plots:

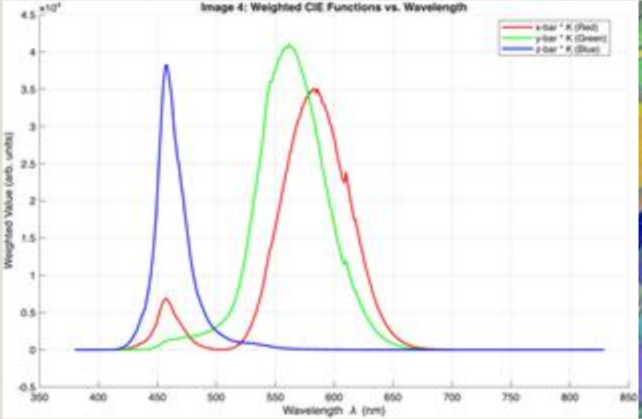
1. Top: Shows the initial plot formed by the JAZ Spectrometer.
2. Bottom Right: Shows the calculated color matching functions.

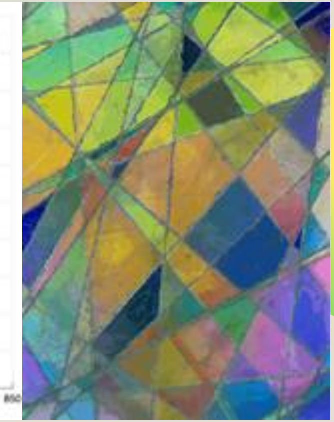
Key Features:

- The green ($\bar{y}K$) function shows the highest peak (around 560 nm).
- The red ($\bar{x}K$) function shows a peak around 600 nm that is slightly lower than the green peak.
- The blue shows a distinct peak that drops rapidly in higher wavelengths.









Measurements

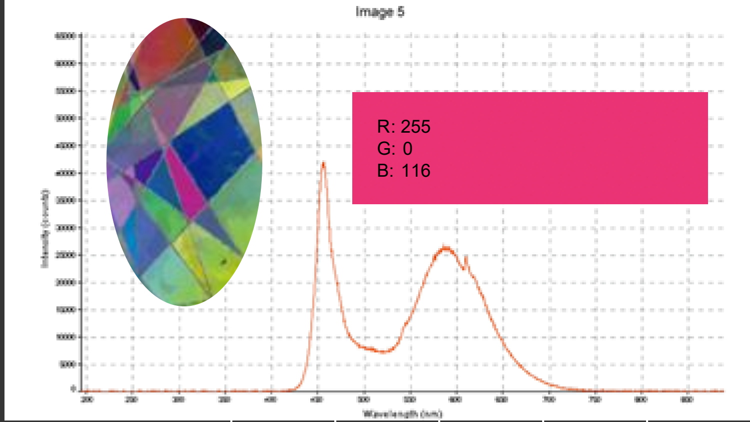
Shape 5 - Pink

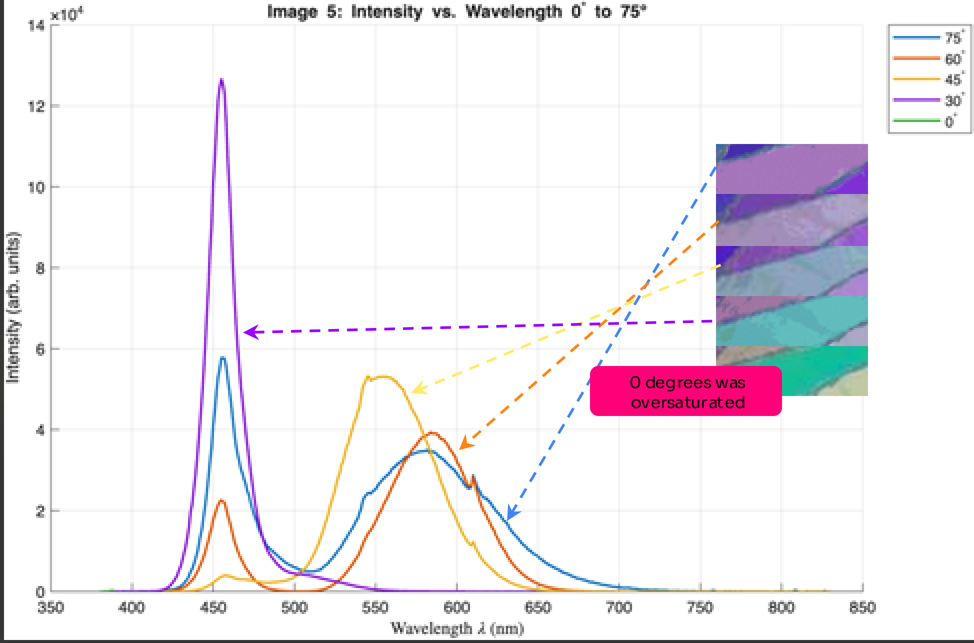
Key Plots:

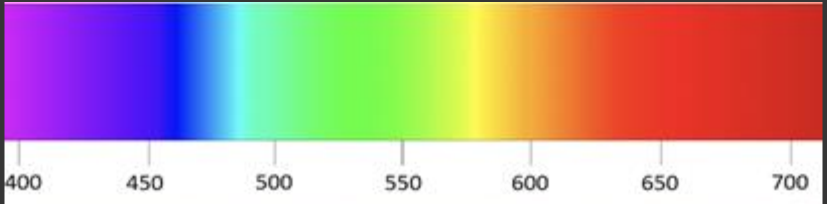
1. Top: Shows the initial plot formed by the JAZ Spectrometer.
2. Bottom Right: Shows the calculated color matching functions.

Key Trends:

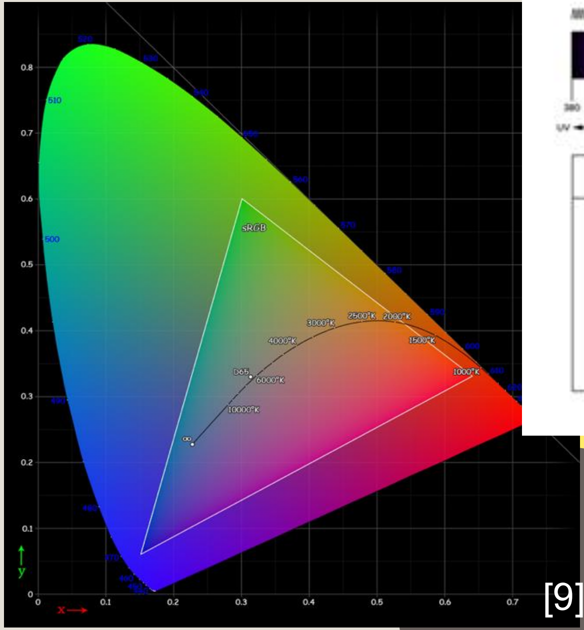
- The curves show a significant peak in the blue/violet region (~450 nm) and a second broad peak in the yellow/red region (~600 nm).
- The combination of these transmission bands produces the pink color we see visually.
- As the angle changes the peaks decrease in intensity.







Spectral Analysis of My Polage



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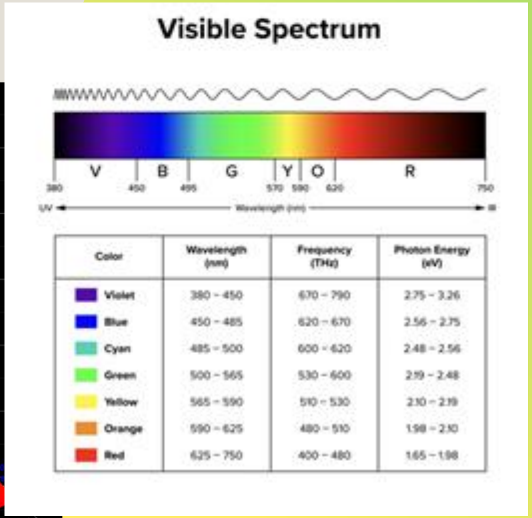


Color	Wavelength (nm)	Frequency (THz)	Photon Energy (eV)
Violet	380 – 450	670 – 790	2.75 – 3.26
Blue	450 – 485	620 – 670	2.56 – 2.75
Cyan	485 – 500	600 – 620	2.48 – 2.56
Green	500 – 565	530 – 600	2.19 – 2.48
Yellow	565 – 590	510 – 530	2.10 – 2.19
Orange	590 – 625	480 – 510	1.98 – 2.10
Red	625 – 750	400 – 480	1.65 – 1.98

[7]

Color Accuracy and RGB Screens

- Digital screens cannot cover the entire range of colors perceivable by the human eye.
- Some of the color matching discrepancies are due to the screen’s limited color gamut and camera’s capacity to match the CIE Standard Observer.

Wavelength-Color Correlation

- The final color we see is determined by the wavelengths that are subtracted from the white light spectrum.
- The degree of polarization rotation applied by the film is inversely proportional to wavelength (retardance).
- The position of the transmission peak corresponds to the perceived color.

Conclusion

[6]

Summary

The project was successful in verifying wavelength variation when broadband light is transmitted through a birefringent film in a polarization gate.

The systematic rotation of the analyzer angle demonstrated the shift in the peak transmission wavelength, validating the $\delta \propto 1/\lambda$ relationship.

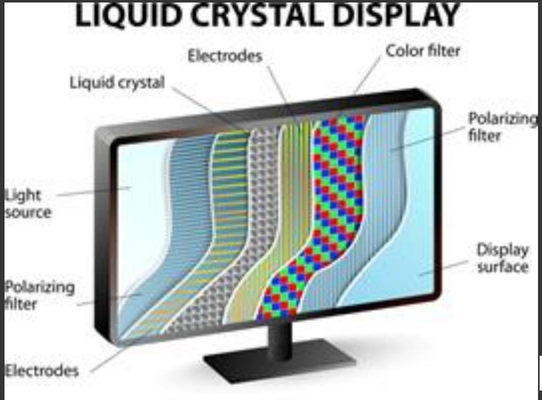
Key Takeaway

The Complementary Color Relationship between the Open Gate (0°) and Closed Gate (90°) configurations was confirmed both visually and spectrally.

The color computed from the raw spectrum ($I(\lambda) \rightarrow$ sRGB) closely matched the photographed color, validating our entire measurement and computational process.

Future Directions

Investigate how the principles of wavelength-dependent retardation are engineered to achieve color control in modern Liquid Crystal Displays (LCDs).



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Resources

Sources

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Slepkov, A.D. (2022). Painting in polarization. *American Journal of Physics*,90(8), 617-624. https://doi.org/10.1119/5.0087800

Image Sources:
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