Polarisation and Birefringence

Lucas Saragosa

Overview

- This experiment investigates how birefringent wave plates affect the polarisation state of laser light.
- We use Jones matrices to model the behavior of light as it passes through wave plates and polarisers.
- By rotating the wave plates, we can analyse changes in polarisation and measure resulting intensities at the detector.
- The results are compared to theoretical predictions to understand the polarisation transformations in detail.

Contents

Experimental Setup

- = 0

Parameters

- A linearly polarised red laser is used, with wavelength 635nm.
- Custom written code was developed, connected via serial USB to the two piezoelectric motors for the polariser and wave plate.
- An Arduino is also used to convert voltage output from the Oscilloscope into a USB format readable by code. Voltage is proportional to intensity here.
- Both wave plates investigated have thickness 3.2mm.
- One set of results takes about 10 minutes to record due to response waiting from motors to report back they have rotated, as well as actual rotation times.

Theory

$$\mathbf{J}(\theta, \delta) = \begin{bmatrix} \cos^2\theta + e^{i\delta}\sin^2\theta & (1 - e^{i\delta})\cos\theta\sin\theta \\ (1 - e^{i\delta})\cos\theta\sin\theta & \sin^2\theta + e^{i\delta}\cos^2\theta \end{bmatrix}$$

- A birefringent material has a refractive index dependent on the polarisation of incoming light, different n for the two perpendicular axes (fast and slow)
- Light with components in both perpendicular directions then undergo a phase delay due to the combined waves called the retardence (delta).
- Theta is the angle of rotation of the wave plate, which we rotate to investigate the different phase delays depending on angle.
- This Jones matrix represents the change which the input electric field vector goes under for an arbitrary birefringent material with phase delay delta.

Theory

$$\boldsymbol{E}_{\text{in}} = e^{i(kz-\omega t)} \begin{bmatrix} E_x \\ E_y \end{bmatrix}$$

$$\mathbf{J}_P = \begin{bmatrix} \cos^2\theta & \cos\theta\sin\theta \\ \cos\theta\sin\theta & \sin^2\theta \end{bmatrix}$$

- The input electric field is a standard solution to the EM wave equation.
- In this experiment, we ensure the input light is horizontally polarised, so the y component is equal to 0 and the x component equal to 1 to simply the theory.
- A polariser only lets through light polarised in a certain orientation. The matrix shows, for an arbitrary rotation, how the change after going through it.
- We can plot the output intensity, the square modulus of the combination of these matrices matching the experimental setup.

Theoretical Results

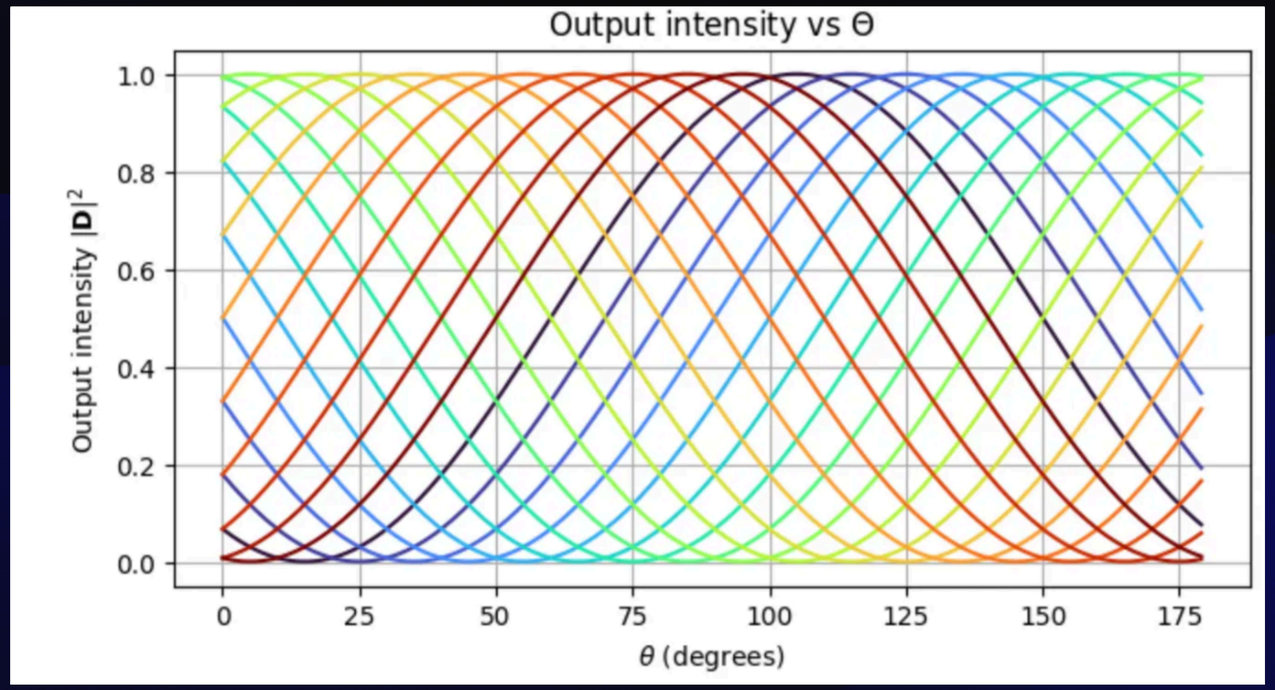

Figure 1: Half wave plate

(180 degree retardation)

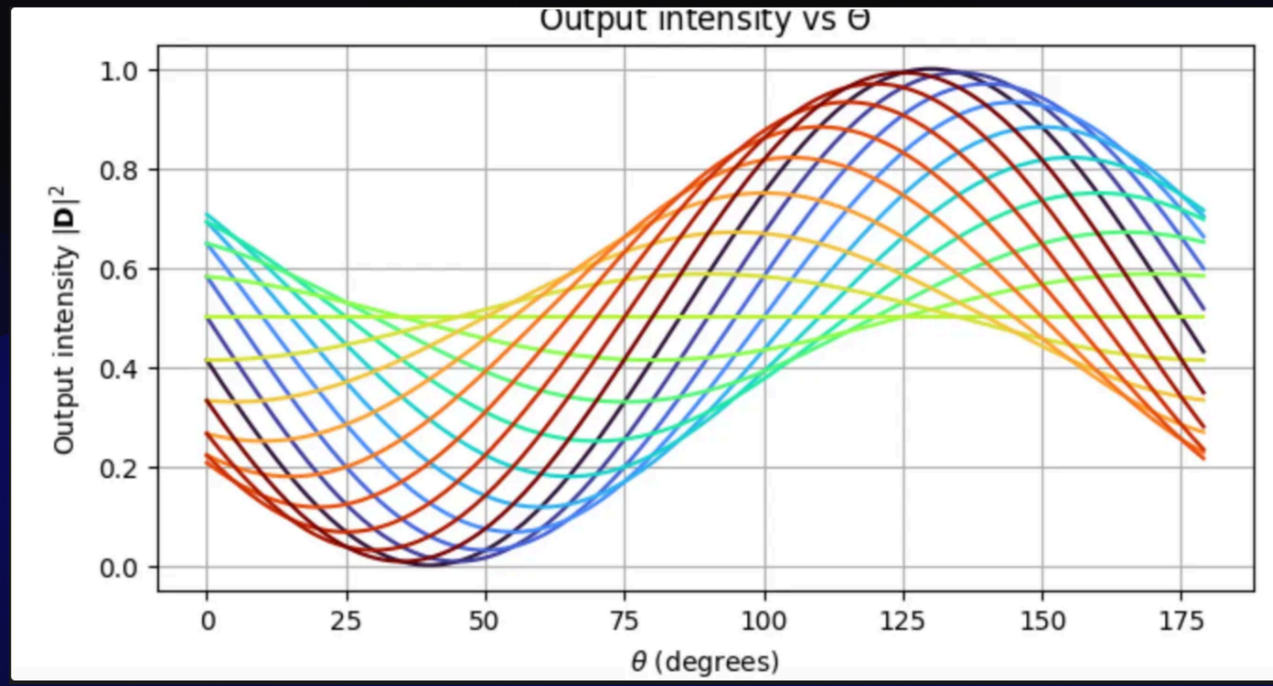

Figure 2: Quarter wave plate

(90 degree retardation)

Results

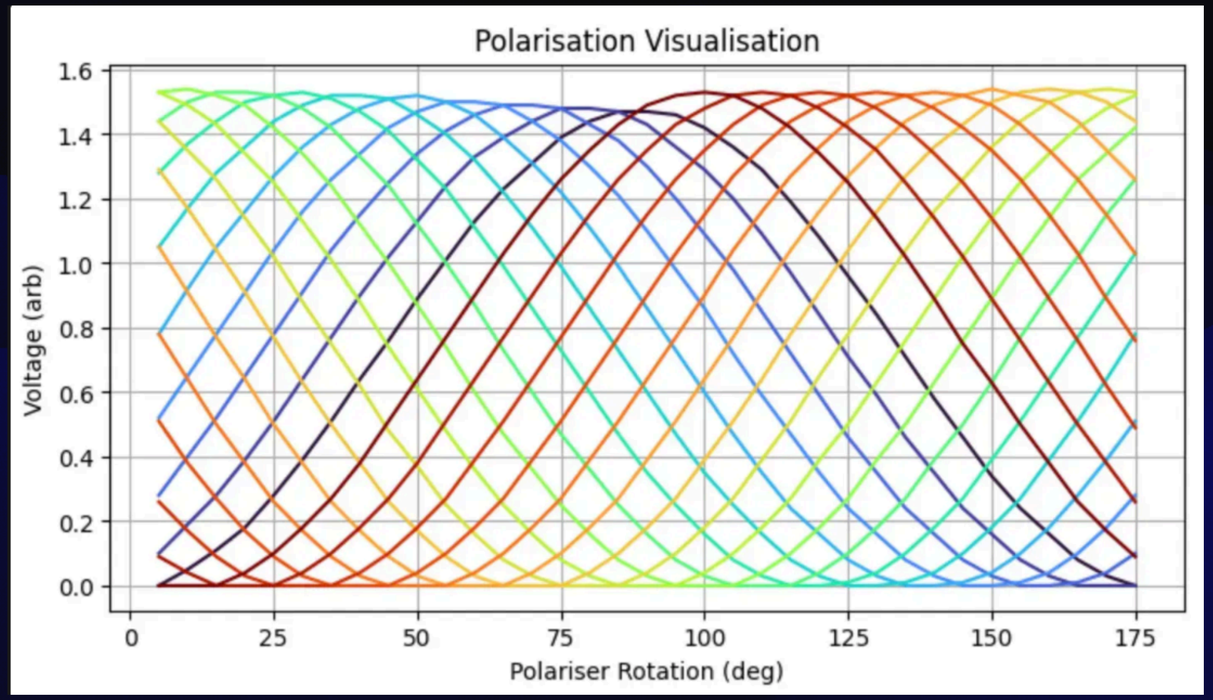

Figure 3: Half wave plate

Experimental results

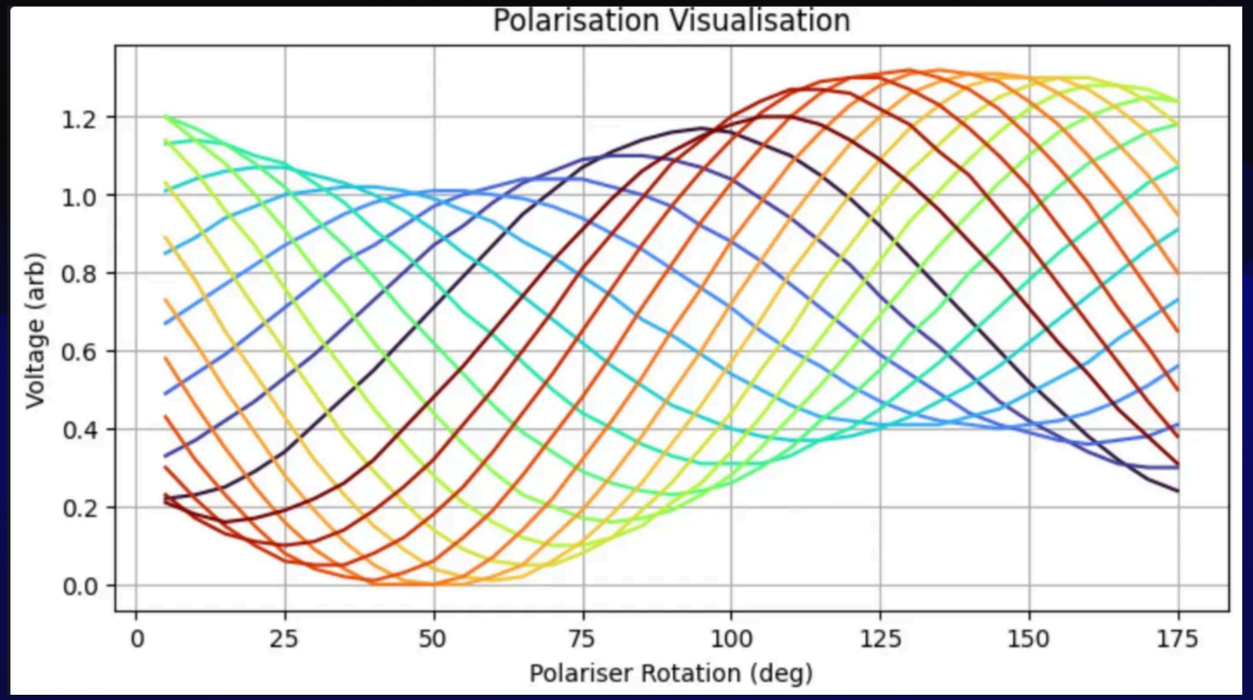

Figure 4: Quarter wave plate

Experimental results

Sellotape Results

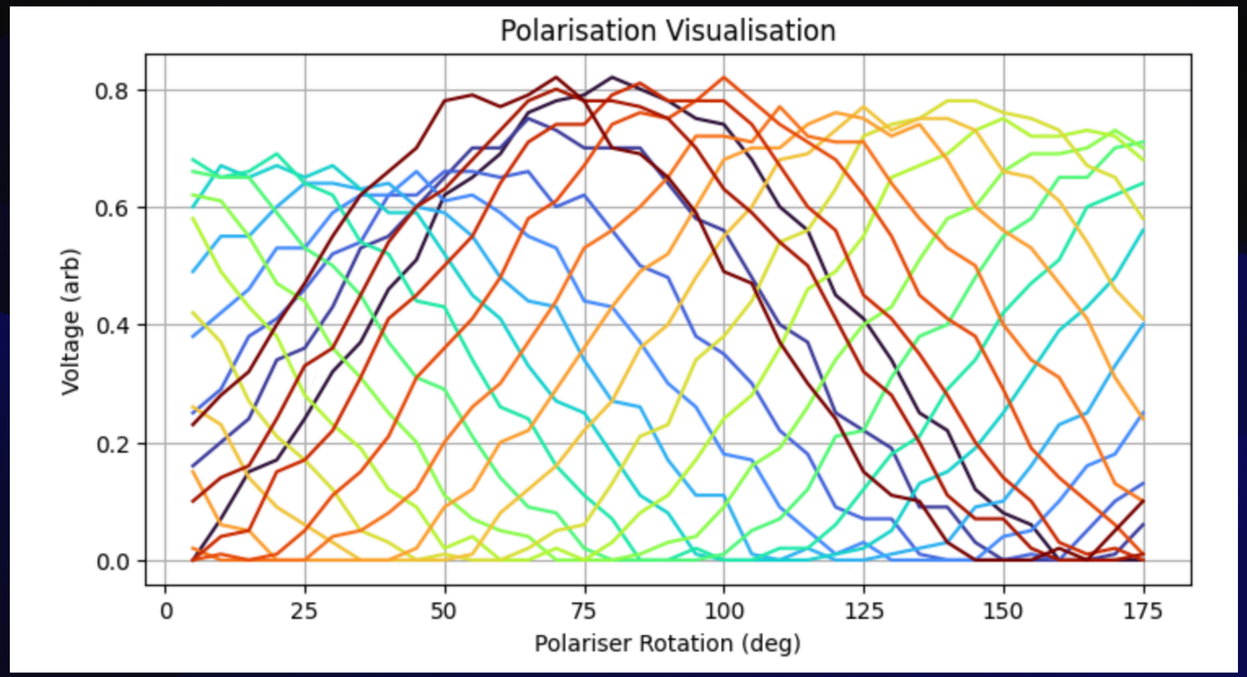

Figure 5: Sellotape Results

Conclusion / Summary

- So far, we have seen how birefringent wave plates modify the polarisation state of the light incoming.
- The observed data matches the theoretical predictions using Jones analysis.
- Rotating the wave plates produce sinusoidal intensity variation.
- Use of sellotape shows consistent polarisation effects similar to half wave plates.
- The results validate the power of Jones calculus on modern polarisation optics.

Next Steps

- Determine distinct values for the retardence for wave plates as well as sellotape with varying number of layers, as well as other parameters such as birefringence,
- Try examining different angle of incidence angles and the results for those,
- Effects of sending the light through liquids and other materials with varying rotations,
- Results of combinations of wave plates,
- Perhaps sellotape stress induced birefringence (photo-elasticity).

Q & A