EXPERIMENT-3

STUDY OF POLARIZATION OF LIGHT

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Int. M.Sc. (B22)

Objectives :

1. To analyze linearly polarized light
2. To verify Malu's Law
3. To rotate the state of polarization of a linearly polarized light using a half-wave plate
4. conversion of linearly polarized light into elliptically/ circularly polarized light using a quarter wave plate.

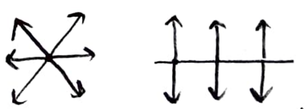
Theory

Polarization is a property of transverse waves where the direction of of oscillations is limited to a particular direction. The polarization of a light wave conventionally refers to the direction of oscillation of the electric field. On passing through certain materials, they can block vibrations in certain directions or ~~or~~ retards them ~~from~~ causing different states of polarization.

(A) Linearly Polarized light

When a beam of unpolarized light is incident on a polarizer made of bifringent material, the transmitted beam is polarized in the direction of its transmission axis. The intensity distribution as a function of the angle b/w transmission axis & polarization state is given by Malu's Law:

$$I = I_0 \cos^2\theta \quad \text{— (1)}$$



unpolarized vs. polarized light

For verifying Malu's Law, we will use an identical analyzer plate after the polarizer. When the axis of the analyzer are parallel (or anti-parallel), the resultant intensity will be maximum & ~~will be~~ zero at $\theta = 90°$ or $270°$.
The light ~~&~~ intensity is measured using a photodetector which measures intensity as proportional to the voltage generated by.

Wave Plate (Retarders)

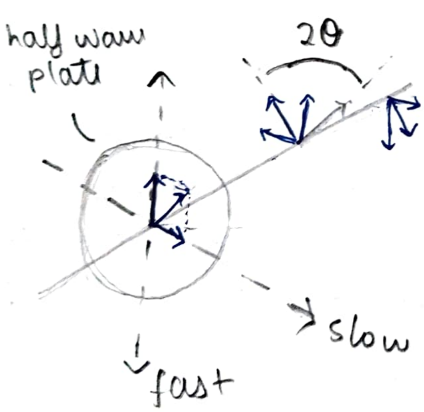
Waveplates retard a particular component of polarization w.r.t. its orthogonal component. It has different refractive indices along two perpendicular axes, which divides the beam into two components – the ordinary & the extraordinary rays – producing a phase difference :–

$$\varphi = \frac{2\pi}{\lambda}(n_o - n_e)d$$

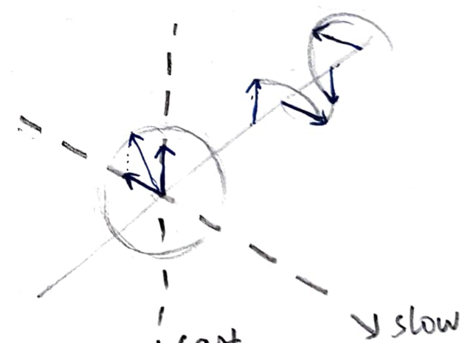
where n_e & n_o are the refractive indices of the ordinary & extraordinary ray axes respectively, d = thickness.

(B) Half-Wave Plates ($\varphi = \pi$)

When phase difference $\varphi = \pi$ due to retarders, a linearly polarized light indicident at an angle θ w.r.t. the fast axis will have its polarization axis rotated by 2θ. The $\perp^r$ component of light w.r.t. fast axis will be at a phase difference π as shown.



half wave plate rotating the plane of polarization



Quarter wave plate converting linear → elliptically polarized

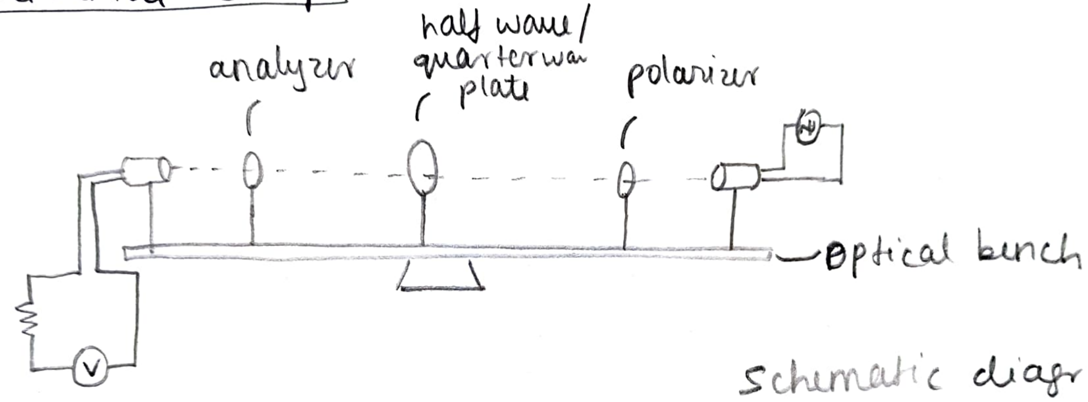
(C) Quarter Wave Plate ($\varphi = \pi/2$)

The emergent light will have circular polarization if the angle b/w polarization axis of the incident linearly polarized light is 45°. For any other value of θ, it will be elliptically polarized.

Apparatus Required

1. He-Ne laser with power supply & mount
2. Polarizer & Analyser
3. Half-wave plate
4. Quarter wave plate
5. Photo detector
6. Multimeter, resistor, breadboard & cables
7. Optical bench w/ post holders

Experimental Setup



Schematic diagram of the optical setup

The setup consists of a He-Ne laser mounted on an optical bench with a polarizer and analyzer placed on it.
The beam is allowed to fall on an affixed photo-detector connected to a digital multimeter which reads a current proportional to the intensity of the falling beam.

Graphs

Here the curve was fitted to a
$y = A\cos^2(Bx+C) + D$
curve w/ best fit values,

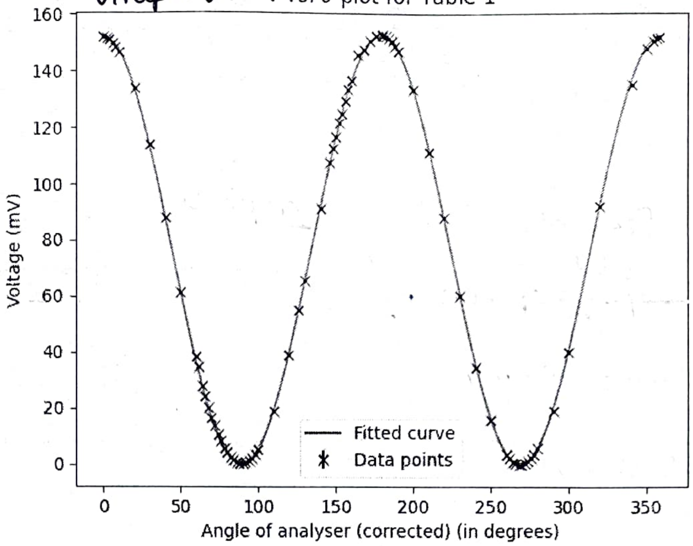
$A = (152.2 \pm 0.04)$ mV

$B \approx 1$

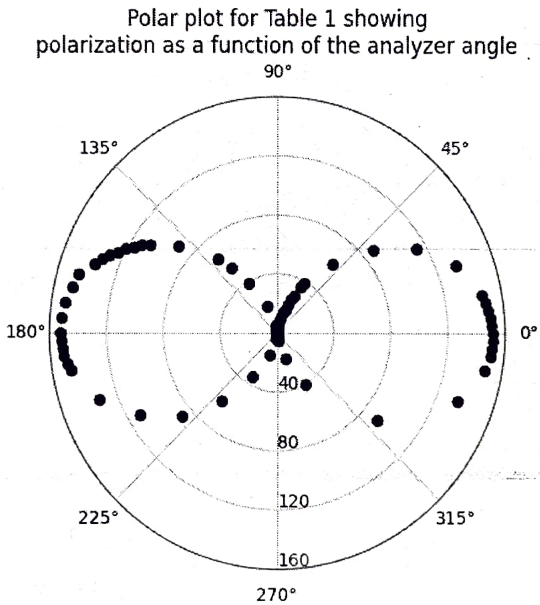
$C \approx D \approx 0$

which is in agreement with Malu's law

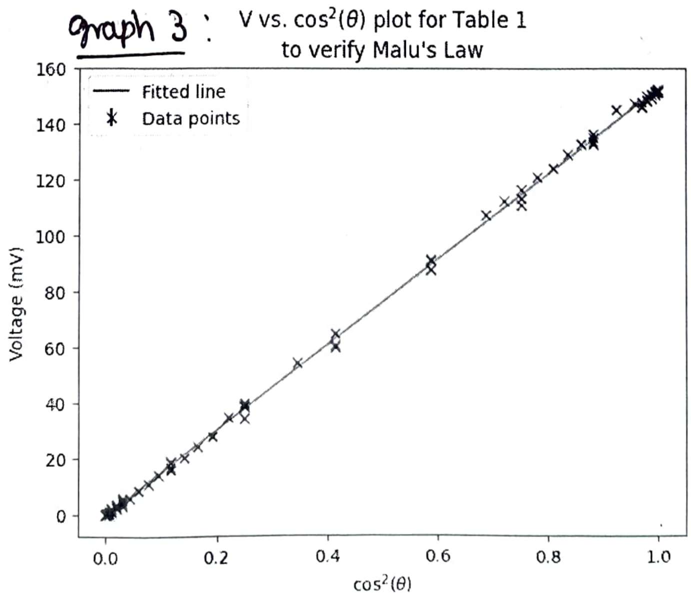
Graph 1:



graph 2



graph 3 :



For the fitted line $y = mx + C$,

$m = (152.6 \pm 0.2)$ mV

$c = -0.04 \pm 0.05$

Here, for the fitted curve
$y = A\cos^2(Bx+C)+D$,

$A = (186.4 \pm 4.1)$ mV

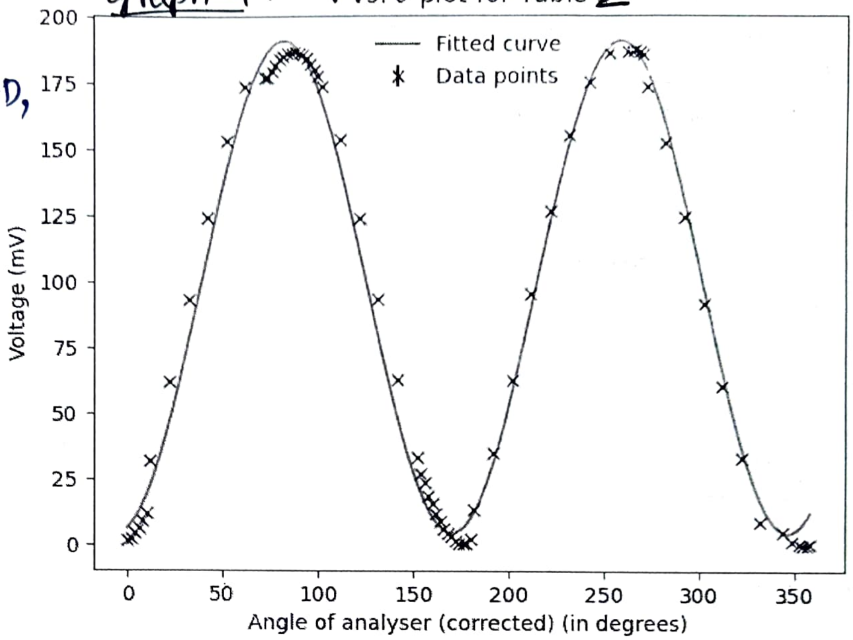
$B \approx 1$

$C \approx 1.6 \approx \pi/2$

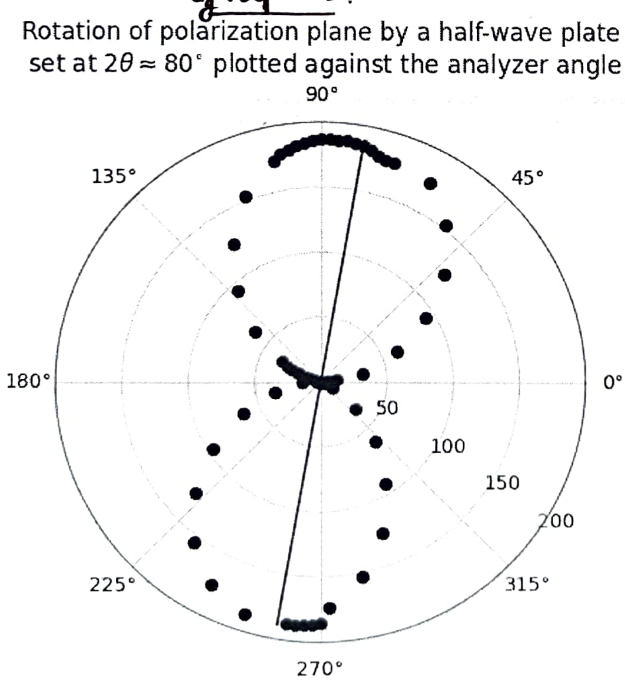
$D \approx 0$

Hence we can see that the angle has shifted by $\sim\pi/2$ (90°)

graph 4 :

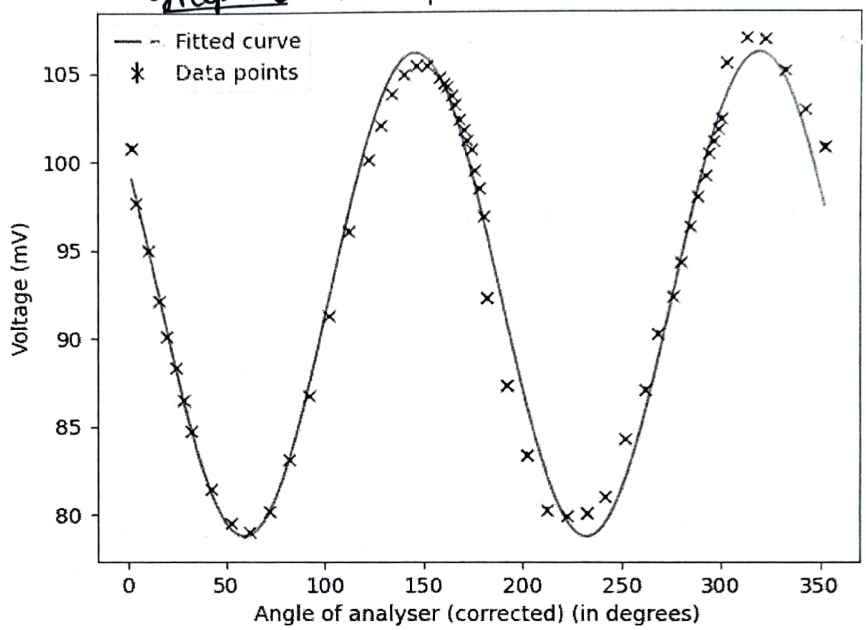


graph 5:



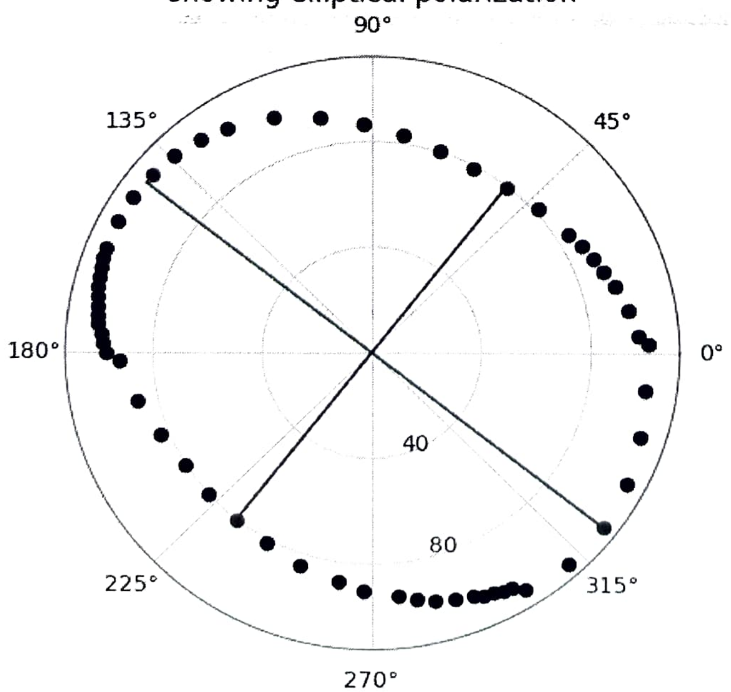
Here, the polar plot more accurately depicts the shift in angle, (which is not exactly 90°, and is infact closer to $\sim 80^\circ$)

graph 6: V vs. θ plot for Table 3



graph 7:

Polar plot for quarter-wave plate set at $\phi = 38^{\circ}$
plotted against the analyzer angle
showing elliptical polarization



Polar plot depicting elliptical polarization (with angle ~ 38°) of light.

Results & Discussion

In this experiment, we successfully analysed different kinds of polarized light. In the first part we studied the effect of the angle of the ~~anglyse~~ analyser on the resultant intensity and the results obtained seemed to follow Malu's law as predicted. The polar plot for intensity vs. ~~the~~ angle of polarizer also resembled that of a $r = \cos^2\theta$ plot.

In the second part of the experiment, we used a half-wave plate to rotate the plane of polarization. A half-wave plate splits the incident light into two components such that the resultant light has a phase shift of π b/w the components — essentially rotating the linearly polarized light through angle 2θ ($\theta = \angle$ b/w polarization vector and the waveplate's fast axis). The resultant light, ~~wave~~ the analyser was found to obey Malu's law with a phase shift of around $2\theta \approx 80°$, which was found from the polar plot. However the waveplate showed a value of $\theta \sim 45°$, so there could be an offsett.

For the third part of the experiment, we used a quarter wave plate to convert linearly polarized light into elliptical. A quarter wave plate introduces a phase shift of $\pi/2$ between the components, resulting in a $e^{i\pi/2} = i$ phase shift between the fast & slow components of the wave. Mathematically,

$$\text{if } \vec{E_i} = (E_f \hat{f} + E_s \hat{s})\, e^{i\phi},$$

$$\vec{E_r} = (E_f \hat{f} + i E_s \hat{s})\, e^{i\phi} \quad \text{, for a quarter wave plate}$$

We were able & to analyse this elliptical polarization by plotting a polar plot between analyzer angle and the output intensity (graph 7)

The axis of the ellipse was found to be rotated ~ 38° as expected.

We were also able to check the polarization state of the unfiltered laser light, ~~and~~ by only using a polarizer and a photodiode. The intensity was found to change w/ the angle of the polarizer & hence the laser is confirmed to ~~produce~~ not produce strictly unpolarized light.

Precautions

1. Rotate the polarizer/analyzer carefully in small steps.
2. Make sure to let the multimeter stabilise before taking readings
3. Make sure the axis of all optical components are parallel before starting the experiment.
4. Properly note dark voltage and ~~or~~ polariser angles to generate corrected outputs.