STUDY OF POLARIZATION OF LIGHT

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1 Abstract

Polarization is an intrinsic property of transverse wave which limits the geometrical orientation of vibration. In case of transverse wave light, when an unpolarized light beam is passed through a birefrigent material certain vibrations are favoured and more readily passable than the vibration in different directions. Thereby light is polarized and the intensity is reduced. In this experient we have analysed different types of polarized light such as linearly polarized light, elliptical polarized beams on passing an unpolarized beam through different materials with birefringent properties of certain crystals (quartz, calcite etc) We have also proven that the intensity of polarized light at different direction of polarization follows Malu's law.

2 Theory

Transverse waves are those where the direction of oscillation is perpendicular to the direction of the propagation wave. Polarization is a property of transverse waves whereby the direction of these oscillations is limited to a particular orientation as shown in the Figure 1. When the wave is passed, certain materials block the vibrations in certain orientations of an unpolarized transverse wave or retards them concerning other orientations, producing a different state of polarization. Light is a transverse electromagnetic wave consisting of the coupled oscillating electric and magnetic fields which are always perpendicular to each other. By convention, the "polarization" of electromagnetic waves refers to the direction of the electric field. Light is said to be unpolarized when its state of polarization changes more rapidly than it can be detected such that polarization averages out in all directions.

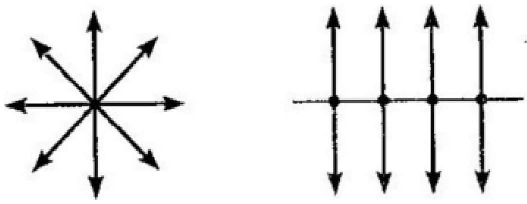

Figure 1: Unpolarized (left) and Polarized Light Beam (right)

2.1 Linearly Polarized Light

When a beam of unpolarized light is incident on a polarizer made of a birefringent material, the transmitted beam is polarized in the direction of its transmission axis. Since an unpolarized light can be substituted with two perpendicular but incoherent vibrations, the intensity of the linearly polarized light is halved ($I_0/2$ for intensity I_0) as one of the vibrational axis is blocked. Any rotation of the polarizer changes the orientation of the linearly polarized light but not its intensity.

An ideal linear polarizer has 100% transmission for a linearly polarized light for an orientation parallel to its transmission axis and zero transmission at an orientation orthogonal to it. The transmission relation with the angle difference of the transmission and polarization axis is given by Malu's law. According to Malu's law:

$$I = I_0 \cos^2 \theta \tag{1}$$

where θ is the angle between between the incident linear polarization and the transmission axis. I_0 is the intensity of the linearly polarized light before transmission (or for $\theta = 0^\circ$) and I is the intensity of the transmitted (rotated) beam.

For verifying Malu's law, we will be using an identical polarizer called an analyzer which will rotate the linearly polarized light coming from the polarizer and by rotating it at an angle with respect to the polarizer's transmission axis. The intensity of transmitted light can be noted using a detector which produces a propotional current in the multimeter.

2.2 Wave Plates (Retarders)

Ideal wave plates modify polarization without attenuating or displacing the beam. They retard a particular component of polarization with respect to its orthogonal component. It divides the incident beam into two rays: one follows the laws of refraction, called the ordinary ray and the other one is called extra-ordinary ray which does not obey the laws of refraction. This is because they have different refractive indices along two perpendicular axes. The refractive indices for the two rays are different which produces a phase difference between the rays given by:

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

where n_o and n_e are refractive index of the ordinary and extra-ordinary rays respectively. d is the thickness and λ

is the wavelength of the laser beam. Therefore the two perpendicular oscillations form a two perpendicular simple harmonic oscillator system oscillating at a phase difference depending on the wave plate used.

- **Half wave plate:**
  A retarder is called a half wave plate when causes the phase difference between the two emergent beams to be π. Therefore a linearly polarized incident at an angle θ with respect to the fast axis will have the the its polarization axis rotated by an angle 2θ, since now the perpendicular component of the light with respect to the fast axis will be at phase difference of π as shown in figure 2.

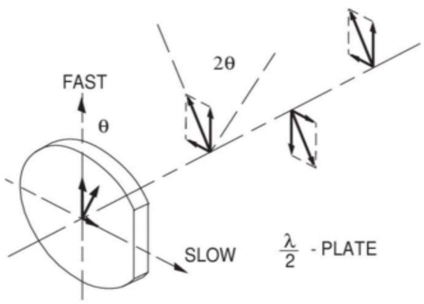

Figure 2: **Half Wave Plate rotating a linearly polarized light beam**

- **Quarter wave plate:**
  When the wave plate produces a phase difference of $\frac{\pi}{2}$, it is called a quarter wave plate. The emergent light beam will have circular polarization if the angle between the polarization axis of the linearly polarized light is at an angle of 45°, otherwise it will be elliptically polarized as shown in figure 3.

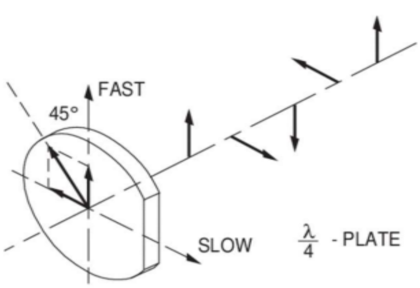

Figure 3: **Quarter wave Plate turning linear polarizationg to circular polarization**

2.3 Experimental Setup and Apparatus

As shown in figure 4, the setup consists of a He-Ne laser with power supply that is mounted on a stand and fixed to an optical bench, while a polarizer and an indentical analyzer is placed in line with it on the bench using post holders to allow the unpolarized beam to fall normally on it. The beam is allowed to fall on an affixed photo-detector connected to a digital multimeter which reads a current propotional to the intensity of the falling beam.

Figure 4: **Experimental Setup**

3 Observation

$Dark\ Current\ Value =\ 0.000\ mA$
$Analyzer\ Offset =\ 110°$
$Angular\ Position\ of\ Polarizer =\ 0°$

3.1 Verification of Malu's Law:

Sl. No	Angular Position of Analyser $(\theta)(^\circ)$	Corrected Position of Analyser $(\theta)(^\circ)$	$(\cos\theta)^2$	Current (I) (μA)
1	0	-110	0.985	265.78
2	2	-108	0.992	269.66
3	11	-99	0.995	264.81
4	15	-95	0.981	263.84
5	17	-93	0.970	258.99
6	23	-87	0.924	234.74
7	42	-68	0.671	165.87
8	55	-55	0.448	111.55
9	70	-40	0.206	50.44
10	80	-30	0.085	19.4
11	86	-24	0.036	4.85
12	90	-20	0.015	0.97
13	97	-13	0.000	0
14	102	-8	0.008	3.88
15	111	1	0.059	24.25
16	126	16	0.235	73.72
17	135	25	0.379	115.43
18	155	45	0.719	203.7
19	162	52	0.821	235.71
20	170	60	0.915	259.96
21	180	70	0.985	273.54
22	184	74	0.997	275.48
23	190	80	0.997	274.51
24	198	88	0.964	261.9
25	212	102	0.821	212.43
26	224	114	0.638	164.9
27	244	134	0.297	72.75
28	260	150	0.085	13.58
29	265	155	0.043	7.76
30	270	160	0.015	0.97
31	277	167	0.000	0
32	289	179	0.043	8.73
33	300	190	0.153	54.32
34	325	215	0.552	169.75
35	335	225	0.719	223.1
36	348	238	0.894	263.84
37	350	240	0.915	275.48
38	354	244	0.949	279.36
39	360	250	0.985	287.12
40	367	257	1.000	303.61

Table 1: Verification of Malu's Law

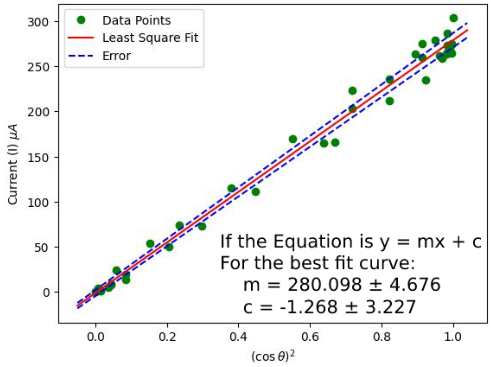

Figure 5: Current (I) vs $\cos^2\theta$

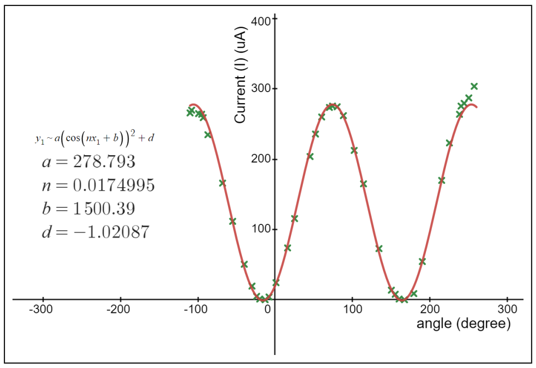

Figure 6: θ vs Current with only analyser

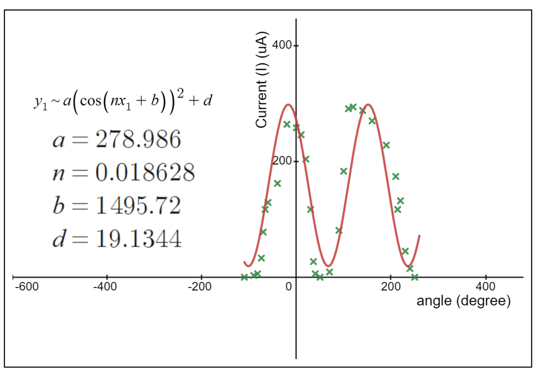

Figure 7: θ vs Current with Half wave plate

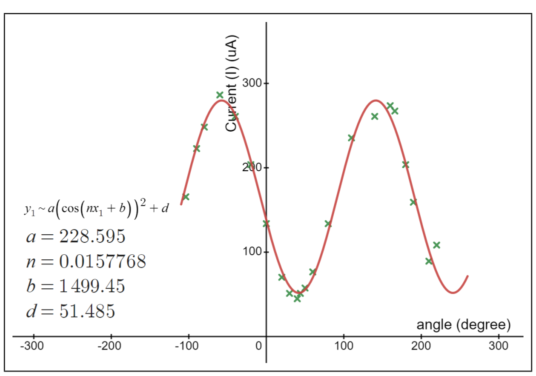

Figure 8: θ vs Current with Quarter wave plate

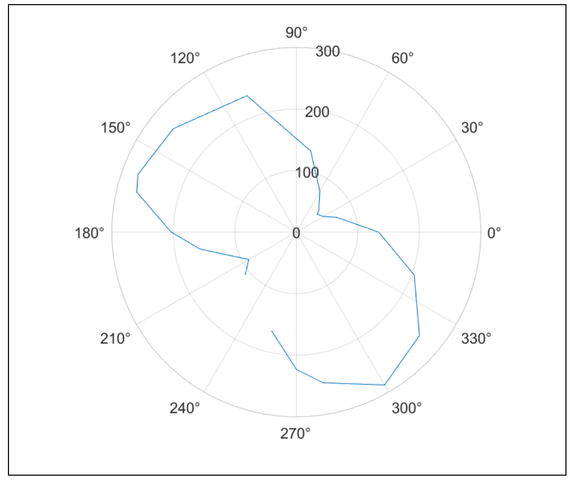

Figure 9: **Polar Graph:** $I\ vs\ \theta$

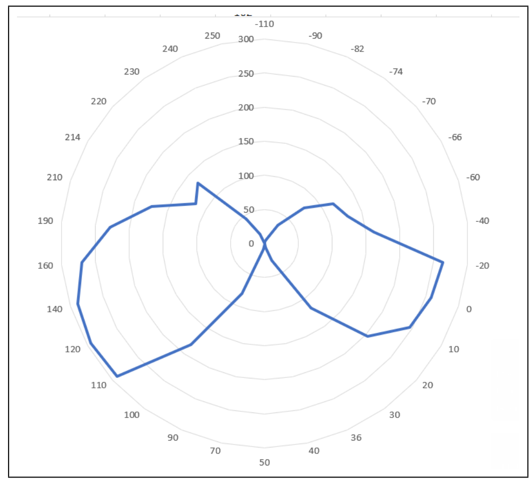

Figure 10: **Polar Graph:** $I\ vs\ \theta$

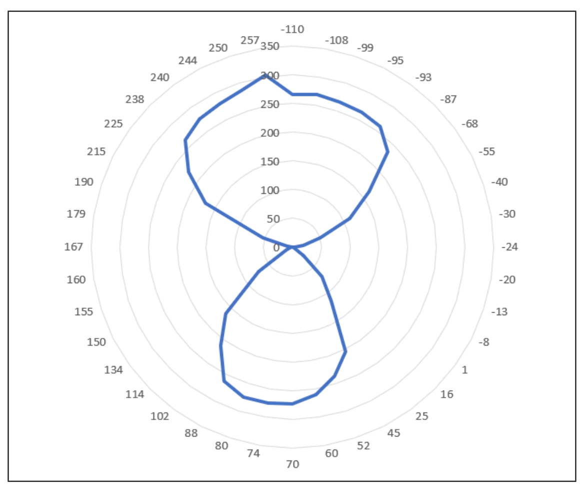

Figure 11: **Polar Graph:** $I\ vs\ \theta$

3.2 Rotation of Polarization:

Half Wave Plate Offset = 20°
Angular Position of Half Wave Plate = 66°
Corrected Angular Position of Half Wave Plate = 46°

Sl. No	Angular Position of Analyser $(\theta)(^{\circ})$	Corrected Position of Analyser $(\theta)(^{\circ})$	Current (I) (μA)
1	0	-110	0
2	20	-90	3
3	28	-82	6
4	36	-74	33
5	40	-70	78
6	44	-66	117
7	50	-60	129
8	70	-40	162
9	90	-20	264
10	110	0	258
11	120	10	246
12	130	20	204
13	140	30	117
14	146	36	27
15	150	40	6
16	160	50	0
17	180	70	9
18	200	90	81
19	210	100	183
20	220	110	291
21	230	120	294
22	250	140	288
23	270	160	270
24	300	190	228
25	320	210	174
26	324	214	117
27	330	220	132
28	340	230	45
29	350	240	15
30	360	250	0

Table 2: For Half-Wave Plate

3.3 Elliptically/ Circularly Polarized:

Quarter Wave Plate Offset = 12°
Angular Position of Quarter Wave Plate = 58°
Corrected Angular Position of Quarter Wave Plate = 46°

Sl. No	Angular Position of Analyser $(\theta)(^{\circ})$	Corrected Position of Analyser $(\theta)(^{\circ})$	Current (I) (μA)
1	6	-104	165.62
2	20	-90	222.95
3	30	-80	248.43
4	50	-60	286.65
5	70	-40	261.17
6	90	-20	203.84
7	110	0	133.77
8	130	20	70.07
9	140	30	50.96
10	150	40	44.59
11	154	44	50.96
12	160	50	57.33
13	170	60	76.44
14	190	80	133.77
15	220	110	235.69
16	250	140	261.17
17	270	160	273.91
18	276	166	267.54
19	290	180	203.84
20	300	190	159.25
21	320	210	89.18
22	330	220	108.29

Table 3: For Quarter-Wave Plate

4 Results

- From Table 1, Figure 6 and Figure 5, we find that the intensity of the polarized light follows Malu's law, as I is proportional to $\cos^2\theta$.
- From Table 2 and Figure 7, we find that for the half wave plate kept at $\theta = 46^{\circ}$ angle, we obtain two maximas at 29° and 204° showing that the light beam has rotated by an angle of $90^{\circ} \approx\ 2\theta$.
- From Table 3, Figure 8 and Figure 9, we obtain a peanut shaped graph indicating an elliptically polarized light beam for the quarter wave plate angular position of 46°. We can clearly see from Figure 8 that the intensity of the beam never goes to 0 and hence the beam is elliptically polarized.

5 Error and Discussion

This experiment doesn't have any such calculations. So, there is no such error which should be calculated and stated. But, there are a lot of errors which can be discussed.

- **Error in Equipments:** The lazer intensity hardly stabilizes ever and the intensity of the beam keeps on changing. So, the readings keep on changing frequently. **I suspect the problem is with the photodiode and not with the lazer**. We went to the lab 2 days and came back without taking any reading. then on the third day we were fortunate to get a good lazer and got good reading.
- The lab manual asks us whether the lazer gives out a polarized light or not. To answer that question, I would say, that it gives **polarized light**. This is because, with only the polariser present between the photodiode and the lazer, the intensity changes with the angle of the polariser.
- In Figure 6 and Figure 8, there is not very significant error in the data. But, in Figure 7, there is a lot of error in the data. This is because, the lazer intensity keeps on changing and hence the readings keep on changing. So, the data is not very accurate.

References

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