PSE605A (Photonics Lab Techniques)

Lab Report: Experiment 3
EO Effect

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1.1 Objective

- **To study the electro-optic effect in a Lithium Niobate crystal**
- **To measure the half-wave voltage.**

1.2 Apparatus

He-Ne laser (632.8nm), Half-wave plate, Polarizer, Analyzer, Lithium Niobate crystal in a holder, Photodetector, Digital meter, DC power supply

Experimental Setup:

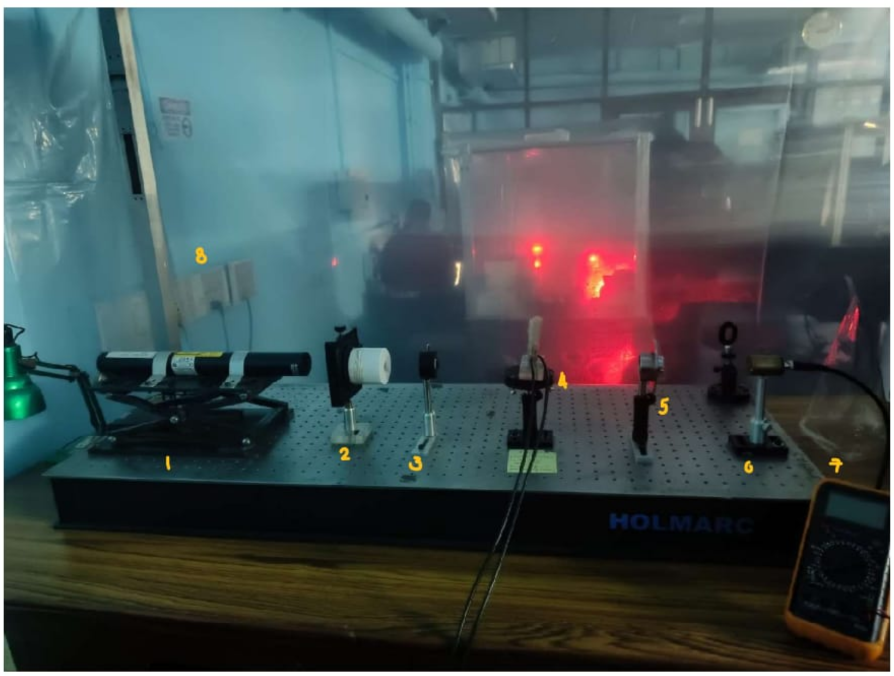

Figure 1: set up

1.3 Procedure

1. The experimental arrangement is shown in Fig. The crystal is mounted in the holder and the two terminals across the crystal are connected to the high-voltage power supply. The laser beam is allowed to pass through the crystal. 2. The laser beam is aligned in such a way as to get the 45^{o} angle of polarization concerning the crystal axis when the beam is propagating along the z-direction using a half-wave plate. 3. Now polarizer (with an axis at 45^{o}) is put after the half wave plate and the wave plate is rotated slightly to make sure 45-degree polarized light has been obtained. 4. The beam is allowed to fall on the detector after passing through the analyzer placed after the crystal. The analyzer is rotated to obtain minimum output. 5. Now the voltage is applied and increased in steps of about 270 volts up to about 1200 volts. 6. For each applied voltage the detector output readings are taken on the meter. 7. A graph is plotted between the voltage and detector output, and is curve fitted into the following formula to obtain V1/2, V is the applied voltage.

$$I \ \alpha \ Sin^2\left(\frac{\pi V}{2V_{1/2}}\right)$$

Steps 5 to 7 are repeated by rotating the analyzer to obtain maximum output.

1.4 Observation Values

1.4.1 At Maximum

Table 1: Dependence of intensity on Voltage at maximum

S. No	Voltage (V)	Intensity
1	0	160.7
2	280	163.1
3	330	163.0
4	380	162.6
5	430	162.2
6	480	161.7
7	530	161.4
8	580	160.7
9	630	160.5
10	680	159.9
11	730	160.1
12	780	159.6
13	830	159.3
14	880	159.4
15	930	159.7
16	980	160.2
17	1030	160.6
18	1080	161.1
19	1130	161.8
20	1180	162.5

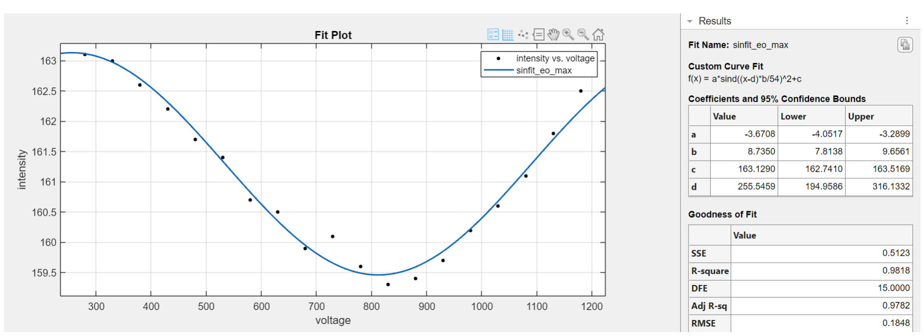

Figure 2: intensity vs voltage

1.4.2 At Minimum

Table 2: Dependence of intensity on Voltage at minimum

S. No	Voltage (V)	Intensity
1	0	94.6
2	270	68.0
3	320	62.4
4	370	57.4
5	420	55.6
6	470	57.4
7	520	64.1
8	570	71.7
9	620	80.3
10	670	87.0
11	720	92.4
12	770	96.7
13	820	98.4
14	870	97.5
15	920	97.0
16	970	95.6
17	1020	93.0
18	1070	86.1
19	1120	76.3

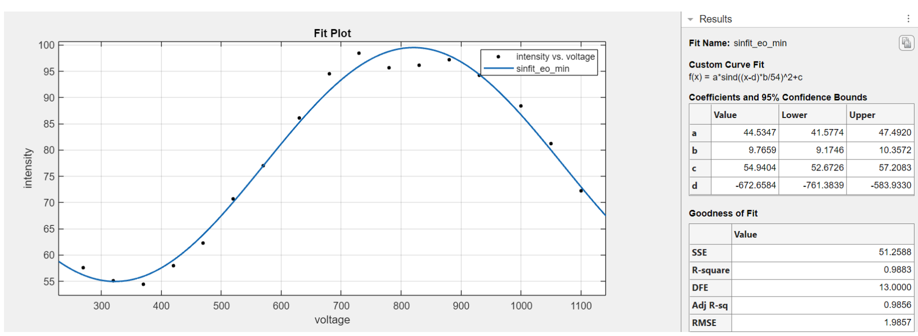

Figure 3: intensity vs voltage

1.5 Experimental Analysis: Half wave voltage calculation

1.5.1 Method 1: Difference method

- For 'At Maximum' - take data from the plot Half wave voltage,

$$V_{1/2} = 814.760 - 255.342$$
$$= 559.418\ V$$

- For 'At Minimum' - take data from the plot Half wave voltage,

$$V_{1/2} = 819.449 - 322.301$$
$$= 497.148\ V$$

1.5.2 Method 2: Curve fit method

For curve fit , we use the following formula

$$y = aSin^2\left(\frac{(x-d)b}{54}\right) + c$$

We know that half-wave voltage,

$$V_{1/2} = \left(\frac{\pi P}{2b}\right)$$

here P=54

- For 'At Maximum', from plot 'b'= 8.7350 Half wave voltage,

$$V_{1/2} = \left(\frac{180 * 54}{2 * 8.7350}\right)$$
$$= 556.382\ V$$

- For 'At Minimum', from plot 'b'= 9.7659 Half wave voltage,

$$V_{1/2} = \left(\frac{180 * 54}{2 * 9.7659}\right)$$
$$= 497.650\ V$$

1.6 Error Analysis: Half wave voltage

1.6.1 For Method 1:

- ’At Maximum’ case:
  Error= 662.609-559.418=103.191
  Percentile error= (103.191/662.609)*100% = 15.57 %

- ’At Minimum’ case:
  Error= 662.609-497.148 = 165.461
  Percentile error= (165.461/662.609)*100% = 24.97 %

1.6.2 For Method 2:

- ’At Maximum’ case:
  Error= 662.609-556.382 = 106.227
  Percentile error= (106.227/662.609)*100% = 16.03%

- ’At Minimum’ case:
  Error= —662.609-497.650—=164.959
  Percentile error= (164.959/662.609)*100% =24.89%

1.7 Observations

- During the experiment, data is taken at two conditions, keeping the analyzer at maximum and minimum intensities. For each case, the intensity changes with the input voltage in square of sinusoidal manner. It indicates the electro-optic effect in Lithium Niobate crystal.
- At the maximum or minimum intensity, the output fluctuates more.

1.8 Precautions

- Do not look at the laser ray directly.
- Room should be dark. Otherwise, it will add noise to the detector.
- Alignment should be done perfectly. Otherwise, output intensity will be less. That will affect the data.
- Don’t touch the optical table when the switch of input voltage is on.
- After changing the voltage, the output reading should be taken when it is stabilized.
- Before switching off the input voltage, make sure the knob is at zero.

1.9 Discussion and Conclusion

- With changing the input voltage, the output intensity changes. It refers to the polarization axis rotates due to applying a perpendicular electric field. It indicates the transverse electro-optic effect in Lithium Niobate crystal.
- The approximate error in calculating half-wave voltage is 16% for maximum intensity and 25% for minimum intensity. This error is not ignorable. I think it happens due to the fluctuation at low voltage. To fix it, stabilized input voltage has to be used.

2 Faraday-Effect

2.1 Objectives

- **To calculate the verdet constant of a Terbium doped glass rod**
- **To observe the change in verdet constant of Terbium doped glass rod w.r.t wavelength**

2.2 Apparatus

3 Lasers (405nm, 532nm, 650nm), pair of polarizers mounted in graduated circular scales, Terbium doped glass rod, solenoid, detector, digital meter, mounts, power supply

Experimental Setup:

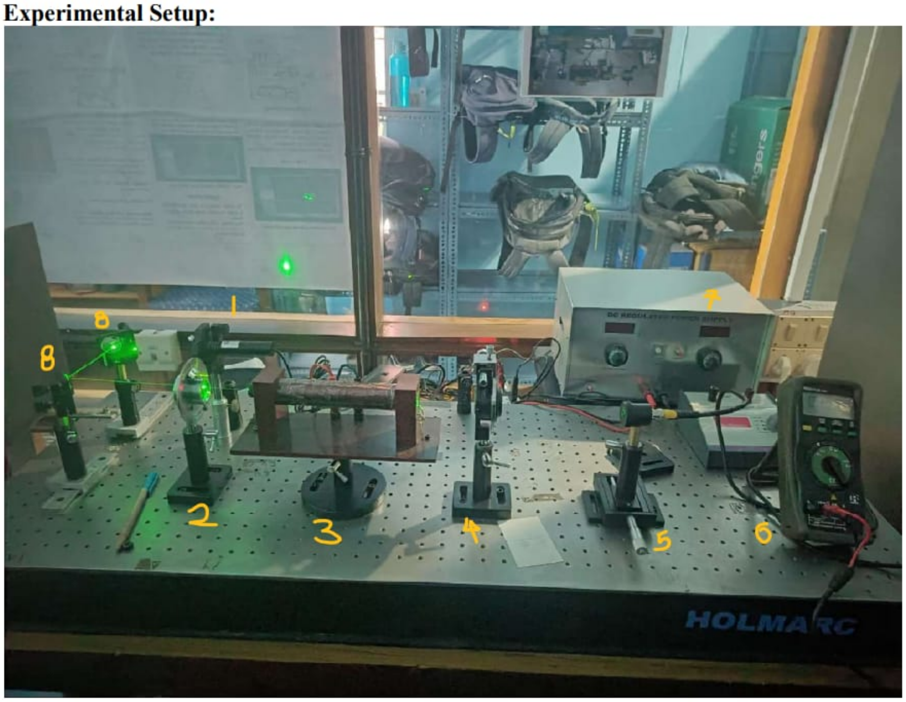

Figure 4: set up

2.3 Procedure

The entire setup is aligned such that the light from the laser passes through the center of the quartz sample to the pin-hole photodiode. With the magnetic field turned off, the laser light is polarized by the polarizer and the analyzer is adjusted such that the photodiode shows just above minimum intensity, say V volt in multi-meter. Hence the angle corresponding to this intensity is chosen as $\theta 0$. Now when the current is turned on, there is a magnetic field within the solenoid causing the plane of polarization of the light to rotate.$\theta 0$ is no longer the angle corresponding to V volt; the analyzer is rotated to find the new angle θ called to get the same V volt in multi-meter. The rotation θ is calculated for different currents and hence different magnetic fields. The process is also repeated for the remaining lasers.

2.4 Observation Values and Calculation

Given, L= 0.027 m
We know Verdet constant,

$$V = \theta/HL$$

or,

$$V = 1/(slope * L)$$

N=total turn/length=1660/0.15=11066.667

2.4.1 Red Laser

Table 3: Red Laser(λ=650 nm)

S.No	Voltage (mV)	Current (A)	Magnetic Field (H) ($H = 0.0126 * NI$)	Rotation (θ)	Relative error $\|\theta - \theta 0\|$)
1	251	0.00	0.000	82.3	0.0
2	251	0.30	41.832	82.0	0.3
3	251	0.60	83.664	81.5	0.5
4	251	0.96	133.862	81.9	0.4
5	251	1.33	185.455	80.7	1.2
6	251	1.59	221.710	80.4	0.3
7	251	1.90	264.936	80.0	0.4
8	251	2.19	305.373	79.6	0.4
9	251	2.50	348.600	79.2	0.4
10	251	2.81	391.826	79.0	0.2
11	251	3.00	418.320	78.6	0.4
12	251	3.23	450.391	78.3	0.3

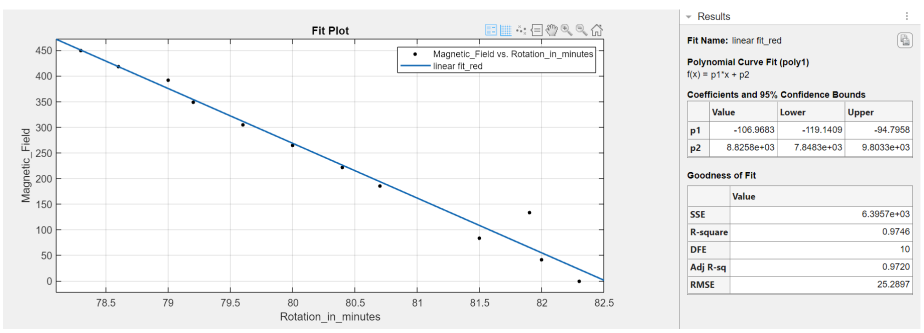

Figure 5: magnetic field vs rotation in minutes (red laser)

from the plot, slope (p1)= 106.9683
Verdet constant(for red laser),

$$V = 1/(0.027 * 106.9683) = 0.3462 \; minute/Oe/cm$$

2.4.2 Green Laser

Table 4: Green Laser(λ=532 nm)

S.No	Voltage (mV)	Current (A)	Magnetic Field (H) ($H = 0.0126 * NI$)	Rotation (θ)	Relative error $\lvert\theta - \theta 0\rvert$)
1	249.8	0.00	0.000	256.4	0.0
2	249.8	0.30	41.832	256.2	0.2
3	249.8	0.60	83.664	255.8	0.4
4	249.8	0.90	125.496	256.1	0.3
5	249.8	1.20	167.328	255.6	0.5
6	249.8	1.50	209.160	255.0	0.6
7	249.8	1.80	250.992	254.5	0.5
8	249.8	2.10	292.824	254.0	0.5
9	249.8	2.40	334.656	253.5	0.5
10	249.8	2.70	376.488	252.9	0.6
11	249.8	3.00	418.320	252.2	0.7
12	249.8	3.30	460.152	251.4	0.8

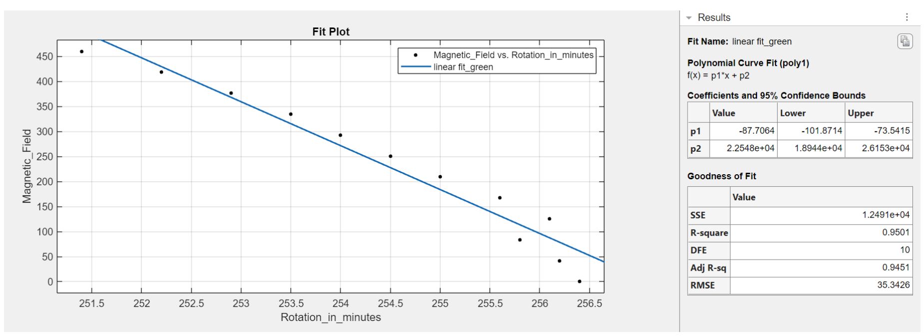

Figure 6: magnetic field vs rotation in minutes (green laser)

from the plot, slope(p1)= 87.7064
Verdet constant(for green laser),

$$V = 1/(87.7064 * 0.027) = 0.4222\ minute/Oe/cm$$

2.4.3 Violet Laser

Table 5: Violet Laser(λ=405 nm)

S.No	Voltage (mV)	Current (A)	Magnetic Field (H) ($H = 0.0126 * NI$)	Rotation (θ)	Relative error $\|\theta - \theta 0\|$)
1	310.1	0.00	0.000	276.7	0.0
2	310.1	0.30	41.832	273.0	3.7
3	310.1	0.60	83.664	271.5	1.5
4	310.1	0.90	125.496	270.0	1.5
5	310.1	1.25	174.300	268.5	1.5
6	310.1	1.50	209.160	267.5	1.0
7	310.1	1.80	250.992	266.5	1.0
8	310.1	2.10	292.824	264.6	1.9
9	310.1	2.40	334.656	263.3	1.3
10	310.1	2.70	376.488	262.0	1.3
11	310.1	3.00	418.320	260.6	1.4
12	310.1	3.30	460.152	261.6	1.0

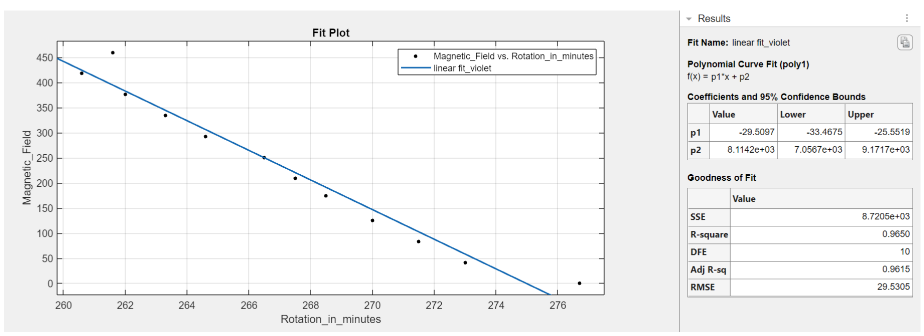

Figure 7: magnetic field vs rotation in minutes (violet laser)

from the plot, slope= 29.5097
Verdet constant(for violet laser),

$$V = 1/(0.027 * 29.5097) = 1.2551\ minute/Oe/cm$$

2.5 Verdet Constant

S. No	Wavelength (nm)	Verdet Constant (minute/Oe/cm)
1	650 (red)	0.3462
2	532 (green)	0.4222
3	405 (violet)	1.2251

Table 6: verdet constant

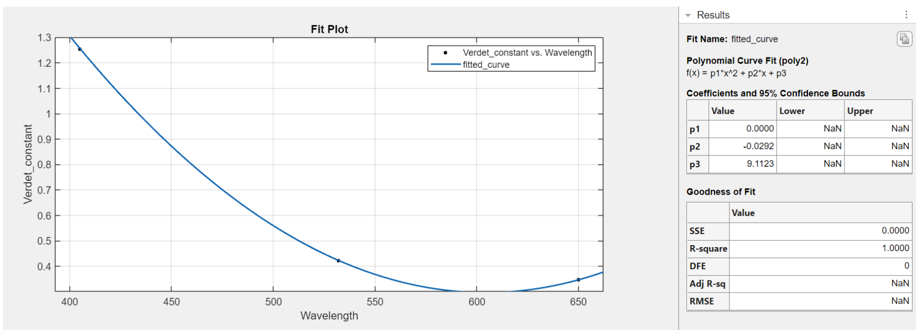

Figure 8: verdet constant vs wavelength

2.6 Error Analysis

For Red laser, the theoretical value of verdet constant is 0.33 minute/Oe/cm
Error in verdet constant,

$$\delta V = (0.3462 - 0.33)\ minute/Oe/cm$$

$$= 0.0162\ minute/Oe/cm$$

Percentile error in verdet constant

$$(\delta V/V)100\% = (0.0162/0.33) * 100\%$$

$$= 4.91\%$$

Percentile error in verdet constant for red laser is 4.91%

2.7 Observations

- With changing the current, the output intensity changes.
- With changing equal amounts of input current, the rotation of the polarization axis is also almost equal for a specific wavelength.

- For red laser, the output intensity fluctuates at low current input.
- With increasing the wavelength, the verdet constant decreases.

2.8 Precautions

- Do not look at the laser ray directly
- Room should be dark. Otherwise, it will add noise to the detector.
- Alignment should be done perfectly. Otherwise, it will affect the data.
- The output intensity should be fixed at the mean point of the maximum and minimum intensity.
- To remove the error of perpendicularity, the vernier reading should be taken perfectly.
- While taking reading through the lens, laser rays should be blocked by paper.
- While rotating the analyzer to adjust the output intensity, the input current should be fixed.
- To remove the heating issue, turn off the input voltage while taking the scalar reading in the analyzer.

2.9 Discussion and Conclusion

- With changing the input current, the output intensity changes. It refers that the polarization axis rotates due to applying a parallel magnetic field. It indicates the magneto-optic effect of Terbium doped glass rod.
- For a constant wavelength, the magnetic field vs rotation curve is linear. It indicates verdet constant depends on the material only.
- With increasing the wavelength, the Verdet constant decreases. It means the rotation of the polarization axis is less for a higher wavelength for a constant magnetic field.
- The error in calculating verdet constant is approximately 5%. I think the experimental value of the verdet constant at 650 nm is not bad. We might get more perfection if the heating effect is removed.