**Roll No:** 20PH20014
**Name:** Jessica John Britto

# Optics Lab
# PH29204

## EXPERIMENT-5

## Verification of Malus Law

**Aim:** To verify Malus Law.

**Apparatus:** A diode laser, a polarizer-analyzer pair, photodetector, detector output measuring unit (microammeter), dial fitted to the polarizer, and an optical bench.

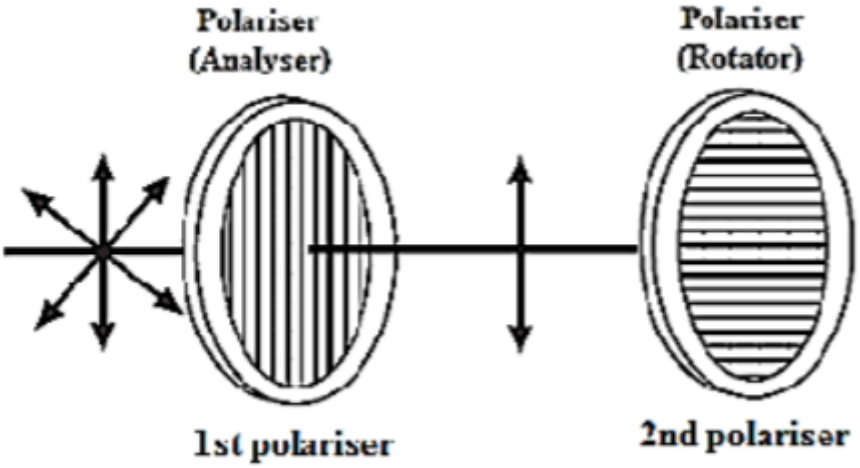
**Theory**: A polarizer only allows light that is vibrating in a particular plane to pass through it. This plane forms the "axis" of polarization. Unpolarized light vibrates in all planes perpendicular to the direction of propagation. If unpolarized light is incident upon an "ideal" polarizer, only half will be transmitted through the polarizer. Since in reality, no polarizer is "ideal" less than half the light will be transmitted. The transmitted light is polarized in one plane. If this polarized light is incident upon a second polarizer, the axis of which is oriented such that it is perpendicular to the plane of polarization of the incident light, no light will be transmitted through the second polarizer. However, if the second polarizer is oriented at an angle so that it is not perpendicular to the first polarizer, there will be some component of the electric field of the polarized light that lies in the same direction as the axis of the second polarizer, thus some light will be transmitted through the second polarizer (see the bottom figure). The component, E, of the polarized electric field, $E_0$, is found by:

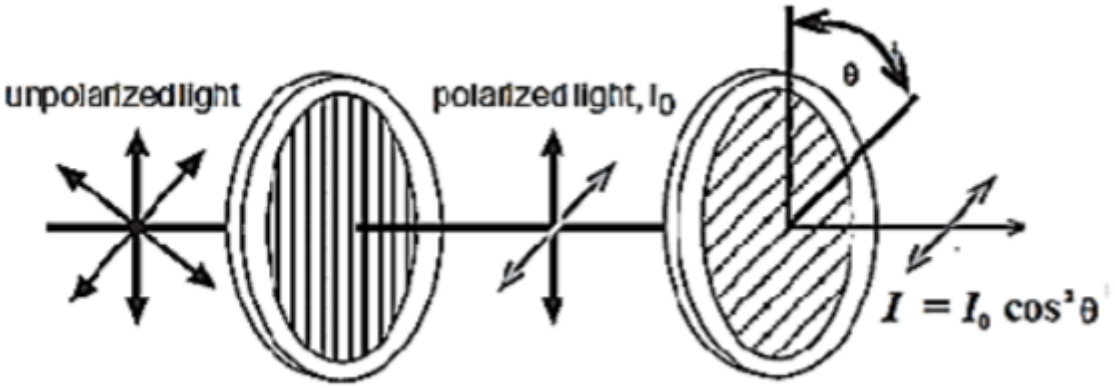
$$E - E_0 cos\theta$$

Since the intensity of the light varies as the square of the electric field, the light intensity transmitted through the second filter is given by:

$$I = I_0 cos^2\theta$$

where $I_0$ is the intensity of the light passing through the first filter and θ is the angle between the polarization axes of the two filters.






Experimental setup

Working Formula-

The intensity of the transmitted light is given by

$$I = A_t^2$$

$$I = A_0^2 cos^2\theta$$

$$I = I_0 cos^2\theta$$

where

$I_t$ is the intensity of light transmitted through the analyzer

$I_0$ is the intensity of the incident plane-polarized light and

θ is the angle between the axis of the polarizer and analyzer

## Observations:

**Table-1**

Position of polarization axis or transmission axis of 1st polarizer $\varphi_0 = 85^\circ$ and $I_0 = 18$ mA,

L.C = 2°

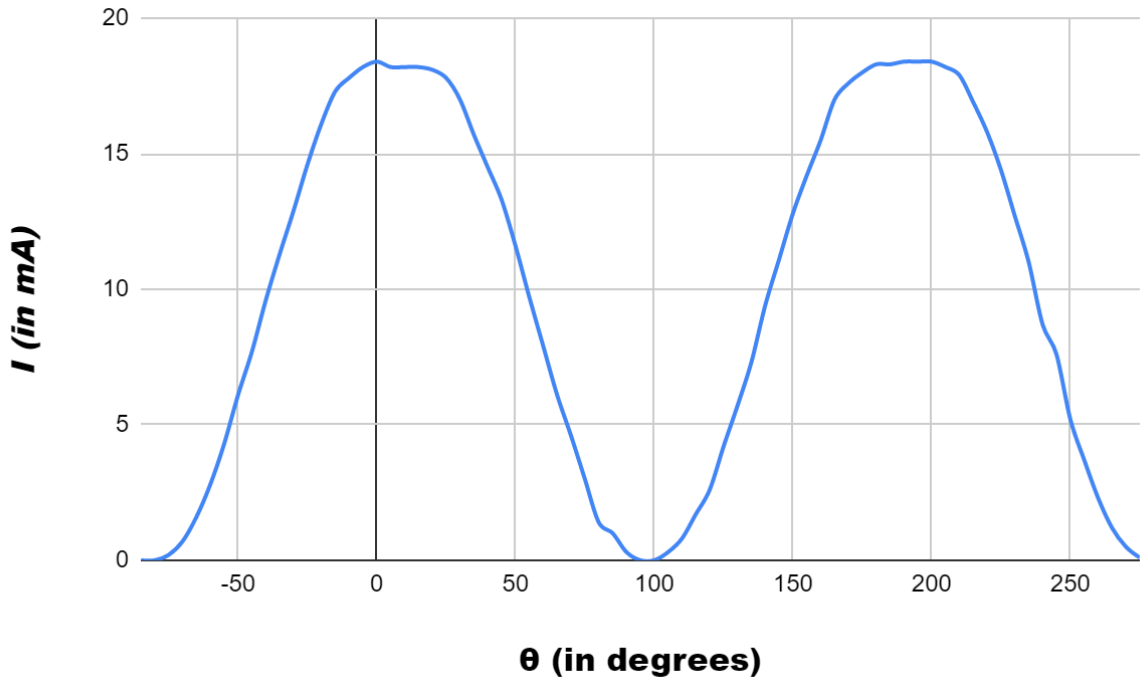
| Sl. No. | φ (Degree) | $\theta = (\varphi - \varphi_0)^\circ$ | I (mA) | $\cos^2\theta = \frac{I}{I_0}$ |
|---|---|---|---|---|
| 01 | 0 | -85 | 0.0 | 0 |
| 02 | 5 | -80 | 0.0 | 0 |
| 03 | 10 | -75 | 0.2 | 0.01 |
| 04 | 15 | -70 | 0.7 | 0.04 |
| 05 | 20 | -65 | 1.6 | 0.09 |
| 06 | 25 | -60 | 2.8 | 0.15 |
| 07 | 30 | -55 | 4.3 | 0.23 |
| 08 | 35 | -50 | 6.1 | 0.33 |
| 09 | 40 | -45 | 7.7 | 0.42 |
| 10 | 45 | -40 | 9.6 | 0.52 |
| 11 | 50 | -35 | 11.3 | 0.61 |
| 12 | 55 | -30 | 12.9 | 0.70 |
| 13 | 60 | -25 | 14.6 | 0.79 |
| 14 | 65 | -20 | 16.1 | 0.88 |
| 15 | 70 | -15 | 17.3 | 0.94 |
| 16 | 75 | -10 | 17.8 | 0.97 |

| | | | | |
|---|---|---|---|---|
| 17 | 80 | -5 | 18.2 | 0.99 |
| 18 | 85 | 0 | 18.4 | 1.0 |
| 19 | 90 | 5 | 18.2 | 0.99 |
| 20 | 95 | 10 | 18.2 | 0.99 |
| 21 | 100 | 15 | 18.2 | 0.99 |
| 22 | 105 | 20 | 18.1 | 0.97 |
| 23 | 110 | 25 | 17.8 | 0.96 |
| 24 | 115 | 30 | 17.0 | 0.92 |
| 25 | 120 | 35 | 15.7 | 0.85 |
| 26 | 125 | 40 | 14.5 | 0.79 |
| 27 | 130 | 45 | 13.3 | 0.72 |
| 28 | 135 | 50 | 11.6 | 0.63 |
| 29 | 140 | 55 | 9.7 | 0.53 |
| 30 | 145 | 60 | 7.9 | 0.43 |
| 31 | 150 | 65 | 6.1 | 0.33 |
| 32 | 155 | 70 | 4.6 | 0.25 |
| 33 | 160 | 75 | 3.0 | 0.16 |
| 34 | 165 | 80 | 1.4 | 0.1 |
| 35 | 170 | 85 | 1.0 | 0.05 |
| 36 | 175 | 90 | 0.3 | 0.01 |
| 37 | 180 | 95 | 0.0 | 0 |
| 38 | 185 | 100 | 0.0 | 0 |
| 39 | 190 | 105 | 0.3 | 0.01 |
| 40 | 195 | 110 | 0.8 | 0.04 |
| 41 | 200 | 115 | 1.7 | 0.09 |
| 42 | 205 | 120 | 2.6 | 0.14 |
| 43 | 210 | 125 | 4.2 | 0.23 |
| 44 | 215 | 130 | 5.7 | 0.31 |
| 45 | 220 | 135 | 7.3 | 0.39 |
| 46 | 225 | 140 | 9.4 | 0.50 |
| 47 | 230 | 145 | 11.1 | 0.60 |
| 48 | 235 | 150 | 12.8 | 0.69 |
| 49 | 240 | 155 | 14.2 | 0.77 |
| 50 | 245 | 160 | 15.5 | 0.84 |
| 51 | 250 | 165 | 17.0 | 0.92 |
| 52 | 255 | 170 | 17.6 | 0.96 |
| 53 | 260 | 175 | 18.0 | 0.98 |
| 54 | 265 | 180 | 18.3 | 0.99 |
| 55 | 270 | 185 | 18.3 | 0.99 |
| 56 | 275 | 190 | 18.4 | 1.0 |
| 57 | 280 | 195 | 18.4 | 1.0 |
| 58 | 285 | 200 | 18.4 | 1.0 |
| 59 | 290 | 205 | 18.2 | 0.99 |
| 60 | 295 | 210 | 17.9 | 0.97 |
| 61 | 300 | 215 | 16.9 | 0.92 |
| 62 | 305 | 220 | 15.8 | 0.86 |

| | | | | |
|---|---|---|---|---|
| 63 | 310 | 225 | 14.4 | 0.78 |
| 64 | 315 | 230 | 12.7 | 0.68 |
| 65 | 320 | 235 | 11.0 | 0.58 |
| 66 | 325 | 240 | 8.7 | 0.47 |
| 67 | 330 | 245 | 7.6 | 0.42 |
| 68 | 335 | 250 | 5.2 | 0.28 |
| 69 | 340 | 255 | 3.7 | 0.20 |
| 70 | 345 | 260 | 2.3 | 0.12 |
| 71 | 350 | 265 | 1.2 | 0.06 |
| 72 | 355 | 270 | 0.5 | 0.03 |
| 73 | 360 | 275 | 0.1 | 0.01 |

## Graph:

**Plot of *I (mA) vs θ*:**

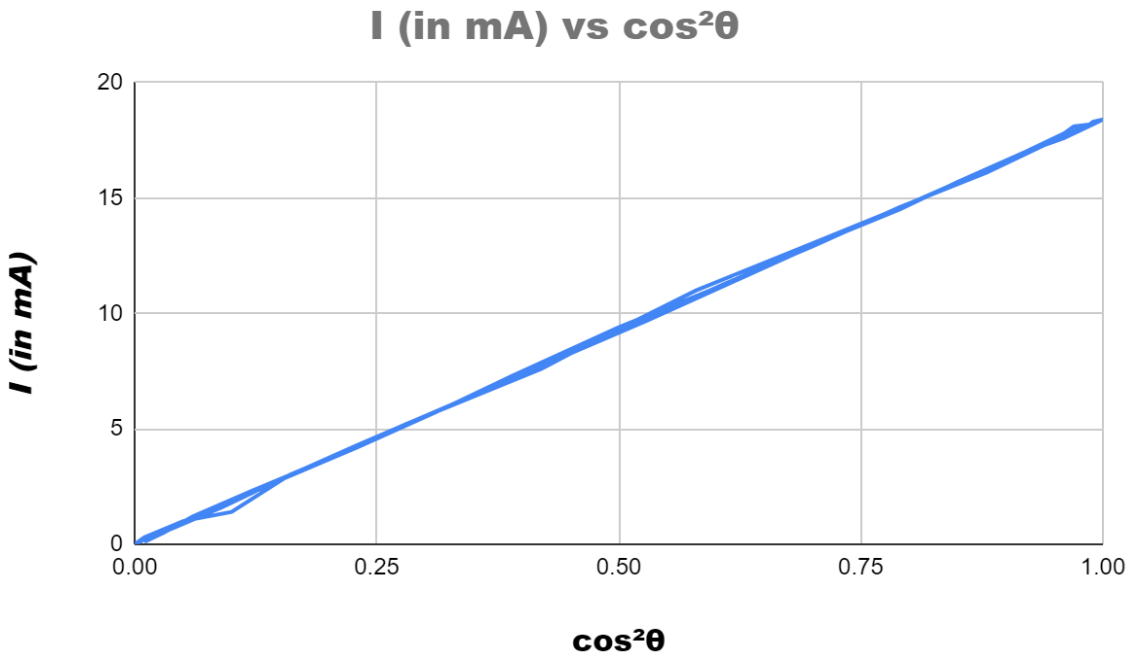



**Graph-1**

**Scale:**

X-axis: 1 unit = 50°
Y-axis: 1 unit = 5 mA

**Plot of *I (in mA) vs cos²θ*:**




**_____Graph-2**

**Scale:**

X-axis: 1 unit = 0.25 units
Y-axis: 1 unit = 5 mA

**Plot of $\frac{I}{I_0}$ *vs cos²θ*:**

Table-2: Verifying Malus Law-

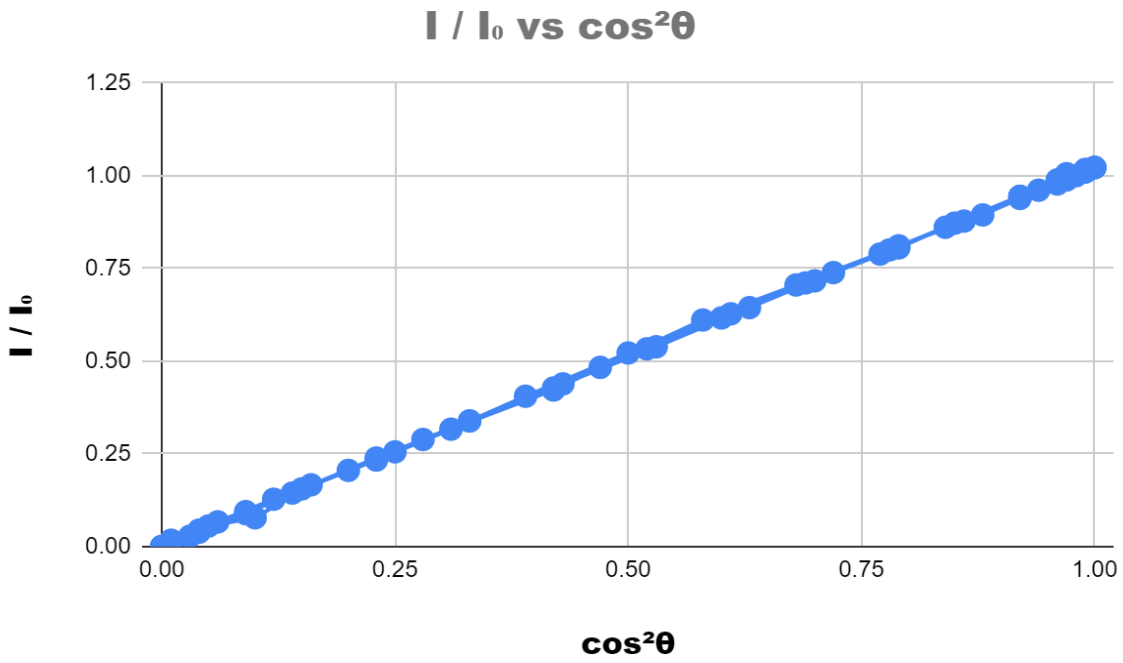
| $cos^2\theta = \frac{I}{I_0}$ | $\frac{I}{I_0}$ |
|---|---|
| 0 | 0 |
| 0 | 0 |
| 0.01 | 0.01111111111 |
| 0.04 | 0.03888888889 |
| 0.09 | 0.08888888889 |
| 0.15 | 0.1555555556 |
| 0.23 | 0.2388888889 |
| 0.33 | 0.3388888889 |
| 0.42 | 0.4277777778 |
| 0.52 | 0.5333333333 |
| 0.61 | 0.6277777778 |
| 0.7 | 0.7166666667 |

| | |
|---|---|
| 0.79 | 0.8111111111 |
| 0.88 | 0.8944444444 |
| 0.94 | 0.9611111111 |
| 0.97 | 0.9888888889 |
| 0.99 | 1.011111111 |
| 1 | 1.022222222 |
| 0.99 | 1.011111111 |
| 0.99 | 1.011111111 |
| 0.99 | 1.011111111 |
| 0.97 | 1.005555556 |
| 0.96 | 0.9888888889 |
| 0.92 | 0.9444444444 |
| 0.85 | 0.8722222222 |
| 0.79 | 0.8055555556 |
| 0.72 | 0.7388888889 |
| 0.63 | 0.6444444444 |
| 0.53 | 0.5388888889 |
| 0.43 | 0.4388888889 |
| 0.33 | 0.3388888889 |
| 0.25 | 0.2555555556 |
| 0.16 | 0.1666666667 |
| 0.1 | 0.07777777778 |
| 0.05 | 0.05555555556 |
| 0.01 | 0.01666666667 |
| 0 | 0 |
| 0 | 0 |
| 0.01 | 0.01666666667 |
| 0.04 | 0.04444444444 |
| 0.09 | 0.09444444444 |
| 0.14 | 0.1444444444 |
| 0.23 | 0.2333333333 |
| 0.31 | 0.3166666667 |
| 0.39 | 0.4055555556 |
| 0.5 | 0.5222222222 |
| 0.6 | 0.6166666667 |
| 0.69 | 0.7111111111 |
| 0.77 | 0.7888888889 |

| | |
|---|---|
| 0.84 | 0.8611111111 |
| 0.92 | 0.9444444444 |
| 0.96 | 0.9777777778 |
| 0.98 | 1 |
| 0.99 | 1.016666667 |
| 0.99 | 1.016666667 |
| 1 | 1.022222222 |
| 1 | 1.022222222 |
| 1 | 1.022222222 |
| 0.99 | 1.011111111 |
| 0.97 | 0.9944444444 |
| 0.92 | 0.9388888889 |
| 0.86 | 0.8777777778 |
| 0.78 | 0.8 |
| 0.68 | 0.7055555556 |
| 0.58 | 0.6111111111 |
| 0.47 | 0.4833333333 |
| 0.42 | 0.4222222222 |
| 0.28 | 0.2888888889 |
| 0.2 | 0.2055555556 |
| 0.12 | 0.1277777778 |
| 0.06 | 0.06666666667 |
| 0.03 | 0.02777777778 |
| 0.01 | 0.005555555556 |

Clearly from table-2, $\frac{I}{I_0} \approx cos^2\theta$, hence, we can say that Malus Law has been verified.

Therefore, we get the following graph of $\frac{I}{I_0}$ *vs* $cos^2\theta$ -




**Graph-3**

**Scale:**

X-axis: 1 unit = 0.25 units
Y-axis: 1 unit = 0.25 units

Slope of graph-3 is 1.023409639

## Error Analysis:

**Working Formula-**

$I = I_0 cos^2\theta$

On taking log on both sides and differentiating the above equation, we get -

$$\frac{\Delta I}{I} = \frac{\Delta I_0}{I_0} + 2\,tan\theta \bullet \frac{\Delta\theta}{\theta}$$

$\Delta I_0 = 0.1mA$, $\Delta\theta = 2^\circ = 0.0349$ radians

$$\frac{\Delta I}{I} = \frac{0.1}{18} + 2tan(45^0) \bullet 0.0349 = 0.075$$

$\Delta I = 13.3 \bullet 0.075 = 0.997\ mA$

Percentage error in I is 7.5%

## Results:

1. Clearly, from graph-3, Malus Law has been verified since $\frac{I}{I_0} \approx cos^2\theta$. Hence, Malus Law has been verified.
2. The intensity measured is I = (13.300 + 0.997) mA

## Precaution:

1. Analyzer and Polarizer should be at the same horizontal level.
2. The analyzer must be rotated by small angles (5o- 100). Changing values abruptly may cause errors.
3. The experiment should be performed in dark room.
4. The photodetector is a very sensitive device. It should be adjusted well (at appropriate height) to receive maximum current.
5. Zero error must be noted in the measuring instruments.
6. To reduce statistical error in measurements, at least 3-5 readings must be taken.
7. Parallax and back-lash errors during measurement must be avoided.

## Discussion:

1. The current (proportional to light intensity), noted for different angles of rotation of the analyzer, follows a cosine curve for $360^{o}$ of rotation, indicating the validity of equation-2. The experimentally measured current ($I_{expt}$) and ($I_{theo}$) that were calculated using the equation $I_{theo} = I_{max} \cos^2\theta$ agree within the limits of the experimental error.
2. The relative intensity of the light emerging from the analyzer is maximum at 0° and 180° and it attains minimum value at 90° and 270°. In between, it varies as a Cosine function as indicated by the graph.
3. The light intensity $I_{expt}$ versus $\cos^2\theta$ curve is a straight line, as expected, with a unit slope indicating the correctness of Malus's law.