Malus law

Aim :

To determine the relationship between the intensity of the transmitted light through analyzer and $'\theta'$ the angle between the axes of polarizer and analyzer and to verify Malus Law.

Apparatus Used :

A diode laser, a polarizer-analyzer pair, photo detector, detector output measuring unit (micro ammeter), dial fitted to the polarizer and an optical bench .

Formula Used : Intensity of the transmitted light is given by

$$I_t = A_t^2 = A_o^2 \cos^2\theta = I_o \cos^2\theta$$

Where I_t is the intensity of the light transmitted through the analyzer;

I_o is the intensity of the incident plane polarized light and

θ is the angle between the axis of polarizer and analyser

Theory:

The light coming from the Sun, candle light, and light emitted by a bulb is an ordinary light and is known to be un-polarized. In an un-polarized light electric and magnetic field vectors vibrate in all possible directions perpendicular to each other and also perpendicular to the direction of propagation of light. **Unpolarised light** can be represented as shown in fig. 1(a). The unpolarised light can be considered to be composed of two linear orthogonal polarization states with complete incoherence.

When unpolarized light is incident on an ideal polarizer, the intensity of the transmitted light is one-half of the incident light. Also if the polarizer is rotated w.r.t. incident light there is no change in the irradiance of the transmitted light i.e. its intensity remains half of the incident light.

Polarization:

Certain transparent materials such as Nicol, Tourmaline are capable of filtering and allowing light waves having vibrations in only one plane. Such materials are called Polaroids. This filtering is possible due the structure of the material that is having its cells arranged in a straight line manner only in one direction (parallel to the pass axis of polarizer) which is represented in fig. 1(b) & fig. 1(c).

This phenomenon of filtering and producing light waves having vibrations confined to one particular direction is called polarization. Polarization is a property of a material by which light waves are filtered and made directional.

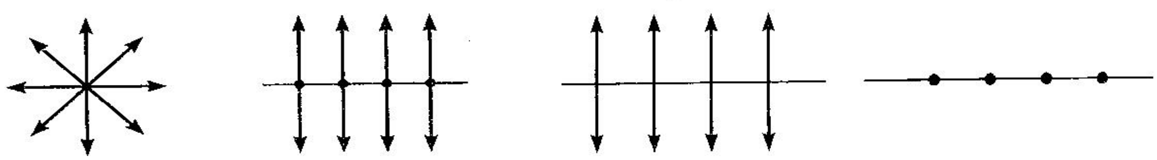
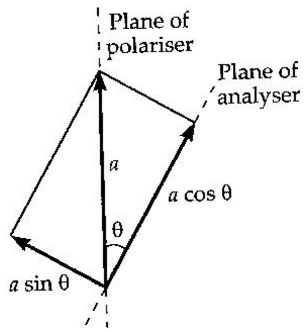


Figure 1(a) Figure 1(b) Figure 1(c)

Malus's Law:

When light falls on a polarizer, the transmitted light gets polarized. The polarized light falling on another Polaroid, called analyzer, transmits light depending on the orientation of its axis with the polarizer. The intensity of light transmitted through the analyzer is given by Malus' law. The law describes how the intensity of light transmitted by the analyzer varies with the angle that its plane of transmission makes with that of the polarizer. The law can be stated in words as follows:

The intensity of the transmitted light varies as the square of the cosine of the angle between the two planes of transmission.



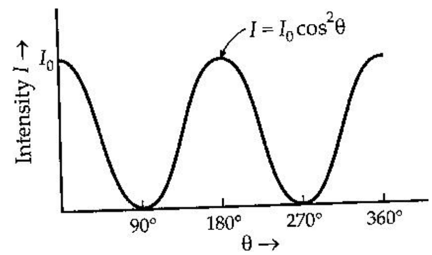


Figure 2

If A_o is the amplitude of the incident light and (At) is amplitude of the light transmitted through the analyzer; which in inclined at an angle θ with the polarizer then (fig 2 & 3),

$A_t = A_o \, Cos\theta$ ……………………………………………………1

As Intensity $\propto$ (amplitude)^2

$\mathbf{I_t = A_t^2 = A_o^2 \, Cos^2\theta = I_o \, Cos^2\theta}$ ………………………………..2

Where I_t is the intensity of the light transmitted through the analyzer; and I_o is the intensity of the incident plane polarized light.

Consider the two extreme cases illustrated by this equation:

1 If θ is zero, the second polarizer (analyser) is aligned with the first polarizer, and the value of $\cos^2\boldsymbol{\theta}$ is one. Thus the intensity transmitted by the second filter is equal to the light intensity that passes through the first filter. This case will allow maximum intensity to pass through.

2 If θ is 90˚, the second polarizer (analyser) is oriented perpendicular to the plane of polarization of the first filter, and the $\cos^2(90˚)$ gives zero. Thus no light is transmitted through the second filter. This case will allow minimum (zero) intensity to pass through.

The light intensity cannot be measured directly. The light energy is converted into electrical energy using photo detectors such as a photo cell or light dependent resistor (LDR). In such photo detectors the current produced is directly proportional to the light intensity.

$I_t \propto$ current

$I_t = K$ *current

The constant K appearing here is nothing but the conversion efficiency of photo detector. Using this concept Malus's law (equations 1 and 2) is verified in this experiment. The angles are noted experimentally from the dial fitted to the Polaroids.

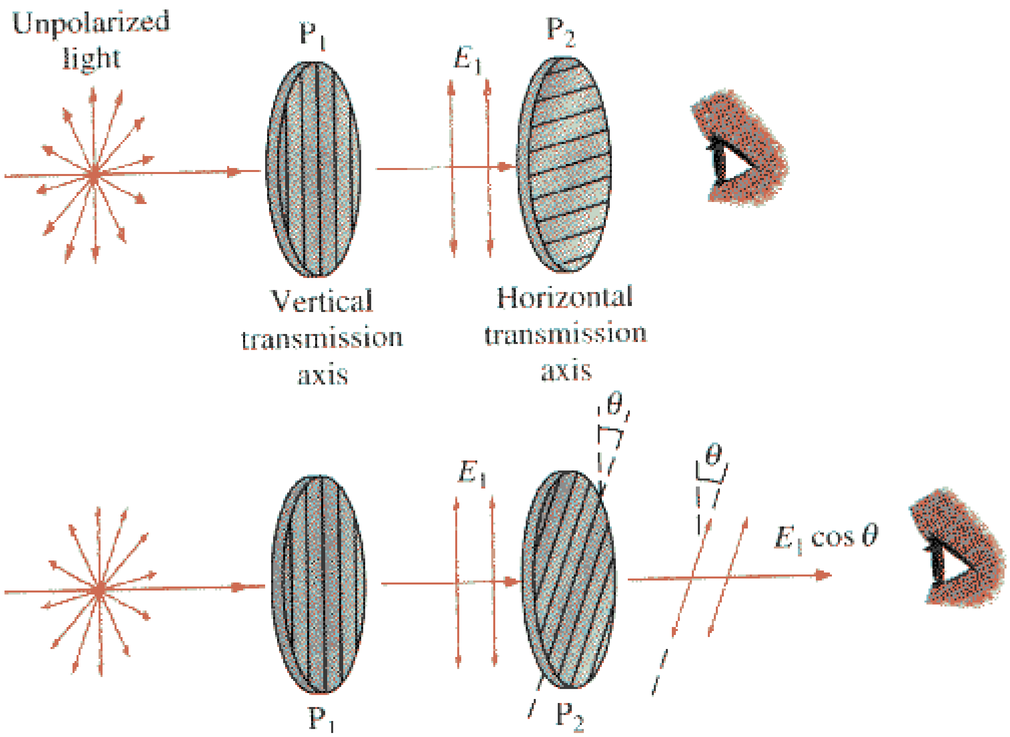


Figure 3

Experimental Procedure

1. Set up the laser, photodiode, the polarizer and analyser as shown in Figure 4 to test Malus's Law.

2. Make sure the polarizer and analyser are normal to the laser beam and that the beam passes through a "good" portion of the polarizers – look for minimal scattering, etc.

3. When the laser is going through polarizer, analyser and then into a detector make sure polarizer and analyser transmission axes are parallel. That way you can work with an offset from 0^o. To do this, keep the polarizer fixed and rotate the analyser until you observe a maximum in transmission. Note down maximum current I_{max} and angle as ϕ_o. At this point the pass axes of polarizer and analyser are parallel.

4. Rotate the analyzer in 10^o increments from ϕ_o to get 'θ' in a range 0^o to 360^o. Take readings of the intensity at each angle. The intensity of light beam that passes through polarizer and analyser was measured by the light sensor. The rotary motion sensor measures the angle that was obtained from rotating the second analyzer relative to the first polarizer.

5. In each case the current is noted and tabulated in Table-1.

6. Plot a graph taking the current 'I_{expt}' along Y-axis and angle of rotation of analyzer on the X-axis. From the graph the cosine nature of the curve is clearly evident, validating the Malus' law.

7. Cos θ, $Cos^2\theta$, I_{theo} are calculated and presented in Table-1. Plot two more graphs showing the variation of I_{expt} vs $Cos^2\theta$ and I_{expt} vs I_{theo}

8. The slope of straight line in graph I_{expt} vs I_{theo} is calculated. Slope ≈1

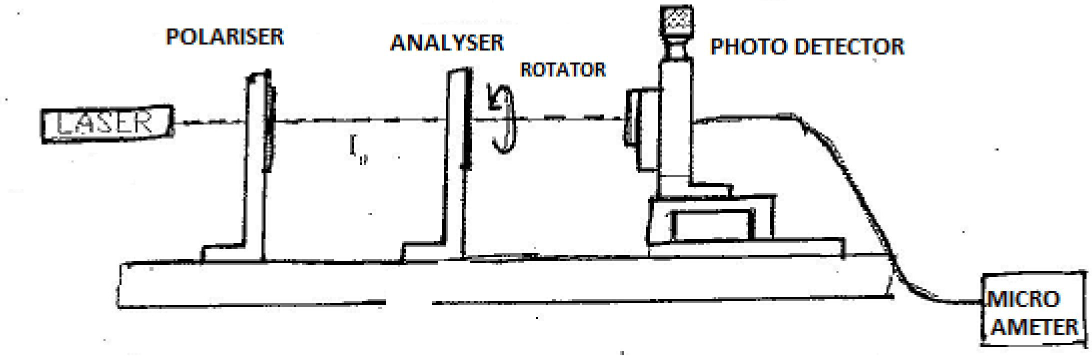


Figure :4

OBSERVATIONS

Angle of Analyzer when current is maximum ϕ_o = …..(degrees)

Maximum Current I_{max} = ….. (μamp)

S.No.	Angle of Analyzer ϕ (degrees)	Angle between the axes of polarizer and Analyzer 'θ' = $\phi - \phi_o$ (degrees)	Cos θ	$Cos^2\theta$	Current (≡Intensity) I_{expt} (μamp)	Current 'I_{theo}' $I_{theo} = I_{max} * Cos^2\theta$ (μamp)
1						
2						
3						
4						
..						
..						
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RESULTS

Write on your own how the Malus law have been verified from your experimental data.

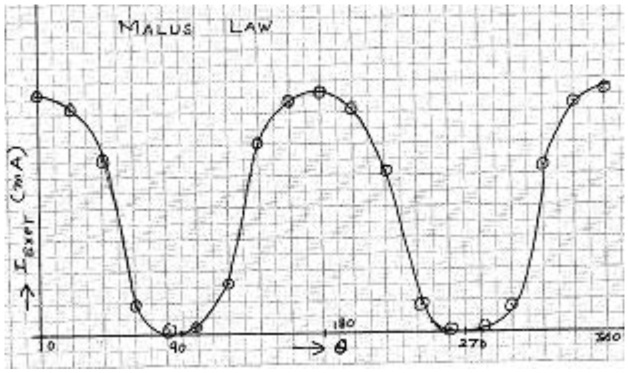

Figure 5

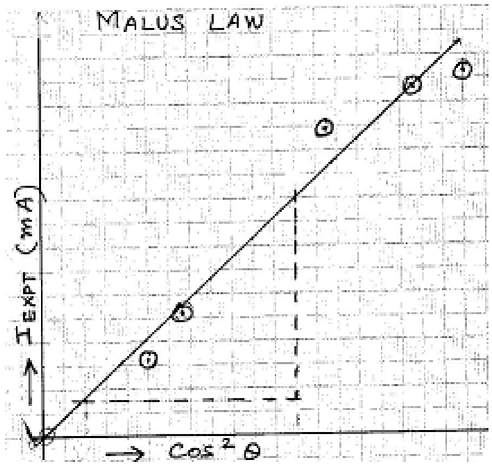

Figure 6

DISCUSSION

1. The current (proportional to light intensity), noted for different angles of rotation of the analyzer, follows a cosine curve for 360° of rotation, indicating the validity of equation-2. The experimentally measured current (I_{expt}) and (I_{theo}) that calculated using 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 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 unit slope indicating the correctness of the Malus's law.

Precautions:

1. Analyzer and Polarizer should be at same horizontal level.

2. Analyzer must be rotated by small angles (5^o- 10^0). Changing values abruptly may cause errors.

3. Experiment should be performed in dark room.

4. Photo detector is a very sensitive device. It should be adjusted well (at appropriate height) to receive maximum current.

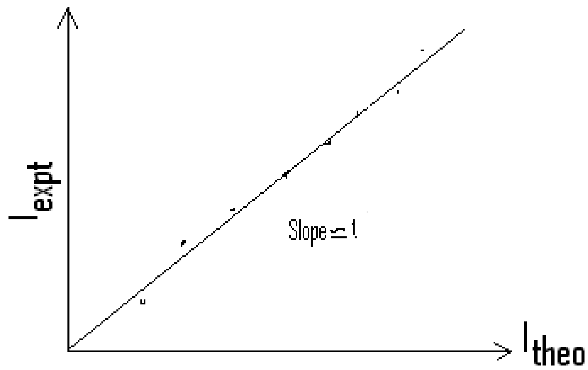

Figure 7