# Optics

Polarisation

3B PHYSICS EXPERIMENT

# Malus' Law

## VERIFY MALUS' LAW FOR LINEARLY POLARISED LIGHT.

- Measure the intensity of light $I$ transmitted through a polarising filter as a function of the angle of rotation of the filter.

- Verify Malus' law.

UE4040100

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Fig. 1: Measurement set-up.

## GENERAL PRINCIPLES

**Light, being a transverse wave, can be polarised, for example by allowing it to pass through a polarising filter. In a linearly polarised light wave, both the electric field $E$ and magnetic field $B$ oscillate in distinct planes. The orientation direction of the electric field oscillation is called the polarisation direction.**

In this experiment light passes through two filters termed the polariser and the analyser, which are aligned at an angle of $\varphi$ to one another. The polariser only allows one linearly polarised component of the light to pass through it. The electric field of this component may be deemed to have an amplitude $E_0$.

The amplitude of the component after passing through the analyser filter is given by

$$(1) \quad E = E_0 \cdot \cos \varphi .$$

This is a measure of the amount of light which can pass through the analyser (Fig. 3).

The intensity of the light corresponds to the square of the electric field strength. The intensity of light beyond the analyser is therefore as follows:

$$(2) \quad I = I_0 \cdot \cos^2 \varphi ,$$

where $I_0$ is the intensity of light after passing through the polariser.

Equation (2) is a statement of Malus' law. This will be verified in the experiment by measuring the light intensity using a light sensor. In this experiment, the intensity of light measured for an angle $\varphi = 90°$ should be equal to that of the ambient light. This value should be subtracted from all the other intensity measurements.
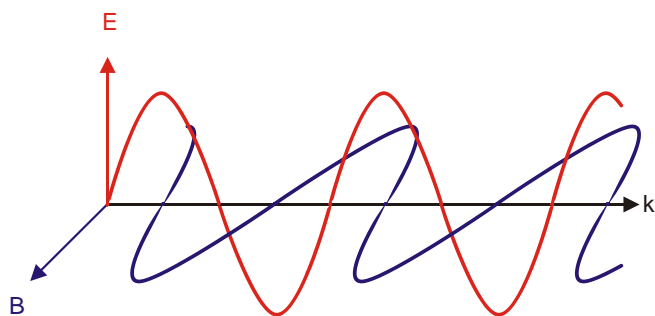
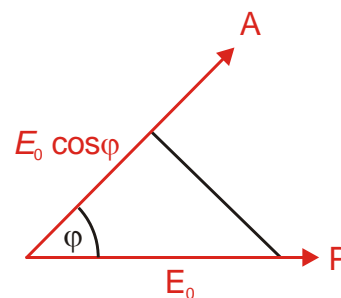Fig. 2: Illustration showing the definition for direction of polari-sation.



Fig. 3: Illustration of how the electric field beyond the analyser is calculated.

## LIST OF EQUIPMENT

| 1 | Optical Precision Bench D, 50 cm | U10302 | 1002630 |
|---|---|---|---|
| 4 | Optical Rider D, 90/50 | U103111 | 1002635 |
| 1 | Optical Lamp, Halogen | U21881 | 1003188 |
| 1 | Transformer 12 V, 60 VA | U13900 | 1000593/ 1006780 |
| 2 | Polarisation Filter on Stem | U22017 | 1008668 |
| 1 | Light Sensor | U11364 | 1000562 |
| 1 | 3B NET*log*™ | U11300 | 1000539/40 |

**Optional:**

| 1 | 3B NET*lab*™ | U11310 | 1000544 |
|---|---|---|---|

## SET-UP AND PROCEDURE

- Set up the apparatus for the measurement as shown in Fig. 1.

**Note:**
Precise positioning of the two polarisation filters along the optical bench is not critical to the results of this measurement.

- Use a miniDIN cable to connect the light sensor to analog input A or B on the 3B NET*log*™ unit. Turn on the 3B NET*log*™ unit and wait for it to detect the sensor.

- Start the computer running 3B NET*lab*™ software. Connect the 3B NET*log*™ unit to the computer. Configure the input as described in the 3B NET*lab*™ software instructions.

**Note:**
Measurement points can also be obtained without using the 3B NET*lab*™ software by reading them from the 3B NET*log*™ display.

- Select "manual measurement" from the menu option "Measurement interval/Rate:". Set the number of measurements to be made to 37.

- Set both polarisation filters to 0° with the help of the angle scale and markings on the rotating base.

**Note:**
The polarisation filter nearest the optical lamp acts as the polariser and the one nearer the light sensor is used as the analyser.

- Do not change the set-up of the polariser any more but adjust the analyser to an angle of 10°.

- Click the "Measure" button in 3B NET*lab*™ to record the light intensity. Clicking the "Measure" button a second time stops the measurement.

**Note:**
Once a measurement point has been measured once, that measurement cannot be repeated.

- Adjust the analyser in 10° steps up to and including 360° and, for each of these angle settings, record the light intensity as described above (Table 1).

## SAMPLE MEASUREMENT

Tab. 1:  Measured light intensity $I_m$ and light intensity corrected for ambient light $I$ at various angles $\varphi$ between polariser and analyser.

| $\varphi$ | $I_m$ / lux | $I = I_m - I_m(90°)$ / lux |
|---|---|---|
| 0° | 4.0440 | 3.6705 |
| 10° | 3.9050 | 3.5315 |
| 20° | 3.5500 | 3.1765 |
| 30° | 3.1210 | 2.7475 |
| 40° | 2.4720 | 2.0985 |
| 50° | 1.7910 | 1.4175 |
| 60° | 1.2080 | 0.8345 |
| 70° | 0.7581 | 0.3846 |
| 80° | 0.4502 | 0.0767 |
| 90° | 0.3735 | 0.0000 |
| 100° | 0.4906 | 0.1171 |
| 110° | 0.8805 | 0.5070 |
| 120° | 1.3440 | 0.9705 |
| 130° | 1.9340 | 1.5605 |
| 140° | 2.7330 | 2.3595 |
| 150° | 3.3640 | 2.9905 |
| 160° | 3.7710 | 3.3975 |
| 170° | 4.0140 | 3.6405 |
| 180° | 4.0320 | 3.6585 |
| 190° | 3.8410 | 3.4675 |
| 200° | 3.3710 | 2.9975 |
| 210° | 2.7950 | 2.4215 |
| 220° | 2.1880 | 1.8145 |
| 230° | 1.5000 | 1.1265 |
| 240° | 0.9986 | 0.6251 |
| 250° | 0.5849 | 0.2114 |
| 260° | 0.3802 | 0.0067 |
| 270° | 0.3653 | -0.0082 |
| 280° | 0.5882 | 0.2147 |
| 290° | 0.9939 | 0.6204 |
| 300° | 1.5770 | 1.2035 |
| 310° | 2.2280 | 1.8545 |
| 320° | 2.8030 | 2.4295 |
| 330° | 3.3850 | 3.0115 |
| 340° | 3.7280 | 3.3545 |
| 350° | 3.9810 | 3.6075 |
| 360° | 4.0360 | 3.6625 |

## EVALUATION

The specifications of the polarisation filters state that they will block out > 99.9% of light at wavelengths $\lambda = 450 - 750$ nm. This means that, to a good approximation, the light intensity measured at $\varphi = 90°$ is equivalent to the ambient light.

- Subtract the light intensity $I_m(\varphi = 90°)$ from each of the light intensity measurements $I_m$ in Table 1, i.e. for all angles $\varphi$ (Table 1).
- Plot the light intensity $I$ after correction for ambient light as a function of the angle $\varphi$ on a graph (Fig. 4).
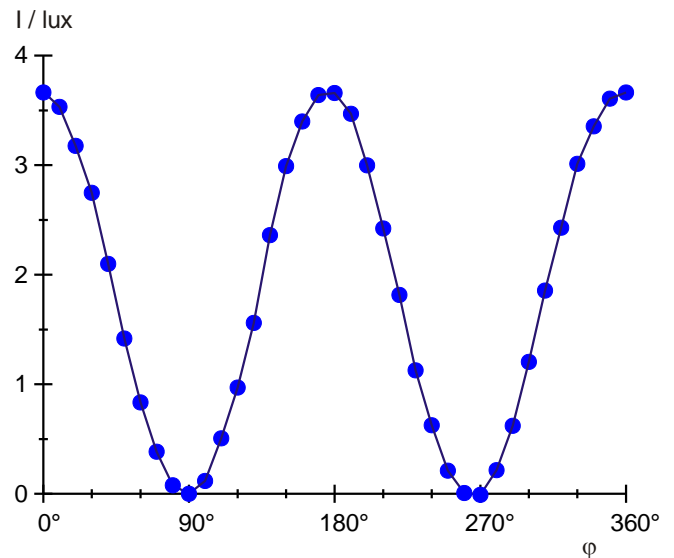


Fig. 4: Light intensity $I$ as a function of the angle $\varphi$ between the polariser and the analyser.

The shape of the curve matches what would be expected from equation (2).

- Work out the value of $\cos^2(\varphi)$ for all angles $\varphi$ where $0 \leq \varphi \leq 90°$ (Table 2) and copy the corresponding values of light intensity $I$ from Table 1 into Table 2.

Tab. 2:  Light intensity $I$ corrected for light intensity and values of $\cos^2(\varphi)$ where $0 \leq \varphi \leq 90°$.

| $\varphi$ | $\cos^2(\varphi)$ | $I$ / lux |
|---|---|---|
| 0° | 1.00 | 3.6705 |
| 10° | 0.97 | 3.5315 |
| 20° | 0.88 | 3.1765 |
| 30° | 0.75 | 2.7475 |
| 40° | 0.59 | 2.0985 |
| 50° | 0.41 | 1.4175 |
| 60° | 0.25 | 0.8345 |
| 70° | 0.12 | 0.3846 |
| 80° | 0.03 | 0.0767 |
| 90° | 0.00 | 0.0000 |

- Plot the corrected light intensity $I$ against $\cos^2\varphi$ on a graph (Fig. 5).

The measurement values lie along a straight line of gradient $I_0$ through the origin, as expected from equation (2).
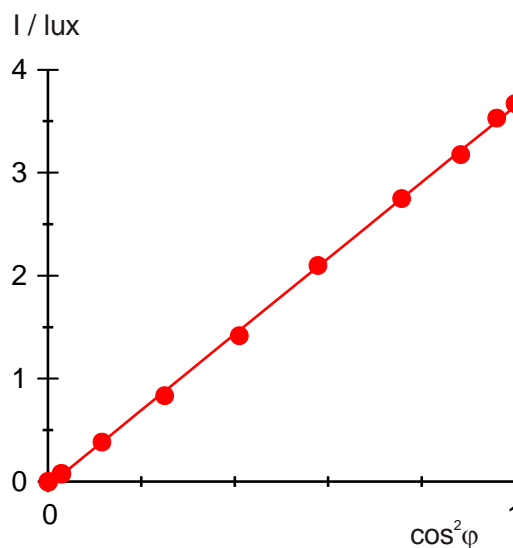


Fig. 5: Light intensity $I$ as a function of $\cos^2\varphi$.