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.

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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 φ 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 φ = 90° should be equal to that of the ambient light. This value should be subtracted from all the other intensity measurements.

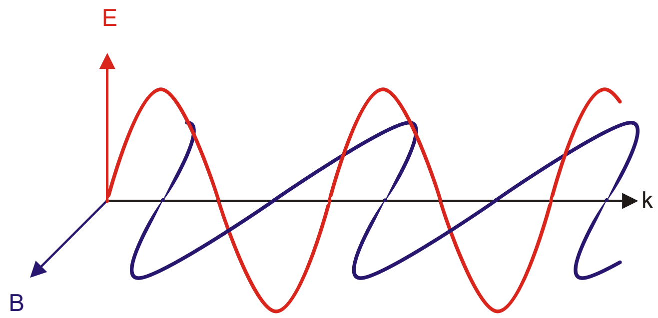

Fig. 2: Illustration showing the definition for direction of polarisation

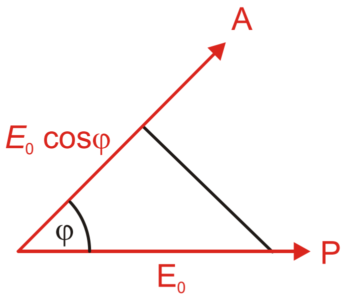

Fig. 3: Illustration of how the electric field beyond the analyser is calculated

LIST OF EQUIPMENT

1	Optical Precision Bench D, 50 cm	U10302	1002630
4	Optical Rider D, 90/50	U103111	1002635
1	Optical LED Lamp	U21882	1020630
2	Polarisation Filter on Stem	U22017	1008668
1	Holder for Light Sensor		1022269
1	Light Sensor, ThreeRanges	UCMA-BT50i	1021502
1	Sensor Cable	UCMA-BTsc1	1021514
1	Data Logger		
1	Software		

More information about digital measurement can be found on the experiment's webpage in the 3B Webshop.

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.

- Connect the light sensor to the data logger using the sensor cable and start the software.
- 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 anymore.
- Adjust the analyser in 10° steps up to and including 360° and, for each of these angle settings, record the light intensity point by point (Table 1).

SAMPLE MEASUREMENT

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

φ	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 λ = 450 – 750 nm. This means that, to a good approximation, the light intensity measured at φ = 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 φ (Table 1).
- Plot the light intensity I after correction for ambient light as a function of the angle φ on a graph (Fig. 4).

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

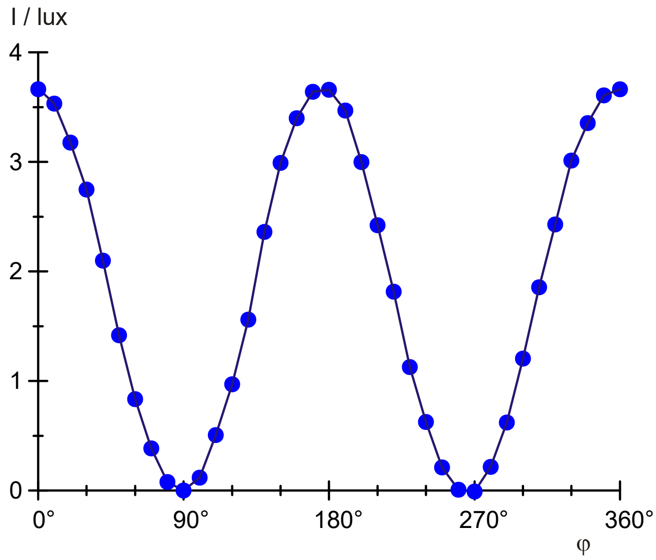

Fig. 4: Light intensity I as a function of the angle φ between the polariser and the analyser

- Work out the value of $\cos^2(\varphi)$ for all angles φ 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 $0 \leq \varphi \leq 90°$

φ	$\cos^2(\varphi)$	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).

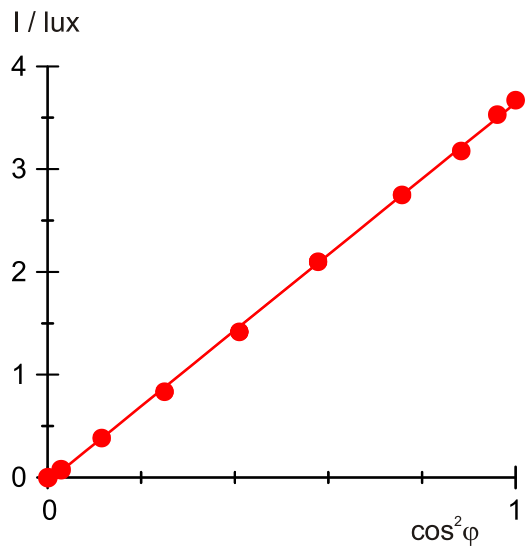

Fig. 5: Light intensity *I* as a function of $\cos^2\varphi$