LD
Physics
Leaflets

P5.4.1.4

Malus' Law

Objectives of the Experiment

- Understanding the polarization of light.
- Investigations of the functional principle of a polarizer and an analyzer.
- Qualitative validation of Malus' Law.

Principles

The phenomena of electrodynamics and magnetism were unified by the Maxwell equations for *electromagnetism*. The Maxwell equations in a vacuum can be solved by wave functions and thus describe electromagnetic waves. Such waves are transverse waves, i.e. the propagation direction $\vec{k}$ of the wave is always perpendicular to the electric field $\vec{E}$ and the magnetic flux density $\vec{B}$:

$$\vec{k}\cdot\vec{E} = \vec{k}\cdot\vec{B} = 0. \qquad (1)$$

This property of the electromagnetic waves is instrumental for the phenomenon of polarization. Light is an electromagnetic wave as well. Polarization of light is the direction of the vector $\vec{E}$ or $\vec{B}$ in the plane perpendicular to $\vec{k}$. The unpolarized light is composed of superimposed waves with all possible directions of $\vec{E}$ and $\vec{B}$ combined. If the direction is constant in time, we have *linear polarization*. The E field periodically changes its sign and absolute value. For *circular polarization*, the vector $\vec{E}$ rotates in the plane perpendicular to the direction of propagation $\vec{k}$ and has a constant absolute value.

The thermally generated light (lightbulb) is unpolarized and consists of light waves that are linearly polarized in all directions in the plane perpendicular to $\vec{k}$. When passing through a polarization filter with polarization direction $\vec{v}$, each vector $\vec{E}$ is reduced to its projection

$$E_v = \vec{E}\cdot\vec{v} = E\cos\theta \qquad (2)$$

in the light beam. Here, θ is the angle between $\vec{E}$ and $\vec{v}$. The light intensity averaged over all angles θ is halved. The light is also completely linearly polarized, i.e. the entire E field

$$\vec{E}_v = E_v\vec{v} \qquad (3)$$

is parallel to $\vec{v}$. The intensity

$$I_0 = (E_v)^2 \qquad (4)$$

Of the polarized light is a square functions of the E field.

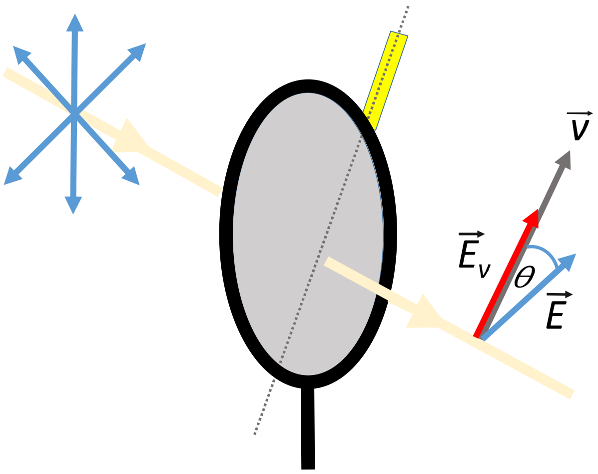

Figure 1: A light beam is linearly polarized in the polarization direction upon passing through a polarization filter.

When passing through a further polarization filter with polarization direction $\vec{w}$, forming an angle α with $\vec{v}$, the vector $\vec{E}_v$ is reduced to its projection

$$E_w = \vec{E}_v\cdot\vec{w} = E_v\cos\alpha \qquad (5).$$

The intensity

$$I = (E_w)^2 = (E_v)^2\cos^2\alpha \qquad (6)$$

is again a square function of the E field. Figure 1 schematically shows the functional principle of a polarization filter. Substituting equation (4) into equation (6) yields Malus' Law follows

$$I = I_0\cos^2\alpha\,. \qquad (7)$$

In the present experiment, Malus' Law will be confirmed quantitatively.

Apparatus

1	Halogen lamp, 12 V, 50/100 W	450 64
1	Halogen bulb, 12 V/100 W, G6.35	450 63
1	Picture slider	450 66
1	Transformer, 2 ... 12 V, 120 W	521 25
1	Iris diaphragm	460 26
2	Polarization filters	472 401
1	Lens in frame, f=100 mm	460 03
1	Solar cell, STE 2/19	578 62
1	Holder for plug-in elements	460 21
1	Digital multimeter 3340	531 183
1	Small optical bench	460 43
6	Leybold multiclamp	301 01
2	Stand base, V-shaped, large	300 01
2	Connecting lead, 32 A, 100 cm, black	501 33
1	Connecting lead 19A,	
3	100 cm, red/blue, pair	501 46

Safety Note

Watch for heat development of the halogen lamp and do not cover the ventilation slots!

Experiment set-up

The experiment set-up is shown in Figure 2.

- Attach the small optical bench to the stand base.
- Carefully align the optical bench in a horizontal position.
- Insert the halogen bulb into halogen lamp and mount the latter to one end of the optical bench. Use Leybold multiclamps for all optical devices.
- Mount the picture slider with the heat protection filter for absorption of the infrared component in the halogen light to the halogen lamp.
- Mount the iris diaphragm on the optical bench in front of the halogen lamp so that the distance between the picture slider and the iris diaphragm is approximately 2 - 5 mm.
- Adjust the aperture of the iris diaphragm to a diameter of 2 - 4 cm.
- Connect the halogen lamp to the transformer with the black connecting leads.
- Mount the holder for the plug elements at the other end of the optical bench and insert the solar cell.
- Connect the solar cell to the digital multimeter to measure the current and set it to the finest current measurement.
- Move the Leybold multiclamp with the lens f = +100 along the optical bench until the image of the iris diaphragm is focussed on the solar cell. If necessary, hold up a piece of white paper.
- Mount the two polarizing filters between the lens and the solar cell and set them to 0°.

Figure 3: Experiment set-up, Malus' Law.

Performing the experiment

In the experiment, the current of the solar cell is measured, which is proportional to the light intensity. Equation (7) thus also applies to the measured currents.

- Set both polarization filters to 0° and record the solar cell current. Thus, α= 0° and the current value corresponds to I_0.
- Adjust the polarization filter on the solar cell from 0° to 180° in increments of 10°. Record the angle difference α as well as the solar cell current I.
- The current value at α = 90° corresponds to the background and must be subtracted from each current value for the analysis.

Measurement example

For the measurement, the angle difference α between the polarization filters was varied from 0° to 180° in increments of 10°. The measurement example is shown in Figure 3.

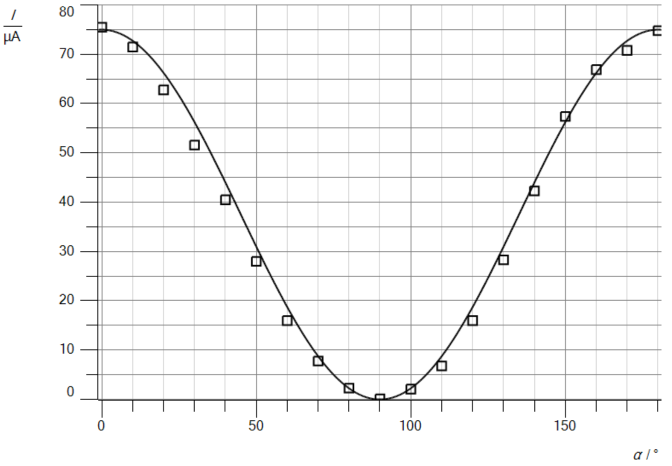

Figure 2: Measurement example, Malus' Law: (☐) measured values, (—) equation (7) for measured current I_0= 75 µA.