OP 4.1
Determining the plane of polarization of a polarized laser beam - Malus law

Is a laser equipped with a so-called Brewster window, it emits linearly polarized light whose plane of polarization can be determined using a polarizing filter as an analyzer.

Material

Optical profile-bench, l 1000mm	08370-00	1x
Diodelaser 0.2/1 mW; 635 nm	08760.99	1x
Fixing unit for diode laser	08384-00	1x
Multimeter ADM2, demo., analogue	13820.01	1x
Slide mount for optical bench	09822-00	2x
Mount with scale on slide mount	09823-00	2x
Lens, mounted, f +100 mm	08021.01	1x
Diaphragm holder, attachable	11604.09	1x
Polarising filter, 50 mm x 50mm	08613.00	1x
Photoelement f. opt. base plt.	08734.00	1x
Screen, translucent, 250x250 mm	08064.00	1x

Setup

Part 1: Determination of the polarization plane of polarized laser light

Fig. 1 shows the experimental setup.

Figure 1: Experimental Set-up

- The diode laser and the translucent screen are fixed in the slide mounts of the optical bench and placed at the ends of the optical bench.
- For expansion of the laser light a mount with scale with mounted lens is put into the light beam
- In the second mount with scale the diaphragm holder is mounted with the polarizing filter. The correct direction of the polarization filter is indicated by the perforation. This should be at the top when the line marking of the diaphragm

holder is on the 0° position of the scale. The polarizing filter is positioned immediately behind the lens.

Part 2: Determination of light intensity as a function of the filter position (Malus law)
- The translucent screen is replaced by the photoelement which is connected to the power input of the demo multimeter.
- The mount with scale and lens is removed.
- The distance between the photocell and the diode laser is now about 40 cm. Both are aligned such that the active area of the photocell is fully illuminated.

Experiment
Part 1: In a darkened room the polarizing filter is rotated slowly and the resulting luminance is observed on the screen. The filter setting for minimum brightness is noted. Instead of searching for the angle for maximum brightness, it is always more useful to find the brightness minimum because the eye can detect differences in brightness for this case better.
The laser is operated in the 1 mW mode.
Note: For security reasons it should be avoided that the laser beam can get into the eyes neither directly nor indirectly by reflections.

Part 2: First, the dark current i_0 is registered when laser is switched off. Subsequently, the polarizing filter is adjusted in the angular range of $\alpha = \pm$ 100° in 10° steps. The corresponding current i of the silicon diode is noted. In the area of the intensity maximum and -minimum the angular change is carried out in 5° steps. From the measured current values the dark current i_0 needs to be subtracted. The respective ratio $i\text{-}i_0 / i_{max} - i_0$ is plotted in a diagram against the angle φ.
The measuring curve needs to be compared with the corresponding $\cos^2$ curve.

Method:
Is an unpolarized light beam going through a polarization filter (polarizer), which may consist of a dichroic film in the simplest case, only this portion of light is passing, whose plane of polarization coincides with the polarization direction of the filter.
If this linearly polarized light (coming out of the polarizer) is brought to a second filter (analyzer), whose plane of polarization is rotated against the polarization level SE of amplitude E0 of the electric field of the light (Figure 2), only the amount

$$\vec{E} = \vec{E}_0 \cdot \cos\varphi \qquad (1)$$

is passed.

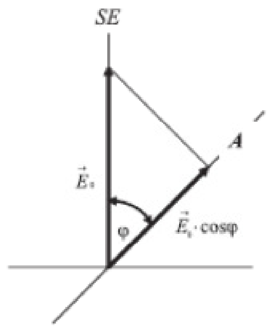

Figure 2: Proportion of the transmitted through an analyzer linearly polarized light

Being SE and A perpendicular to each other, then $\varphi = 90°$ and the analyzer is becoming opaque.

The light intensity is proportional to the square of the amplitude of the light, so it applies for the intensity I of the light behind the analyzer:

$$\frac{I}{I_0} = \frac{\vec{E}^2}{\vec{E}_0^2} = \cos^2\varphi \quad \text{oder} \quad I = I_0 \cdot \cos^2\varphi \qquad \text{(Malus law)} \qquad (2)$$

To determine the light intensity a photo element is used whose photocurrent is directly proportional to the intensity of the incident light.

Result

In the first part of the experiment the minimum intensity of the transmitted linearly polarized laser light can be found at a position of the analysator of $\alpha = -35°$. This means that the direction of polarisation of the laser light is rotated by 90° thereto. Thus, the diode laser emits linearly polarized light whose plane of polarisation is inclined at 55° from the vertical.
In Table 1, the results obtained from the second part of experiment are shown. The silicon diode provided under the experimental conditions without the laser light a dark current of $i_0 = 0.25\ \mu A$ which has been already taken into account in the table values.

Table 1:

α / °	i-i_0 / µA	$(i$-$i_0)$ / $(i_{max}$-$i_0)$	α / °	i-i_0 / µA	$(i$-$i_0)$ / $(i_{max}$-$i_0)$
-100	109,8	0,68	10	89,8	0,55
-90	97,8	0,60	20	107,8	0,67
-80	75,8	0,47	30	131,8	0,81
-70	47,8	0,30	35	139,8	0,86
-60	25,8	0,16	40	149,8	0,93
-50	7,55	0,05	45	159,8	0,99
-45	2,35	0,01	50	161,8	1,00
-40	0,39	0,00	55	161,8	1,00
-35	0,35	0,00	60	159,8	0,99
-30	3,35	0,02	65	151,8	0,94
-25	8,55	0,05	70	142,8	0,88
-20	15,25	0,09	80	119,8	0,74
-10	31,8	0,20	90	89,8	0,55
0	59,8	0,37	100	69,8	0,43

In Fig.3 the normalized intensity ratio $(i$-$i_0)/(i_{max}$-$i_0)$ is plotted as a curve as a function of the angle α.To be able to compare it with the prediction made by (2), the figure shows also the corresponding $\cos^2$ curve. To calculate these must be taken into account that the angle α + = 55° for the defined in (2) angle $\varphi = 0°$ is to be used, because, by definition, is φ is the angle between the plane of polarization of light and position of analyzer.

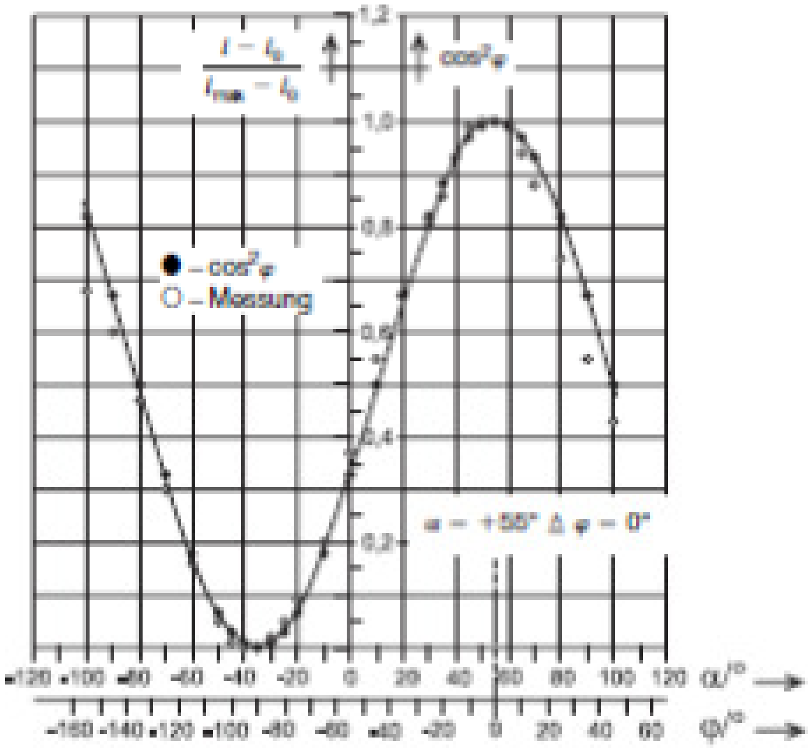

Figure 3: The normalized light intensity as a function both of the analyzer angle α (open circles) and as a function of the angle φ between polarization direction of the light and the analyzer (filled circles).

Both curves are almost identical which can be seen as a confirmation of the law according to Malus.