First name ....

Date ....

Last name ....

Degree program name ....

Exercise 363

The polarization of Light - verification of Malus' law

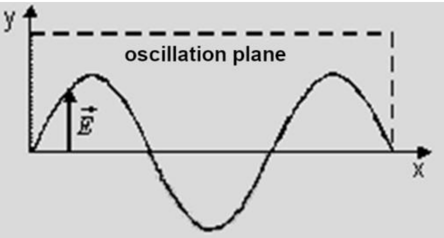
The initial value of the angle α_0…..°

No.	***Angle*** **α [°]**	***Photocurrent*** **I [μA]**	**I/I_{max}**	**No.**	***Angle*** **α [°]**	***Photocurrent*** **I [μA]**	**I/I_{max}**	**No.**	***Angle*** **α [°]**	***Photocurrent*** **I [μA]**	**I/I_{max}**
1				25				49			
2				26				50			
3				27				51			
4				28				52			
5				29				53			
6				30				54			
7				31				55			
8				32				56			
9				33				57			
10				34				58			
11				35				59			
12				36				60			
13				37				61			
14				38				62			
15				39				63			
16				40				64			
17				41				65			
18				42				66			
19				43				67			
20				44				68			
21				45				69			
22				46				70			
23				47				71			
24				48				72			

Polarization of light

Polarization is a phenomenon that occurs only for the transverse wave. A transverse wave is a wave in which the direction of vibration of the electric field intensity vector $\vec{E}$ lies in a plane that is perpendicular to the wave propagation direction (x). The oscillation vectors $\vec{E}$ are parallel to each other at all points of the wave and form an *oscillation plane* with the direction of wave motion (Fig. 1). An example of a transverse wave are electromagnetic waves of various lengths such as radio waves, microwaves, light waves, and X-rays.

Fig. 1



Polarization does not occur for *longitudinal wave* in which direction of vibration is consistent with the direction of wave propagation. An example of a longitudinal wave is a sound wave.

If the electric vector $\vec{E}$ vibrates only in one plane of vibrations, then the light is *linearly polarized* (Fig. 2, a). Most of the light we see, such as the light emitted by the sun and incandescent light bulbs, is *non-polarized* (Figure 2, c). This is because the resultant wave, which is the sum of the waves emitted by individual atoms of the light source, is an unpolarised wave. Waves with different polarization planes are emitted with the same probability. The light can also be partially polarized - that is, it can be a mixture of linearly polarized light and an unpolarised light (Fig. 2, b). Fig. 2 shows the vibrations of the electric vector in the plane (z, y) perpendicular to the direction of light propagation (x): for linearly polarized (a), partially polarized (b) and unpolarised (c) light.

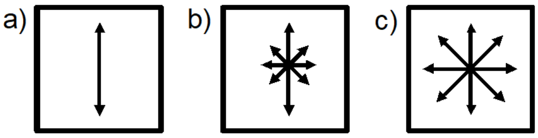


Fig. 2

Since light (electromagnetic radiation) is a transverse wave, therefore, it can undergo polarization, that is, ordering the direction of vibration of the electric field intensity vectors of the light wave .

Light polarization occurs during:

1. *selective absorption,*
2. *double refraction of the light beam in anisotropic crystals having the property of birefringence (e.g. calcite crystal),*
3. *reflection and refraction of light from the dielectric*
4. *light scattering.*

An object that polarizes light is called a *polarizer*, while a polarizer that is used to check the state of light polarization is called an *analyser*.

Light polarization by selective absorption is used in polarizing filters, e.g. polaroids. *Polaroid* consists of a plastic film stretched in one direction and attached to the glass. It consists of chains of molecules being in parallel order. Such ordered system absorbs light that is polarized parallel to the ordered molecules, and transmits the light that is polarized perpendicular to them. This type of polarizer is used in the exercise.

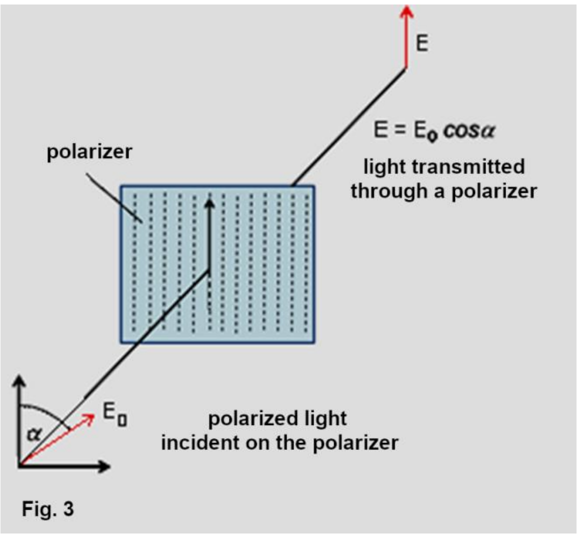


Fig. 3

If a beam of linearly polarized light with an electric field vibration amplitude E_0 falls on the polarizer and the polarization plane of the polarizer forms an angle α with the polarization plane of the incident light beam, then the polarizer transmits only light that is parallel to the polarization direction of a polarizer. The beam amplitude (E_0) after passing through the polarizer will be reduced to
$E = E_0 \cos \alpha$.

The intensity of the light beam is proportional to the square of the electric field amplitude, therefore the intensity of the beam coming out of polarizer (I) is given by:

$$I = I_0 \cos^2 \alpha \qquad (1)$$

where: I –intensity of the light beam coming out of the polarizer I_0 –intensity of the incident light beam, α -the angle formed between the polarization plane of the polarizer and the polarization plane of the incident light beam.

Equation (1) is known as the ***Malus' law*** and determines the intensity of polarized light after passing through a polarizer. This law was discovered by the French physicist Etienne-Louis Malus. *The intensity of linearly polarized light passing through the polarizer is equal to the intensity of the light incident on the polarizer multiplied by the square of the cosine of the angle formed between the polarization plane of the incident light and the polarization plane of the polarizer.*

Verification of *Malus' Law*

To verify the Malus' law, one should investigate the dependence of the intensity of light that passed through a system of polarizers (adjustable and stationary) and incident on the surface of a photocell (detector) depending on the polarization angle of light , α, determined by the rotation of the moving polarizer. Based on the results obtained, a graph of the dependence $I/I_{max} = f(\alpha)$ should be plotted. The scheme of the measuring setup is shown in Fig. 4.

1 – light source (source of unpolarised light)
2 – power supply
3 – adjustable polarizer
4 – stationary polarizer (with the optical axis set to 0°)
5 – photocell
6 – digital meter (microammeter)

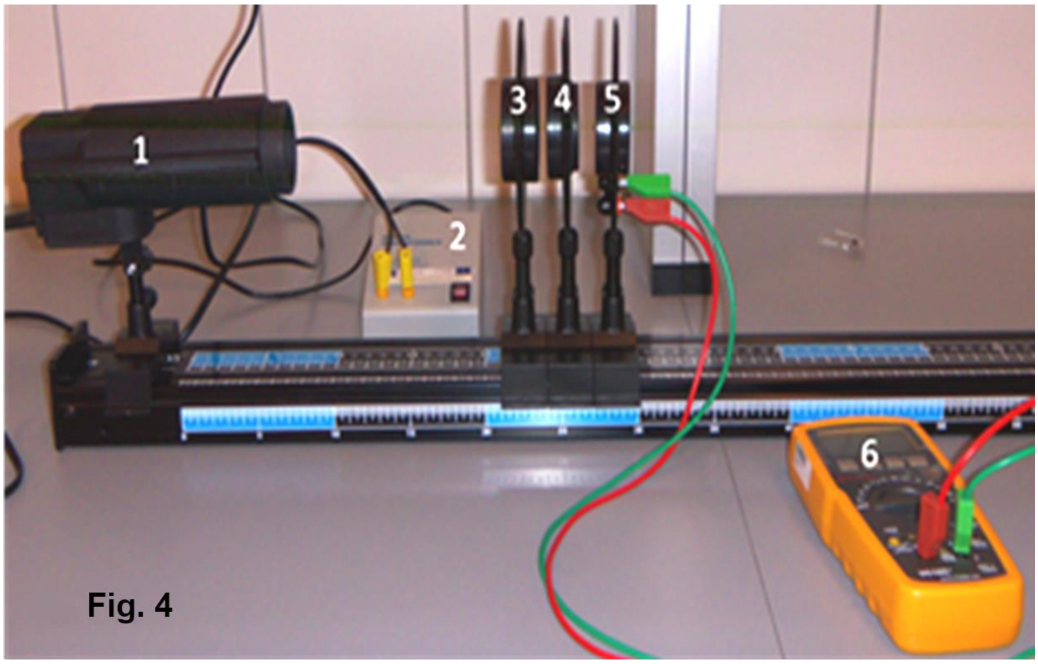


Fig. 4

Performance of the task

1. Turn on the power supply and the source of non-polarized light.

   Attention! **Your photocell should by illuminated only by your light source. Verify, if neighbouring light sources do not illuminate your photocell!!!**
2. Set the adjustable polarizer to the position corresponding to α_0.
   Record the value of the angle α_0 and the corresponding readings of the I_0 (μA) in the table**.** ***The value of the angle α_0 is given by the exercise instructor.***
3. Rotate the adjustable polarizer by 5°. Read and note the values of angle α and the corresponding photocurrent intensity I (μA). Measurements should be taken every 5° to complete the measurement table.

   Angle reading should be done looking straight ahead of the polarizer (as perpendicular to the scale as possible) to avoid parallax error (Fig. 5).

   Reading: a – correct
   b, c – incorrect

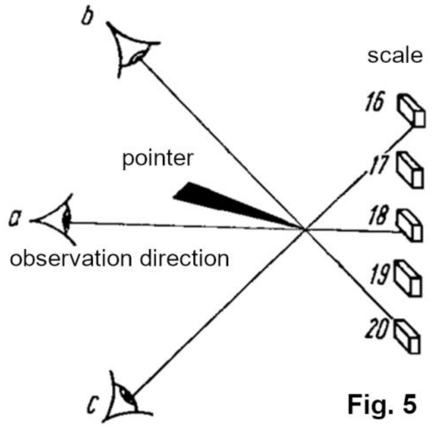


Fig. 5

4. From the measurement data in the table –read the maximum current value I_{max} from the measured data in the table.
5. Calculate the I/I_{max} ratio for all measurements.
6. To check Malus' law, plot the dependence of I/I_{max} on the angle α ($I/I_{max} = f(\alpha)$). Superimpose the results obtained, in the form of points on the graph of the function y = $\cos^2\alpha$ (drawn as a solid line) found on the last page of the instructions for the exercise. **The points must be a different colour than the graph of the function.**

Calculation of the uncertainties

In the case of a digital ammeter, the measurement accuracy is 1%. Taking into account other possible reasons for the inaccuracy of the measurement of the I/I_{max} (e.g. the effectiveness of polarizers lover than 100% etc.np.) assume that the accuracy of the I/I_{max} measurement is 2% of full scale.

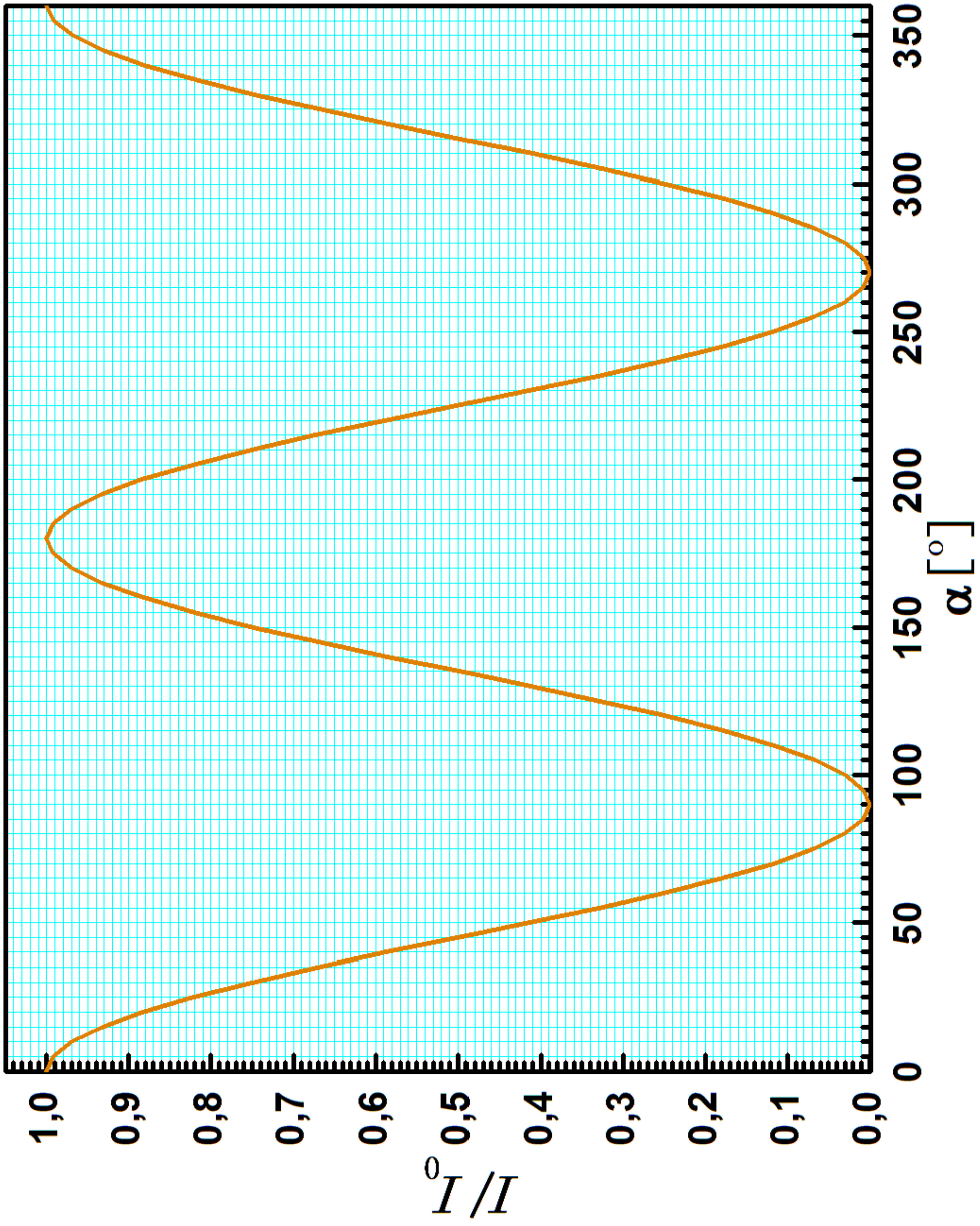
For the accuracy of reading the angle value from the polarizer scale, take ± 2.5°.

The resulting accuracy of the measurements (for α points being multiples of 30°) should be marked on the graph in the form of rectangles surrounding data points.

Questions for discussion

1. Based on the data obtained from the measurements plotted on the graph and taking into account the accuracy of the measurements, can Malus' law be considered confirmed in the exercise?

2. List and describe several applications of polarization of light in devices found in your environment (3 examples).


I/ I0
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
0
50
100
150
200
250
300
350
α [°]