

**OPTICS**  
**POLARIZATION**  
**Practical 16**  
**LINEARLY POLARIZED LIGHT**

**Part 1. DETERMINATION OF PERMITTIVITY OF GLASS BY THE POLARIZATION METHOD**

**1 Introduction**

As is well known, the reflectance of linearly polarized light from a dielectric mirror depends on the angle of incidence and on the direction of the electric vector  $E$  of the light wave relative to the plane of incidence. If the electric vector  $E$  of the incident wave is perpendicular to the plane of incidence, then the reflectance is:

$$R_{\perp} = \left( \frac{E_{ref}}{E_{inc}} \right)^2 = \frac{\sin^2(\varphi - \psi)}{\sin^2(\varphi + \psi)}, \quad (1)$$

where  $\varphi$  - is the angle of incidence,  $\psi$  - is the angle of refraction; reflection occurs at any angle of incidence.

If the electric vector  $E$  is parallel to the plane of incidence, then the reflection coefficient is:

$$R_{\parallel} = \frac{\tan^2(\varphi - \psi)}{\tan^2(\varphi + \psi)}. \quad (2)$$

Expressions (1) and (2) are called Fresnel's formulas.

Using the law of refraction, one can easily find the angle of incidence at which the reflection in case (2) is absent:

$$\tan \varphi_{Br} = n, \quad (3)$$

where  $n$  - is the refractive index of a given dielectric.

This relation is called Brewster's law and states that the angle of incidence  $\varphi_{Br}$  at which reflection is absent is called Brewster's angle or the polarization angle. Knowing the polarization angle, one can determine the permittivity of a given dielectric as follows:

$$\varepsilon = n^2 = \tan^2 \varphi_{Br}. \quad (4)$$

**2 Experimental setup**

Referring to Fig. 1, the experimental setup consists of the goniometer with the polarizer  $P$  mounted on the collimator  $C$ , which can be rotated relative to the optical axis of the collimator, and is used in the proposed practical to determine the angle of total polarization. The natural light becomes linearly polarized after passing through the polarizer. Rotating the polarizer, one can change the polarization of light emerging from the collimator. The dielectric mirror  $M$  is mounted on the stage of the goniometer. One can change the angle of incidence of the beam by rotating the mirror  $M$  relative to the vertical axis of the goniometer. The ray reflected from the mirror is observed through the telescope  $T$ , the position of which can be used to calculate the angle of incidence of the beam on the mirror. The radiation spectrum of the lamp  $L$  can be changed by means of the filter  $F$ .

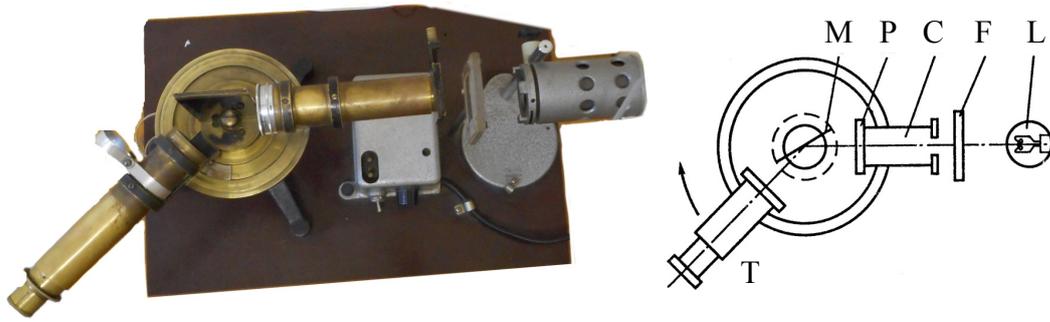


Fig. 1. An image and a schematic of the setup.

### 3 Measurement and data processing

Place the mirror  $M$  parallel to the optical axis of the collimator and, aligning the image of the slit with the cross of the threads in the pipe, determine the zero position of the telescope  $\alpha_0$  along the limb of collimator. Then turn the telescope through an angle of 10-15 degrees and tune the position of the mirror so that the image of the slit again coincides with the cross-pointer. Rotating the polarizer  $P$ , observe the change in the intensity of the beam reflected off the mirror. Do the same observations, increasing the angle of rotation of the telescope. When the brightness of the image of the slit begins to change appreciably, the angle of rotation of the telescope should be increased through smaller steps about 5 degrees. After reaching the values of  $\alpha$  at which by turning the analyzer it is possible to achieve almost complete suppression of the reflected beam, reduce the step of change of the angle down to 1 degree or less.

#### Task 1. Determination of the permittivity of glass

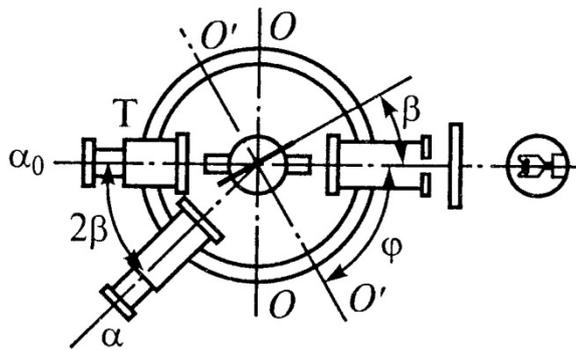


Fig. 2.

In this task you need to find several close values of  $\alpha$  for which the intensity of the reflected beam is close to zero at some position of the polarizer, calculate the average value of  $\alpha_{aver}$  and calculate the polarization angle, starting from the following guess (see Fig. 2): if the mirror is rotated by an angle  $\beta$ , then the image of the slit observed with the telescope is rotated by an angle  $2\beta$ . Then the angle of incidence of the ray on the mirror will be determined as follows:

$$\varphi = 90^\circ - \beta.$$

Knowing the initial position of the telescope  $\alpha_0$ , and the new position  $2\beta$ , one can find  $\varphi$ :

$$\varphi = 90^\circ - \frac{(\alpha_0 - 2\beta)}{2}.$$

Using expression (4), find the permittivity of glass the mirror is made of.

# PART 2. DETERMINATION OF THE TRANSMISSION COEFFICIENT OF THE POLARIZERS AND VALIDATION OF THE MALUS'S LAW

## 1 Introduction

If a beam of natural light passes through an ideal polarizer, then, because of the statistical symmetry of the oscillations of the vector  $E$ , the light intensity decreases by the factor of two, and the light turns into linearly polarized light. The intensity of light transmitted through two ideal polarizers is related to the initial intensity  $I_0$  as:

$$I = \frac{I_0}{2} \cos^2 \theta, \quad (6)$$

where  $\theta$  - is the angle between the transmission axes of the polarizers (Malus's law). The reflection of light off the surfaces of the polarizers is not taken into account in (6).

In the case of real polarization devices, the relation between  $I_0$  and  $I$  will be somewhat different, first, because it is impossible to achieve strictly linear polarization, and secondly, because of the inevitable absorption of light by the material of each polarizer in addition to 50% of the natural light incident on the first polarizer.

It is proposed to investigate experimentally the change in the intensity of light passing first through one, and then through two polarizers. Changing the angle between the transmission axes of the polarizers, it makes possible to verify experimentally Malus's law (6).

The polarizers used in this practical are made of thin films of an anisotropic material (for example, polyvinyl covered with iodine).

The change in the intensity of light can be traced by the change in the illumination of the photocell, connected to a galvanometer. The scale of the galvanometer is often graduated directly in units of illumination - lux (in this case the device is called a luxmeter).

## 2 Experimental setup

The setup, which is used to determine of the transmittance coefficient of polarizers and validation of Malus's law, is shown in Fig. 3. It consists of the light source 5, polarizer unit 6 with the scale 4 and the photocell 7. A luxmeter photocell, which allows to measure the illumination directly in luxes, is used in this practical. The luxmeter has several measurement ranges, use the limit "0-100 lux" while measuring.

The polarizer unit consists of the supporting cylinder 1 and two reclining rings 2 with polarizers fixed in them. The upper operation position of the rings with polarizers is fixed by a ball lock. The polarizers can be rotated in their frames. The arrow pointer 3 is attached to the frame of one of the polarizers, which makes it possible to measure the rotation angle of the polarizer along the scale 4.

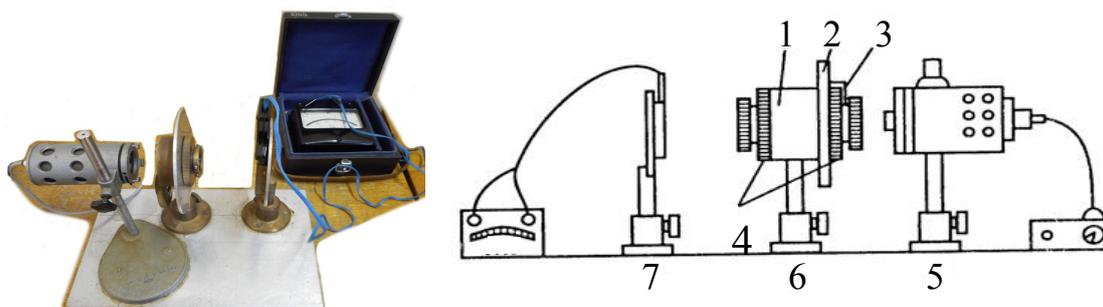


Fig. 3. An image and a schematic of the setup.

### 3 Measurement and data processing

#### Task 1. Determination of the transmittance of polarizers

Make sure that the lamp adjustment knob is in the extreme left position (turned home counter-clockwise). Mount the photocell on the stand 7, put the switch of the luxmeter measurement range in the position "0 - 100 lx".

Move away both rings with polarizers, switch on the illuminator and, increasing the glow of the lamp, bring the illumination of the photocell to  $E_0 = 80$  lx. It is convenient to use the diaphragm of the illuminator for accurate adjustment of illumination to a certain level.

After placing one of the polarizers onto the mount 6, one needs to measure the illumination  $E_1$ , then put the second polarizer onto the other end of the mount 6 and measure the illumination  $E_2$ , while axes of both polarizers are parallel.

Repeat the same measurements, changing the order of the introduction of the polarizers and with a different value of the initial illumination. From these measurements, one can determine the transmittance of the polarizers – for a single one ( $E_1/E_0$ ) and for two polarizers together ( $E_2/E_0$ ).

Put down the measurement results into table 1.

#### Task 2. Validation of the Malus's law.

By adjusting the glow of the lamp and using the diaphragm of the illuminator, set the illumination of the photocell  $E_{max} \approx 40$  lx, while the axes of the polarizers are parallel. This task can be performed at an arbitrary initial position of the polarizer parallel axes relative to the scale. But it is more convenient to orient the polarizers so that counting on the scale would directly give the value of the angle  $\theta$  that appears in Malus's law.

Turning the polarizers, along the rim with an arrow, one needs to measure the illumination  $E_\theta$  at ten different values of the angle  $\theta = 0; 10; 20; \dots; 90^\circ$ . Repeat the measurements by changing the angle  $\theta$  from  $90^\circ$  to  $0^\circ$ . At the end of the measurement, it is necessary to close the photocell with a lid and put it into the case of the luxmeter.

Average the results over two series of measurements and calculate ten values of the ratio  $E_\theta/E_{max}$ .  $E_{max}$  is the value of illumination, while the axes of the polarizers are parallel.

Put down the measurement results into the table 2. Plot the dependence  $E_\theta/E_{max} = I_\theta/I_{max} = f(\theta)$ . Add the theoretical curve  $\cos^2(\theta) = f(\theta)$  on the same graph and compare the obtained curves.

### 4 Questions

1. What are the theoretical premises, which allow one to derive expressions (1) and (2)?
2. Indicate the polarization states of the reflected light beam off a dielectric if the angle of incidence is equal to Brewster's angle for several cases: natural light; linearly polarized light in the plane of incidence; linearly light polarized in the plane perpendicular to the plane of incidence.
3. How can one estimate the degree of polarization of partially polarized light?
4. How can one practically determine the plane of oscillations of the light transmitted for a given polarizer?
5. What is the operation principle of polarization prisms (Nicol prism, etc.)?
6. What is a polarizer?