OPTICS
POLARIZATION
Practical 15
ELLIPTICAL POLARIZATION OF LIGHT

1 Introduction

Let a beam of linearly polarized light fall on a plane parallel crystal plate located so that its principal directions are perpendicular to the direction of light propagation. If the direction of the vector *E* in the incident beam propagates at any angle to one of the principal directions of the plate, then it is convenient to consider the oscillations of the vector *E* as the sum of two mutually perpendicular oscillations, expanding *E* along the principal directions of the plate (in the case of a plate of mica, these directions are called β and γ-directions).

Due to the anisotropy of the crystal, the propagation velocities of the components along these directions will be different and at the exit from the plate one will have two mutually perpendicular oscillations with a phase difference:

$$\Delta\varphi=\frac{2\pi(n_\gamma-n_\beta)d}{\lambda}, \qquad (1)$$

where d - is the thickness of the plate, λ - is the wavelength in vacuum, n_γ and n_β - are the refractive indices for the components of the corresponding directions.

Thus, after passing through the crystalline plate, the linearly polarized light becomes polarized elliptically: the tip of the light vector *E* in this case describes an ellipse, the direction of the axes and the shape of which depend on the thickness and material of the plate, and on the orientation of the vector *E* in the incident beam relative to the principal directions of the plate.

In laboratory practicals, the so-called "quarter-wave" and "half-wave" plates, for which the phase shift between the components of the vector *E* along the principal directions are equal to $\pi/2$ and π, respectively, are used very often.

For example, passing through the quarter-wave plate, linearly polarized light becomes elliptically polarized, with the axes of the ellipse coinciding with the principal directions of the plate.

A crystal plate, placed in the path of linearly polarized light so that one of its principal directions coincides with the direction of the vector *E* of the incident wave, obviously does not introduce any changes into the state of polarization, and the light remains linearly polarized. The latter circumstance makes it possible to determine the main directions of the plate. To do that one needs to place the plate between two crossed polaroids and to orient it so that the intensity of light after the second polaroid again becomes minimal.

A $\lambda/4$-plate can also be used as a phase difference compensator – one can convert elliptically polarized light into linearly polarized light with such a plate.

The goal of this practical is to give students an opportunity to determine the principal directions of the crystalline (mica) plate, to become familiar with the operation principal of $\lambda/4$ and $\lambda/2$ plates, and also to obtain elliptically polarized light and circularly polarized light with a $\lambda/4$-plate.

2 Experimental setup

A schematic of the experimental setup is shown in Fig.1. A beam of natural light from the illuminator *I* passes through the filter *F*, which passes a relatively narrow spectral interval, and falls on the polarizer *P*. Further in the path of the light beam, various mica plates ($\lambda/4$ or $\lambda/2$) can be placed. The light passes through the second polarizer, which acts as an analyzer *A,* after the plate. Between the polarizer *P* and the analyzer *A*, an auxiliary lens *L* can be placed. The photocell *PC* is used as the light detector, which is connected to a galvanometer (luxmeter - *LM*) calibrated in luxes (SI units: lx). The readings of the luxmeter are proportional to the intensity of light falling on the photocell. The photocell is closed with a special protective cover, which is removed immediately before the measurement starts. After the measurement is completed, the photocell must be closed with the cover.

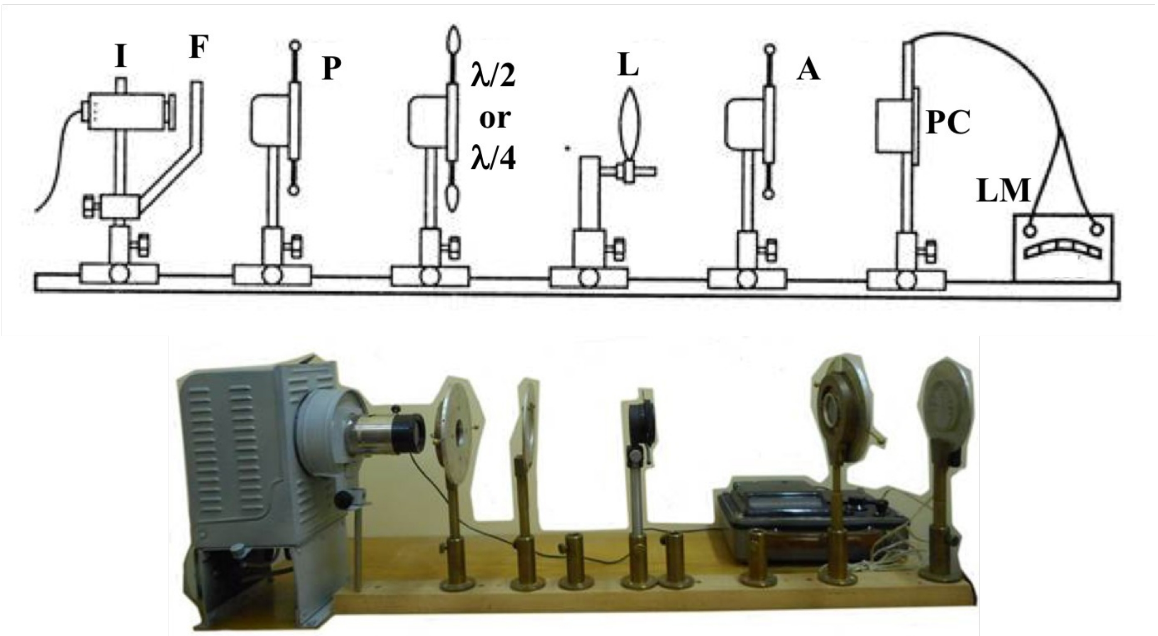

Fig. 1. A schematic and an image of the setup.

3 Measurement and data processing

Task 1. Determination of the principal directions of the crystalline plate

Place the filter corresponding to the plate under test in front of the illuminator, and get light polarized in the vertical plane, by rotating the polarizer. The polarizer is tightened in a frame so that this position corresponds to the division of the scale "0". Rotating the analyzer, one needs to achieve minimum illumination of the photocell. Recording the corresponding angle between the axes of the polarizers.

Place the *λ/4* test plate between the polarizers and, rotating it, again achieve minimum illumination of the photocell. One needs to find four positions, which correspond to minimum illumination, record the corresponding scale divisions of the plate and find the angle between the principal directions of the plate.

Task 2. Producing elliptically polarized light by means of a *λ/4* plate.

Set the plate *λ/4* so that one of its principal directions is at an angle $\varphi = 20°$ to the polarizer axis. Rotating the analyzer, measure the intensity of light passing through it, changing θ (the angle between the polarizer axis and the analyzer) from 0° to 360° with a step of 15°.

Do the same measurements for the other two values of the angle φ ($\varphi = 0°$ and $\varphi = 45°$) and plot the graphs in the polar coordinates

$$I = f(\theta)(\theta = 0°; 15°; 30°, \ldots, 360°)$$

for all the three cases, indicating on the graph the orientation of the polarizer axes and the principal directions of the plate. Note in the report what kind of polarization corresponds to each of the obtained curves.

Task 3. Determination of the polarization of light propagated through a plate

Do the measurements described in **task 2**, using the *λ/2* plate for the selected filter, determining the principal directions of this plate in advance and orienting it so that one of the principal directions is at an angle of 45° with the polarizer axis.

Plot the graph of the *I(θ)* dependence, indicating the orientation of the principal directions of the plate and the axis of the polarizer. Note how the polarization of the light beam has changed after the *λ/2* plate.

Task 4. Producing color images of crystalline plates

When performing this task, one should use the illuminator without the filter. Put the screen instead of a photocell, which should be closed with the cover and removed), and insert a special plate, which is made of several overlapping mica leaves, between the polarizers. Using a lens, obtain a sharp image of the plate on the screen. Changing the orientation of the polarizer and the analyzer relative to the plate, one ought to trace the change in the color of the image, sketching the most specific cases and explain the change in the color of the image, while rotating the polarizers relative to each other and relative to the plate (see Fig. 2).

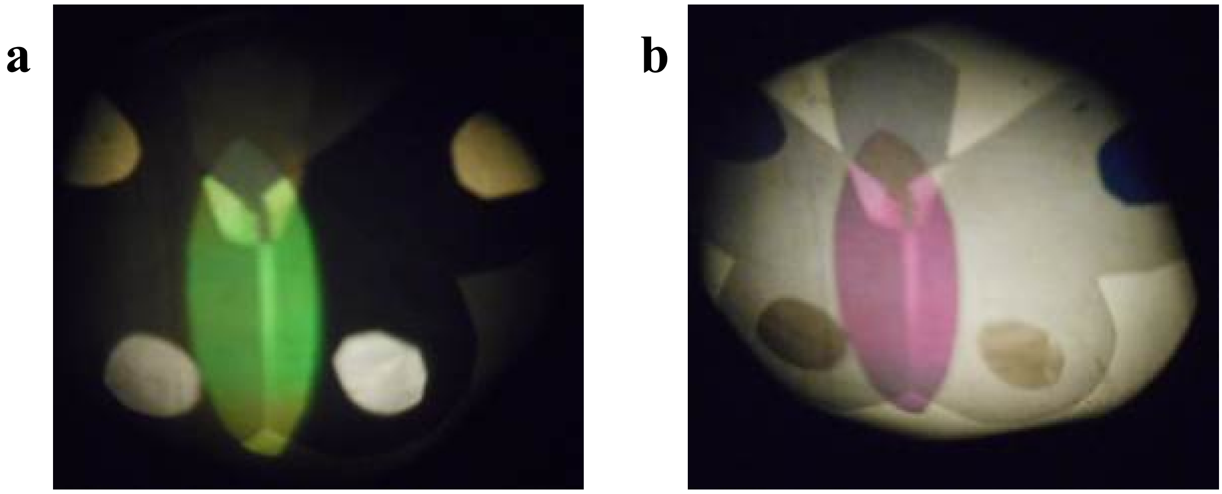

Fig. 2. The examples of the observable images. a and b – are the first and the second specific cases of the image.

Task 5. Study of crystalline plates in monochromatic light

Put any filter and, rotating the analyzer, observe the distribution of illumination of the image of the plate on the screen. Explain the result of the observations. Draw an approximate distribution of the darkest areas of the image. Without changing the orientation of the elements of the setup, change the filter. Draw the position of the darkest areas once again, compare it with the first sketch and explain the result.

4 Questions

1. What curve will one get if one joins the tips of the vectors E of a linearly polarized plane wave at different points of space at the same instant moment of time? What about a wave polarized elliptically?
2. What material properties determine the thickness of a quarter-wave plate? What about the half wave plate?
3. How can one experimentally distinguish the circularly polarized light from the natural light?
4. How can one experimentally distinguish partially polarized light from elliptically polarized light?
5. How can one determine the direction of rotation of the light vector (E) in the case of elliptical polarization?
6. What is a polarizer?