Optics

Polarization
Pockels effect

Demonstrating the Pockels effect in a conoscopic beam path

Objects of the experiment

■ To identify the optical axis of the birefringent crystal of the Pockels cell in a conoscopic beam path.

■ To demonstrate the *Pockels* effect in a conoscopic beam path.

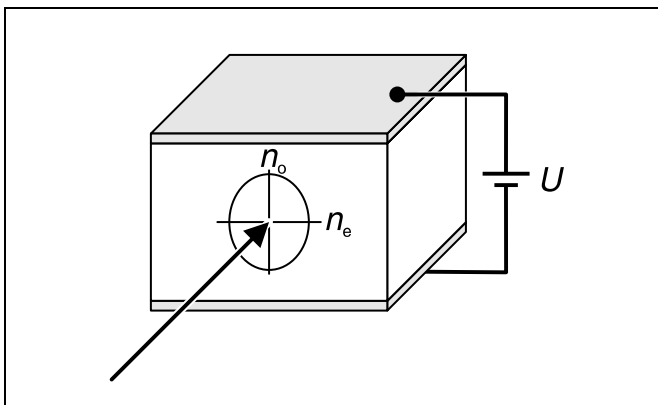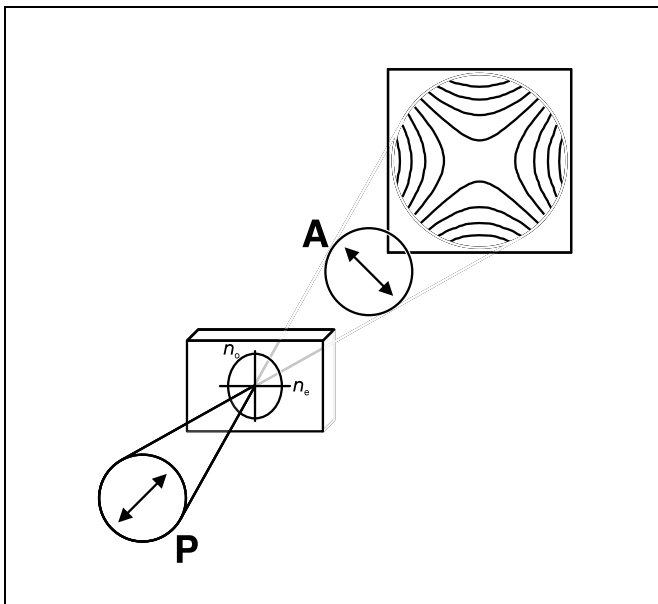■ To measure the half-wave voltage of the Pockels cell.

Fig. 1: Schematic diagram of a Pockels cell in transverse configuration

Fig. 2: Diagram of a conoscopic beam path for demonstrating birefringence

Principles

The Pockels effect

The *Pockels* effect is the name given to the occurrence of birefringence and to the change in existing birefringence phenomena in an electric field linearly proportional to the electric field strength. It is related to the *Kerr* effect, although in the latter case the birefringence increases exponentially with the electric field strength. For reasons of symmetry, the Pockels effect can only occur in crystals with no inversion center, whereas the Kerr effect can occur in all substances.

When the direction of the light beam and the optical axis of birefringence are perpendicular to each other, we call this a "transverse configuration" (see Fig. 1). The electric field is applied in the direction of the optical axis. For Pockels cells in the transverse configuration, lithium niobate ($LiNbO_3$) is most often used.

Lithium niobate crystals are optically uniaxial, negatively birefringent and have the main refractive indexes $n_o = 2.29$ for the ordinary beam, and $n_e = 2.20$ for the extraordinary beam (measured using the wavelength of the He-Ne laser, $\lambda = 632.8$ nm.

Birefringence in a conoscopic beam path

The proof of birefringence in a conoscopic beam path is described in numerous optics textbooks. A crystal with plane-parallel cut faces is illuminated with a divergent, linearly polarized light beam, and the light passing through it is observed behind a perpendicularly aligned analyzer (see Fig. 2). The optical axis of the birefringence is clearly apparent in the interference image, as it is indicated by the symmetry in its vicinity. In this experiment, the optical axis is parallel to the entrance and exit surfaces; this is why the interference pattern consists of two sets of hyperbolas [1] which are rotated by 90° with respect to one another. The real axis of the first hyperbola set is parallel to the optical axis, while that of the second set is perpendicular to the optical axis.

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Apparatus

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1 Pockels cell	472 90
1 High-voltage power supply, 10 kV	521 70
1 He-Ne laser, linearly polarized	471 480
1 Lens in holder, f = 5 mm	460 01
1 Lens in holder, f = 50 mm	460 02
1 Polarization filter . . . . from	472 40
1 Optical bench, 1 m, standard cross-section	460 32
5 Optics riders, H = 60 mm, W = 36 mm . . .	460 353
1 Translucent screen	441 53
1 Saddle base	300 11
1 Safety connection lead, red	500 641
1 Safety connection lead, blue	500 642
1 Safety connection lead, 10 cm	500 604
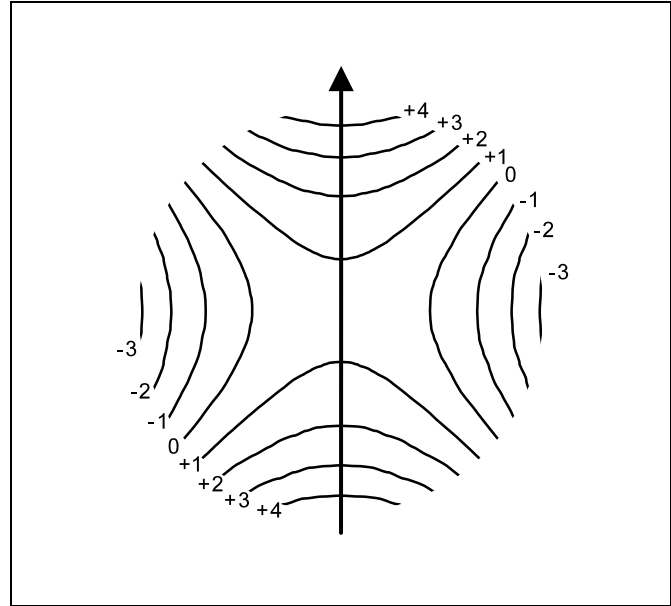
Fig. 3: Interference pattern in the conoscopic beam path with the optical axis of the crystal in the direction of the arrow. The numbers represent the path difference between the ordinary and the extraordinary partial beam. Thus for example the lines with the value +1(−1) have the path difference Δ_{m+1} (Δ_{m-1})

The dark lines of the interference image are caused by light rays for which the difference between the optical paths of the extraordinary and the ordinary partial beam in the crystal is an integral multiple of the wavelength. These light rays retain their original linear polarization after passage through the crystal, and are extinguished in the analyzer. The light rays reaching the center of the interference image are normally incident on the surface of the crystal. For these rays, the path difference between the extraordinary and the ordinary partial beam is

$$\Delta = d \cdot (n_o - n_e), \tag{I}$$

where $d = 20$ is the thickness of the crystal in the direction of the beam. The path difference corresponds to approximately 2800 wavelengths of the laser light used. however, Δ is not usually precisely a whole multiple of λ, but rather lies between two values, $\Delta_m = m \cdot \lambda$ and $\Delta_{m+1} = (m + 1) \cdot \lambda$. The dark lines in the first hyperbola set thus correspond to the path differences Δ_{m+1}, Δ_{m+2}, Δ_{m+3}, etc., and those of the second set to Δ_m, Δ_{m-1}, Δ_{m-2}, etc. (Fig. 3). The position of the dark lines, or better their distance from the center, depends on the magnitude of the difference between Δ and $m \cdot \lambda$.

The Pockels effect magnifies or reduces the difference of the main refractive indices $n_o - n_e$, depending on the sign of the applied voltage. This in turn alters the difference $\Delta - m \cdot \lambda$, and thus the position of the dark interference lines. If the so-called half-wave voltage U_π is applied, the value of Δ is changed by one-half wavelength. The dark interference lines shift to the positions of the bright lines, and vice versa. This process repeats itself each time the voltage is increased by U_π.

Safety note

The He-Ne laser fulfills the German technical standard "Safety Requirements for Teaching and Training Equipment – Laser, DIN 58126, Part 6" for class 2 lasers. When the precautions described in the Instruction Sheet are observed, experimenting with the He-Ne laser is not dangerous.

■ Never look directly into the direct or reflected laser beam.

■ Do not exceed the glare limit (i.e. no observer should feel dazzled).

Setup

Notes:

Carry out all measurements in a darkened room.
Do not insert the rods of the optical components all the way in the optics riders, so that subsequent fine adjustment of the height can be carried out.

Fig. 4 shows the experiment setup; the position of the left edge of each optics rider is given in cm.

Setting up the optical components:

– Mount the He-Ne laser, the 5-mm lens **(a)** and the 50-mm lens **(b)**. Carefully turn the laser and the 5-mm lens and adjust their heights so that optimum illumination of the 50-mm lens is achieved.

– Set up the translucent screen at a suitable distance, and attach a piece of white paper to the screen.
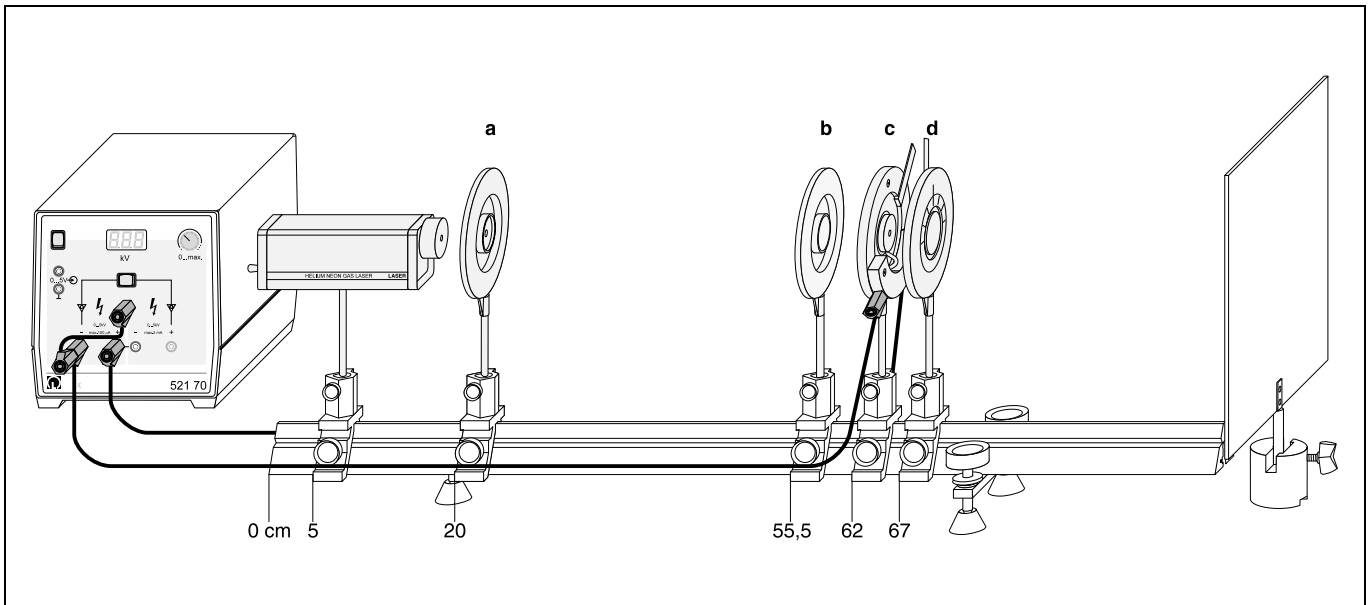
Fig. 4:   Experiment setup for demonstrating the Pockels effect
         (a) Lens, f = 5 mm
         (b) Lens, f = 50 mm
         (c) Pockels cell
             (pointer position: ± 45° with respect to analyzer)
         (d) Polarization filter as analyzer
             (pointer position: ± 90° to polarization direction of laser)

–   Set up the polarization filter as the analyzer and vary the direction of polarization until you obtain the minimum intensity on the screen.
–   Add the Pockels cell to the assembly and slide it into the exact position of the minimum beam cross-section. Observe the screen and make sure that light reflections on the interior surfaces of the crystal and the plate capacitor in the Pockels cell are avoided.
–   Turn the pointer by either +45° or –45° with respect to the analyzer.

Fine adjustment:

–   Adjust the height of the laser, the 5-mm lens and, if necessary, the Pockels cell as well until the center of the hyperbola sets in the interference pattern is in the center of the field of view.
–   If necessary, turn the Pockels cell on the rod axis.

Electrical connections:

–   Connect the Pockels cell to the left output of the high-voltage power supply (max. short-circuit current 100 µA); be sure to connect the minus-socket to the ground socket.
–   Turn the potentiometer of the power supply all the way to the left; then switch on the high-voltage power supply and activate the left-hand output with the selector button.

Carrying out the experiment

a) Demonstrating birefringence:

–   Compare the position of the hyperbola set in the interference pattern with the position of the pointer on the Pockels cell.
–   Slowly vary the position of the pointer on the Pockels cell and note the changes in the interference pattern.

b) Demonstrating the Pockels effect:

–   Return the pointer on the Pockels cell to the initial position (+45° or –45° with respect to the analyzer).
–   Slowly increase the voltage *U* (do not exceed 2 kV!) and observe the changes in the interference pattern.
–   Reduce the voltage to 0 V, connect the plus-socket of the high-voltage power supply to the ground socket and reverse the connections on the Pockels cell.
–   Once again, increase the voltage *U* (do not exceed 2 kV!) and observe the changes in the interference pattern.

c) Determining the half-wave voltage:

–   Set the voltage to *U* = 0 V and mark the dark lines of the interference pattern on the piece of paper using a green pen.
–   Slowly increase the voltage *U* and record each value at which the bright and dark interference lines are exactly congruent with the markings on the piece of paper.

Measuring example and evaluation

a) Demonstrating birefringence:

When the Pockels cell is rotated around the axis of the light beam, the interference image turns as well. In this case, the real axis of the first hyperbola set is always parallel to the optical axis of the crystal (indicated by the direction of the pointer).

Maximum bright-dark contrast is achieved when the angle between the optical axis and the analyzer is ± 45°. The screen is dark when the optical axis is parallel or perpendicular to the analyzer.

b) Demonstrating the Pockels effect:

When the voltage has the correct polarity, the dark interference lines of the first hyperbola set (real axis of the hyperbolas parallel to the optical axis of the crystal) move toward the center as the voltage increases, while those of the second hyperbola set move away from the center.

The two hyperbolas with the path difference $\Delta_{m+1} = (m + 1) \cdot \lambda$ move to the center at a voltage U_1 (see Fig. 5); thus, the center is dark. When the voltage is increased further, the two hyperbolas change over to the second hyperbola set and there become continuously larger. At a voltage U_2 the next two hyperbolas move across the center to the other hyperbola set, the following two at a voltage $U3$ and so on. The interval between the voltages U_1, U_2 and U_3 corresponds to twice the half-wave voltage (see below).

When the polarity of the voltage is reversed, the hyperbolas move in the opposite direction. Thus, the difference of the main refractive indexes $n_o - n_e$ increases or decreases due to the Pockels effect, depending on the polarity of the voltage.

c) Determining the half-wave voltage:

Table 1: Measurement results for determination of the half-wave voltage

$\dfrac{U}{kV}$	Brightness on translucent screen at the marked location
0.0	Dark
0.52	Bright
1.01	Dark
1.52	Bright
1.91	Dark

At the values for the voltage U given in Table 1, the intensity of the lines at the marked points in the interference pattern change from bright to dark, as the path difference between the ordinary and the extraordinary partial beam changes by one-half the wavelength. The difference between these voltages is the half-wave voltage U_π. This has a value of approx. 0.5 V.

The change in the birefringence $\delta n_o - \delta n_e$ after applying the half-wave voltage is very small. Using equation (I), we can calculate

$$\frac{\lambda}{2} = d \cdot (\delta n_o - \delta n_e), \qquad\qquad (II)$$

and obtain

$$\delta n_o - \delta n_e = 16 \cdot 10^{-16}$$

Bibliography

[1]   M. Born and E. Wolf, *Principles of Optics,* Pergamon Press

Fig. 5:   Changes in the conoscopic interference image due to the Pockels effect; the respective hyperbola of the interference order m + 1 are emphasized with bold lines