Pockels effect: transmitting information using modulated light

Objects of the experiments

- Modulating light by means of a Pockels cell.
- Demonstrating the transmission of a sound signal using modulated light.
- Investigating the influence of the operating point on the modulation.

Principles

Pockels effect

The occurrence of birefringence or the variation of existing birefringence in an electric field as a linear function of the electric field strength is called *Pockels* effect.

In the case of transverse configuration of the Pockels cell, the direction of the light ray is perpendicular to the optical axis of birefringence (see Fig. 1). The electric field is applied in the direction of the optical axis. Most commonly, lithium niobate ($LiNbO_3$) is used for Pockels cells in transverse configuration.

Lithium niobate crystals are optically uniaxial, negatively double-refracting with the principal refractive indices n_o = 2.29 for the ordinary ray and n_e = 2.20 for the extraordinary ray (measured at the wavelength λ = 632.8 nm of a He-Ne laser).

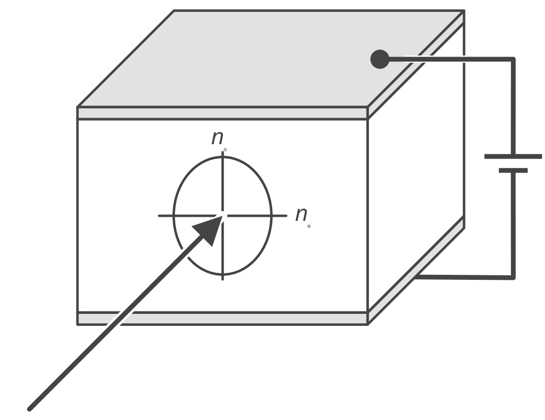

Fig. 1 Diagram of a Pockels cell in transverse configuration

Birefringence in the parallel path of ray

The double-refracting crystal is illuminated with linearly polarized, parallel laser light. The optical axis of the crystal is rotated by an angle of 45° relative to the polarization of the incident light. A polarization filter set to an angle of 0° is used as an analyzer.

The path difference between the ordinary and the extraordinary partial ray is

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

where d = 20 mm is the thickness of the crystal in the direction of the ray. The path difference corresponds to about 2800 wavelengths of the laser light used. In general, however, Δ is not exactly an integer multiple of λ, but will probably lie between two values $\Delta_m = m \cdot \lambda$ and $\Delta_{m+1} = (m + 1) \cdot \lambda$.

If the difference of the optical paths for the ordinary and the extraordinary partial ray is an integer multiple of the wavelength ($\Delta = m \cdot \lambda$), the linear polarization of the ray after passing the crystal is the same as the original polarization, and the ray passes the analyzer. If the difference is greater by half a wavelength ($\Delta = (m+1/2) \cdot \lambda$),? the ray behind the crystal is linearly polarized as well, however, the polarization plane is rotated by 90°, and the ray is absorbed by the analyzer. If the path difference has other values, circularly polarized light arises, which is partially absorbed.

Depending on the sign of the applied voltage, the difference between the principal refractive indices $n_o - n_e$ is increased or decreased due to the Pockels effect. This leads to a change of the difference $\Delta - m \cdot \lambda$ and thus of the intensity of the light behind the analyzer. If the so-called half-wave voltage U_π is applied, Δ changes by half a wavelength so that the light intensity changes, e.g., from bright to dark. If the voltage U is varied, a regular increase and decrease of the light intensity is observed (see Fig. 2, page 2).

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Apparatus

1 Pockels cell	472 90
1 high-voltage power supply, 10 kV	521 70
1 function generator P	522 56
1 set of 6 safety adapter sockets, black	500 98
1 He-Ne laser, linearly polarized	471 840
1 polarization filter	472 401
1 precision optical bench, standardized cross section, 1 m	460 32
4 optics rider, H = 60 mm, B = 36 mm	460 353
1 photoelement STE 2/19	578 62
1 holder for plug-in elements	460 21
1 AC/DC amplifier, 30 W	522 61
1 broad-band speaker	587 08
1 saddle base	300 11
1 safety connecting lead, red	500 641
1 safety connecting lead, blue	500 642
2 safety connecting leads, 50 cm	500 621
2 pairs of cables 100 cm, red and blue	501 46

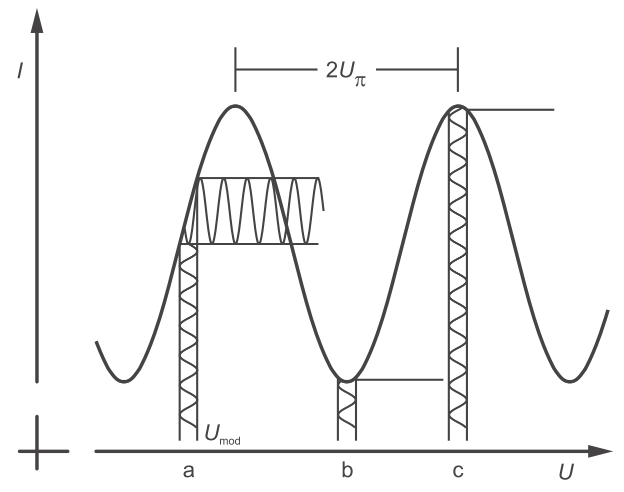

Fig. 2 Variation of the intensity I of the transmitted light in response to the variation of the high voltage U at the Pockels cell and modulation at three different operating points a, b and c.

Modulation

If an alternating voltage from the function generator with an amplitude of a few volts is superimposed on the direct voltage at the crystal, the birefringence of the crystal and thus the intensity of the transmitted light varies slightly in response to the alternating voltage. The light intensity is modulated with the signal from the function generator thus transmitting information over large distances. For receiving the signal, the light intensity is measured with a photoelement. The variation of the intensity is amplified and made heard.

Depending on what direct voltage is selected, the alternating voltage leads to more or less strong variations of the light intensity as is seen in Fig. 2. The operating point is determined by the direct voltage selected. The variation of the light intensity is proportional to the derivative of the curve at the selected position. Therefore the effect of the modulation is weak in the minimum (operating point b) and in the maximum (operating point c) of the light intensity. If half the light intensity is transmitted (operating point a), the modulation has its maximum and the received signal is loudest.

Safety notes

The He-Ne laser meets the safety requirements laid down in DIN 58126, Part 6, for class 2 lasers which are used for teaching purposes. If the safety notes 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.
- Never exceed the threshold line of glare (i.e. no observer shall feel dazzled).

Setup

Remarks:
Carry out measurements in a darkened room. The rods of the optical devices should not be completely inserted in the optics riders so that fine adjustment of the height remains possible.

The experimental setup is illustrated in Fig. 3.

Setting up the optical components:

– Mount the He-Ne laser, the Pockels cell and the polarization filter; carefully rotate the laser and adjust its height until an optimum illumination of the crystal is reached.
– Insert the photoelement in the holder for plug-in elements, and mount it on the optical bench.
– Set the pointers of the Pockels cell and the polarization filter to 0°.

Fine adjustment:

– Readjust the height and direction of the laser, the Pockels cell and the photoelement until the laser beam passes well through the crystal and impinges on the sensitive part of the photoelement.
– Set the pointer of the Pockels cell to +45° or –45°. The pointer of the polarization filter remains at 0°.

Electrical connection:

– If necessary, mount two safety adapter sockets to the output of the function generator P in order to be able to plug in the safety connecting leads.

  The high voltage is taken from the left output (max. 100 μA) of the high-voltage power supply. For the cabling safety connecting leads have to be used.

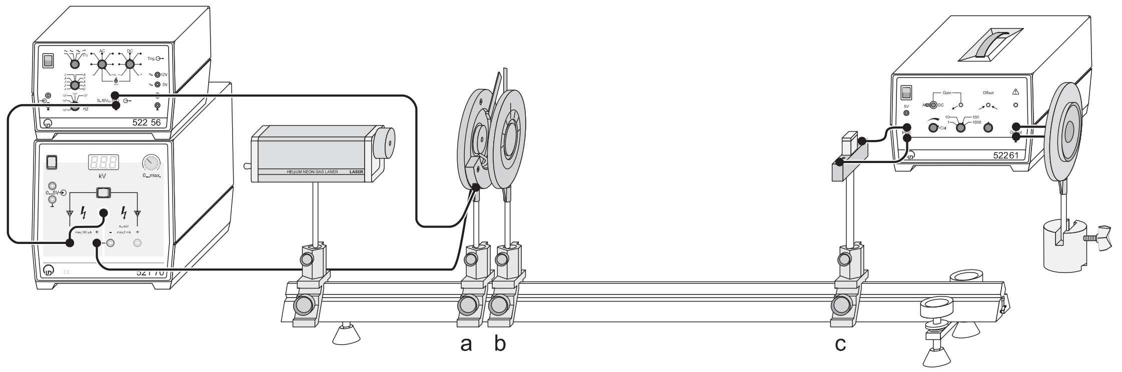

Fig. 3 Experimental setup for demonstrating signal transmission through the Pockels effect
a Pockels cell (pointer position: ±45° relative to the analyzer)
b Polarization filter as analyzer (pointer position: ±0° relative to the direction of polarization of the laser)
c Photoelement as detector on holder.

- Connect the negative socket to the ground socket and the grounded socket to the ground of the function generator P. Connect the output of the function generator to the negative socket (blue) of the Pockels cell. Connect the positive socket of the Pockels cell to the positive socket of the high-voltage power supply.
- For connecting the photoelement, plug two cables into the holder for plug-in elements near the element. Guide these cables to the input of the AC/DC amplifier. Connect the output of the AC/DC amplifier to the speaker.
- Turn the potentiometer of the high-voltage power supply to the left stop, switch the high-voltage power supply on, and activate the left output using the selector switch.
- Switch the function generator on. At the beginning set the output amplitude (AC) to zero.

Further settings:

Signal shape:	sine
Frequency:	800 Hz
DC	centre position

- Switch the AC/DC amplifier on, and select the following settings:

AC Gain:	100, i.e. left knob to CAL., middle knob to 100
Offset:	centre position

Carrying out the experiment

a) Receiving the modulated signal:

- Set the high voltage so that the laser beam has medium brightness on the photoelement. The brightness should not be at its maximum.
- Set the output amplitude of the function generator P to its maximum.

  The signal of the function generator is heard from the speaker.
- Confirm that the signal of the function generator is really transmitted by changing the frequency and the signal shape (sine, delta, square-wave).
- For demonstrating that the signal is transmitted via the light ray and not in another way, e.g. by electric interference, interrupt the light ray with your hand.

b) Influence of the operating point on the modulation:

- Search a minimum of the light intensity by varying the high voltage.

  The transmitted signal becomes weaker.
- Search a neighbouring minimum of the light intensity.

  The difference between the two high voltages is twice the half-wave voltage (2 U_π).
- Search a maximum of the light intensity by changing the high voltage by the half-wave voltage.

  In this case, too, the transmitted signal is not heard. Although the light intensity is high, there is only weak modulation.
- Change the high voltage by half the half-wave voltage.

  The result is medium brightness of the light. As now the operating point is located at the position of maximum slope, the received signal is loudest.

Measuring example and evaluation

a) Receiving the modulated signal:

The output voltage of the function generator leads to a variation of the light intensity which is received by the photoelement and made audible in the amplifier. When the light ray is interrupted, the speaker falls silent.

b) Influence of the operating point on the modulation:

As shown in Fig. 2, the change in modulation and thus in volume of the received signal is proportional to the derivative of the light intensity I with respect to the voltage U. However, it is not proportional to the light intensity. At maximum light intensity (operating point c), no signal is heard because in the maximum the derivative of the light intensity with respect to the voltage is zero.