Investigation the Kerr effect in nitrobenzene

Experiment Objectives

- Detecting the Kerr effect.
- Observing the brightness behind crossed polarization filters depending on the voltage applied.
- Determining the half-wave voltage depending on the wavelength.

Experiment description

In 1875, John Kerr discovered electric fields in isotropic substance generate a double refraction. This effect is called the Kerr electro-optic effect. The double refraction's growth is proportional to the square of the electric field's strength – as opposed to the linear electro-optic Pockels effect in anisotropic substance.

For symmetry, the double refraction's optical axis is in the field direction. The fabric's normal refractive index n without an electrical field is modified by applying a field in the parallel oszillation direction to the extraordinary refractive index n_e and in the perpendicular oszillation direction to the ordinary refractive index n_o. The two indices have the following relationship:

$$n_e - n_o = K \cdot \lambda \cdot E^2$$

where K: Kerr constant
λ: wavelength of the light used
E: electric field strength.

The experiment detects the Kerr effect in nitrobenzene, where the Kerr constant is particularly high. The liquid is in a glass vessel with a submerged parallel plate capacitor (Kerr cell).

This Kerr cell is between two polarization filters: the polarizer and the analyzer. The path of the light that goes through the polarizer is parallel to the parallel plate capacitor's plates and thus perpendicular to the field lines. The light's degree and direction of polarization behind the Kerr cell can be observed with the analyzer.

An electric field is established by applying a voltage to the capacitor. In this field, the nitrobenzene molecules are partially polarized and orient themselves in the field direction. Light with an electrical vector in the field direction propagates more slowly than light with an electrical vector perpendicular to the field direction.

In this experiment, the incident light is linearly polarized at 45° to the electric field. This light can be considered as a superposizion of two in-phase oscillating light waves, one of which is polarized in the field direction and the other polarized perpendicular to the field direction.

Since both components in nitrobenzene have different phase velocities when an electric field is applied, a phase difference is formed by the Kerr cell between the components upon exit.

For the phase difference Δ:

$$\Delta = 2\pi \cdot K \cdot l \cdot \left(\frac{U}{d}\right)^2$$

where d: distance between capacitor plates
l: length of the capacitor plates (optical path)
U: voltage applied.

This phase difference leads to an elliptically polarized wave upon heterodyning. With the polarization filter behind the Kerr cell (analyzer), the elliptically polarized waves can no longer be fully erased.

With the half-wave voltage, where the phase difference just reaches a half wavelength ($\Delta = \pi$), the Kerr cell behaves like a $\frac{\lambda}{2}$ plate, i.e. the polarization plane is turned by 90°. The following applies:

$$U_{\frac{1}{2}} = \frac{d}{\sqrt{2 \cdot K \cdot l}}$$

The experiment first detects the Kerr effect qualitatively, by observing the effect of the applied voltage on the light behind parallel and crossed polarization filters.

It then examines the reduction with various color filters behind parallel polarization filters. The half-wave voltage is determined where the reduction is the greatest.

The Kerr constant for each wavelength is calculated using these results.

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Equipment

1	Kerr cell	473 31
1	Nitrobenzene, 250 ml	673 9410
1	Prism table	460 25
1	Optical bench, standard cross section, 1 m	460 32
6	Optics riders 60/50	460 373
1	Halogen lamp 12 V, 50/100 W	450 64
1	Halogen bulb 12 V/100 W, G6.35	450 63
1	Picture slider	450 66
1	Monochromatic filter, red	468 03
1	Monochromatic filter, yellow	468 05
1	Monochromatic filter, yellow-green	468 07
1	Monochromatic filter, blue-violet	468 11
2	Polarization filters	472 401
1	Lens in frame, f = +100 mm	460 03
1	Screen, translucent	441 53
1	Transformer 2 to 12 V, 120 W	521 25
1	High-voltage power supply 10 kV	521 70
2	Cable for high voltages, 1 m	501 05
2	Connecting lead 32 A, 100 cm, black	501 33

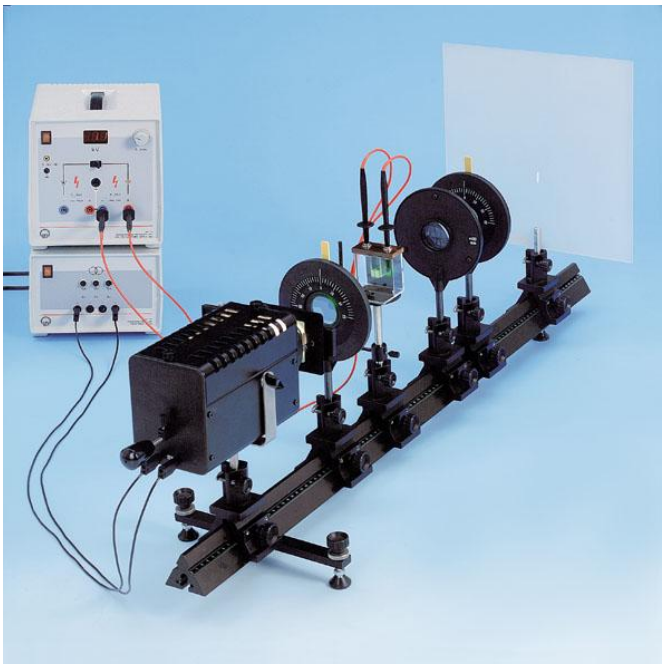

Figure 1: Experiment setup

Safety note

Nitrobenzene is poisonous and may have a carcinogenic effect:

- by inhalation
- by contact with skin
- by swallowing

Therefore, the following directions must be observed:

- Only carry out the experiments in well-ventilated areas
- Do not inhale fumes
- Fill and empty the Kerr cell under a fume hood

Buildup of explosive mixtures in the air is possible. Fill the Kerr cell to a few millimeters above the capacitor plate to avoid flashovers.

Experiment Setup

Forming the Kerr cell:

Fill the Kerr cell's cuvette very carefully with nitrobenzene to about 2/3 (fluid level about 3.5 cm) and attach it securely to the prism table with the clamping spring. Carefully attach the mount and parallel plate capacitor. The fluid level thus rises by a few millimeters. The nitrobenzene may absolutely not overflow.

Connect the Kerr cell to the high-voltage power supply's 5 kV / 2 mA output. Arrange the cables such that the mount and parallel plate capacitor are stable in the cuvette.

Turn the voltage selector switch initially to about the middle of the scale (which corresponds to an idle voltage of about 2.5 kV). Observe the voltage display. Due to diminishing conduction, the voltage slowly rises. After the voltage rises to about 2 kV, further increase the voltage using the voltage selector switch and observe the voltage indicator until it reaches about 4 kV. Leave the Kerr cell unchanged for about 2 hours. The cell is then ready for measurement.

Do not reverse at the Kerr cell any more to avoid the risk of spark gaps.

Optical assembly:

Attach the equipment to the optical bench according to Figure 1.

Initially set both polarization filters (polarizer and analyzer) to 0°.

Set the halogen lamp so that the ignition coil is in the same plane as the lens.

Represent the capacitor gap clearly on the screen with the lens f = 100 mm.

Carrying out the Experiment

1. Qualitative preliminary experiments:

Set the polarizer at 45° and the analyzer first parallel (45°) and then perpendicular (-45°) to it. Increase the voltage and observe the image of the capacitor gap (visual field) on the screen.

Repeat the experiment with the angles 0° and 90°.

2. Determining the half-wave voltage:

For parallel polarization filters at 45° to the electric field, initially place the blue-violet monochromatic filter in the slider and slide it into the beam's path. Increase the voltage until the capacitor gap's image is as dark as possible and read the half-wave voltage.

Repeat the experiment with the other monochromatic filters.

Measurement Example

The Kerr cell gets darker behind parallel polarization filters at 45° with increasing voltage, and it gets brighter with crossed polarization filters.

In the range around 3 kV, the capacitor gap's image takes on different colors.

If the polarization filters are set to 0° and/or 90°, the voltage applied has no effect on the brightness.

Table 1: Half-wave voltage and resulting Kerr constant

	blue-violet	yellow-green	yellow	red
Medium wavelength λ (nm)	440	540	580	650
Half-wave voltage $U_{\frac{1}{2}}$ (kV)	2.9	3.2	3.4	3.8
Kerr constant K ($10^{-14}\ \frac{m}{V^2}$)	330	271	240*	192

* Literature value for 589 nm: $K = 245 \cdot 10^{-14}\ \frac{m}{V^2}$

Calculation of the Kerr constants with:

$$K = \frac{d^2}{2 \cdot l \cdot U_{\frac{1}{2}}^2}$$

and

$d = 1 \cdot 10^{-3}$ m

$l = 18 \cdot 10^{-3}$ m

Figure 2: Kerr constant as a function of the wavelength with nitrobenzene

Evaluation

Applying a field makes nitrobenzene birefringent (Kerr effect).

The greater the voltage applied, i.e. the field strength, the greater the double refraction.

The greater the wavelength, the smaller the double refraction, i.e. the smaller the Kerr constant.

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