

# EXPERIMENT 11

## THE KERR EFFECT

### AIM:

Verifying the Kerr effect and calculating Kerr's constant.

### APPARATUS:

1 Prism table, 1 Small optical bench, 1 Pair of polarizing filters, 1 Halogen lamp with holder, 1 Picture slider, 2 Lens in frame (100mm), Bench clamp riders, 1 Kerr cell, 1 High-voltage power supply unit, Connecting leads, 1 Translucent screen, nitrobenzene.

### METHODOLOGY:

When a substance (especially a liquid or a gas) is placed in an electric field its molecules may become partly oriented making the substance anisotropic and birefringent ; that means it can refract light differently in two directions. This effect is called electro-optical Kerr effect or simply Kerr effect and was discovered in 1875.

This birefringence increases quadratically with the electric field strength. For reasons of symmetry, the optical axis of birefringence lies in the direction of the electric field. The normal refractive index of the substance is changed to  $n_e$  for the direction of oscillation parallel to the applied field, and to  $n_o$  for the direction of oscillation perpendicular to it.

The change in index is given by:

$$n_e - n_o = K \lambda E^2 \quad (11.1)$$

K is the Kerr constant for the medium

$\lambda$  Is the wavelength of the light used

E is the electric field strength

This difference in index of refraction causes the material to act like a waveplate when light is incident on it in a direction perpendicular to the electric field. If the material is placed between two "crossed" (perpendicular) linear polarizers, no light will be transmitted when the electric field is turned off, while nearly all of the light will be transmitted for some optimum value of the electric field. Higher values of the Kerr constant allow complete transmission to be achieved with a smaller applied electric field.

Some polar liquids, such as nitrotoluene ( $C_7H_7NO_2$ ) and nitrobenzene ( $C_6H_5NO_2$ ) exhibit very large Kerr constants. A glass cell filled with one of these liquids is called a *Kerr cell*. These are frequently used to modulate light, since the Kerr effect responds very quickly to changes in electric field. Light can be modulated with these devices at frequencies as high as 10 GHz. Because the Kerr effect is relatively weak, a typical Kerr cell may require voltages as high as 30 kV to achieve complete transparency. This is in contrast to Pockels cells, which can operate at much lower voltages.

The Kerr effect is usually demonstrated by placing a Kerr cell containing nitrobenzene between two flat parallel plates spaced several millimeters and applying a high voltage on the plates.

If the field is such that the cell retards the extraordinary ray by half wavelength, the polarization rotation will be  $90^\circ$ . If a pair of polarizers is put around the cell, oriented at  $45^\circ$ , the assembly acts as a shutter. The voltage needed to do this is called the *halfwavelength* voltage. At the halfwavelength voltage, the following is true:

$$(n_e - n_o)L = \lambda / 2 \quad (11.2)$$

Where

L is the distance in the Kerr cell covered by the light

$\lambda$  is the wavelength of the light

In general the optical difference in paths for 2 waves is  $(n_e - n_o)L$  and this corresponds to a phase displacement of:

$$\Delta = (n_e - n_o)L / \lambda \quad (11.3)$$

It can also be shown that the phase displacement is proportional to length L and the square of polarization P. If we anticipate that the polarization is a linear function of the electric field strength E and the proportionality factor is designated by K, then the following relation is obtained:

$$\Delta = KE^2L \quad (11.4)$$

Thus if the phase difference between the ordinary ray and the extraordinary ray equals to  $\lambda/2$  then we have  $\Delta = (\lambda/2) / \lambda = 1/2$

In addition if  $E = V/d$ , where V=applied Voltage and d the inter-electrode distance we can say that:

$$\Delta = K V^2 L / d^2 \quad \text{and} \quad V^2 = d^2 \Delta / K L$$

## **PROCEDURE:**

### **IMPORTANT SAFETY NOTES:**

**Nitrobenzene is an extremely strong liver poison.** It can enter the body if the vapour is breathed in, in the event of skin contact or by swallowing. Spark discharge may cause the nitrobenzene to explode. It is therefore important that the following safety notes are taken:

- Carry out the experiment in a well-ventilated room.
- Avoid skin contact with nitrobenzene.
- Do not breathe in the vapour.
- Fill and empty the Kerr cell under the extraction hood.
- Fill the Kerr cell that the liquid level is several millimetres above the condenser gap in order to avoid spark discharge.
- Activate the cell as follows before starting measurements:
  - Fill the cell with nitrobenzene so that it is 2/3 full and connect to the high-voltage power supply unit. Use the 5 kV, 2 mA output. Set the voltage selector switch to the scale center (2.5 kV).
  - Allow the cell to stand for some time, occasionally looking at the voltage display on the high-voltage power supply unit. The cell is ready for measurement when the voltage has risen to approximately 2 kV.
  - Identify the polarity of the cell. Always use the cell with the same polarity because there is otherwise a danger of spark discharge.

### **Setting up the optical apparatus:**

1. Set up the apparatus on the optical bench as shown in Figure 1 and make the electrical connections. Equip the halogen lamp and the picture slider with heat insulation filter (to prevent the nitrobenzene from being heated up) and switch on.
2. Set both polarizing filters to  $0^\circ$ .
3. Set the high-voltage power supply unit to zero. Mount the Kerr cell on the prism table and place the capacitor gap on the optical axis. Form an image of the light coil in the opening of the 100 mm lens. Move the lens so that a sharp image of the capacitor gap is formed on the screen.

### **Carrying out the experiment:**

1. Set the polarizer to  $45^\circ$  and the analyzer to  $-45^\circ$  so that the field of view is darkened.  
Note: The field of view is lit up as soon as a high voltage is applied to the capacitor gap.

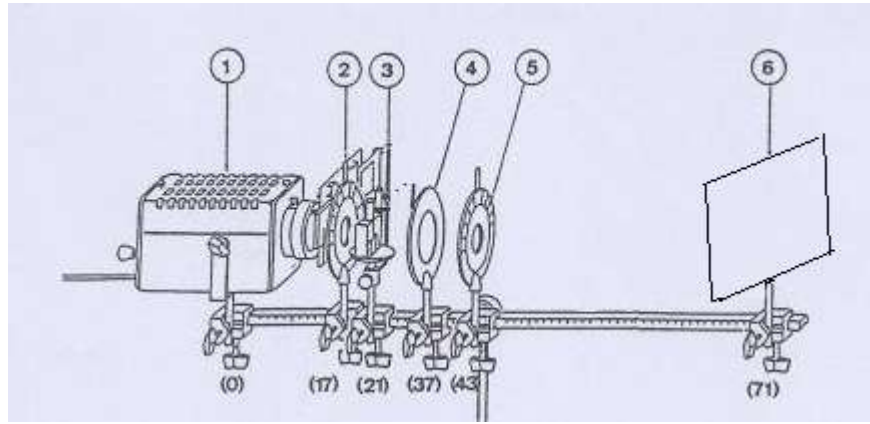


Figure 11.2: Optical setup (1) Light source (2) Polarizer (3) Kerr cell (4) Lens (5) Analyzer (6) Screen.

2. Starting from 0 kV, increase the voltage gradually until you reach 5 kV noting how the intensity changes. Record (in Table 1) the voltage values at each maximum and minima where the maximum intensities correspond to relative path difference  $\Delta=1/2, 3/2, 5/2...$  and the minimum intensities correspond to relative path difference  $\Delta=0, 1, 2, 3...$  ( $\Delta=0$  at 0 kV).
3. Plot  $\Delta$  vs.  $V^2$ .
4. Using the slope, calculate Kerr constant. (Note:  $d = 1 \text{ mm}$  and  $l = 2 \text{ cm}$ )

**TABLE 1**

| $\Delta$ | V (volt) | $V^2$ (volt <sup>2</sup> ) |
|----------|----------|----------------------------|
| 1/2      |          |                            |
| 1        |          |                            |
| 3/2      |          |                            |
| 2        |          |                            |
| .        |          |                            |
| .        |          |                            |
| .        |          |                            |
| .        |          |                            |