EXPERIMENT PROCEDURE

• **Demonstrate birefringence in a conoscopic beam path.**

• **See how the birefringence changes when an electric field is applied.**

• **Determine the half-wave retardation voltage.**

OBJECTIVE

Demonstration of Pockels effect in a conoscopic beam path

SUMMARY

The Pockels effect is an electro-optical effect in which an electric field within a suitable material splits a light beam into two beams polarised perpendicular to one another. This ability to produce optical birefringence derives from the differing refractive indices depending on the direction of propagation and polarisation of the light. In the case of the Pockels effect, this increases linearly with the strength of the electric field as is demonstrated in this experiment using a lithium niobate crystal (LiNbO$_3$) placed in the path of a conoscopic beam. The interference pattern is formed by two sets of hyperbolae, from which the position of the optical axis for the birefringence can be seen directly.

REQUIRED APPARATUS

Quantity	Description	Number
1	Pockels Cell on Stem	1013393
1	Optical Precision Bench D, 100 cm	1002628
3	Optical Rider D, 90/50	1002635
2	Optical Rider D, 90/36	1012401
1	He-Ne Laser	1003165
1	Achromatic Objective 10x / 0.25	1005408
1	Polarisation Filter on Stem	1008668
1	Convex Lens on Stem f =+50 mm	1003022
1	Projection Screen	1000608
1	High-Voltage Power Supply E 5 kV (230 V, 50/60 Hz)	1013412 or
	High-Voltage Power Supply E 5 kV (115 V, 50/60 Hz)	1017725
1	Pair of Safety Experiment Leads, 75 cm	1002849

BASIC PRINCIPLES

The Pockels effect is an electro-optical effect in which an electric field within a suitable material splits a light beam into two beams polarised perpendicular to one another. This ability to produce optical birefringence derives from the differing refractive indices depending on the direction of propagation and polarisation of the light. In the case of the Pockels effect, this increases linearly with the strength of the electric field as is demonstrated in this experiment using a lithium niobate crystal (LiNbO$_3$) placed in the path of a conoscopic beam.

The crystal in this case is located inside a Pockels cell in transverse alignment, where an electric field is applied across the crystal in the direction of the optical axis for the birefringence (see Fig. 1). The light beam passing perpendicularly through the crystal splits into an ordinary and an extraordinary, i.e. one polarised in the direction of the optical axis for the birefringence and another polarised perpendicular to it. In the case of lithium niobate, the refractive index for the ordinary beam for n_o = 2.29 as measured at the wavelength of an He-Ne laser λ = 632.8 nm while that for the extraordinary beam is n_e = 2.20. The path difference between the ordinary and extraordinary beams is as follows:

$$(1) \qquad \Delta = \mathrm{d} \cdot (n_o - n_e),$$

where d = 20 mm, the thickness of the crystal in the direction of the beam.

Demonstration of the birefringence uses a classical beam path as suggested for the purpose in numerous optics text books. The crystal is illuminated by a divergent, linearly polarised light beam and the transmitted light is observed behind an orthogonal analyser. The optical axis of the birefringence is highly visible in the interference pattern since it stands out from the background due to its symmetry. In this experiment, it is parallel to the entry and exit surfaces on the crystal, therefore creating an interference pattern with two sets of hyperbolae rotated by 90° with respect to one another. The actual axis of the first set of hyperbolae is parallel to the optical axis of the birefringence and that of the second set is perpendicular to it.

The dark bands in the sets of hyperbolae arise for beams where the difference between the optical paths of the ordinary and extraordinary beams in the crystal are an integer multiple of the wavelength. These beams retain their original linear polarisation on passing through the crystal and get blocked by the analyser.

The path difference corresponds to about 2800 wavelengths of the laser light being used. However, in general Δ is not precisely an integer multiple of the wavelength λ, but rather lies between two values $\Delta_m = m \cdot \lambda$ and $\Delta_{m+1} = (m + 1) \cdot \lambda$. For the dark lines of the first set of hyperbolae the path differences are Δ_{m+1}, Δ_{m+2}, Δ_{m+3}, etc. Those for the second set correspond to Δ_m, Δ_{m-1}, Δ_{m-2}, etc. (see Fig. 2). The position of the dark bands, or more accurately their distance from the centre, depends on the difference between Δ and $m \cdot \lambda$. The Pockels effect increases or decreases the difference between the primary refractive indices $n_o - n_e$ depending on the sign of the voltage applied. This means that the difference $\Delta - m \cdot \lambda$ changes and so therefore does the position of the dark interference bands. If the so-called half-wave retardation voltage U_π is applied, then Δ changes by one half of the wavelength. Then the dark interference bands shift to the position of the bright bands and vice versa. This process is repeated every time the voltage is increased by U_π.

EVALUATION

For a voltage U_1 the dark interference bands of order +1 are located precisely in the centre. For the next voltage U_2 it is those of order +2 which are in the centre. Then the half-wave voltage is as follows:
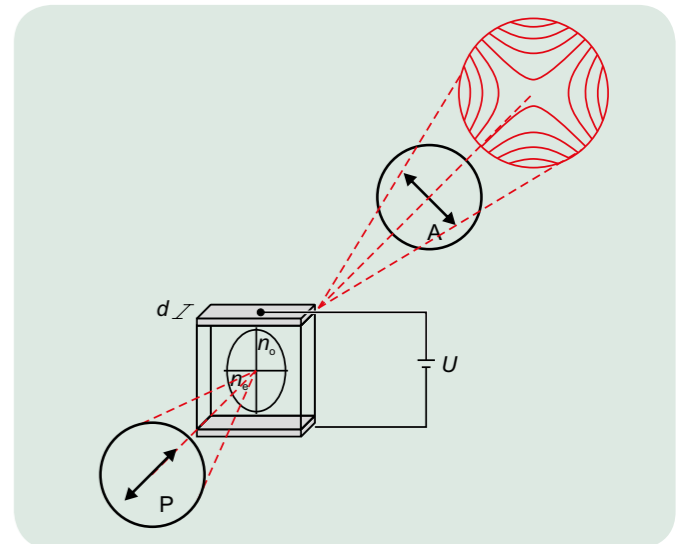
$$U_\pi = \frac{U_2 - U_1}{2}$$

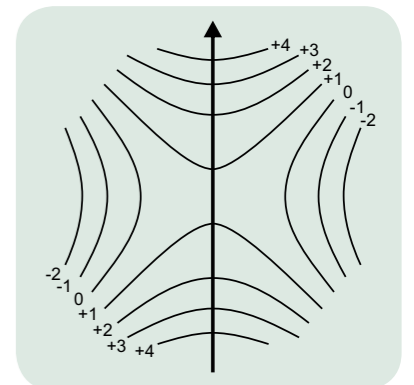Fig. 1: Schematic of Pockels cell in a conoscopic beam path between the polariser and analyser

Fig. 2: Interference pattern with optical axis of crystal in the direction of the arrow. The indices of the dark interference bands indicate the path difference between the ordinary and extraordinary beams in units of the wavelength.
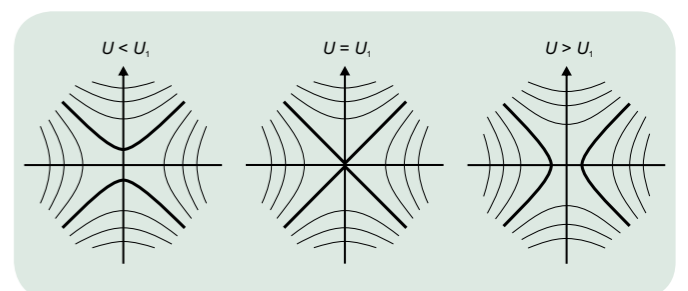

Fig. 3: Change in interference pattern due to Pockels effect. The hyperbolae indicated by thicker lines are those of order +1 in the interference pattern.