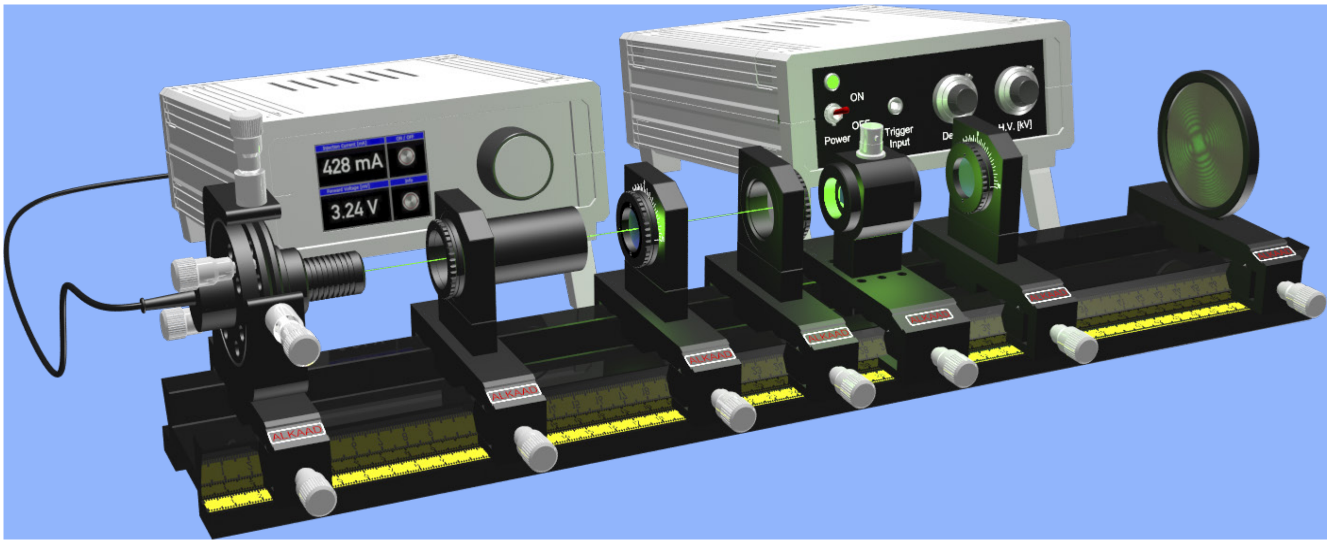
PE-0100 Double Refraction of Light



Keywords

Birefringence
Conoscopic imaging
Quarter and half waveplate
Ordinary and Extraordinary beam
Crystalline quartz
Pockels Cell
Jones matrix
Iceland Spar (Calcite)

Introduction

In 1669, Erasmus Bartholin was the first one who reported his observations on double refraction. He investigated a crystal of calcite: not the only crystal which shows double refraction, but a crystal with an extraordinary high markedness of this phenomenon. His discovery and its first scientific explanation by Christian Huygens in 1674 marked the beginning of the studies on optical crystal properties. More than 100 years later, crystal optics got further insights through Dominique Arago, who studied the polarization and optical activity, and Jean-Baptiste Biot who defined the first principles of crystal optics, by differentiating in particular, uniaxial and biaxal crystals principles which are still valid today. Birefringent materials are important components in optics, for example as half and quarter wave plates, precision polarizer to tune laser lines. The experiments may start with the observation of birefringence shown by calcite crystal. The green probe laser is directed to the calcite and the splitting of the laser beam in ordinary and extraordinary rays are observed. The polarization of these rays is measured by using the rotary polarisation analyser. As an example of a biaxial crystal a Pockels cell containing a Lithium Niobate crystal is used. In a conoscopic set-up impressive interference pattern are created when the high voltage is applied. Furthermore, the optical retardation for different voltage levels is measured and the half wave voltage is determined.

How it works

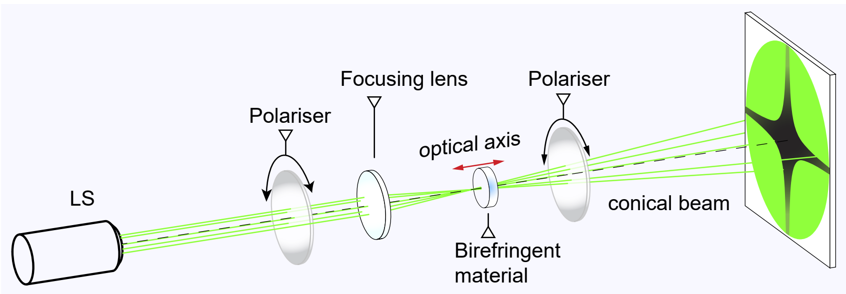


Fig. 1: The optical axis of the birefringent material parallel to the light beam

The creation of an conoscopic image requires a birefringent material where the optical axis is oriented parallel to the incident light beam. In this experiment we are using a laser emitting a wavelength of 532 nm (green). The light passes the first polarizer. A focusing lens creates the "conical" light beam which traverses the birefringent material. The second polarizer is aligned orthogonally to the first one. In direction of the optical axis, the material behaves isotropic and there will be no change in the polarisation stage of the incident light. The corresponding image on the screen remains dark. All other rays propagating inclined to the optical axis undergo a change to their polarisation in such a way that a fraction can pass the orthogonally oriented polarizer.

Consequently, a typical intensity distribution results which is a fingerprint for the specific birefringent material. Areas with same intensity (same retardation) are termed as isogyres, places of same birefringence. Conoscopy is a very important method to find the optical axis of raw crystals in optic manufacturing as well as quality control for LCD displays.

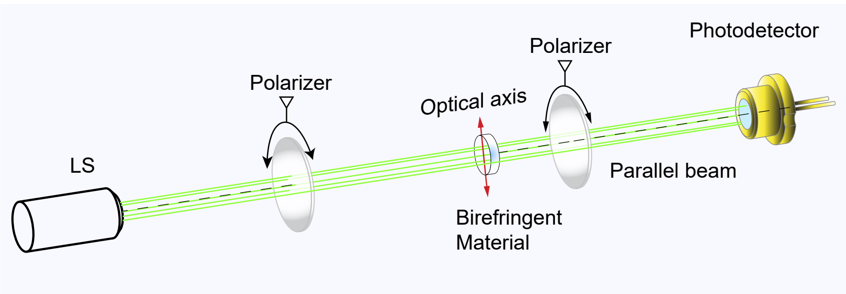


Fig. 4.2: The optical axis of the birefringent material perpendicular to the light beam

Another method to characterise birefringent materials are arrangements where the optical axis of the crystal is perpendicularly oriented to the light source. In such a case, the light is almost parallel. The birefringent material is placed between two rotatable polarizers. By means of a photodetector, the transmitted intensity is measured as a function of the angle orientation of either the birefringent material or the polarizer. Without any material between the two polarizer the famous Malus' law can be verified.

$$I = I_0 \cdot \cos^2(\vartheta)$$

Whereby υ is the angle position between both polarizers. In case they are oriented to the same angle the value of υ is zero and we obtain maximum transmission. In they are orthogonally aligned to each other the value of υ is 90° resulting in zero transmission. Placing a half wave plate between the polarizers results in an increase in the transmission. In a certain position the transmission becomes maximum, that means that the half wave plate turns the polarisation by 90°. In the same way we examine the behaviour of a quarter wave plate. It turns out that such a plate converts linear light into circular ones provided the optical axis of the plate is oriented by 45° with respect to the polarisation direction of the light.