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New method to determine the optical rotatory dispersion of inorganic crystals applied to some samples of Carpathian Quartz ☆

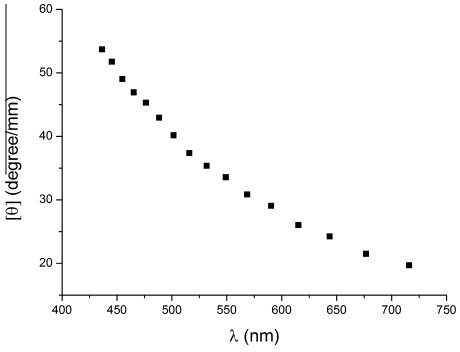
Dan Gheorghe Dimitriu *, Dana Ortansa Dorohoi

Faculty of Physics, "Alexandru Ioan Cuza" University, 11 Carol I Blvd., RO-700506 Iasi, Romania

HIGHLIGHTS

- Optical rotatory dispersion is estimated using channeled spectra.
- Optical rotatory dispersion decreases with light wavelength increasing.
- The proposed method is validated by data from literature.

GRAPHICAL ABSTRACT



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ABSTRACT

A new method to determine the optical rotatory dispersion (ORD) in the visible range, based on a channeled spectrum obtained with a uniax inorganic crystal introduced between two crossed polarizers with its optical axis parallel to the light propagation direction is detailed in this paper. When the studied inorganic crystals are transparent, this method permits the estimation of the optical rotatory dispersion in the visible range, for which the cheap polarizers are available. The speed of the measurements is very high, because the estimations are made from the channeled spectrum obtained for a single arrangement of the optical components. By using a computer, ORD is quickly determined for the visible range. The results obtained by this method for some Carpathian Quartz samples are consistent with those from literature. The proposed method can be also applied in UV and IR spectral ranges, when the anisotropic layers are transparent and the linearly polarized radiations can be obtained.

Introduction

The optical rotation (OR) and optical rotatory dispersion (ORD) have been observed in 1811 by François Arago and then studied and interpreted by Jean Baptiste Biot one year later [1]. Biot explained the phenomena by rotation of the polarization direction around the direction of light traveling and by the dependence of the rotation angle on the light wavelength, respectively. Biot made experiments with two sorts of quartz, left-handed and right-handed quartz, showing that the two sorts rotate in opposite sense the polarization plane. The changes in color of the anisotropic plates placed between crossed polarizers has been explained the ORD phenomenon.

Optical activity is a type of birefringence consisting in turning the light polarization plane about the light propagation direction [2,3]. The strength of the optical activity is quantified by the difference

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* Corresponding author. Tel.: +40 232 201183; fax: +40 232 201150.
E-mail address: dimitriu@uaic.ro (D.G. Dimitriu).

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$$\Delta n = n_l - n_r \quad (1)$$

between the refractive indices of the material, measured for right-, respectively left-circularly polarized waves. The difference (1) is material-dependent and it is a dispersive parameter (depends on the light wavelength). The variation in rotation of the polarization plane with the light wavelength is called optical rotatory dispersion (ORD).

Some trials to explain the origin of optical activity in inorganic crystals were made [4,5] and the optical activity was associated with bended bonds created by vacancies. The bended pattern of charge distribution creates a situation where electric and magnetic dipole moments have parallel components; consequently, their contribution is more significant than the one derived from atomic polarizability.

In this paper a new method is proposed for determining the optical activity of the inorganic crystals based on the channeled spectra obtained with the experimental device described in the next section.

Theoretical models permit to express the birefringence of the anisotropic layers by a function on the light wavelength. In order to validate the model, a well known inorganic crystal, quartz, was used to obtain experimental results. Quartz from Maramures (Romania) Mountains [6–10], with birefringence evaluated by other methods was used to obtain channeled spectra. Wood interferential filters [8] were obtained in our laboratory, based on the linear dispersion of Carpathian Quartz.

Theoretical and experimental studies of dispersive optical activity [11–14] in inorganic crystals, particularly in quartz, were made by other authors due to the ORD importance in understanding the interaction between light and transparent condensed media. New insights into the physics of light, the structure of molecules, and the nature of living matter relived the ORD importance in physics, chemistry, and biology over the past two centuries [1].

Experimental results

The Carpathian Quartz samples were characterized from the crystallinity point of view by using a Panalytical – model X'Pert Pro X-ray diffractometer with Cu Kα source (I = 30 mA, U = 45 kV) for $2\theta \in [5^\circ - 90^\circ]$ and a step of 0.004°. It crystallizes in a hexagonal system (a = 4.9134; b = 4.9134; c = 5.4052) [7–9].

The diffractograms of Carpathian Quartz are identical with those obtained for standard quartz from the database [11], proving its purity from the chemical point of view. They are transparent in the visible range and can be used in achieving electro-optical devices.

The experimental device which permits to record the channeled spectrum with a spectrophotometer consists of two crossed polarizers and a uniax thick anisotropic layer with its optical axis oriented along the light propagation direction. The device is introduced in the measure beam of the spectrophotometer (Specord UV VIS Carl Zeiss Jena with acquisition system). The natural light (emitted by the spectrophotometer source) incident on the device as a parallel beam, becomes linearly polarized after the first polarizer. The modifications induced by the anisotropic layer in the light polarization state are analyzed with the second polarizer.

Two identical polarizers with their transmission directions in parallel are introduced in the comparison beam of the spectrophotometer, for compensation reasons. With this device, a channeled spectrum can be obtained, from which the difference Δn can be estimated.

A channeled spectrum has been obtained for a quartz crystal (L = 50 mm) cut perpendicular to optical axis and introduced between crossed polarizers.

Theoretical background

According to the Fresnel theory [7], a linear polarized radiation is equivalent with two circularly polarized (right and left) radiations, with the same propagation direction and equal amplitudes.

Let us consider the phenomena induced by light propagation through the experimental device. After the first polarizer, the light becomes linearly polarized with its electric field parallel to the transmission direction of the polarizer. The uniax anisotropic layer is traversed (crossed) by light parallel to its optical axis. Light changes its azimuth in the anisotropic layer. Consequently, after the second polarizer the flux density differs from zero. The angle between the initial position of the second polarizer and its position for which the flux density becomes null measures the rotation angle of the light polarization plane.

The rotation angle for a given component of light, with the wavelength λ_0, can be expressed as

$$\theta = \frac{k_l - k_r}{2} L = \frac{\pi}{\lambda_0}(n_l - n_r)L = \frac{\pi}{\lambda_0}\Delta n L \quad (2)$$

The rotation angle (the dihedral angle between the light polarization planes at the entrance and the emergent light from anisotropic layer), can be written as:

$$\theta = [\theta]L \quad (3)$$

where

$$[\theta] = \frac{\pi}{\lambda_0}(n_l - n_r) \quad (4)$$

is named specific rotation, the rotation angle determined by a unitary (L = 1 mm) anisotropic layer. As it results from relation (4), the specific rotation depends on the wavelength of light, both directly, by the factor $1/\lambda_0$ and also by dispersion of the refractive index.

When the two polarizers are crossed and the device is illuminated by monochromatic radiation, in the absence of the anisotropic layer the flux density is null after the second polarizer. When an anisotropic crystal, introduced between the two crossed polarizers, has $n_l = n_r$, the flux density after the second polarizer is also null. In the condition $n_l \neq n_r$, the flux density after the second polarizer differs from zero. It results that the emergent radiation remains linearly polarized, but the azimuth of the electric field intensity differs from zero.

In order to obtain null flux after the second polarizer, this must be rotated by the angle θ. The rotation angle of the analyzer measures the optical activity of the used anisotropic crystal. The reciprocal orientation of the transmission directions of the polarizers (which are initially crossed) and the new orientation of the electric

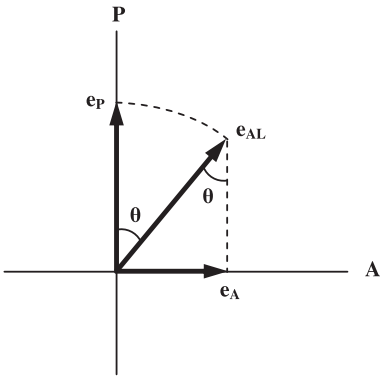

Fig. 1. Reciprocal orientation of the transmission directions of the two polarizers (P and A) and the orientation of the electric field intensity after anisotropic layer (AL).

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