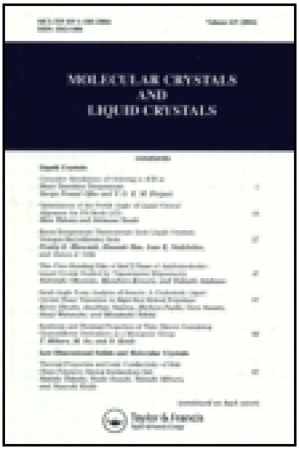

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Some Optical Properties of the Elaidicum Acid in Mesophase

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Some Optical Properties of the Elaidicum Acid in Mesophase

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The liquid crystal (smectic C* type) properties of the elaidicum acid, from 28°C to 51°C have been studied and utilised in this paper.

The electrical potential, the capacitance and the electric current intensity versus applied voltage on a membrane of liquid crystal were measured.

The experimental results of these measurements and the microstructural aspects show that this acid has the dielectric properties of a liquid crystal and is ferroelectric. The dependence of the current on time, when an electric field is applied and removed, were investigated, too, the results confirming the previous conclusions.

Taking into account these findings, different liquid crystal cells were realised and utilised for the "nonlinear lens" effect. This is the external self-focusing of laser light in the liquid crystal film. A He-Ne laser (λ = 6328 Å, P = 16–20 mW) was utilised for the experimental setup.

The f^{NL} change with the sample thickness and with the temperature was determined, the optical nonlinearity ε_2 versus the liquid crystal thickness was graphically represented, too. The study of the pattern—obtained on a screen in far field—show that the sample have a great optical nonlinearity, even at low optical powers. The different behaviour at heating and cooling confirms the ferroelectricity of this substance.

I. INTRODUCTION

The elaidicum acid is an unsaturated fatty acid, having liquid crystal properties in the chiral smectic C* phase at usual temperatures (28°C–51°C):

$$\begin{array}{l} CH_3\text{—}(CH_2)_7\text{—}C\text{—}H \\ \qquad\qquad\qquad\quad \| \\ \qquad\qquad\quad H\text{—}C\text{—}(CH_2)_7\text{—}COOH \end{array}$$

This paper presents their liquid crystal dielectrical properties, experimentally detected.

Different thin samples of elaidicum acid were realised and are presented from nonlinear optical point of view (membranes, plane-parallel and wedge cells).

II. LIQUID CRYSTAL PROPERTIES OF THE ELAIDICUM ACID

Elaidicum acid membranes, situated between two aqueous symmetrical phases, were utilised for dielectrical property measurements.

A membrane can be modeled by a capacitor, or many capacitors in series. Experimentally, we have determined the electrical potential of the membrane versus neighbouring aqueous solutions as a function of temperature, between 15°C and 55°C, for a time of 5–10 minutes. (If the experiment is longer, the membrane can break).

The membrane forms at room temperature, over an orifice of 1–1.6 mm^2, realised in a Mylar, situated between two aqueous compartments, which have wolfram electrodes of 1.5–2 mm^2.

The brushing or droppering technique[1] is utilised, with elaidicum acid in CCl_4 10% solution.

The dependence of the electrical potential versus temperature is exponential (Figure 1a, b), according to the relation:

$$V = V_0 \exp[-aT] \tag{1}$$

The specific capacitance of the membrane versus the electrical applied voltage (at 25°C and 474 Hz) is measured too (Figure 1c).

A logarithmical decrease of the capacitance with the increasing voltage is observed, which is a feature for nonlinear dielectrics.

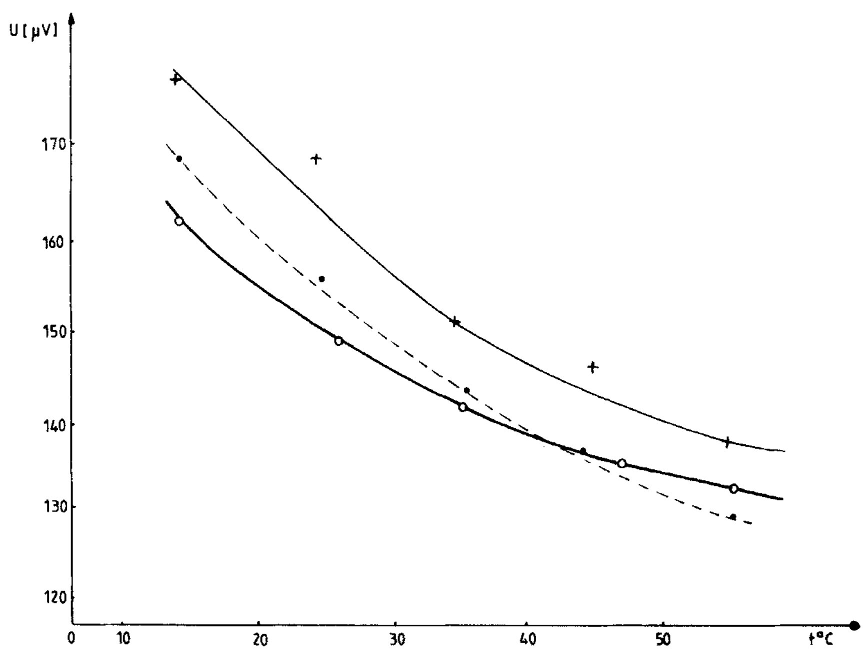

FIGURE 1(a) Dependence of the membrane potential versus temperature for some fatty acids: ×, arachidicum acid; •, lauricum acid; ○, elaidicum acid.

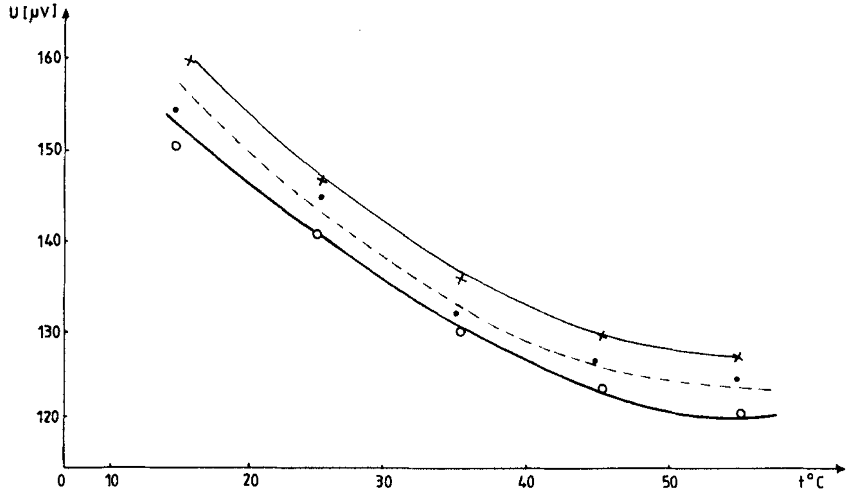

FIGURE 1(b) Dependence of the membrane potential versus temperature for a mixture: fatty acid-colesterolum; ×, 66% - 33%; •, 50% - 50%; ○, 33% - 66% by weight.

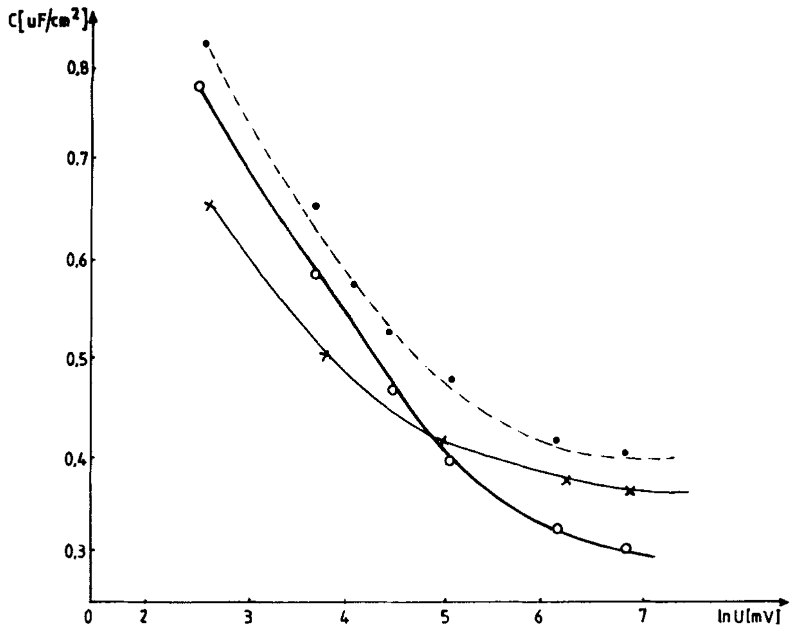

FIGURE 1(c) Membrane specifical capacitance versus applied voltage at 25°C and 474 Hz: •, arahidicum acid; ○, lauricum acid; ×, elaidicum acid.

These results, together with the dependence $I = I(U)$, presented in Figure 2a and $I = I(t)$ in Figure 2b (t being the time), show a ferroelectric smectic liquid crystal behaviour of this acid.

Because of the ferroelectricity, we consider it is chiral, therefore uniaxial.

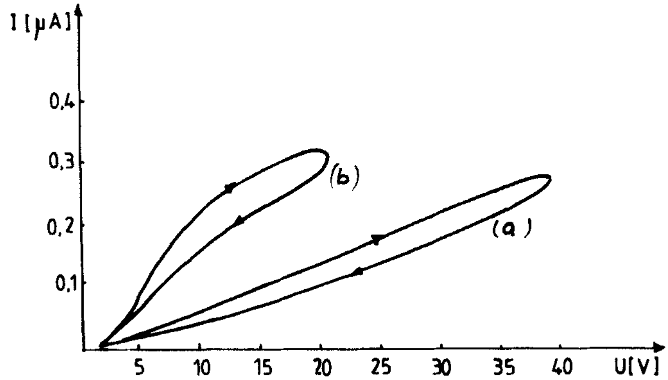

FIGURE 2(a) Electrical current intensity versus applied voltage $I = I(U)$ without (a) and with light (b).

III. NONLINEAR LIQUID CRYSTAL LENS

A liquid crystalline material can have a large field-induced change in the refractive index. This is the orientational mechanism of optical nonlinearity in liquid crystals, manifested in increasing divergence of the transmitted laser beam as well as the formation of rings.

The central part of a laser Gaussian beam sees a larger refractive index than the edge, and the beam appears to focus by itself. Since the liquid crystal sample is like a thin film, the self-focusing of light is external.

We are made a very thin liquid crystal cell with elaidicum acid, the substance being introduced by capillarity from isotropical phase, between transparent conducting lamellae of SnO_2 without Mylar spacing.

The sample has homeotropic structure[2]: From the data obtained with a laser He-Ne ($\lambda = 6328$ Å, P = 16 mW) results that the sample operates like a lens, with an increasing focal length, when the temperature is decreasing—in the mesophase range (Figure 3).

The dependence of the laser beam divergence versus the focal length is obtained by replacing the sample, localised at the beam waist, with glass lenses, whose focal length was known (Figure 4).

A new sample, with a wedge shape, was constructed, by putting only one 12 μm Mylar at an end of the cell. The cell length was 22 mm (Figure 5). This length was divided in six zones and the optical emergent power was measured.

The incident He-Ne laser beam was focused on the cell, obtaining an incident optical intensity of about 16 W/cm^2. The sample was biased with V = 10V at ν = 10 Hz.

With the aid of Figure 4, the dependence of the "nonlinear lens" focal length f^{NL} versus cell thickness d_i ($i = 1-5$) was graphically determined (Figure 6).

The temperature is maintained constant with a device presented in Figure 7.

A decrease of f^{NL} upon increasing d is observed, in agreement with some other results for nematics.[3]

The aspect, form and dimensions of pattern obtained on a screen in far-field is

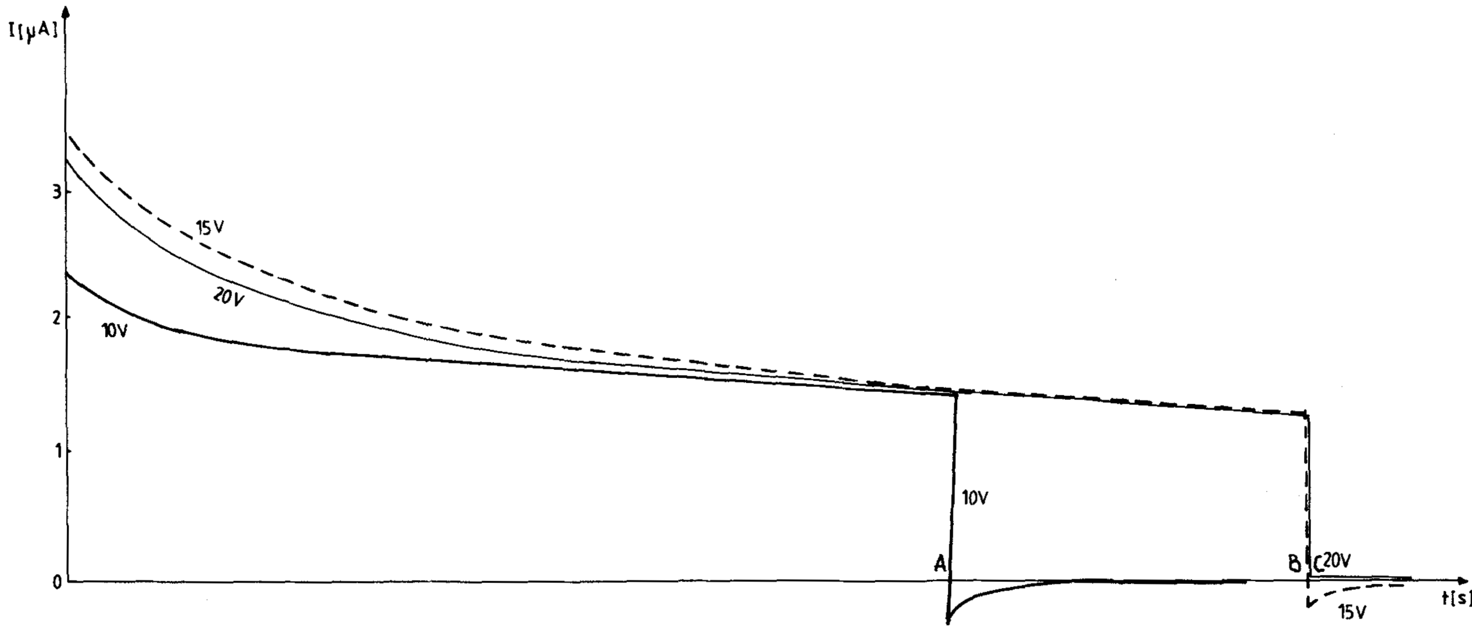

FIGURE 2(b) Dependence of the current intensity I versus time $I = I(t)$ at different applied voltages. In A, B, C the electric field is removed. Times scale: 20 sec/cm.

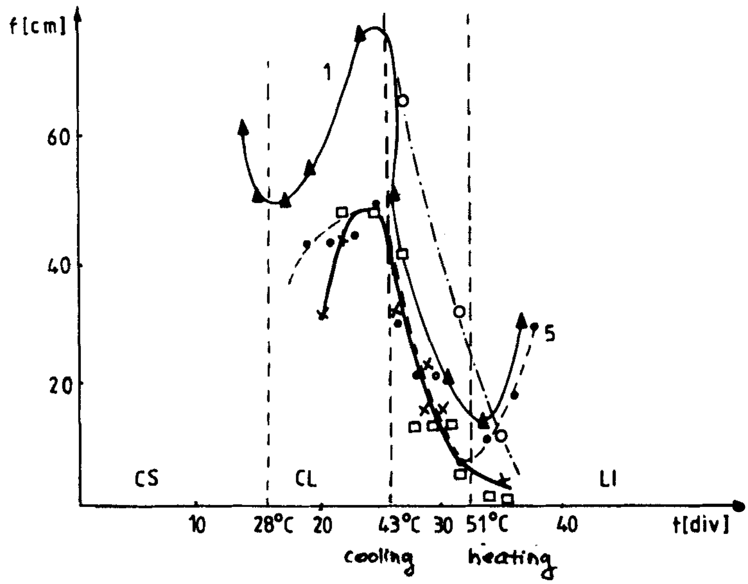

FIGURE 3 "Nonlinear lens" focal length versus temperature for the wedge elaidicum acid cell. Focal length behaviour dependence on the variation sense of the temperature is observed: CS, solid crystal; CL, liquid crystal; LI, isotropic liquid; ○, liquid crystal cell without Mylar; ▲, d_1 = 8,5 μm; ●, d_5 = 4,5 μm; □, d_3 = 6,5 μm; ×, d_4 = 5,5 μm.

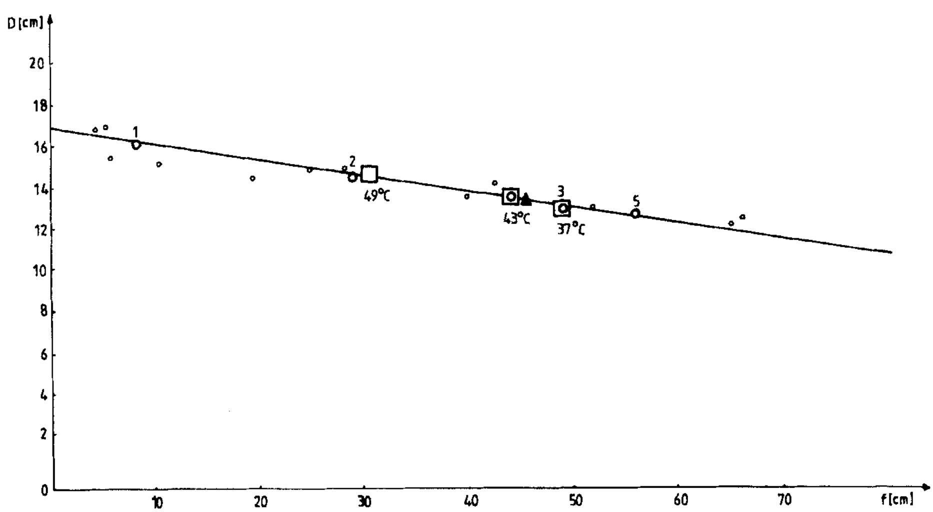

FIGURE 4 Beam divergence D versus focal length f for: ○, linear lens; ◯, elaidicum acid wedge cell (1 – d_1; 2 – d_2; 3 – d_3; 5 – d_5); □, elaidicum acid without Mylar cell; ▲, another fatty acid (arachidonicum acid).

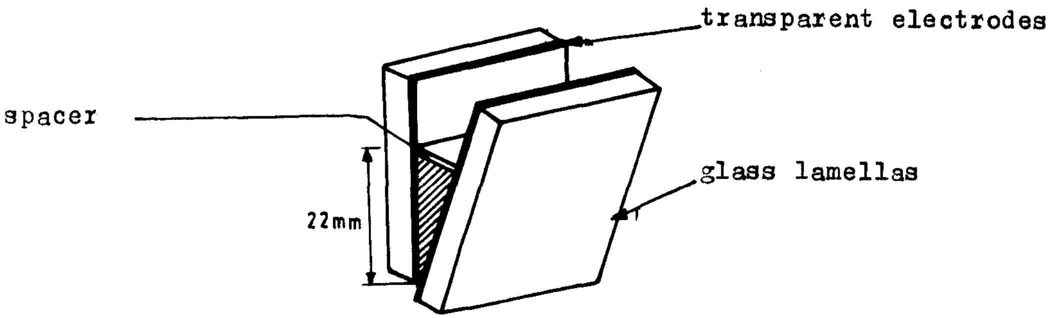

FIGURE 5 The wedge LC cell.

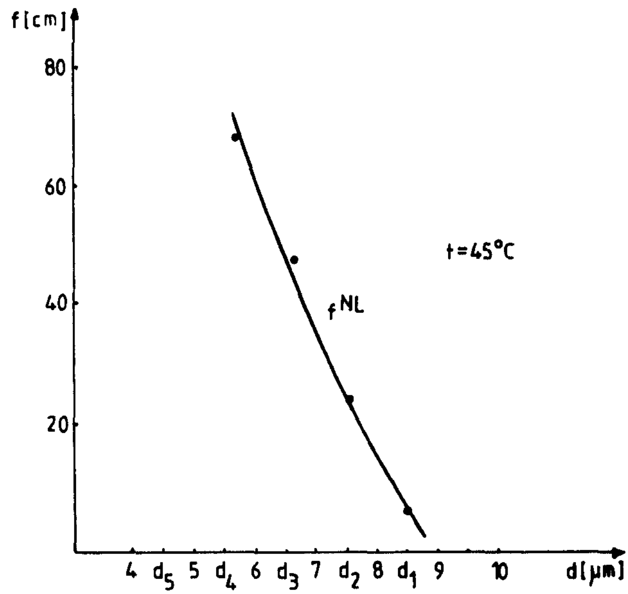

FIGURE 6 Nonlinear focal length versus cell thickness. d_1 – d_5, wedge cell thickness in different points.

presented in Figure 8a, b. The beam pierced the two extremities of the cell, in temperature range of 11°C–60°C. The pattern confirms the phase transitions:

$$\text{solid crystal} \xrightarrow{28°\text{C}} \text{liquid crystal} \xrightarrow{51°\text{C}} \text{isotropic liquid}$$

Under $t = 42°\text{C}$ ($\pm$ 0,5°C) the image becomes opaque and the light scattering is increased. But the fringe pattern, obtained in isotropic phase remains the same.

In "d_2" position, at $t = 51°\text{C}$ (—heating—at $U = 10\text{V}$, $\nu = 10$ Hz), the ring pattern is like in Figure 8a. The phase shift between the "top" of the laser Gaussian beam and his "edge" is 10π (incident power about 16 mW).

Upon cooling, at 42°C, the diffraction pattern has the form of Figure 8b. These remarks, together with the focal length versus temperature dependence from Figure

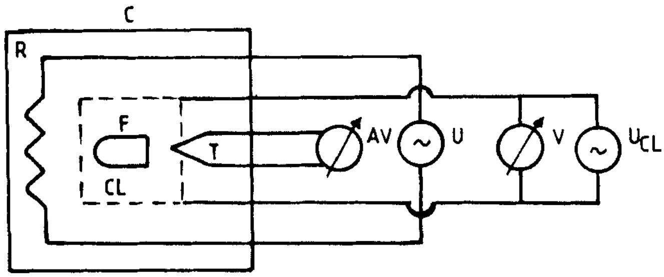

FIGURE 7 Thermostated cell for LC heating: C, thermostated cell; CL, liquid crystal cell; F, quartz window; R, heating resistor; U, electrical generator (f = 50 Hz) for R; T, copper-constantan thermocouple; AV, voltmeter; V, electronic voltmeter; U_{CL}, frequency generator.

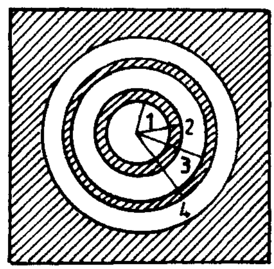

FIGURE 8(a) The aspect, form and dimensions of the diffraction pattern for wedge cell of elaidicum acid at heating: (d_2 = 7,5 μm), t = 51°C, U = 10 V, ν = 10 Hz, P = 16 mW, D_1 = 2,5 cm, D_2 = 3,5 cm, D_3 = 4,5 cm, D_4 = 5,5 cm, $\varphi = 2\,N\pi = 10\pi$.

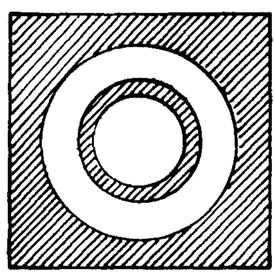

FIGURE 8(b) The same at cooling t = 42°C, $\varphi = 6\pi$.

3, show a different behaviour of sample in the heating and cooling processes. This behaviour was demonstrated for another ferroelectric liquid crystals, too.

In this temperature range, the focal length of the "nonlinear lens" is directly proportional with cell thickness d, being useful for practical applications.

Similar optical effects at low optical power have been reported for nematics, and an expression for nonlinear lens convergence was derived.[3]

Based on these considerations, as well as on the uniaxiality property of chiral smectics, we can derive the optical nonlinearity versus the cell thickness, for different incidence angles and different optical powers (Figure 9).

It is remarkable that the nonlinearity depends on the thickness, the same way as for nematics.[3]

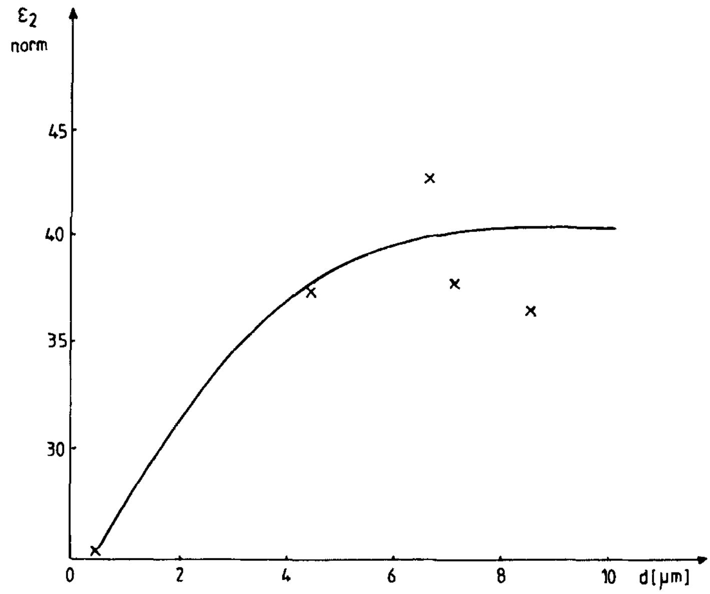

FIGURE 9 Optical normate nonlinearity $\varepsilon_{2\,\mathrm{norm}}$ versus cell thickness d, $\varepsilon_{2\,\mathrm{norm}} = \varepsilon_2/\sqrt{\varepsilon_0}\, w_0^4/\cos \alpha P_{\mathrm{in}}$.

IV. CONCLUSIONS

Several facts have been reported in this paper. The first is the existence of a mesomorphic domain of temperatures for the elaidicum acid. This acid presents dielectrical properties, ferroelectricity and was identified as chiral smectic C*.

On the other hand, this liquid crystal has a great optical nonlinearity, the same as other classes of liquid crystals. This fact is proved by their "lens like" behaviour when a laser focused beam is incident on the liquid crystal sample (external self-focusing of light).

The focal length dependence versus temperature confirms the limit of the mesomorphysm domain and the ferroelectricity property.

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