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H. Herba[a]; A. Drzymała[a]
[a] Institute of Mathematics and Physics, I. łukasiewicz Technical University, Rzeszöw, Poland

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Anisotropic attenuation of acoustic waves in nematic liquid crystals

by H. HERBA and A. DRZYMAŁA
Institute of Mathematics and Physics, I. Łukasiewicz Technical University, Rzeszów, Poland

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Velocity and attenuation measurements for the 5 MHz ultrasonic wave were carried out in two nematic liquid crystals with a uniform orientation created by a magnetic field. Calculations show agreement of the results with those for the viscosity coefficients measured with non-acoustic methods.

1. Introduction

The theoretical basis for the rheology of nematic liquid crystals, treated as incompressible liquids, was formulated by Ericksen and Leslie [1–3] as well as by Parodi [4]. The flow of a nematic compound without assuming its incompressibility has been considered by Foster *et al.* [5] and by Huang [6]. Foster *et al.* also introduced a relation decribing the behaviour of the sound wave attenuation coefficient as a function of the angle 8 between the direction of sound wave propagation and that of the nematic director, when the effect of heat conduction is negligible.

The relation may be presented as

$$\alpha(\theta) = \frac{\omega^2}{2\rho c^3}\{((2\nu_1 + \nu_2 - \nu_4 + 2\nu_5) - (2(\nu_1 - \nu_4 + \nu_5)\sin^2\theta - \tfrac{1}{2}(\nu_1 + \nu_2 - 2\nu_3)\sin^2 2\theta\}, \qquad (1)$$

where ν_i $(i = 1, \ldots, 5)$ is a viscosity coefficient, ω is the frequency of the acoustic wave, ρ is the density of the nematic, and c is the wave velocity. The coefficients of the angular terms can be written as

$$\left.\begin{aligned} A &= \frac{\omega^2}{2\rho c^3}(2\nu_1 + \nu_2 - \nu_4 + 2\nu_5), \\ B &= \frac{\omega^2}{2\rho c^3}(2(\nu_1 - \nu_4 + \nu_5)), \\ C &= \frac{\omega^2}{2\rho c^3}\frac{1}{2}(\nu_1 + \nu_2 - 2\nu_3); \end{aligned}\right\} \qquad (2)$$

it is easy to see that:

$$\alpha(0) = A, \qquad \alpha(\Pi/2) = A - B, \qquad \Delta\alpha = \alpha(0) - \alpha(\Pi/2) = B. \qquad (3)$$

The anisotropy of the velocity is not predicted by Foster's theory. The occurrence of this phenomenon at high frequencies may be due to the fact, that the response of the compound to compression takes the same time. If the time of the applied stress is short in comparison with this response time, the compressibility may be anisotropic.

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2. Experimental

An ultrasonic set making it possible to measure the attenuation and the ultrasonic wave velocity in liquid crystals was used. The orientation of the director may be obtained by using a magnetic field. Using a water ultrathermostat, a temperature stabilization not worse than 0·1°C was obtained. The attenuation and the ultrasonic wave velocity measurements were carried out using a 0·7 T magnetic field. Measurements were carried out for the two nematic liquid crystals: 4-*n*-pentyl-4′-cyanobiphenyl (5CB) and 4-*n*-methoxybenzoate 4-*n*-pentylphenyl (MBPP). The transition temperatures of these liquid crystals are given in the table.

The transition temperatures of the liquid crystals studied.

Liquid crystal		T_{CN}/°C	T_{NI}/°C
4-*n*-pentyl-4′-cyanobiphenyl (5CB)	Microscopic observation on cooling	18·9	33·9
	DSC heating	–	35·0
4-*n*-methoxybenzoate-4′-*n*-pentylphenyl (MBPP)	Microscopic observation on cooling	25·1	40·4
	DSC heating	–	41·3

3. Results

Measurements of the attenuation and the velocity of the ultrasonic wave at 5 MHz as a function of temperature and the angle between the direction of the wave propagation and the director were carried out. Measuring results $\alpha(\theta)$ for CB and MBPP were typical for nematics [7–11]. The ultrasonic wave velocity was measured using the pulse–phase method. The results of the velocity measurements are shown in figure 1. The anisotropy of the velocity $\Delta V/V$ is smaller than 10^{-4}.

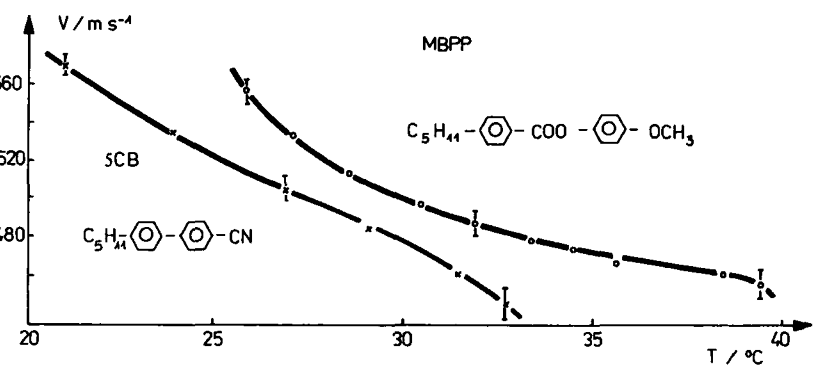

Figure 1. The sound velocity as a function of temperature for 5CB (x) and MBPP (o).

Equation (1) was fitted to the results obtained at a given temperature by the least squares method thus determining the values of A, B and C, cf. equation (2)). The determined values of A and B have a simple physical meaning. The value A then corresponds to the value of the ultrasonic attenuation for the angle $\theta = 0°$, and the values $A - B$ corresponds to that for the angle $\theta = 90°$. The ratio B/A determines the relative anisotropy of the attenuation. The temperature dependences of A, $(A - B)$ and B/A are presented in figures 2 and 3.

Knowing the values of A and B, it is possible to calculate the bulk viscosity coefficients ν_4 and ν_5. However, it is essential to know the coefficients of shear viscosity

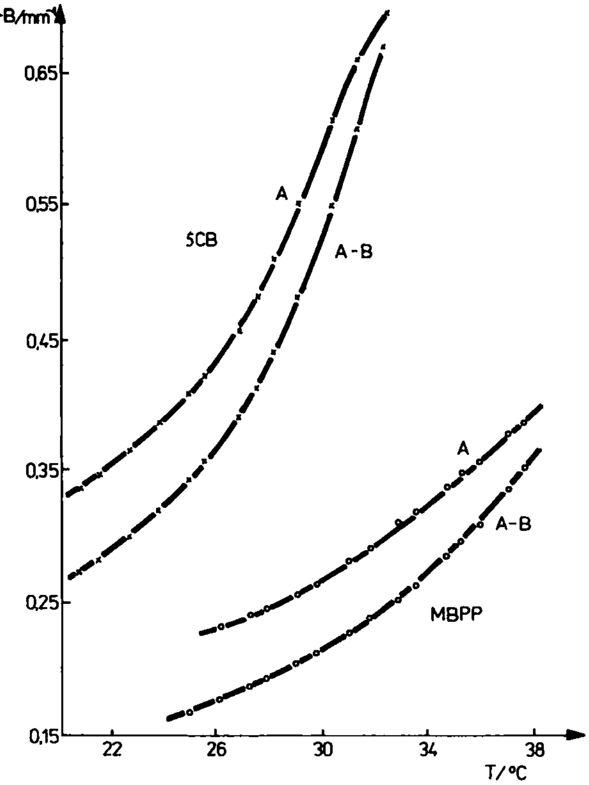

Figure 2. The temperature depencence of A and A–B for 5CB (x) and MBPP (O).

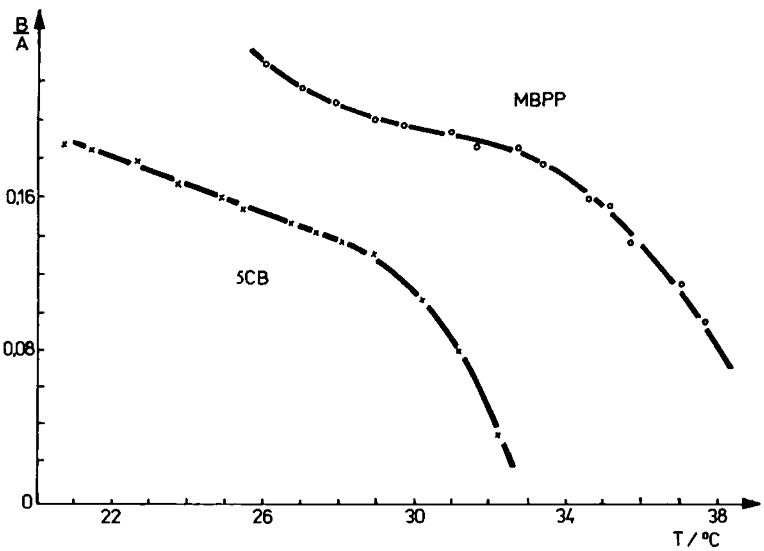

Figure 3. The temperature dependence of the B/A ratio for 5CB (x) and MBPP (O).

v_1, v_2, v_3 and to make an assumption that the effect of heat conduction on equation (1) is negligible. It is not possible to determine the effect of heat conduction for the nematics investigated since the amount of data is not sufficient. However, that is possible for nematic MBBA making use of the data taken from [12–15]. In this respect, at 30°C heat conduction for *A* and *B* constitutes respectively 0·32 per cent and 0·03 per cent of the shear viscosity effect. The values of ν_4 and ν_5 were calculated by assuming the viscosity coefficients for the liquid crystals investigated given in paper [16].

The dependence of the bulk viscosities on temperature are shown in figure 4. The value *C*, equation (2), depends only on the shear viscosity coefficients. Using the values given in [16], certain comparisons were made which are presented in figure 5; the points show the experimental errors as vertical lines.

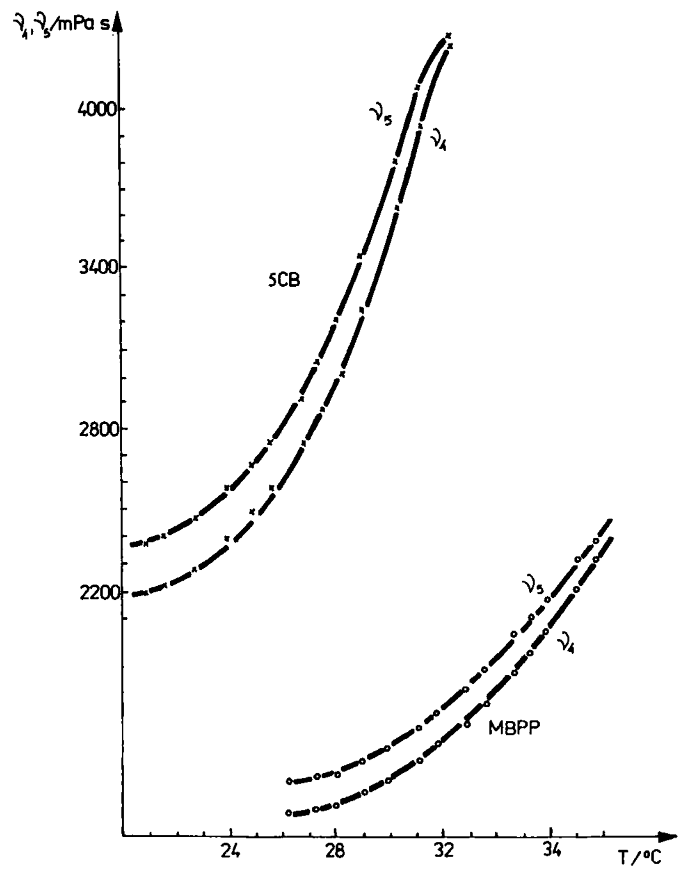

Figure 4. The temperature depencence of the bulk viscosities for 5CB (x) and MBPP (O).

4. Conclusion

The measurements show good agreement with Foster *et al.*'s hydrodynamic theory [5] and that of Huang with experiment. This is evident from the quality of the fit of the theoretical curves to the experimental data. For the liquid crystals investigated under our experimental conditions (5 MHz), the anisotropy of the ultrasonic wave attenuation coefficient is due mainly to the anisotropy of the bulk viscosities which are many times greater than the shear viscosity.

The determination of bulk viscosity values for 5CB, the material has the characteristics of a model nematic liquid crystal, may be important for the interpretation of other physical phenomena.

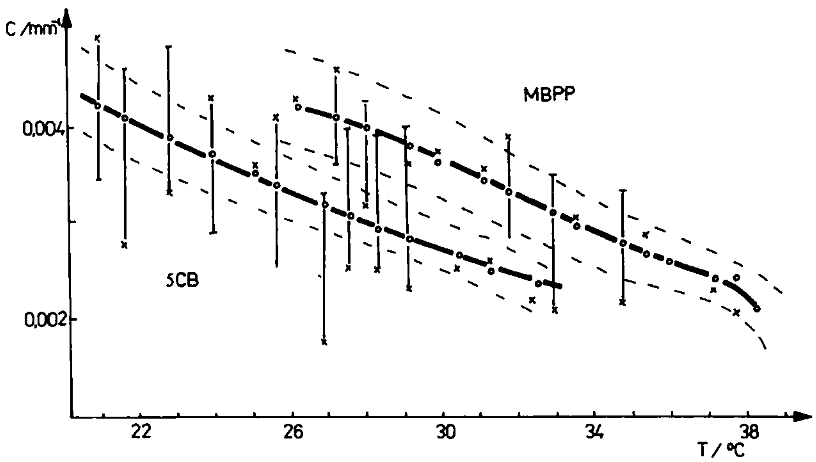

Figure 5. A comparison of the temperature dependences of C (O), and the value $\omega^2(\nu_1 + \nu_2 + 2\nu_3)/4\rho c^3$ (x), for 5CB and MBPP.

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