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TEMPERATURE DEPENDENCE OF MAGNETIC SUSCEPTIBILITY IN THREE NEMATIC LIQUID CRYSTALS

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Results are presented of an experimental study of temperature dependence of magnetic susceptibility in the isotropic state and mesophase of nematic liquid crystals by Gui's relative method.

The change in magnetic susceptibility of nematic liquid crystals in the mesophase with temperature is quite significant. This occurs because of changes in the ordering of molecules which have high anisotropy. The relationship between $\Delta\chi$ and molecular ordering permits determination of the degree of order [1], which is one of the most important characteristics of nematic liquid crystals [2], and is employed in a number of theories of the liquid crystal state. At the present time this quantity can be determined by various methods [3, 4]; however, the most reliable values of degree of order are considered to be those obtained by experimental measurement of anisotropy in magnetic susceptibility [4]. Using $\Delta\chi$ values and the Fredericks phenomenon, one can determine elastic constants, which are of great significance in the further development of continuum theory [4, 5].

In the present study χ was measured by Gui's relative method. Analysis of the results obtained with the apparatus and technique described in [6] revealed that the zero position of the balance beam, and thus, the distance between the coil and the suspension system magnet varies even for constant bridge unbalance. The cause of this is a change in the optical properties of the glass belljar covering the scales each time it is installed, together with time and temperature changes in the characteristics of the photosensors and illuminator. The relative error in determination of magnetic susceptibility thus reached 2%. The major contribution to this error comes from variation in the distance between coil and magnet for repeated measurements, while a contribution an order of magnitude smaller is produced by uncertainty in the position of the ampul between the electromagnet pole pieces.

To eliminate this shortcoming, a copper calibration weight was employed. By using special equipment it was possible to weigh this weight before each measurement without uncovering the scale. Then by choosing the zero position of the balance beam at the point where the current flowing through the coil is constant while the calibration weight is being weighed, we preserve the distance between coil and magnet, and the position of the ampul between the polepieces is unchanged. Since changes in ampul position between the polepieces have an insignificant effect on measurement accuracy, for convenience such changes may be neglected over the course of a single experiment (the error then does not exceed 0.1%, while the change in distance between coil and magnet may be considered, if in the computation formula instead of the current passing through the coil and the proportional force acting on the specimen, we take the ratio of this current force to the current force existing during weighing of the calibration weight. Evaluation of results from measurements performed with the calibration weight indicate that the maximum relative error in χ determination does not exceed 0.5% and is produced by the error in measurement of the force acting on the empty ampul (0.1%), on the ampul with specimen (0.1%), and by calibration error.

Degasified double distilled water was used as a reference substance. Its magnetic susceptibility at 20°C was taken equal to $0.720 \cdot 10^{-7}$ $cm^3 \cdot g^{-1}$. The temperature change of the water χ agreed with the results of [7].

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TABLE 1. Temperature Dependence of Magnetic Susceptibility and Anisotropy of Same for n-Amyl-cyandiphenyl

τ	$-\chi \cdot 10^6$, $cm^3 \cdot g^{-1}$	$\Delta\chi \cdot 10^7$, $cm^3 \cdot g^{-1}$	τ	$-\chi \cdot 10^6$, $cm^3 \cdot g^{-1}$	$\Delta\chi \cdot 10^7$, $cm^3 \cdot g^{-1}$
0	0,684		7,4	0,614	1,05
0,4	0,637	0,71	9,4	0,611	1,10
1,0	0,631	0,80	10,9	0,609	1,13
2,1	0,626	0,87	12,7	0,607	1,16
3,6	0,622	0,93	13,7	0,606	1,17
5,0	0,619	0,98	15,5	0,604	1,20
6,1	0,617	1,01	17,4	0,603	1,22

TABLE 2. Temperature Dependence of Magnetic Susceptibility and Anisotropy of Same for MBBA

τ	$-\chi \cdot 10^6$, $cm^3 \cdot g^{-1}$	$\Delta\chi \cdot 10^7$, $cm^3 \cdot g^{-1}$	τ	$-\chi \cdot 10^6$ $cm^3 \cdot g^{-1}$	$\Delta\chi \cdot 10^7$, $cm^3 \cdot g^{-1}$
0	0,646		10,0	0,575	1,07
0,6	0,599	0,71	13,2	0,572	1,11
0,9	0,596	0,75	17,3	0,567	1,19
1,9	0,592	0,81	21,0	0,564	1,23
5,0	0,583	0,95	23,5	0,562	1,26
7,2	0,579	1,01	27,0	0,561	1,28

TABLE 3. Temperature Dependence of Magnetic Susceptibility and Anisotropy of Same for EBBA

τ	$-\chi \cdot 10^6$, $cm^3 \cdot g^{-1}$	$\Delta\chi \cdot 10^7$ $cm^3 \cdot g^{-1}$	τ	$-\chi \cdot 10^6$, $cm^3 \cdot g^{-1}$	$\Delta\chi \cdot 10^7$, $cm^3 \cdot g^{-1}$
0	0,640		15,5	0,567	1,10
0,1	0,595	0,68	20,4	0,564	1,14
0,7	0,589	0,77	27,7	0,560	1,20
1,6	0,585	0,83	35,5	0,557	1,25
2,8	0,582	0,87	39,6	0,555	1,28
3,9	0,580	0,90	42,9	0,554	1,29
6,1	0,576	0,96	48 6	0,552	1,32
8,3	0,573	1,01	55,3	0,550	1,35
11,3	0,571	1,04	61,0	0,548	1,38

To calculate the magnetic susceptibility of water density data from [8] were used. Results of χ studies of butyl alcohol, benzol, and special purity acetone at 20°C agreed within 0.2% with the results of [9-11].

The thermostat apparatus described previously in [6] was replaced by a glass double-walled bath, through which the heat exchange liquid was pumped. Temperature was measured to an accuracy of 0.05°. The transparency of the temperature stabilization equipment permitted visual observations during the experiments (to investigate the character of the nematic-isotropic transition and the correctness of the specimen suspension).

The ampul was filled with the material to be studied under vacuum. A special funnel was built for this purpose. The liquid crystal compound, which has a solid phase at room temperature, was poured into the funnel, and evacuated together with the ampul in an LR-402 drying cupboard. The degasified material then fused and flowed from the funnel into the ampul.

The materials with melting points below room temperature were inserted into the ampul in the mesophase. The ampul and specimen were heated to the temperature of transition of the liquid crystal into the isotropic state and evacuated.

The temperature dependence of magnetic susceptibility in the isotropic state and mesophase of three nematic liquid crystals was studied: n-amyl-cyandiphenyl, n-methoxybenzylidene-butalanalid (MBBA), and n-ethoxybenzylydene-butylaniline (EBBA). The following values were obtained for the nematic-isotropic transition temperature (T_t): 35.6, 41, 79.8°C. Experimental results obtained for χ and $\Delta\chi$ as functions of τ (where $\tau = T_t - T$) are presented in Tables 1-3. Anisotropy of the magnetic susceptibility was calculated with the formula

$$\Delta\chi = \frac{3}{2}(\chi_{\parallel} - \bar{\chi}),$$

where $\chi_{\parallel}$ is the magnetic susceptibility in the mesophase parallel to the field, and χ is the susceptibility in the isotropic state.

All materials studied were diamagnetic and their magnetic susceptibility in the isotropic state is practically temperature independent. The susceptibility is discontinuous upon the nematic-isotropic transition and decreases in absolute magnitude with further reduction in temperature. The anisotropy of the susceptibility is positive, and increases with reduction in temperature, due to an increased degree of molecular ordering.

Data are available on the magnetic susceptibility of MBBA in [12-14]. The results of our χ measurements agree with those of [13, 14]. The data presented in [12] are 4% higher than ours, although the agreement is good for $\Delta\chi$. Thus, the deviation in magnetic susceptibility is evidently due to systemic error introduced in the calibration procedure in [12].

The experimental results for magnetic susceptibility in the mesophase as a function of τ can also be represented analytically by expressions obtained empirically by the method of least squares with a computer:

$$\chi_{\parallel} = (-0.653 + 0.02137\tau^{0.300}) \cdot 10^{-6}\ \text{cm}^3 \cdot \text{g}^{-1}\ \text{(n-amyl-cyandiphenyl)},$$
$$\chi_{\parallel} = (-0.615 + 0.01910\tau^{0.320}) \cdot 10^{-6}\ \text{cm}^3 \cdot \text{g}^{-1}\ \text{(MBBA)},$$
$$\chi_{\parallel} = (-0.602 + 0.01428\tau^{0.324}) \cdot 10^{-6}\ \text{cm}^3 \cdot \text{g}^{-1}\ \text{(EBBA)}.$$

Values calculated from these expressions deviate from experiment by no more than 0.2%. Similar expressions can easily be obtained for the temperature dependence of anisotropy in the magnetic susceptibility, and for a known degree of monocrystalline anisotropy, for the degree of ordering.

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