NOTATION

x, current coordinate; ℓ, meniscus coordinate; $T(x)$, vapor–gas mixture temperature; P_0, total mixture pressure at channel mouth; P_{01}, partial vapor pressure at channel mouth; $P_2(x)$, partial gas pressure; $P(x)$, mixture pressure; $P_S(\ell)$, saturated vapor pressure above liquid meniscus; P_ℓ, vapor–gas mixture pressure above meniscus; ∇T, temperature gradient; μ_1, molecular mass of mixture; μ_2, molecular mass of gas; D, vapor diffusion coefficient in gas; ρ_1 and ρ_2, densities of vapor and gas; j_1 and j_2, density of vapor and gas fluxes; η, dynamic viscosity coefficient of vapor–gas mixture; L_0, molar heat of evaporation of liquid at temperature T_0; Kn, Knudsen number; r, capillary radius; $P_0 - P_{01}$, partial gas pressure at channel mouth.

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DETERMINATION OF THE THERMAL CONDUCTIVITY AND THERMAL DIFFUSIVITY OF SOLIDS BY UNILATERAL SOUNDING OF THE SURFACE

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The article analyzes the possibility of determining thermophysical characteristics by nondestructive unilateral sounding of a flat surface. Curves are presented for selecting the optimum regime of the experiments in dependence on the dimensions of the sounded body.

The application of methods of nondestructive inspection of the thermophysical properties of materials under real conditions is impossible without taking into account the geometric dimensions of the body and its heat exchange with the environment. We will examine the effect of these factors on the result of measurement with the so-called isothermal sondes which are used in building, geology, refrigeration engineering [1-3]. Figure 1 shows a variant of the sonde for determining thermal conductivity λ and thermal diffusivity a of isotropic materials in the range λ = 0.03-10 W/(m·°K). The copper core with a flat circular contact area is surrounded by an adiabatic shell with a heater. The system of automatic temperature control SART-1 ensures that the temperatures of the core and of the shell are equal to each other, thus preventing heat losses from the core to the environment. The device is enclosed in a metal housing which can be shifted along the tubular supports. Before the experiment the sonde was mounted above the surface of the investigated body, and the core was overheated by ϑ_1 = 10-15°K relative to the initial temperature of the material, and then the sonde was lowered onto the surface. The magnitude of the overheating was measured by a battery of differential thermocouples, and with the aid of the regulator SART-2 it was maintained at a constant level during the entire experiment. Thermal conductivity and thermal diffusivity can be determined from the time dependence of the integral thermal flux proceeding from the core to the material [3]:

$$q(\tau) = 4r_0\vartheta_1\left[\lambda(1-\mathrm{Bi}_1^{-1}) + 1.4r_0\frac{\lambda}{\sqrt{a}}(1-2\mathrm{Bi}_1^{-1})\frac{1}{\sqrt{\tau}}\right], \tag{1}$$

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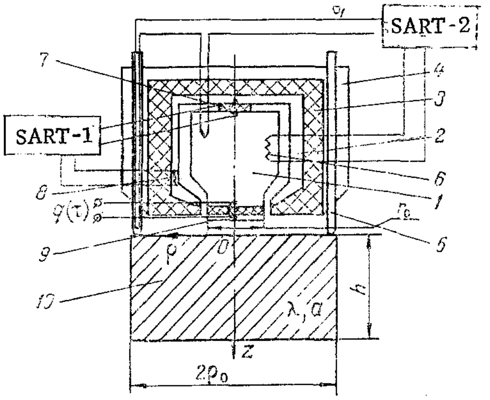

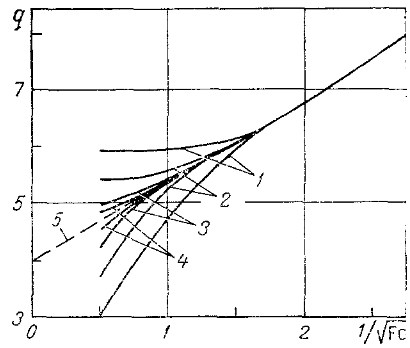

Fig. 1 Fig. 2

Fig. 1. Measuring sonde: 1) copper core; 2) adiabatic shell; 3) foam plastic insulation; 4) housing; 5) supports; 6) core heater; 7) semiconductor thermopile; 8) shell heater; 9) thermometer; 10) investigated material.

Fig. 2. Dependence of the thermal flux expressed in relative units and proceeding from the sonde into the investigated material on $1/\sqrt{\mathrm{Fo}}$ with the values $\mathrm{Bi}_1 = 100$, $\mathrm{Bi}_2 = 0$: 1) $h = 1$; 2) 1.5; 3) 2; 4) 2.5; 5) $h = \infty$.

which was obtained for the investigated body in the form of a half-space with a heat-insulated surface. The term $\mathrm{Bi}_1 = r_0/\lambda P_C$ in relation (1) is a correction not exceeding 0.1. Special traits of its being taken into account, and also methods of measuring $q(\tau)$ were dealt with in [2-4].

On account of the axial symmetry of the temperature field induced by the sonde, we examine a bounded cylinder with radius ρ_0 and height h (Fig. 1) to analyze the effect of the boundaries on the result of the measurement. We assume that the initial temperature field in the cylinder is uniform and we take it as the beginning of the reading; then we will seek the thermal flux from the sonde to the material from the solution of the boundary problem

$$\frac{\partial \vartheta}{\partial \mathrm{Fo}} - \frac{1}{\rho}\frac{\partial}{\partial \rho}\left(\rho \frac{\partial v}{\partial \rho}\right) - \frac{\partial^2 \vartheta}{\partial z^2} = 0 \tag{2}$$

with the zero initial condition

$$\vartheta(\rho, z, 0) = 0 \tag{3}$$

and the compound boundary condition on the contact surface

$$\left.\frac{\partial \vartheta}{\partial z}\right|_{z=0} = \begin{cases} \mathrm{Bi}_1(\vartheta_{z=0} - \vartheta_1), & \rho \leqslant 1, \\ \mathrm{Bi}_2(\vartheta_{z=0} - \vartheta_2), & 1 < \rho \leqslant \rho_0, \end{cases} \tag{4}$$

where $\mathrm{Fo} = (a\tau)/r_0^2$; $\mathrm{Bi}_2 = (r_0\alpha)/\lambda$.

Since the heat transfer coefficient on the surfaces $\rho = \rho_0$, $z = h$ is usually unknown, it is expedient to obtain the extreme estimates corresponding to the values of the heat transfer coefficient $\alpha = \infty$ and $\alpha = 0$:

$$\vartheta|_{z=h} = \vartheta|_{\rho=\rho_0} = 0 \tag{5}$$

or

$$\left.\frac{\partial \vartheta}{\partial z}\right|_{z=h} = \left.\frac{\partial \vartheta}{\partial \rho}\right|_{\rho=\rho_0} = 0. \tag{6}$$

By changing the dimensions of the cylinder, we can calculate at what values of ρ_0, h they begin to affect the dependence q(Fo), and thus we can determine the limits of application of the method of measurement. The analytical solution of the system (2)-(6) is difficult, it was therefore integrated by a numerical method of variable directions [5] on a nonuniform spatial network. The smallest spatial cells were chosen near the point with the coordinates $\rho = 1$, $z = 0$, where the local thermal flux attains its maximum.

The results of the calculation of the time dependence of $q(Fo^{-0.5})$ for the flux through the region of contact $0 \leq \rho \leq 1$, $z = 0$ are presented in Fig. 2. The curves show the value of h, where the value $h = \infty$ corresponds to the half-space. The curves lying above the line $h = \infty$ correspond to the boundary conditions of the first kind ($\vartheta = 0$) on all the surfaces of the cylinder with height h and radius ρ_0, except the side $z = 0$. Below are the curves corresponding to the second limit case, i.e., ideal heat insulation of these same boundary surfaces. For values $Bi_1 \geq 100$, the curves obtained as a result of numerical integration practically coincide with each other, except the range of values $Fo < 0.1$. Beginning at $Fo = 0.5$, the dependence of the flux q on $Fo^{-0.5}$ is close to linear with slope 1.4. The family of curves $q(Fo^{-0.5})$ can be used for determining the time of the experiment for bodies with specified dimensions. For instance, if we have to measure the thermophysical characteristics of a plate of thickness $\delta = 4 \cdot 10^{-3}$ m of glass with the approximate value $a = 4 \cdot 10^{-7}$ m²/sec by a sonde with $r_0 = 2 \cdot 10^{-3}$ m, we find from the curves that to the linear part of the dependence there corresponds the range of numbers $Fo = 0.5$-1.2. Consequently, the working time of the experiment has to be chosen within the limits $\tau = 5$-12 sec.

Heat exchange in the surface of the investigated body adjacent to the contact area leads to a change of the slope of the linear part of the curve $q(Fo^{-0.5})$ and to a change of the absolute magnitude of the thermal flux. A calculation carried out for $Bi_2 \leq 0.1$ shows that the relative deviation of the magnitude of the thermal flux from the values corresponding to ideal heat insulation of the surface, i.e., $Bi_2 = 0$, does not exceed 1.5-2%, and the sign of the deviation depends on the magnitude of ϑ_2. With $\vartheta_2 = 2.5$°K the relative deviation is minimal, and this has to be taken into account when the design of the sonde is chosen.

The data of the numerical calculation were compared with the results of an experiment for determining the thermal conductivity of organic glass on a device after [3] with specimens in the form of plates 1 to 25 mm thick. We used sondes with $r_0 = 1 \cdot 10^{-3}$ m and $r_0 = 3 \cdot 10^{-3}$ m. constancy of the overheating of the surface was ensured with an error of 1-2%. On the side of the plate opposite the contact face, boundary conditions of the first kind (the temperature was maintained equal to the initial temperature of the material) or of the second kind (the surface was heat insulated) were modeled. In dependence on this the sign of the deviation of the curves corresponded to that shown in Fig. 2. The difference between the absolute values of the thermal flux determined experimentally and the values obtained by numerical integration of the problem (2)-(6) amounted to 5-7%; this does not exceed the theoretical error of the method of measurement which is estimated at 10%.

The suggested method may also be used for determining the time of experiments with other types of boundary conditions in the region of contact of the sonde with the material. The form of relation (4) is thereby changed, and this entails the necessity of going again through the calculating procedure. However, with sondes producing an axisymmetric temperature field and usually operating with $Fo \geq 0.5$, the depth of penetration of the temperature field depends weakly on the kind of boundary conditions; this makes it possible to use the obtained curves $q(Fo^{-0.5})$ for engineering estimates of the effect of the final dimensions of a body on the result of measurements using such methods.

NOTATION

ϑ, temperature of the investigated material; ϑ_1, overheating temperature of the sounded part of the surface relative to the initial level; ϑ_2, temperature of the medium near the region of contact with the material; λ, thermal conductivity; a, thermal diffusivity; P_c, specific contact thermal resistance; α, heat-transfer coefficient; q, heat flux; ρ, z, τ, dimensionless coordinates and time; ρ_0, h, dimensionless radius and height of a cylindrical body, respectively; r_0, radius of contact of the measuring sonde with the material; Fo, Fourier number; Bi, Biot number; δ, thickness of the plate.

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EXPERIMENTAL DETERMINATION OF THE THERMODYNAMIC PROPERTIES OF THREE NEMATIC LIQUID CRYSTALS

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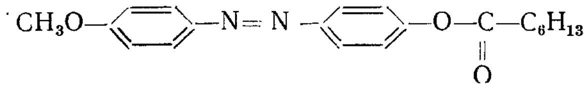
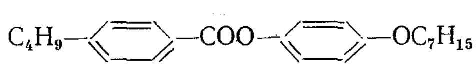
The results of measurements of the density, the magnetic susceptibility, the molar specific heat, and the heat of the nematic – isotropic transition are reported.

The efficient design of new types of liquid-crystal devices, the development of theoretical concepts about the liquid-crystalline state, and advances in the well-conceived synthesis of promising liquid-crystal materials may be attributed to the extent of knowledge of the most important physical properties of existing liquid crystals. Unfortunately, despite the heightened interest in liquid crystals both in the Soviet Union and abroad, experimental data on the physical properties of these objects are extremely sparse, and those which are available suffer from low accuracy and have been obtained from samples with varying degrees of purity. Consequently, the postulated models and the analytical relations derived theoretically on the basis thereof have not been adequately tested, so that their application for calculating the properties of liquid crystals is not yet justified. For example, it has been shown previously [1] within the framework of molecular-statistical theory [2] that the calculated values of the specific heats are in good agreement with the experimental, but large (four- to sixfold) discrepancies are observed for the heats of the nematic – isotropic transition. It is difficult to ascertain the causes of such a large discrepancy, because the data of different authors are used in the calculations and comparisons. Naturally, it is preferable to base the verification and substantiation of any particular model on results obtained from the same sample or from samples having the same degree of purity.

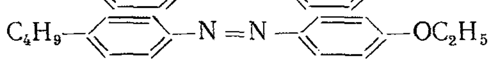
In the present article, therefore, we report an experimental study of the temperature dependences of the density, the magnetic susceptibility, and the molar specific heat, as well as the heat of the nematic – isotropic transition. We investigated the three analytically pure nematics N-62, N-72, and N-100, which were not subjected to additional purification. The structural formulas of these substances have he following form:



(N-62)



(N-72)



(N-100)

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