ACOUSTICAL MEASUREMENTS

APPARATUS FOR THE AUTOMATIC MEASUREMENT OF
LOW-FREQUENCY ACOUSTICAL PARAMETERS OF
ANISOTROPIC LIQUIDS

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A measurement and computing system designed for acoustical investigations of liquid crystals, magnetic fluids, etc., in the frequency range 0.15-1.2 MHz is described.

The measurement cell of the system (Fig. 1) comprises an acoustic cavity resonator similar to that described in [1]. It is formed by a pair of meniscus-shaped quartz piezoelectric transducers 1 of diameter 30 mm with outside and inside radii of curvature equal to 75 mm and 500 mm, respectively. The piezoelectric transducers are mounted in continuous slots in a ring 2 of nonmagnetic stainless steel, separated by a distance of 5 mm. The use of meniscus-shaped piezoelectric transducers significantly reduces the dissipation of acoustic energy in the resonator and, as a result, promotes a substantial increase in its $Q$ [1]. This makes it possible to measure acoustical parameters, beginning with a frequency of 0.15 MHz, in samples having a volume of 4 ml, which is an order of magnitude smaller than for a resonator with using conventional planar piezoelectric transducers. This fact is decisive in studies of anisotropic liquids, because it permits a sufficiently uniform, directional magnetic field to be obtained with a magnet of acceptable dimensions.

The acoustical parameters of the investigated samples are determined from equations given below and from measurements of the resonance frequency and $Q$ of the resonator as a four-terminal electrical network.

The ultrasound velocity is

$$ c = c_s f_k/f_{sk}, $$

where $c_s$ is the sound velocity in the standard liquid, and $f_k$ and $f_{sk}$ are the frequencies of the $k$th resonance in the investigated and standard liquids, respectively.

The ultrasound absorption coefficient is

$$ \alpha = \pi (1/Q_0^2 - 1/Q)/\lambda, $$

where $\lambda$ is the ultrasound wavelength in the investigated liquid, $Q_0$ is the intrinsic quality factor of the resonator, which characterizes the losses in it, and $Q$ is the quality factor of the resonator filled with the investigated liquid.

The anisotropy of the absorption coefficient is given by the expression

$$ \Delta \alpha = \alpha_p - \alpha_n = \pi (U_n/U_p - 1)/\lambda Q. $$

Here the index $n$ indicates mutually perpendicular orientation of the induction vector of the aligning magnetic field and the wave vector, the index $p$ characterizes their parallel orientation, and $U_n$ and $U_p$ are the corresponding resonator output voltages at a constant input voltage.

The anisotropy of the ultrasound velocity $\Delta c/c$ is determined from the phase--frequency response of the acoustic resonator at a fixed, near-resonance frequency:

$$ \Delta c/c = (c_p - c_n)/c_n = 0.5 (\tan \varphi_p - \tan \varphi_n) (1/Q_0^2 + \Delta \omega/\nu f), $$

where \( \varphi \) is the phase shift of the voltage between the input and output of the resonator. The second term in the last parentheses takes into account the error introduced by the anisotropy of the absorption coefficient; it does not exceed 5\% in practical situations.

In determining the \( Q \) of the resonator it is important to diminish the influence of side resonances on the measurement accuracy. The \( Q \) must therefore be measured for small frequency deviations from resonance, and the only way this can be done with acceptable accuracy is from the phase—frequency response of the resonator. In this case the \( Q \) is calculated from the equation

\[
Q = 0.5 f_2 (\tan \varphi_1 - \tan \varphi_2) / (f_2 - f_1),
\]

where the frequencies \( f_1 \) and \( f_2 \) are chosen so that the absolute value of the phase difference \( \varphi_1 - \varphi_2 \) will not exceed 0.1 rad.

In addition to the above-indicated sample parameters, the apparatus can also be used to measure the dependence of the ultrasound absorption coefficient and velocity on the angle \( \theta \) between the wave vector and the induction vector of the aligning magnetic field. The corresponding dependence is found as the difference between the instantaneous value of the parameter and its value when the indicated vectors are mutually perpendicular. The corresponding equations are obtained from Eqs. (3) and (4) by the trivial replacement of \( c \) and \( c_0 \), indexed for parallel vectors, with the respective functions \( c(\theta) \) and \( c_0(\theta) \). The angular dependences are measured with a 10\% discreteness in the apparatus.

A detailed analysis of the errors of measurement of the acoustical parameters calculated from Eqs. (1) and (2) gives error limits of the order of 0.1\% for the velocity and 2-5\% for the absorption coefficient. The main contribution to the error is from the calibration data on the sound velocity in the standard liquid and on the intrinsic \( Q \) of the acoustic resonator. The calibration of the measurement cell with standard liquids helps to minimize the errors associated with acoustic wave diffraction in a cavity resonator of such small dimensions and intricate shape.

For the anisotropic parameters calculated in our case according to Eqs. (3) and (4) it is more appropriate to use data on the resolution, which is no worse than 0.1\% of the reference value, i.e., of the sound velocity or absorption coefficient in normal orientation of the above-indicated vectors. The resolution is mainly limited by random measurement errors associated with noise in the electrical channels and the discreteness of the readings of the digital instruments used. It is important to note that only nonmagnetic materials are used in the metal parts of the thermostat and measurement cell, thereby eliminating errors associated with their deformation in the spatially alternating magnetic field.

Investigations of liquid crystals and especially their phase transitions, where the acoustical properties often change very abruptly, require the utmost possible temperature stabilization of the sample and, of course, appropriate resolution on the part of the temperature sensors. In the given apparatus the acoustic resonator with the sample is placed in a fast-acting, coaxial-duct thermostat with a high-sensitivity electronic control circuit similar to that described in [2, 3]. This arrangement is capable of maintaining the temperature of the sample within limits of one or two thousandths of a Kelvin around the nominal value for at least three hours, which is sufficient for the longest experiments conducted at a fixed temperature. The sample temperature is measured with a quartz sensor [4] placed in the immediate vicinity of the acoustic resonator, with which it has reliable thermal contact. The temperature—frequency converter is installed in a specially designed arrangement, which is described in detail in [5]. The quartz temperature sensor together with the converter ensures a resolution of 0.0005 K or less for hundreds of hours.

A block diagram of the apparatus is shown in Fig. 2. Here we explain the function of some of the instruments included in the apparatus. A permanent magnet with an induction of approximately 0.3 T is placed on a platform, which can be rotated by an electric