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Abstract

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M. S. PESIN and I. L. FABELINSKII

SPECTROSCOPIC STUDY OF THE PROPAGATION OF HYPERSONIC OSCILLATIONS IN VISCOUS LIQUIDS

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The study of absorption, dispersion, and the propagation velocity of ultrasound and hypersound in liquids from the standpoint of relaxation theory [(1)] has proved very fruitful. It has made it possible to take a rational approach to the choice of objects and methods of investigation and to explain the observed phenomena from both the qualitative and quantitative sides.

In fact, only in some low-viscosity and in a few viscous liquids have the absorption, propagation velocity, and velocity dispersion of sound in the ultrasonic and hypersonic frequency ranges been studied and their relaxation nature demonstrated.

From the standpoint of relaxation theory, of special interest is the study of liquids as they pass from the liquid into the glassy state in the hypersonic frequency region. However, such investigations are limited only to the work of the authors [(2)], which concerns the study of the velocity of hypersound in glycerin over a wide range of viscosities.

The present article gives the results of a spectroscopic study of the propagation velocity of hypersound in triacetin [$C_3H_5(OCOCH_3)_3$] during its transition from liquid to glass, and some new data for glycerin at a temperature of -70° and at temperatures corresponding to the region of the greatest change in the velocity of hypersound. Carrying out such investigations seems to us all the more important because in some works the possibility of observing the fine structure of the Rayleigh line is denied altogether (the possibility of propagation of hypersound at large macroscopic viscosities is denied) in very viscous liquids and glasses [(3)].

Table 1

Temp. t, °C	Viscosity η, poise *	Hypersound velocity V, m/sec	Ultrasound velocity v, m/sec	Temp. t, °C	Viscosity η, poise *	Hypersound velocity V, m/sec	Ultrasound velocity v, m/sec
+72	0.02	1246	1214	−15	4.68	2386	1538

Fig. 1

Figure 1: Fig. 1

Temp. t, °C	Viscosity η, poise *	Hypersound velocity V, m/sec	Ultrasound velocity v, m/sec	Temp. t, °C	Viscosity η, poise *	Hypersound velocity V, m/sec	Ultrasound velocity v, m/sec
+20	0.23	1616	1404	−40	$1.84 \cdot 10^3$	2536	1800
0	0.9	2065	1480	−60	$2.5 \cdot 10^6$	2718	2366

* The viscosity of triacetin at +72 and −60° was estimated by extrapolating the curve of viscosity versus temperature available in the literature [4,5] for the region from +20 to −45°.

In the interference setup used in this work and described in detail earlier [4], a Fabry–Perot etalon was used with a spacer-ring thickness of 3 mm and a camera-objective focal length of 270 mm. The 4358 Å line was used as the exciting light.

the spectrum of mercury in a low-pressure discharge. The error in determining the hypersound velocity was 6-8% of the measured value.

Over the entire interval of temperature variation from +72 to −60° for triacetin and from +150 to −70° for glycerin, and of the corresponding change in the static viscosity η from thousandths of a poise to the viscosity of the glassy state ($\eta > 10^7$ poise), a quite distinct fine structure of the Rayleigh line was observed.

The results of determining the hypersound velocity in triacetin from the positions of the Mandelstam-Brillouin components are given in Table 1 and in Fig. 1. The hypersound frequency is $\omega_{\text{h.s.}} = 4\pi n V \sin \frac{1}{2}\theta/\lambda$, where n is the refractive index, λ is the wavelength of light, and θ is the scattering angle. At a temperature of +20°, for triacetin $\omega_{\text{h.s.}} = 4.71 \cdot 10^{10}$ Hz, and for glycerin $\omega_{\text{h.s.}} = 8.7 \cdot 10^{10}$ Hz. In addition, Table 1 and Fig. 1 give the values of the ultrasound velocity measured by T. S. Velichkina[4] at a frequency of ~ 1 MHz.

Fig. 1. Dependence of the velocity of hypersound and ultrasound in triacetin on temperature: 1–measurements of the velocity in the hypersound frequency range; 2–measurements of the velocity of ultrasound according to the work[4]

On the ultrasound curve, the section on which the velocity could not be measured because of strong absorption is indicated by a dashed line.

Fig. 2 gives graphs of the dependence of $(V^2 - V_0^2)/(V_\infty^2 - V_0^2)$ (here V is the hypersound velocity; V_∞ and V_0 are the known limiting values of the velocity) on the logarithm of the relaxation time τ for triacetin. It was assumed that $\tau = B\eta/T$, where η is the viscosity and T is the absolute temperature.

Fig. 2

Figure 2: Fig. 2

Fig. 2. Dependence of $(V^2 - V_0^2)/(V_\infty^2 - V_0^2)$ on the logarithm of the relaxation time τ for triacetin in the hypersound (I) and ultrasound (II) ranges. 1 and 2 correspond to formula (1) of the relaxation theory, which takes into account one relaxation time

Table 2 gives the results of measurements of the hypersound velocity in pure glycerin (both the data already discussed[(2)] and new data); the data on ultrasonic measurements in glycerin are taken from [(6)].

The curves of the dependence of $(V^2 - V_0^2)/(V_\infty^2 - V_0^2)$ as a function of $\lg \tau$ for glycerin are analogous to the curves in Fig. 2 for triacetin and are not presented here.

In Fig. 2 the theoretical curves 1 and 2 are calculated from the formula of the relaxation theory with one relaxation time

$$\frac{V^2 - V_0^2}{V_\infty^2 - V_0^2} = \frac{\omega^2 \tau^2}{1 + \omega^2 \tau^2}. \tag{1}$$

As is clear from Fig. 2, the experimental curves agree with the conclusions of the relaxation theory only qualitatively.

A quantitative comparison with the relaxation theory, taking into account one relaxation time, leads to a clear discrepancy between the theory and the experimental data. Such a phenomenon has already been observed earlier for certain viscous liquids in the ultrasonic frequency range[(6)]. In this latter case,

Table 2

Temp. t, °C	Viscosity η, poise	Hypersound velocity V, m/s	Ultrasound velocity v, m/s	Temp. t, °C	Viscosity η, poise	Hypersound velocity V, m/s	Ultrasound velocity v, m/s
150	$5 \cdot 10^{-2}$	1580	–	22	9	2900	1900
50	1	1690	–	−27	10^4	3220	2910
45	1.8	2420*	–	−45	$2 \cdot 10^5$	3520	3300
35	32	2800*	1870	−70	10^8	3665*	3400

* New data.

attempts were made to describe the experimental data by an entire spectrum of relaxation times.

A qualitative comparison of the experimental and theoretical curves for hypersound and ultrasound shows that in the hypersound case the agreement of experiment with the theory mentioned is better than in the ultrasound case. It is possible that this means that at very high frequencies certain processes that are significant at low frequencies cease to play a role; however, these questions remain unresolved for the time being.

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Note: Figure translations are in progress. See original paper for figures.