STUDY OF THE HYPERACOUSTIC PROPERTIES OF LIQUIDS USING A HELIUM-NEON LASER

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Abstract

Full Text

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STUDY OF THE HYPERACOUSTIC PROPERTIES OF LIQUIDS USING A HELIUM-NEON LASER

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The use of a laser as a light source in studies of the spectrum of Rayleigh scattering makes it possible to increase substantially the accuracy of measurements of the propagation velocity of hypersound from data on the fine structure of the Rayleigh-scattering line and to determine the amplitude absorption coefficient of hypersound, α, calculated from the formula

$$\alpha_\Gamma = \frac{\pi c}{V_\Gamma} \delta\nu; \tag{1}$$

Here V_Γ is the propagation velocity of hypersound; c is the propagation velocity of light; $\delta\nu$ is the intrinsic half-width of the Mandelshtam-Brillouin component. Similar measurements were first carried out in works ([1,2]).

Fig. 1. Fine structure of Rayleigh light scattering in liquids.
1 –exciting light $\lambda = 6328$ Å; 2 –water; 3 –acetone; 4 –toluene; 5 –cyclohexane; 6 –acetic acid; 7 –water-methyl alcohol

We used a helium-neon laser with a power of 6–10 μW. The wavelength of the exciting light was $\lambda = 6328$ Å. The cuvette with the liquid under study was placed behind the laser resonator. A Fabry-Perot interferometer with resolving ...

intensity $\sim 2 \cdot 10^6$. The accuracy of determining the propagation velocity of hypersound was $\sim 0.5\%$, and that of the amplitude absorption coefficient of hypersound was $\sim 20\%$.*

The following were investigated: toluene, cyclohexane, acetic acid, acetone, water, and water-acetone and water-methyl alcohol solutions containing 0.15 and 0.045 mole fractions of acetone and methyl alcohol, respectively.

Figure 1 shows photographs of the fine structure of the Rayleigh scattering lines.

Table 1

Liquid	t, °C	$f_\Gamma \cdot 10^{-9}$, Hz	V_0, m/sec	V_Γ, m/sec	$\alpha' \cdot 10^{-3}$, cm^{-1}	$\frac{\alpha_0}{f_0^2} \cdot 10^{17}$, sec^2·cm^{-1}
Toluene	21.9	4.47	1315	1343	7.6	7.5
Cyclohexane	21.2	4.17	1280	1314	8.6	180
Acetic acid	21.0	3.58	1144	1175	4.3	138
Acetone	22.0	3.56	1180	1180	4.0	23
Water	21.4	4.38	1488	1476	–	–
Water-acetone, 0.15 mole fraction	21.0	4.74	1572	1573	3.8	100
Water-methyl alcohol, 0.45 mole fraction	21.3	4.50	1525	1519	–	–

(continued)

Liquid	$\frac{\alpha'_\Gamma}{f_\Gamma^2} \cdot 10^{17}$, sec^2·cm^{-1}	$\tau \cdot 10^{10}$, sec	$\frac{\Delta V}{V} \cdot 100$, calc.	$\frac{\Delta V}{V} \cdot 100$, exp.	$I_p/2I$, M.-B., calc.	$I_p/2I$, M.-B., exp.
Toluene	30	0.44	3.6	2.1	0.46	0.42

Liquid	$\frac{\alpha'_\Gamma}{f^2_\Gamma}\cdot 10^{17}$, sec$^2\cdot$cm^{-1}	$\tau\cdot 10^{10}$, sec	$\frac{\Delta V}{V}\cdot 100$, calc.	$\frac{\Delta V}{V}\cdot 100$, exp.	$I_\mathrm{p}/2I$, M.-B., calc.	$I_\mathrm{p}/2I$, M.-B., exp.
Cyclohexane	33	0.81	6.2	2.7	0.68	0.49
Acetic acid	16	1.20	3.1	2.7	0.35	0.18
Acetone	24	–	–	0	0.42	0.40
Water	–	–	–	–	0	0
Water-acetone, 0.15 mole fraction	17	–	–	0	1.06	0.85
Water-methyl alcohol, 0.45 mole fraction	–	–	–	–	–	–

The values of V_Γ and α_Γ obtained by us are given in Table 1. The table also gives the values of the ultrasound propagation velocity V_0, α'_0/f^2_0, and $\alpha'_\Gamma/f^2_\Gamma$, where $\alpha' = \alpha - \alpha_\mathrm{cl}$, α_cl is the amplitude coefficient of sound absorption due to shear viscosity. The frequency of the hypersound oscillations was determined from the formula

$$f_\Gamma = \frac{2v_\Gamma n}{\lambda}\sin\frac{\theta}{2},$$

where n is the refractive index of the liquid under study, λ is the wavelength of the Rayleigh line of light scattering, and θ is the observation angle; in our experiments $\theta = 90^\circ$.

If one assumes that the dispersion of the velocity and of the sound absorption can be described by a single relaxation time τ, then τ is determined by the relation

$$\tau^2\omega^2_\Gamma = \frac{\alpha'_0/f^2_0}{\alpha'_\Gamma/f^2_\Gamma} - 1, \qquad (2)$$

where $\omega_\Gamma = 2\pi f_\Gamma$. Then the expected dispersion of the sound velocity at the hypersound frequency can be found using the equation

$$\frac{(v_\Gamma - v_0)}{v_\Gamma} = \frac{\omega_\Gamma^2 \tau v_0}{4\pi^2} \frac{\alpha'_\Gamma}{f_\Gamma^2} = \tau v_0 \alpha'_\Gamma. \tag{3}$$

* Taking this opportunity, we express our sincere gratitude to V. S. Starunov for consultation during the assembly of the experimental setup.

The observed dispersion of the sound velocity (see Table 1) is smaller than that calculated by formula (3), especially for cyclohexane. Bazyulin[1], and also Lamb and Pinkerton[2], carried out careful measurements of the absorption and propagation velocity of ultrasound in acetic acid at various temperatures and frequencies. They discovered acoustic relaxation in the frequency range 0.5-67.5 MHz.

The dispersion of the ultrasonic velocity was about 1%. The results of measurements of the absorption coefficient[3] can be described by the formula

$$\alpha/f^2 = A/(1 + \omega^2\tau^2) + B;$$

here A characterizes low-frequency absorption of sound, and B, absorption in the high-frequency region. According to the data of Lamb and Pinkerton, α/f^2, with increasing frequency up to 10^8 Hz, decreased to $155 \cdot 10^{-17}$ sec^2/cm and, with further increase in frequency, remained constant, though much larger than α_{cl}/f^2, which indicates the existence of a second relaxation region at higher frequencies. It follows from our measurements that at frequencies $\sim 10^9$ Hz there is a further decrease of α/f^2 from $155 \cdot 10^{-17}$ to $33 \cdot 10^{-17}$ sec^2/cm and an increase of the sound velocity by $\sim 2.7\%$. This shows that the second region of sound dispersion in acetic acid lies in the frequency range $\sim 10^9$ Hz.

In work[4] there are also indications of dispersion of the sound velocity in acetic acid at hypersonic frequencies. But the data[5] on the half-widths of the Mandelstam-Brillouin components are overestimated. If α_{r}/f^2 is calculated from these data, a value greater than for ultrasonic frequencies is obtained, which is improbable.

According to[^7,^8], in toluene and cyclohexane at frequencies 10^9-10^{10} Hz the dispersion of the velocity and absorption of sound is due to vibrational relaxation. It follows from Table 1 that for water, acetone, aqueous solutions of acetone, and methyl alcohol the hypersonic velocity coincides with the ultrasonic velocity within experimental error, while in an acetone-water solution α'_{r}/f^2 in

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[1] P. A. Bazyulin, DAN, **3**, 285 (1936).

[2] J. Lamb, J. M. M. Pinkerton, Proc. Roy. Soc., **199**, 114 (1949).

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[4] R. Y. Chiao, B. P. Stoicheff, JOSA, **54**, No. 10 (1964).

[5] R. Y. Chiao, B. P. Stoicheff, JOSA, **54**, No. 10 (1964).

the hypersonic-frequency region decreases by more than a factor of 5. It is possible that this phenomenon is associated with the presence in acetone-water solutions of strongly developed concentration fluctuations and their relaxation.

For all the liquids we investigated, the ratio of the integral intensity of the central component to the sum of the integral intensities of the Mandelstam-Brillouin components, $I_{\mathrm{c}}/2I_{\mathrm{M.-B.}}$, was found. The obtained values were compared (see Table 1) with those calculated by the Landau-Placzek formula

$$I_{\mathrm{c}}/2I_{\mathrm{M.-B.}} = \beta_s/\beta_t - 1. \tag{4}$$

The comparison shows that for liquids where α'_{r}/f^2 is close to α'_0/f^2, the agreement of the experimental results with the results calculated by formula (4) is satisfactory; where $\alpha'_0/f^2 \gg \alpha'_{\mathrm{r}}/f^2$, the measured ratio $I_{\mathrm{c}}/2I_{\mathrm{M.-B.}}$ proves to be higher than the calculated one.

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REFERENCES

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