STIMULATED AND THERMAL MANDEL'SHTAM-BRILLOUIN SCATTERING AND DISPERSION OF SOUND VELOCITY IN SOLUTIONS

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Submitted 26 June 1967
ZhETF Pis'ma 6, No. 6, 677-681 (15 September 1967)

Burton's measurements [1] of the velocity and absorption of ultrasound in aqueous solutions of tertiary butyl alcohol have shown that the measured quantities have pronounced maxima at concentrations 0.045 and 0.011 molar fractions (m.f.) of alcohol, respectively. The quantity α/f^2 (α - amplitude absorption coefficient, f - frequency corresponding to the maximum of the absorption curve) amounts to 38.5×10^{-15} $\sec^2 \mathrm{cm}^{-1}$ (see dashed curve of Fig. 2). This value exceeds by two orders of magnitude the value calculated for this concentration from the hydrodynamic formula with allowance for shear viscosity only.

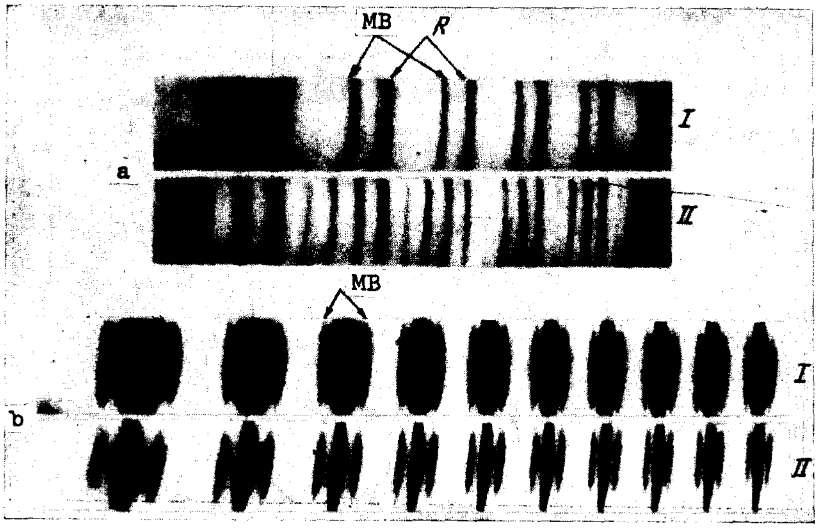

Fig. 1. a - Stimulated Mandel'shtam-Brillouin (MB) scattering in aqueous solution of tertiary butyl alcohol with concentration 0.045 m.f. (I) and in tertiary butyl alcohol (II), R - ruby line; b - thermal MB scattering in aqueous solutions of tertiary butyl alcohol with concentrations 0.11 (I) and 0.3 m.f. (II).

Note. The intense spectral component may be due not only to scattering by density fluctuations, but to parasitic scattering, since we have confined ourselves only to careful filtering of the solutions.

If the large value of α/f^2 in solutions is determined by the large value of the volume viscosity, then it is possible to attempt to estimate the dispersion of the sound velocity on the basis of the Mandel'shtam-Leontovich phenomenological theory [2] developed for the relaxation of volume viscosity. The value of the dispersion is [3]

$$\frac{\Delta v}{v} = \frac{v}{4\pi^2\tau}\,\frac{a_\eta}{f^2}\left(\frac{a}{a_\eta} - 1\right) \simeq \frac{v}{4\pi^2\tau}\,\frac{a}{f^2}, \tag{1}$$

where $v = (1/2)(v_\infty + v_0)$, α_η is the absorption coefficient due to the shear viscosity, and τ is the relaxation time. Burton [1] observed no dispersion of the sound velocity at frequencies 5 - 25 MHz, meaning that $\tau < 1/2\pi f_{\max} \approx 6 \times 10^{-9}$ sec, and we are justified in expecting a sound-velocity dispersion $\Delta v/v > 2.5\%$.

We measured the ultrasound velocity at 2 MHz frequency using the setup described in [4].

The hypersound velocity was determined by measuring the stimulated and thermal Mandel'shtam-Brillouin scattering (SMBS and TMBS) using apparatus described in [5,6]. The SMBS spectra were obtained at a laser power ~20 MW. Typical TMBS and SMBS are shown in Figs. 1a and b.

The measurement results are shown in Table 1 and in Fig. 2. The sound-velocity dispersion was determined from the TMBS data. Its maximum value corresponds to the maximum of ultrasound absorption and is 7.0 ± 1.1%. From the point of view of the theory [2] this means that the investigated solutions are characterized by relaxation times $\sim 10^{-9}$ sec. The relaxation times calculated from the observed dispersion by means of formula (1) are listed in the Table.

Table 1

Ultrasound and hypersound velocities v_u and v_h in aqueous solutions of tertiary butyl alcohol at t = 21°C, and certain parameters calculated from them

Alc. conc. (m.f.)	$f_h^s \cdot 10^9$, Hz $\theta = 180°$	$f_h^t \cdot 10^9$, Hz $\theta = 90°$	v_h^s, m/sec	v_h^t, m/sec	v_u, m/sec	$\Delta v/v$, %	$\alpha/f^2 \cdot 10^{15}$** sec^2/m	$\tau \cdot 10^{10}$, sec	$f_c = 1/2\pi\tau \times 10^9$, Hz
0.000	5.61	4.42	1464 ±16	1488.5 ±1.3*	1488,5 ±1,5	–	0,25	–	–
0.045	6,33	5.06	1642 ±7	1686 ±20	1622 ±3	3,9 ±1,4	10.7	11	0.145
0.110	6.09	4.94	1559 ±10	1627 ±15	1518 ±2	7.0 ±1.1	38,5	22	0.072
0.300	5,33	4.24	1351 ±10	1383 ±13	1337 ±5	3.3 ±1,3	17.0	17	0.094
1.000	4,64	3.66	1164 ±6	1181 ±8	1150 ±2	2.7 ±0,9	5.8	6	0.265

Explanation of indices: s - stimulated, t - thermal, $v = \frac{1}{2}(v_u + v_h^t)$, θ - scattering angle.

* Tyganov's measurements [8].

** Burton's measurements [1].

The ultrasound velocity in the investigated solutions was measured also at 2.55 MHz at t = 27.5°C.* These measurements made it possible to determine the temperature coefficient of the ultrasound velocity $\Delta v_u/\Delta t$ in the investigated solutions, which is listed in Table 2.

Table 2

Alcohol concentration (molar fractions)	0	0.045	0.11	0.3	1.0
$\Delta v_u/\Delta t$, m-sec^{-1}-deg^{-1}	+1.2 (±1)	+3.8 (±0.7)	+0.15 (±0.5)	-0.7 (±1)	-5 (±0.5)

It follows from the data of Table 2 that between the concentrations 0.11 and 0.3 m.f. the solution has a near-zero or even zero temperature coefficient of the ultrasound velocity. Such media are of practical importance for acoustic light modulators.

Attention is called to the fact that the hypersound velocities obtained from the SMBS spectra are lower than those obtained from the TMBS spectra (Table 1). According to an earlier hypothesis this is connected with heating of the liquid in the volume where the SMBS is produced [7]. Since water and solutions up to 0.11 m.f. have a positive temperature coefficient of sound velocity (see Table 2), this mechanism apparently makes a small contribution here, and the effect itself is possibly due to another mechanism [9,10].

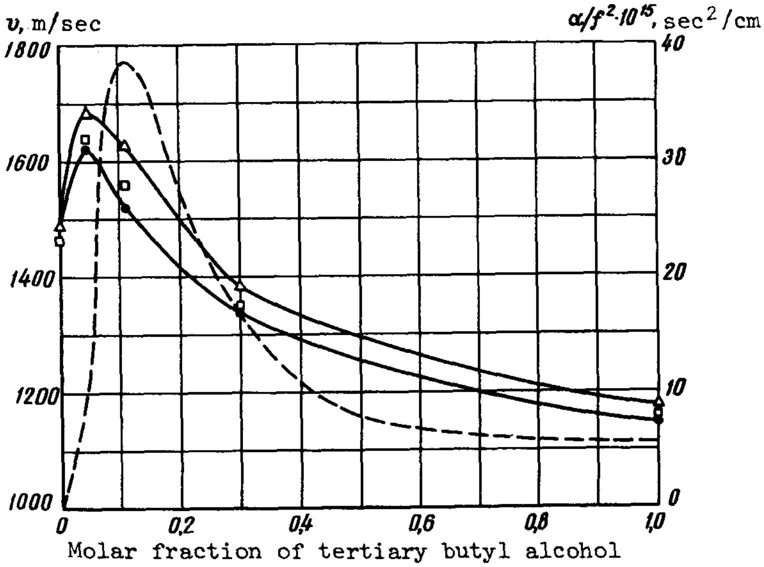

Fig. 2. Velocities of ultrasound (dark circles) and hypersound, measured from the stimulated (squares) and thermal (triangles) Mandel'shtam-Brillouin scattering in aqueous solutions of tertiary butyl alcohol at t = 21°C. Dashed curve - ultrasound absorption measured by Burton in the same solutions at t = 27°C.

It should be noted that the SMBS threshold in tertiary butyl alcohol is lower than the SMBS threshold of water and of solutions (see Fig. 1a).

The authors are grateful to G. I. Zaitsev, S. V. Krivokhizha, E. V. Tiganov, and I. Ya. Dikhter for help with the work.

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[*] These measurements were made by S. V. Krivokhizha.

PLASMA PRODUCED BY A BEAM FROM A NON-Q-SWITCHED LASER ACTING ON A MEDIUM

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Submitted 29 June 1967
ZhETF Pis'ma 6, No. 6, 681-682 (15 September 1967)

Almost all investigations in which a plasma was produced in a laser beam were made with Q-switched lasers which produced radiation of high intensity (upward of a megawatt). Lasers operating under ordinary conditions (with power 1 - 10 kW) were used only to evaporate, ignite, or break down substances, and the plasma produced in such cases was hardly ever investigated, with the exception of the skimpy data obtained with the aid of probes on thermoionic and thermoelectronic emission.

At the same time, plasma produced in this manner is of interest in view of the large energy radiated by non-Q-switched lasers (10 - 1000 J), making it possible to obtain larger amounts of plasma, and in view of the long generation time (on the order of a millisecond) of such lasers, which ensures a long time during which generation accompanied by existence of plasma takes place, and making possible the separation of the neutral particles from the ionic fraction of the plasma.

We have investigated, by microwave and diamagnetism-measurement techniques, the plasma ejected from a target acted upon by a focused beam of an ordinary laser without Q-switching. The investigations were made in the atmosphere and in vacuum, with and without magnetic fields.

The antenna of an 8-mm radio oscillator and a radio detector were placed opposite each other in front of a small target, on which was focused the beam from a ruby laser delivering 10 J in the free-generation regime; the focal distance of the lenses was f = 15 cm when the experiments were made in a vacuum chamber and f = 5 and 15 cm when the experiments were made in air.

In the case of the target in the atmosphere, the microwave overlap signal increased slowly, in a time on the order of fractions of a millisecond. Fig. 1a shows oscillograms of the overlap signal (upper trace) and the signal from a photomultiplier, registering the laser intensity (lower trace), at a sweep duration 900 μsec. Targets of four metals - titanium, copper, aluminum, and stainless steel - were tried. The strongest and longest overlap was obtained with titanium and aluminum targets. For a lens with f = 15 cm, the overlap was observed only for the titanium target. The geometric overlap cross section was close to the cross section of a body with 1 cm diameter (as checked by placing bodies of different diameters and modulating the microwave radiation). The fact that a plasma from a flare of thickness $\sim\lambda$ produced strong overlap of the microwave radiation indicated either that $\omega_p > \omega$ (when $\omega > \nu$) or $\omega_p \sim (\omega\nu/2\pi)^{1/2}$ (when $\nu > \omega$), i.e., $\omega_p > \omega_{cr}$, or else that the plasma concentration is $n_e > n_{cr} \approx 10^{13}$ cm^{-3}. The overlap oscillogram shows a slow growth in the