FINE STRUCTURE OF THE LINE OF THERMAL SCATTERING OF LIGHT, AND PROPAGATION OF LONGITUDINAL AND TRANSVERSE HYPERSOUND IN GLASSES

L. M. Sabirov, V. S. Starunov, and I. L. Fabelinskii
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 31 July 1968
ZhETF Pis. Red. 8, No. 8, 399 - 401 (20 October 1968)

We present in this letter the results of the first investigation of the fine structure of the line of molecular scattering of light (FSMS) in glasses excited by light having

different polarizations, with simultaneous observation of the FSMS spectrum in two mutually perpendicular polarization directions.

The fine structure of the Rayleigh-line wing (FSW), due to modulation of light scattered by anisotropy fluctuations and by transverse sound waves satisfying the Bragg condition, was recently observed in liquids [1]. This cause of the FSW was confirmed by our investigations [2-4] and by those of Stigman and Stoicheff [5]. Consequently, the FSW should be described by formulas of the theory of Leontovich [6] and Rytov [7] (see also [8])[1)]

$$I_{zx}(\omega) = I_{yz}(\omega) = \text{const}\left\{\frac{\omega^2\tau}{\omega^2+\tau^2(\omega^2-\Omega_T^2)^2}+\frac{\tau}{1+\omega^2\tau^2}\right\}, \quad (1)$$

$$I_{yx}(\omega) = \text{const}\left\{\frac{(\omega^2-\Omega_L^2)^2\tau}{(\omega^2-\Omega_L^2)^2+\omega^2\tau^2(\omega^2-\Omega_S^2)^2}+\frac{\tau}{1+\omega^2\tau^2}\right\}. \quad (2)$$

Here

$$\Omega_s = 2n\omega_0 V_s/c\sin\theta/2, \quad \Omega_T = 2n\omega_0 V_T/c\sin\theta/2,$$

$$\Omega_L^2 = \Omega_s^2 - 4/3\,\Omega_T^2, \quad V_s = \left(\frac{\lambda+4/3\mu}{\rho}\right)^{1/2}, \quad V_T = (\mu/\rho)^{1/2}$$

τ - anisotropy relaxation time, λ, μ, ρ - modulus of compression, shear modulus, and density, respectively, and θ - scattering angle.

It follows from (1) that the FSW in I_{zx} should be exactly the same as in I_{yz}, although I_{yz} differs from I_{yx}.

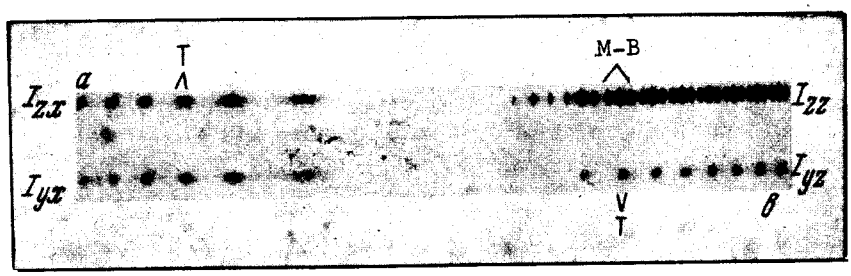

Fig. 1. Fine structure of Rayleigh line wing in quinoline (t = 20°C). T - components due to transverse sound oscillations; M-B - Mandel'shtam-Brilluoin components due to longitudinal sound oscillations. The Fabry-Perot interferometer dispersion region is 0.5 cm^{-1}.

Figures 1a and 1b show the I_{zx} and I_{yz} spectra in quinoline [2,4], demonstrating full qualitative and quantitative agreement between experiment and theory.

Interest attaches to the development of a "transverse" doublet in I_{zx} and I_{yz} with increasing viscosity of the liquid, up to the vitreous state.

In our experiment, no change in the position of the maxima of the doublet ($\Omega_T \sim$ const)

---

1) The scattering plane is xy. The exciting light propagates along the x axis. The scattered light is observed along the y axis. The first index of I_{ik} denotes the polarization direction of the exciting light, while the second index denotes the direction of the polarization of the scattered light.

was observed when the quinoline was cooled from 52° to 2°C, and in the experiments of Stigman and Stoicheff there was noted even a slight decrease of Ω_T in the same temperature interval.

If the Maxwellian viscosity scheme is applicable to this case (although this may not be the situation) and if $\Omega_T\tau > 1$, then μ remains practically constant, this being probably due to the constancy of Ω_T in the small investigated range of η.[1)]

It is clear (for example, from experiment), that when the viscosity is appreciably increased the scheme described above does not take place and μ increases strongly, but the FSMS picture remains similar to that observed in quinoline (Fig. 1) and in other liquids [1, 2, 3, 4], but Ω_T should be larger, and the components of the doublet and the central line should be narrow (τ should be large). Figure 2, on which I_{zx} and I_{yz} of fused quartz are shown, demonstrates this fact.

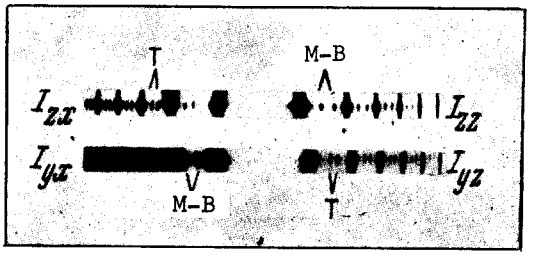

Fig. 2. Fine structure of molecular scattering of light in fused quartz (t = 20°C) at various polarizations of the exciting and scattered light (θ = 90°). Notation and interferometer dispersion are the same as in Fig. 1.

The table shows the the measured shifts of the components of the transverse ($I_{zx} = I_{yz}$) and longitudinal (I_{zz}) doublets for fused quartz and K-8 glass, as well as the elastic moduli calculated from them.

Measured displacements of the fine-structure components of molecular scattering of light in fused quartz and K-8 glass (θ = 90°)

	n	$\Delta\theta_s$, cm^{-1}	V_s, m/sec	$\Delta\theta_T$, cm^{-1}	V_T, m/sec	$\mu \cdot 10^{-11}$, dyne/cm^2	$\lambda \cdot 10^{-11}$, dyne/cm^2
Fused quartz	1,46	0,64	5900	0,41	3800	3,2	3,6
K-8 glass	1,51	0,68	6000	0,41	3600	3	4,3

Particular interest attaches to the I_{yx} spectrum (Fig. 2), which shows, besides a rather intense central line[2)], also Mandel'shtam-Brillouin components having the same displacements as the Mandel'shtam-Brillouin components in I_{zz}, and corresponding to $\omega = \pm\Omega_s$. Weak Mandel'shtam-Brillouin components were observed in I_{yx} in liquid quinoline by Stigman and Stoicheff [5]. The physical cause of the appearance of the Mandel'shtam-Brillouin components in I_{yx}

[1)] The results of [5] are apparently due to a complicated interplay of the "triplet" components (Eq. (1)), due to changes of τ.

[2)] In all spectra of Fig. 2 the central-line intensity depends strongly on the parasitic light scattered by static inhomogeneities.

lies in the fact that the longitudinal and transverse sound waves and the "anisotropy wave" are coupled; this fact is reflected in the Leontovich system of equations [6, 8], from which follow, in final analysis, formulas (1) and (2). The theory of scattering in a solid leads qualitatively to the same result and yields a quantitative expression for the intensities of the corresponding components [8].

Thus, the general picture of the occurrence of the "transverse" doublet has been clarified, but we are still left with the very difficult problem of studying the kinetics of this phenomenon when the viscosity is varied.

The authors thank V. P. Zaitsev and L. A. Zubkov for help with the experiment.

[1] V. S. Starunov, E. V. Tiganov, and I. L. Fabelinskii, ZhETF Pis. Red. 5, 317 (1967) [JETP Lett. 5, 260 (1967)].
[2] I. L. Fabelinskii and V. S. Starunov, Appl. Optics 6, 1793 (1967).
[3] V. S. Starunov, E. V. Tiganov, and I.L. Fabelinskii, Fine Structure of the Thermal Wing of the Rayleigh Line. Paper at III All-union Symposium on Nonlinear Optics, Erevan, 1967.
[4] E. V. Tiganov, Propagation of Longitudinal and Transverse Hypersound in Liquids, Dissertation, Phys. Inst. Acad. Sci., 1967.
[5] G. I. A. Stigman and B. P. Stoicheff, Light Scattering from Shear Waves in Liquids, Preprint, 1968.
[6] M. A. Leontovich, J. Phys. USSR 4, 499 (1941).
[7] S. M. Rytov, Zh. Eksp. Teor. Fiz. 33, 514 and 669 (1957) [Sov. Phys.-JETP 6, 401 and 513 (1958)].
[8] I. L. Fabelinskii, Molekulyarnoe rasseyanie sveta (Molecular Scattering of Light) Nauka, 1965 [Consultants Bureau, 1968].