carriers and agrees well with the theory (V. L. Gurevich, Hutson and White).

In cubic crystals of yttrium iron garnet, investigations were made of the magnon-phonon interactions. Natural magnetoelastic resonance was observed; it constitutes resonant interaction of hypersonic phonons with magnons in equivalent fields of magnetic crystallographic anisotropy.

Magnetoelastic resonance and the accompanying phenomena were investigated in external magnetic fields. With the aid of thin plates, measurements were made of the absorption of hypersonic phonons at resonance. An investigation was made of the acoustic Faraday effects and of birefringence under conditions of homogeneous internal magnetic fields, in the propagation of hypersonic waves in different directions. Direct experiments have shown that in the case of the Faraday effect the spin waves interact with circularly-polarized elastic waves with a corresponding direction of rotation.

The anharmonicity of the interatomic interaction forces in crystals leads to nonlinear effects in the propagation of elastic waves. One of the manifestations of such a nonlinearity is the generation of acoustic harmonics. The generation of the second acoustic harmonic was investigated with an example of lithium-niobate crystals in the propagation of longitudinal waves with fundamental frequency 500 MHz along a threefold axis.

The diffraction of laser radiation by hypersonic waves in crystals is briefly considered. This phenomenon can be used to measure the characteristics of the propagation of hypersonic phonons, and also for the investigation of certain physical properties of crystals (photoelastic constants, polarizability of electron shells, the character of the chemical bond). The contents of the lecture were published in part in the following papers:

1. V. V. Lemanov, G. A. Smolenskii, and A. B. Sherman, Fiz. Tverd. Tela 11, 653 (1969) [Sov. Phys.-Solid State 11, 524 (1969)].

2. A. V. Pavlenko, Yu. M. Yakovlev and V. V. Lemanov, ibid. 11, 3300 (1969) [11, 2672 (1970)].

3. V. V. Lemanov and A. V. Pavlenko, Zh. Eksp. Teor. Fiz. 57, 1528 (1969) [Sov. Phys.-JETP 30, 826 (1970)].

4. V. V. Lemanov, V. Ya. Avdonin, and A. V. Pavlenko, Fiz. Tverd. Tela 11, 3635 (1960) [Sov. Phys.-Solid State 11, 3051 (1970)].

S. A. Akhmanov, Nonlinear Optics of Picosecond Pulses.

1. One of the most important accomplishments of laser physics of the last two or three years is the development of solid-state lasers that generate trains of ultrashort pulses or individual pulses with duration down to 10^{-12} sec and a power density in the collimated beam up to 100 GW/cm^2.[1-3] In spite of the fact that the dynamics of the radiation of such lasers is not yet fully understood and there are a number of obscure spots in the procedure for the measurement of the parameters of short pulses, many laboratories in the U.S.S.R. and abroad use them in their experimental work. It is only possible to speak now with full justification of new physical results obtained with picosecond-pulse lasers. Mention should be made here primarily of the new results obtained in the case of strong action on matter,[4] and various investigations of nonstationary optical phenomena. A discussion of the last group of questions is the subject of the present lecture.

2. Linear nonstationary phenomena which occur when short electromagnetic pulses propagate were discussed already by Brillouin. This pertains to the so-called precursors and dispersion spreading of wave packets (see, for example, [5]). Laser technology has expanded the possibilities of observing linear nonstationary effects; successful experiments were performed on the compression of phase-modulated optical signals,[6] and the lifetimes of the excited states in the picosecond region have been measured. On the basis of the technique of picosecond pulses, it is possible to develop pulsed methods of measuring the resolving power of optical instruments. Recently, new results were obtained in this field, as well as in the theory; very compact formulation of problems of nonstationary phenomena in the propagation of amplitude- and phase-modulated packets in a linear medium is possible on the basis of the formalism of parabolic equations.

3. Numerous nonstationary problems arise in nonlinear optics of picosecond pulses. Besides the nonstationarities due to the propagation effects (these "wave" nonstationarities are determined, as a rule, by the linear dispersion properties of the medium, i.e., by the inertia of the linear response), a broad class of nonstationary phenomena occurs also as a result of the inertia of the mechanism that realizes the energy exchange between the waves, the inertia of the nonlinear polarization ("local" nonstationarity).

4. For processes of the type of harmonic generation and nonresonant parametric amplification, the nonstationarities usually have a wave character (the settling time of the electronic part of the nonlinear polarization is $\sim 10^{-15}$ sec). A very important circumstance, characteristic of nonstationary and nonlinear optical effects, is in general the strong mutual influence of the spatial and time modulation of the beam, which becomes clearly manifest in the generation of optical harmonics by picosecond pulses. This circumstance can serve as the basis for methods of modulating picosecond pulses.[7, 8]

5. The use of picosecond pulses in experiments on stimulated Raman scattering has made it possible to investigate the dynamics of transient processes in the excitation of vibrational and rotational levels. Under conditions when the motion of the level populations can be neglected and the ratio of the pump pulse duration τ_p to the transverse relaxation time T_2 is $\tau_p/T_2 \ll \Gamma_0 l$ (where Γ_0 is the static gain and l is the length of the interaction region), the line width $\Delta\nu_S$ of the Stokes components increases with increasing $\Gamma_0 l$ for $l < L_{gr} = \tau_p |1/u_p - 1/u_S|^{-1}$ ($u_{p,S}$—group velocities) due to impact excitation of molecular oscillations. The foregoing is illustrated by the diagram of Fig. 1, obtained in the excitation of SRS in benzene by the second harmonic of a neodymium laser operating in the mode-locking regime ($\tau_p \simeq 3\times 10^{-2}$ sec, $P_p \simeq$ 100 GW/cm^2). The rate of growth of $\Delta\nu_S$ can be determined from the nonstationary theory of scattering.[11-13] Measurements of the dependence of $\Delta\nu_S$ on l, carried out in a wide range (for both $l < L_{gr}$ and for $l > L_{gr}$) have enabled us to trace the nonmonotonic dependence of $\Delta\nu_S$ on l. When

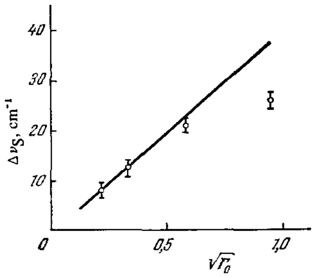

FIG. 1. Dependence of the width of the spectral line of the first Stokes component of SRS in benzene on the pump intensity in essentially nonstationary conditions. The straight line characterizes the theoretical line width in the case of pumping with a rectangular pulse.

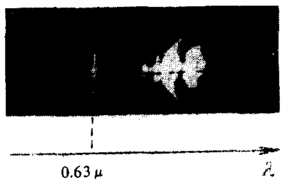

FIG. 2. Frequency-angle distribution of the SRS Stokes band connected with the O–H valence vibrations in water.

$l < L_{gr}$ we have $\Delta\nu_S \sim \ln(l)$; when $l > L_{gr}$ we have $\Delta\nu_S \sim l^{-1}$. In strong fields of picosecond pulses, a noticeable change in the populations of the vibrational levels is possible. This leads to the occurrence of an axial anti-Stokes radiation, to periodic amplitude modulation of the Stokes radiation and of the pumping. These effects were observed in carbon disulfide. At an intensity ~ 100 GW/cm^2, an important role may be played by the high-frequency Stark effect.[15] Owing to the corresponding change of the refractive index, it is possible to observe quasistatic self-focusing of picosecond pulses. Very interesting data on the dynamics of molecular oscillations can be obtained with the aid of biharmonic picosecond pumping; a convenient pair of frequencies is the neodymium-laser emission plus its second harmonic.

6. In the field of picosecond pulses, we succeeded in exciting effective SRS on infrared-active oscillations in water and other liquids (see [9, 14] and also [10]). In water there was excited in SRS a broad band corresponding to O–H oscillations. The frequency-angle structure of the spectrum is shown in Fig. 2. In the excited band one can see clearly the fine angle structure (arcs), the appearance of which, in our opinion, can be ascribed to coherent four-photon interactions of infrared photons ($\lambda \simeq 3\,\mu$) and Stokes photons ($\lambda \simeq 0.65\,\mu$), in accordance with the scheme

$$\omega'_C - \omega'_{IR} = \omega''_C + \omega''_{IR}.$$

The momentum-conservation conditions are satisfied as a result of the anomalous dispersion in the IR absorption band; the SRS of picosecond pulses in water and in aqueous solutions of salts is accompanied by anomalous broadening of the spectrum, which reaches 10^3 cm^{-1} (see [15]).

7. An important group of nonstationary problems is connected with the study of the excitation of SRS by broadband optical signals experiencing simultaneously phase and amplitude modulations. An analysis of the problem is contained in [12]. A very important circumstance is that if dispersion is neglected the intensity of a given spectral component of a Stokes wave excited by Gaussian pumping (for example, by a laser with non-synchronized modes) increases like $\exp(\alpha \bar{I}_p l)$ where $\bar{I}_p$ is the average pump intensity.

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Translated by J. G. Adashko