

flux density from a gasdynamic laser with a spot area of 100 cm^2 .

We note that in our experiments, the luminous energy drawn from the continuous beam to vaporize a unit mass of light kerosene was 10^4 J/g , which is much larger than the $700\text{--}100 \text{ J/g}$ of heat required to boil and vaporize kerosene. The difference can be explained by the dissipation of heat in raising the temperature of the remaining mass of liquid.

The pulsed beam with a pulse duration of $1 \mu\text{sec}$ did not allow time for the heat released to leave the absorption layer during the pulse ($\sqrt{kt} \ll l_a$), and the greater part of the energy went into vaporization. At a pulse energy of 1 J , a pulse duration $\sim 1 \mu\text{sec}$, and a 2-Hz repetition frequency in a partially focused beam with a spot 2 mm in diameter, we obtained vaporization of a layer of kerosene at $dM/dt \approx 0.05 \text{ g}$ in 30 min ; the energy consumed was 2400 J/g , or one-quarter of the amount used by the continuous beam.

The transition to short pulses, high powers, and more strongly absorbing pollutants could reduce the energy consumed in vaporization, not only by reducing the amount of energy used to heat the unvaporized liquid, but also due to ignition of combustible films. We note that pure surface absorption (with a heating depth of 10^{-5} cm) and flame combustion may occur at high power densities.

Burning of the films can be intensified by the addition of a small amount of a coloring agent or minute inhomogeneities that absorb the radiation and cause strong local overheating. This was observed experimentally on addition of various particles (corundum, sand, etc.) or dyes to the surface layer. Here the energy consumed to vaporize a unit mass of the layer was reduced to a fraction in an unfocused, unswitched beam.

A linear beam track on the surface of the liquid can be used to limit spreading and for boundary vaporization of the film along the confinement perimeter. Confinement by an extended beam track was studied. At a linear output of $\approx 20 \text{ W/cm}$ in the continuous laser beam and a track width of $\sim 1 \text{ cm}$, a sharp and stable boundary was drawn around the petroleum on the water surface. The confinement of spreading can be attributed not only to vaporization of the layer, but also to swelling, convective upwelling, and spreading of the heated water. These changes were easily observed visually on the water surface.

It is possible to clean up a layer of liquid by erupting or splashing it up off the water surface and then removing or collecting the spray. This kind of separation may involve vaporization of a thin layer of water under the layer of kerosene, which does not absorb as strongly as the water, and upward ejection of the kerosene by the steam. Eruption can also be accomplished by the vaporization pressure of the polluting layer itself. This method for separation of the liquids is economical, since it does not require vaporization of all of the liquid to be removed. Under the pulsed-laser beam we observed strong spattering of petroleum and kerosene to heights of $20\text{--}30 \text{ cm}$ above the surface of the water (to which it returned in a fraction of a second) and settling of the spray on the mirror, lens, and screen; the energy consumed per unit mass of erupted liquid was much smaller than the energy required for vaporization.

Beam cleaning of liquid surfaces can be used not only

as a measure against pollution of the natural water surfaces of seas, rivers, and lakes, but also in applied and experimental physics. For example, vaporization and burnoff of surface pollutants can be used for purification of liquids in the laboratory. Local pulsed vaporization or burnoff of the film (which then flows in to fill the hole) can be used for bleaching, Q-switching, reflection modulation, light transmission, and many other purposes.

In addition to infrared laser radiation, powerful microwave electromagnetic radiation in the millimeter and submillimeter bands, which is absorbed in a thin layer at the surface of the water, can also be used for vaporization and burning off of surface layers.

The authors thank Academician P. L. Kapitza, whose seminar paper drew the attention of physicists to problems of the struggle against global environmental pollution, and Prof. N. V. Karlov, who made possible the experimental part of this study.

¹G. A. Askar'yan, E. K. Karlova, R. P. Petrov, and V. B. Studenov, *ZhETF Pis. Red.* **18**, 665 (1973) [*JETP Lett.* **18**, 389 (1973)].

V. M. Agranovich, B. N. Mavrin, and Kh. E. Sterin. Effects of Strong Anharmonicity of Phonons and Their Damping in Polariton Raman Scattering. Polaritons are usually understood to be electromagnetic-field quanta in dielectric crystals. In the language of the microscopic theory, polaritons arise as new elementary excitations of the medium when the interaction (mixing) of excitons or Born phonons with transverse photons is taken into account. For the long-wavelength range, however, the polariton dispersion law $\omega = \omega(\mathbf{k})$ can be found within the framework of macroscopic electrodynamics if the dielectric tensor $\epsilon_{ij}(\omega, \mathbf{k})$ of the medium is assumed known in some approximation. But if instead the dispersion law and the field amplitudes in the polariton are known, the inverse problem can be solved, i.e., the tensor $\epsilon_{ij}(\omega, \mathbf{k})$ can be reconstructed (see^[1,2]). First-order Raman scattering of light (RSL) by polaritons in crystals without inversion centers (such crystals have a nonzero nonlinear polarizability tensor χ_{ijl} , which determines the intensity of the process), while enabling us at once to obtain the above information on the properties of the polaritons, can also be used to analyze effects of strong anharmonicity of the phonons, which results in some cases in the formation of states in which phonons are bound to one another (biphonons). For example, when a polariton branch crosses an energy band corresponding to the presence of two free optical (like or unlike) phonons in the crystal, the polariton spectrum is found to be highly sensitive to phonon anharmonicity. That is to say, if this anharmonicity is strong enough and the biphonon state is formed, a gap whose width is proportional to the phonon anharmonicity constant is formed in the polariton spectrum as a result of Fermi resonance even when damping is quite weak^[3,4]. The existence of this gap has now been observed experimentally^[5-7] (Fig. 1), an observation that is, in virtue of the above, an indirect proof of the formation of biphonon states in the cases studied in^[5-7].

Dissipation of electromagnetic-field energy in the crystal broadens the lines of RSL by polaritons. A theory of RSL by polaritons with consideration of damping was first developed in^[8], but in^[9] and later in^[10-12], a formula was obtained for the intensity of RSL by polaritons that is valid in a broader range of polariton fre-

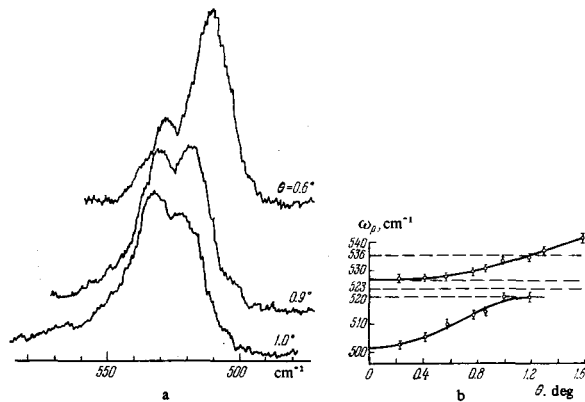


FIG. 1. a) Fermi-resonance doublets of class A_1 polariton with combination tone in LiNbO_3 crystal (scattering geometry $y(zz)y$; k_p in x, y plane; θ is the scattering angle inside the crystal; crystal temperature 100°K); b) polariton frequency ω_p plotted against θ in the Fermi resonance region (536 cm^{-1} —combination tone, 523 cm^{-1} —middle of gap; gap width $\approx 7\text{ cm}^{-1}$; for greater detail see [5]).

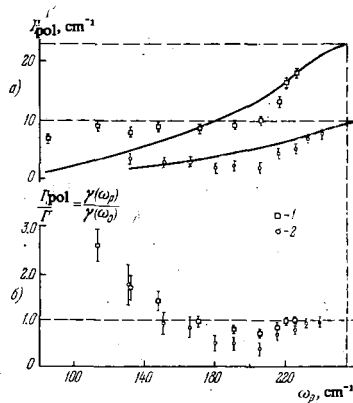


FIG. 2. a) Measured polariton line width Γ_{pol} as a function of frequency ω_p of class A_1 polariton in LiNbO_3 crystal (solid line— $\Gamma(\omega)$ at $\gamma(\omega_{\text{TO}}) = \text{const}$; the measurements were made by a special technique using a specially shaped diaphragm (to be published)); b) ratio $\gamma(\omega)/\gamma(\omega_{\text{TO}})$ as a function of the frequency ω in LiNbO_3 . 1) 290°K , $\omega_{\text{TO}} = 255\text{ cm}^{-1}$, $\gamma(\omega_{\text{TO}}) = 23.5^{-1}$; 2) 100°K , $\omega_{\text{TO}} = 260\text{ cm}^{-1}$, $\gamma(\omega_{\text{TO}}) = 10\text{ cm}^{-1}$.

quencies. If the dielectric constant of the crystal has the form

$$\epsilon(\omega) = \epsilon_\infty - \frac{(\epsilon_0 - \epsilon_\infty) \omega_{\text{TO}}^2}{\omega^2 - \omega_{\text{TO}}^2 + i\gamma(\omega)\omega},$$

in the conventional notation for the polariton-frequency range under study, then according to [9], the width of the line formed on RSL by a polariton with wave vector k and frequency ω is given by

$$\Gamma(\omega) = \frac{\gamma(\omega)(\epsilon_0 - \epsilon_\infty)\omega_{\text{TO}}^2\omega^2}{\epsilon_\infty(\omega_{\text{TO}}^2 - \omega^2)^2 + (\epsilon_0 - \epsilon_\infty)\omega_{\text{TO}}^2\omega^2}.$$

It follows from this equation that study of polariton RSL line widths enables us to reconstruct the $\gamma(\omega)$ dependence and, consequently, by using also the $\omega = \omega(k)$ dependence, to reconstruct completely the complex dielectric constant $\epsilon(\omega)$. Figure 2 presents results of such an investigation for a lithium niobate crystal at various temperatures. We note in the above connection that studies of $\gamma(\omega)$ with $\omega \ll \omega_{\text{TO}}$ for crystals with $\omega_{\text{TO}} \gg \omega_{\text{D}}$ (ω_{D} is the Debye frequency), where we might expect relationships of the type of Urbach's rule for $\gamma(\omega)$, would be of special interest.

We note in conclusion that the tensor $\chi_{ijl} = 0$ in centrally symmetrical crystals (CSC) and that the usual

method with RSL on polaritons cannot be used to reconstruct $\epsilon(\omega)$. However, the situation changes if we revert to RSL by surface polaritons under conditions such that the CSC under study is bounded along at least one of its interfaces by a medium that does not have an inversion center. Since the electromagnetic field in a surface polariton at distances on the order of its wavelength is nonzero on both sides of the interface and, consequently, also in the region in which $\chi_{ijl} \neq 0$, the intensity of RSL by the surface polariton is found to be significant and, as indicated by the calculations of [13], quite sufficient for experimental observations of the effect. This conclusion is also in agreement with the results of [14], in which RSL was observed experimentally for the first time on a surface polariton in a medium without an inversion center (GaAs; sapphire substrate). Naturally, the peaks corresponding to excitation of bulk polaritons were most strongly in evidence in the RSL spectrum of [14], and this interfered with observation of the effect. But in the "inverted" situation discussed in [13], in which the absence of an inversion center is guaranteed by the choice of substrate, no bulk polaritons of the CSC should be excited at all.

- ¹ V. M. Agranovich and V. L. Ginzburg, *Kristaloptika s uchetom prostranstvennoĭ dispersii i teoriya éksitonov* (Dispersion in Crystal Optics and the Theory of Excitons), Nauka, Moscow, 1965 [Wiley, 1968].
- ² V. M. Agranovich, *Teoriya éksitonov* (The Theory of Excitons), Nauka, 1968.
- ³ V. M. Agranovich and I. I. Lalov, *Fiz. Tverd. Tela* **13**, 1032 (1971) [*Sov. Phys.-Solid State* **13**, 859 (1971)]; *Zh. Eksp. Teor. Fiz.* **61**, 656 (1971) [*Sov. Phys.-JETP* **34**, 350 (1972)].
- ⁴ V. M. Agranovich, *Éffekty sil'nogo anharmonizma v spektrakh kombinatsionnogo rasseyaniya sveta* (Effects of Strong Anharmonicity in Raman Light Scattering Spectra), Supplement to the book by H. Poulet and J.-P. Mathieu, *Vibrational Spectra and Symmetry of Crystals* (Russ. Transl.), Mir, Moscow, 1973 [Engl. transl., Gordon and Breach, 1969].
- ⁵ B. N. Mavrin and Kh. E. Sterin, *ZhETF Pis. Red.* **16**, 265 (1972) [*JETP Lett.* **16**, 187 (1972)].
- ⁶ F. X. Winter and R. Claus, *Optics Comm.* **6**, 22 (1972).
- ⁷ V. F. Kitaeva, L. A. Kulevskii, Yu. N. Polivanov, and S. N. Poluéktov, *ZhETF Pis. Red.* **16**, 23 (1972) [*JETP Lett.* **16**, 15 (1972)].
- ⁸ H. J. Benson and D. L. Mills, *Phys. Rev.* **B1**, 4835 (1970).
- ⁹ V. M. Agranovich and V. L. Ginzberg, *Zh. Eksp. Teor. Fiz.* **61**, 1243 (1971) [*Sov. Phys.-JETP* **34**, 662 (1972)].
- ¹⁰ A. S. Barker and R. Loudon, *Rev. Mod. Phys.* **44**, 18 (1972).
- ¹¹ L. Laughman, L. W. Davis, and T. Nakamura, *Phys. Rev.* **B6**, 3322 (1972).
- ¹² V. I. Emel'yanov, Candidate's Dissertation (Moscow State University, 1973).
- ¹³ V. M. Agranovich, *ZhETF Pis. Red.* **19**, 28 (1974) [*JETP Lett.* **19**, 16 (1974)].
- ¹⁴ D. J. Evans, S. Ushioda, and J. D. McMullen, *Phys. Rev. Lett.* **31**, 369 (1973).

I. M. Khalatnikov. *Phase Transitions in He³*. Superfluidity is a characteristic property of quantum fluids consisting of Bose particles (for example, of He⁴ atoms). Quantum fluids consisting of Fermi particles (for exam-