LARGE-ANGLE SCATTERING OF RUBY LASER EMISSION

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The emission of a Q-switched laser was focused by a cylindrical lens into a cell with a liquid. After overcoming a certain clearly pronounced threshold, an intense light beam was excited in the medium, directly along the focal line of the lens perpendicular to the main beam.

The scattering was observed in benzene, acetone, toluene, nitrobenzene, and o-xylol with approximately equal threshold, on the order of $(5 - 6) \times 10^8$ W/cm^2 (in the focal region), and also in water at a somewhat larger threshold. The cross section of the initial beam at the focus was on the order of 0.1 x 1 cm. The polarization of the radiation was perpendicular to the focal line. The polarization remained the same after scattering. There was no resonator for the scattered radiation.

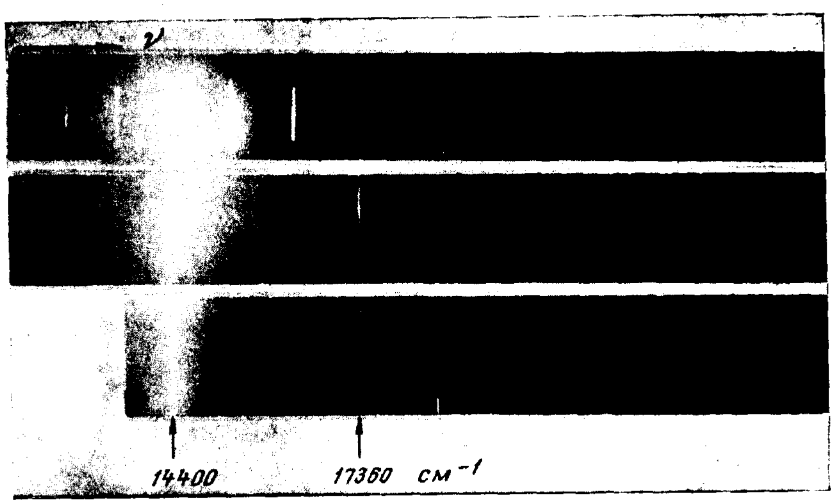

Fig. 1. Spectrograms of scattering: a - in benzene, b and c - in acetone. In the lower part are shown the mercury reference lines.

The scattering spectrum in benzene and acetone is shown in Fig. 1. It consists of several Stokes and anti-Stokes components, which are identified with Raman scattering lines 992 cm^{-1} for benzene and 2962 cm^{-1} for acetone. In addition, an unshifted component, 14 400 cm^{-1}, which is the most intense, is observed. The total intensity of the scattered radiation was not less than 10% of the initial value. The number of components increased with increasing intensity of the initial beam. A certain correlation was observed in their angular distributions. Unfortunately, it was impossible to perform exact measurements, owing to the large angular scattering patterns.

The distribution of the radiation of the unshifted component in the near and far bands in acetone are shown in Fig. 2. The angular scattering pattern is connected with the direction of the focal line (90° in Fig. 2), and is symmetrical with respect to this direction in the scattering plane. With increasing intensity, the pattern broadened, up to 15°. The fine structure observed in the angular distribution is apparently due to interference.

The spectral structure of the unshifted component of scattering was investigated with the aid of a Fabry-Perot interferometer (Fig. 3). For comparison, a beam of the main radiation, was was bounded in angle by a slit diaphragm to prevent its mixing with the scattered beam at the entrance of the interferometer, was directed to the interferometer after passing through the cell. The obtained interference patterns are angular distributions similar to those shown in Fig. 2, on which the interference rings of the interferometer are superimposed.

An analysis of the results has shown that in scattering through 90° there is no addi-

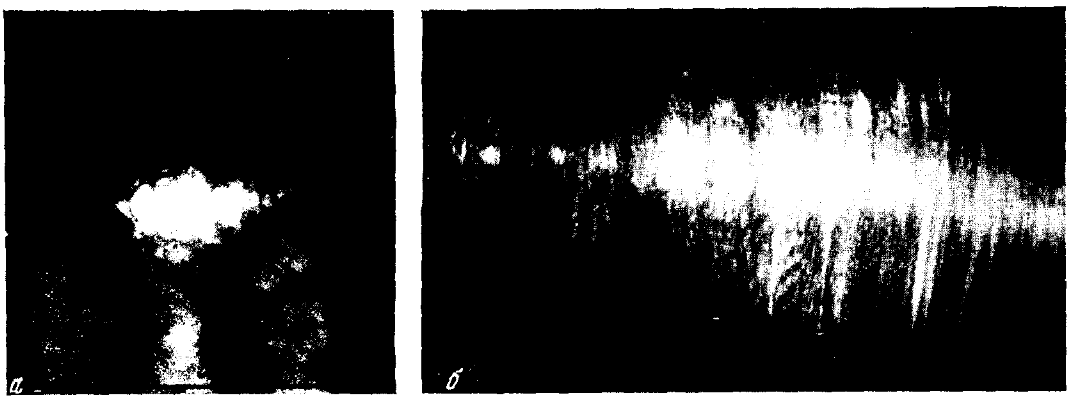

Fig. 2. Distribution of radiation scattered in acetone through 90°: a - near zone, b - far zone.

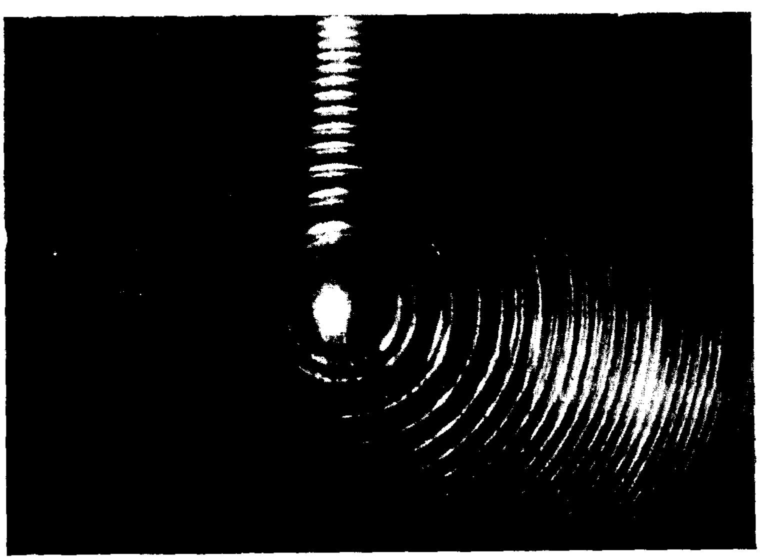

Fig. 3. Interference pattern of Fabry-Perot interferometer for the central scattering component. The vertical band in the center of the ring system corresponds to the spectrum of the main radiation passing through the cell.

tional frequency shift, within the limits of the line width. The frequency components observed in the scattering are 180° Mandel'shtam-Brillouin components, which are present in the spectrum of the main radiation passing through the cell. Similar results were obtained also in [1]. We have noted, however, that the main frequency of the generator, as a rule, is missing from the scattering or is less intense, even though its intensity is highest in the initial beam. This contradicts the thermal scattering mechanism. In addition, the scattering threshold observed by us is much lower than in [1].

We propose that the observed effect is due to four-photon parametric scattering. A degenerate case of such scattering, when two strong waves traveling in one direction interact with two weak waves having the same frequency and propagating at a certain angle, was already investigated theoretically [2] and experimentally [3]. The optimal angle in such an interaction is approximately 2°. However, if we consider two strong opposing waves, it turns out that when the intensity is sufficiently large the energy of these waves can effectively become transferred into two weak opposing waves of the same frequency, propagating at an arbitrary angle to the initial one. The wave-vector diagram of such an interaction can be represented by a closed equilateral quadrangle. The conditions for the space-time synchronism are satisfied here automatically at any point of the medium. In our experiment, such opposing waves are present, but not at the fundamental frequency of the generator, but at the frequencies of the Stokes components of the Mandel'shtam-Brillouin scattering. The waves scattered through 180° by the hypersonic wave pass through the generator and return to the interaction region. This can explain why the fundamental frequency of the generator is missing from the 90° scattering. The direction of the scattering is specified in this case by the form of the region of the maximum field. The accumulation of the interaction will be maximal along the focal line of the cylindrical lens.

A theoretical analysis of Maxwell's equations with allowance for the nonlinear terms responsible for this effect has shown that the system has a threshold which is determined from the expression

$$2\pi\omega\chi_3^{1111}|E|^2 \geq \alpha c,$$

and a critical interaction length

$$l = \frac{\pi c}{2(2\pi\omega\chi_3^{1111}|E|^2 - \alpha c)},$$

on which the amplitude of the stationary solution increases without limit independently of the value of the initial amplitude. Here E is the intensity of the strong field, χ_3^{1111} the real part of the component of the nonlinear susceptibility tensor [4], α the absorption amplitude coefficient, and ω the angular frequency. Under our conditions, the threshold density of the radiation flux is approximately 3×10^7 W/cm^2, and the length employed in the experiment becomes critical at a flux $\geq 5 \times 10^9$ W/cm^2.

We also considered theoretically the more general case of four-photon interaction, when the frequencies of the scattered waves are different and the initial two waves with frequency

ω propagate at an angle to each other. An analysis of the corresponding equation has shown that when the space-time synchronism conditions are satisfied ($\omega_1 + \omega_2 = 2\omega$; $\Sigma\vec{k}_i = 0$) the threshold scattering has the same order of magnitude as in the degenerate case. Apparently one can hope that such a mechanism of scattering can be used to produced parametric amplifiers and generators which can be tuned in a wide range. The dispersion present in real isotropic media makes it possible to satisfy the synchronism conditions in the tuning range from 0.1 ω to 1.9 ω. Particularly favorable cases for lowering the scattering threshold are those in which any one of the frequencies of the interacting waves or their pairwise sums and frequencies are close to the natural frequencies of the transitions in the medium.

[1] G. I. Zaitsev, Yu. I. Kyzylasov, V. S. Starunov, and I. L. Fabelinskii, ZhETF Pis. Red. 6, 802 (1967) [JETP Lett. 6, 255 (1967)].

[2] R. Y. Chiao, P. L. Kelley, and E. Garmire, Phys. Rev. Lett. 17, 1158 (1966).

[3] R. L. Carman, R. Y. Chiao, and P. L. Kelley, ibid. 17, 128 (1966).

[4] C. C. Wang, Phys. Rev. 152, 149 (1966).

STRONG-CURRENT PLASMA ACCELERATOR WITH CLOSED ELECTRON DRIFT

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Two types of injectors are in use in thermal nuclear research: pulsed plasma guns and ordinary ion sources. For a number of reasons, neither can be regarded as an appropriate source for a thermonuclear reactor. An "ideal" plasma injector would be a source with pulse duration from 10 μsec to 10 msec, capable of ensuring impurity-free ion currents on the order of 0.1 - 1 kA with particle energy in the 1 - 10 kV range. Such injectors can be produced by using the principle of the plasma accelerator with closed drift, described in a number of papers (see, for example, [1]). We developed and investigated a strong-current plasma accelerator, a diagram of which is shown in Fig. 1.

The physical process in the system reduces, in general outline, to the following. Owing to the presence of a radial magnetic field, it is possible to produce a distributed longitudinal electric field in a coaxial accelerating channel by creating a potential difference between the anode and the cathode. Under the influence of the crossed fields, the electrons drift in azimuth

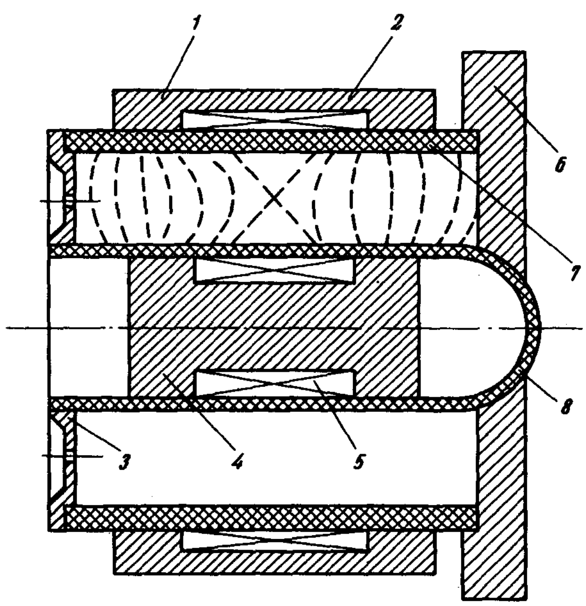

Fig. 1. Diagram of accelerator: 1 - external magnetic circuit, 2 - coil, 3 - anode, 4 - internal magnetic circuit, 5 - coil, 6 - cathode, 7 - external insulator, 8 - internal insulator.