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# DEVELOPMENT OF STIMULATED MANDEL'SHTAM-BRILLOUIN SCATTERING WITH TIME IN NITROGEN GAS AT 150 ATMOSPHERES

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The stimulated Mandel'shtam-Brillouin scattering (SMBS) previously observed in hydrogen, nitrogen, and oxygen at increased pressure [1] was produced in the focused beam of a ruby-laser giant pulse, and plasma production was observed at the same time. It is therefore important to ascertain in which time interval the SMBS arises and develops relative to the time of plasma occurrence.

On the other hand, up to four Stokes components and one anti-Stokes component of SMBS were observed in the earlier experiment [1]. If we attribute the appearance of these components to successive scattering [2] then, taking into account the conditions of the experiment in [1], the appearance of all the component would call for a long time. It is therefore necessary to explain the mechanism that produces these components.

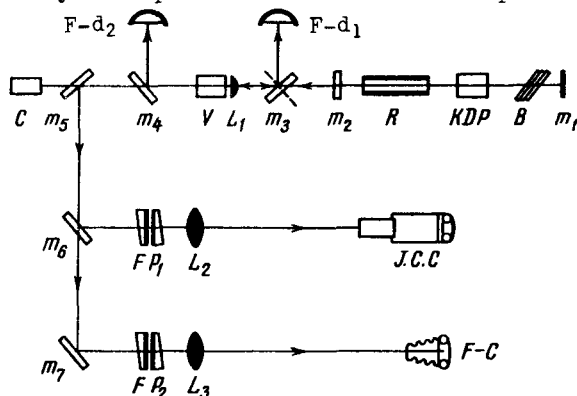


Fig. 1. Experimental setup:  $m_1$  - dielectric mirror ( $R = 100\%$ ); B - Brewster stack, KDP - Pockels cell (KDP crystal); R - ruby, 120 mm long, 12 mm dia.;  $m_2$  - dielectric mirror ( $R = 30\%$ );  $m_3$ ,  $m_4$  - plane-parallel glass plates; F-d<sub>1</sub>, F-d<sub>2</sub> - photodiodes; V - gas chamber; L<sub>1</sub> - lens ( $f = 3$  cm);  $m_5$ ,  $m_6$ ,  $m_7$  - silvered mirrors ( $R = 80, 50, 96\%$ , respectively); C - calorimeter, F-P<sub>1</sub>, F-P<sub>2</sub> - Fabry-Perot interferometers (dispersion region  $0.166 \text{ cm}^{-1}$ ); L<sub>2</sub>, L<sub>3</sub> - objectives ( $f = 80$  and  $70$  cm, respectively); J.C.C. - electron-optical converter; F-C - photo-camera.

We report in this letter an investigation of the evolution of the SMBS and the plasma in time. We used a high-speed time-scan method with an electron-optical converter, developed in [3]. The apparatus was of the same type as described in [4].

The experimental setup, which is shown in Fig. 1, has made it possible to record simultaneously, with the aid of photodiodes (FEK-09), the time variation of the integral intensity of the transmitted and back-scattered light, and to obtain with the aid of Fabry-Perot interferometers and an electro-optical converter (PIM-3) both the integral and the time-scanned spectrograms of the SMBS.

The over-all time resolution was 1.5 - 2 nsec and was determined by the time necessary to establish the interference pattern in the Fabry-Perot interferometer. The power of the giant

laser pulse used in the investigation was 40-50 MW at a duration  $\sim 20$  nsec. The light was focused with a lens of  $f = 3$  cm inside a gas chamber filled with nitrogen at 150 atm. Up to four Stokes components were observed in the SMBS spectrum.

Figure 2a shows by way of an example the recorded giant pulse of the transmitted light

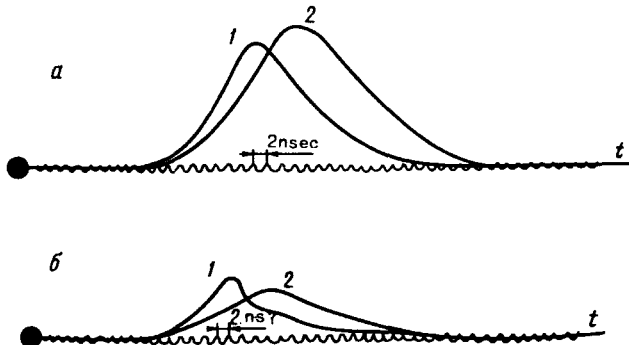
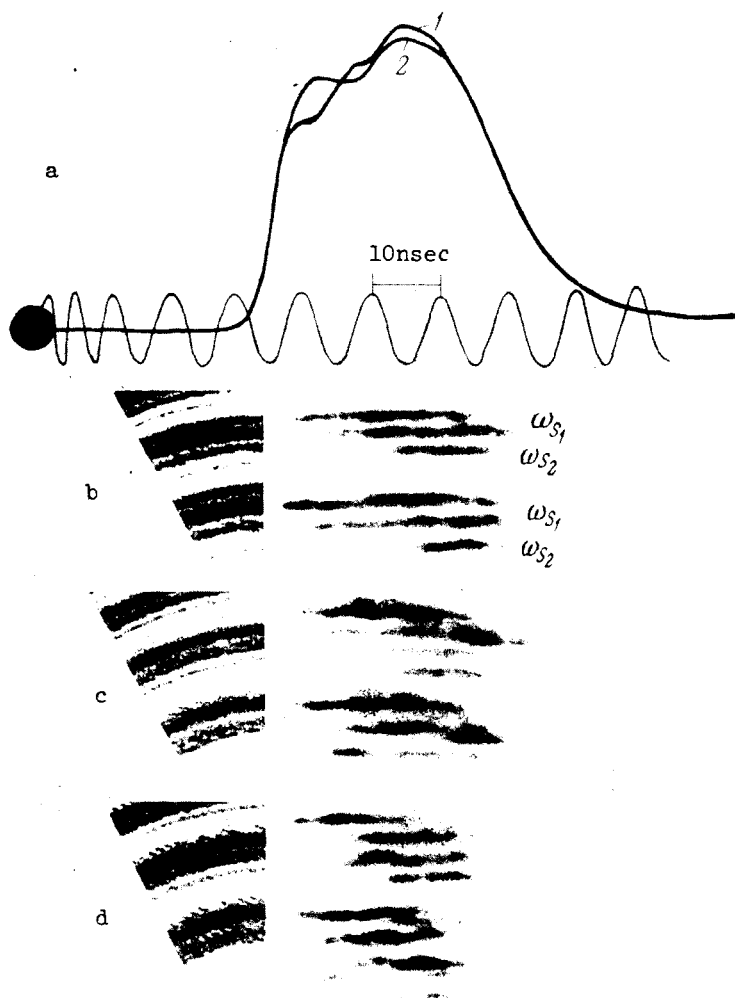


Fig. 2. Superimposed oscillograms of incident radiation and that passing through the gas chamber (explanation in text).



when neither plasma nor SMBS is produced (curve 1). Curve 1 of Fig. 2b corresponds to a pressure of 1 atm, at which there is no SMBS, only plasma.

Curve 2 of Fig. 2b corresponds to a pressure of 150 atm, when both SMBS and plasma are produced. The waveform of the exciting pulse (curve 1) was recorded here with the aid of F-d<sub>1</sub> (the plane-parallel plate m<sub>3</sub> occupied here the position designated by the dashed line in Fig. 1).

From a comparison of the curves of Fig. 2 it is seen that the interaction between the back-scattered radiation and the laser emission in the laser itself causes a change in the waveform of the laser pulse, which can lead in turn to a delay in the instant of plasma formation.\*

Calorimetric measurements have shown that the total energy of the transmitted light, when plasma is produced at 1 atm, is about 40% smaller than the energy of the transmitted light at 150 atm, when the SMBS precedes the plasma.

In successive scattering, the SMBS components appear after 7-8 nsec, which agrees with the geometrical dimensions of the setup, and the plasma appears

Fig. 3. Simultaneously obtained oscillograms and interferograms of scattered radiation at a pressure of 150 atm in the chamber: a - oscillograms obtained from F-d<sub>1</sub>; b-d (left) - integral oscillograms from F-d<sub>2</sub>; b-d (right) - SMBS spectra time-scanned with EOC (time scale the same as on oscillograms a, time increases from left to right).

8-10 nsec later than at atmospheric pressure, when there is no SMBS. This case corresponds to curves 1 and 2 of Fig. 2b and curve 1 of Fig. 3a. \*\*

In addition to the mechanism of successive SMBS, there can also be realized an SMBS mechanism whereby a Stokes component of frequency  $\omega_{s_1}$  reaches an intensity high enough to give rise to a similar component of frequency  $\omega_{s_2}$  without amplification in the ruby. In this case the SMBS component ( $\omega_{s_1}$ ) propagating in the direction of the laser emission will be registered by interference at the instant of its occurrence, while the component ( $\omega_{s_2}$ ) will be registered after amplification in the laser, see Fig. 3a (curve 2) and Figs. 3c,d.

Such a scattering, occurring in the region of interaction of the light waves, will be called here repeated stimulated Mandel'shtam-Brillouin scattering.

It can be seen sometimes that the  $\omega_{s_2}$  component consists of two lines of unequal intensity. The more intense line is shifted in frequency by  $\sim 0.006 \text{ cm}^{-1}$  and coincides with one of the natural frequencies of the resonator. This shift has probably the same cause as in [5].

The hypersound velocity was calculated from the positions of the SMBS components and found to be  $320 \pm 20 \text{ m/sec}$ .

On the basis of the obtained results we can conclude that the SMBS occurs and lasts until the instant of plasma formation (no SMBS was observed later than this instant). Therefore the isothermal speed of hypersound obtained in [1], and also in [6, 7], cannot be explained by assuming that the thermal conductivity increases [1].

Simultaneous realization of repeated and successive scattering may explain the occurrence of a large number of SMBS components in gases, in spite of the fact that the formation of the plasma interrupts the SMBS.

Intense hypersonic waves may be generated in the scattering volume both in the forward and in the backward direction, which in turn should contribute to the occurrence of "anti-Stokes" components. This may be the cause of the previously observed anti-Stokes component [1].

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\*The curves of Figs. 2a, b are made to coincide at the points at which they begin to deviate from the horizontal.

\*\*Pulsation of the pulse waveform is hardly noticeable in transmitted light (curve 2 of Fig. 2b), but is observed in the backward-scattered radiation (curves 1 and 2 of Fig. 3a). A reduction in the pulsation is made possible by interaction of back-scattered MBC with the laser radiation in the laser itself.