is not the start of the suggested waveguide filament, but the first focus. A detailed investigation[5b] of the influence of different types of nonlinear absorption in the medium (i.e., the imaginary part of the refractive index) on the picture of the beam propagation has shown that, independently of the concrete form of this absorption, a multifocus structure is produced. Recently Dyshko, Lugovoĭ, and Prokhorov investigated also the influence of deviations from a quadratic field dependence of the real part of the refractive index, which can be caused under real conditions by the so called "saturation" of the Kerr nonlinearity (see[7]) or by nonlinear absorption in the medium. Numerical calculations have shown not only that the multifocus structure is preserved qualitatively, but that the corrections to the parameters of the foci are small even quantitatively. Thus, for media with Kerr nonlinearity the multifocus picture of the propagation of light beams turned out to be quite universal, i.e., it should be observed under various physical conditions.

The indicated results pertain to a beam that is stationary in time. Under real conditions, however, the beam power varies with time in accordance with the envelope of the laser pulse. As shown by Lugovoĭ and Prokhorov[6], for giant laser pulses, i.e., pulses with duration on the order of 10^{-8} sec, the foci should move along the beam axis with velocities on the order of 10^9 cm/sec (under typical conditions). Superimposed photographs of the beam propagation, taken from the side, should show thin filaments that are the tracks of the motion of the foci. Thus, the filaments previously observed in the experiment were explained not as being due to waveguide propagation, but as trajectories of moving foci.

Simultaneously with the first experimental confirmations[8,9] of the moving-foci theory, this theory was further extended[8a,10] to include the case of so-called ultrashort laser pulses. It was shown there that the previously established picture of moving foci is retained in this case, too. The only difference lies in the character of the onset and motion of the foci. According to the theory, the velocity of the foci can greatly exceed in this case the velocity of light in vacuum, as was confirmed experimentally in[8b]. The multifocus structure in picosecond laser pulses (with duration $\sim 3 \times 10^{-12}$ sec) was also registered recently in experiments.

Many experimental results have by now been explained on the basis of the theory of moving foci.

[1] R. Y. Chiao et al., Phys. Rev. Lett. 13, 479 (1964).
[2] P. L. Kelley, Phys. Rev. Lett. 15, 1005 (1965).
[3] T. F. Volkov, in: "Fizika plazmy i problema upravlyaemykh termoyadernykh reaktsiĭ" (Plasma Physics and the Problem of Controlled Thermonuclear Reactions), Vol. 3, AN SSSR, 1958, p. 336.
[4] G. A. Askar'yan, a) Zh. Eksp. Teor. Fiz. 42, 1567 (1962) [Sov. Phys.-JETP 15, 1088 (1962)]; b) V. I. Talanov, Izv. vuzov (Radiofizika) 7, 564 (1964).
[5] A. L. Dyshko, V. N. Lugovoĭ, and A. M. Prokhorov, a) ZhETF Pis. Red. 6, 655 (1967) [JETP Lett. 6, 146 (1967)]; b) Zh. Eksp. Teor. Fiz. 61, 2305 (1971) [Sov. Phys.-JETP 34, 1235 (1972)].
[6] V. N. Lugovoĭ and A. M. Prokhorov, ZhETF Pis. Red. 7, 153 (1968) [JETP Lett. 7, 117 (1968)].
[7] R. G. Brewer et al., Phys. Rev. 166, 326 (1968).
[8] M. M. T. Loy and Y. R. Shen, Phys. Rev. Lett. a) 22, 994 (1969); b) 25, 1333 (1970).
[9] V. V. Korobkin et al., ZhETF Pis. Red. 11, 153 (1970) [JETP Lett. 11, 94 (1970)]; N. I. Lipatov et al., ibid. 11, 444 (1970) [11, 300 (1970)].
[10] A. A. Abramov, V. N. Lugovoĭ, and A. M. Prokhorov, ibid. 9, 675 (1969) [JETP Lett. 9, 419 (1969)]; T. K. Gustafson and J. P. E. Taran, IEEE J. Quantum Electron. QE-5, 381 (1970).

V. V. Korobkin. Experimental Investigation of the Propagation of Powerful Radiation in Nonlinear Media. One of the central problems of nonlinear optics is the investigation of the propagation of bounded light beams in nonlinear media, i.e., in media in which the refractive index n depends on the field intensity E of the propagating beam:

$$n = n_0 + \Delta n\,(E^2).$$

This problem has now a rather long history, but still remains timely.

Abundant experimental material on this problem has been accumulated by now. We note first the work of Hercher[1], who was the first to observe filament-like damage in glasses. He did not connect the formation of such faults with changes in the refractive index of the medium. The possibility of such a connection was indicated by Pilipetskiĭ and Rustamov[2], who observed the formation of long radiation "filaments" in liquids. Subsequently, Townes and co-workers[3] have shown experimentally that the change in the transverse distribution of the intensity in the wave beam as it propagates in the nonlinear medium is connected with a change of the refractive index. In 1966, Brewer and Lifsitz[4] reported[4] observation of so-called small-scale "filaments" with diameters up to several microns and with lifetime shorter than 10^{-9} sec. We note also the interesting work by Shimizu[5] and by Zverev and co-workers[6]. Initially, the predominant concept in nonlinear optics was that of waveguide propagation in media with $\Delta n > 0$, and the results of the first experiments were treated precisely from this point of view. This concept, however, could not explain all the experimental results, particularly the short lifetimes of the "filaments."

In 1967, Lugovoĭ and Prokhorov (see[8]) advanced the concept of multifocus structure. In accordance with this concept, a system of focal points is produced in the nonlinear medium during the course of propagation, and these foci move relative to the medium when the radiation power changes. The "filaments" observed in different experiments are indeed the results of such a displacement.

The subsequent experiments were aimed to a considerable degree at an explanation of the validity of one concept or another. Korobkin and Alcock[9] have observed moving foci, apparently for the first time, in an investigation of a laser spark in air.

Loy and Shen[10], in a study of the propagation of laser radiation in nonlinear liquids, have shown that the waveguide regime was not realized in their experi-

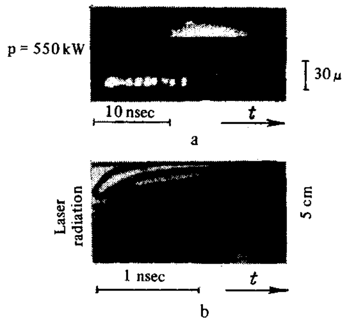

FIG. 1

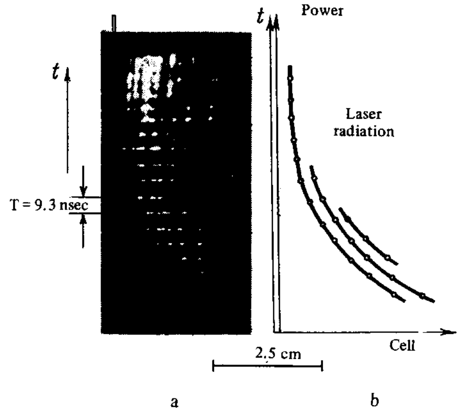

FIG. 2

ments, and the results could be explained only from the point of view of the moving foci.

In 1969, a detailed investigation was made[11] of the propagation of laser radiation in liquids. Single-mode radiation (one angular mode and one axial mode) passed through a cell with the investigated liquid. The radiation entering the cell had a plane phase front and approximately Gaussian transverse distribution. The process was registered with an electron-optical converter operating in the linear scan regime. Figure 1a shows a typical photograph of a time scan of the end face of the cell. This photograph shows clearly the successive passage of the foci of the multifocus structure through the end face (lower trace) when the laser-radiation power (upper trace) is varied. Figure 1b shows a scan of the scattered radiation obtained from the side of the cell. This photograph shows the motion of the individual foci in the direction towards the entrance face. Both the total number of foci and the maximum rate of their motion ($\sim 3 \times 10^9$ cm/sec) agree well with the theoretical calculated values.

The influence of the shape of the laser pulse on the character of the damage in glasses was investigated in[12]. In the case of a bell-shaped pulse, the damage was in the form of a long filament several microns in diameter; in the case of a rectangular pulse, the damage was produced in individual points. These results are likewise in good qualitative agreement with the concept of the multifocus structure. Similar conclusions are reached also by the authors of[13], who investigated the character of the damage in sapphire.

The multifocus-structure theory has predicted that in the case of ultrashort pulses, with duration $\tau < l/c$ (where l is the length of the cell), the focus splits after its production into front and rear focal points. The rear point becomes stationary relative to the medium after a certain time, while the front point moves with superluminal velocity. Loy and Shen[10] have confirmed experimentally that the front point moves with a superluminal velocity that reaches a value 2c.

We have investigated in detail the multifocus structure for the case of ultrashort pulses. Radiation from a neodymium laser operating in the axial-mode locking regime, passed through a cell with the investigated liquids (nitrobenzene or carbon disulfide). A typical photograph of the scan, obtained with an electron-optical converter, and taken from the side of the cell, is shown in Fig. 2a. It is seen from the photograph that the points where the rear foci stop actually exist. The intensity of scattering from these points is much higher, as it should be. The number of focal points increases with increasing beam power. These experiments are also in satisfactory agreement with the theory (Fig. 2b).

Mention should also be made of changes in the broadening of the spectrum of ultrashort pulses, which according to[14] can also be attributed from the point of view of the multifocus structure. Finally, only this theory can explain certain stimulated-Raman-scattering features connected with the generation of ultrashort pulses[10c].

Thus, summarizing all the results, it can be stated that the multifocus-structure concept has been experimentally confirmed.

[1] M. Hercher, J. Opt. Soc. Am. **54**, 563 (1964).
[2] H. F. Pililetskiĭ and A. R. Rustamov, ZhETF Pis. Red. **2**, 88 (1965) [JETP Lett. **2**, 55 (1965)].
[3] E. Garmire et al., Phys. Rev. Lett. **16**, 347 (1966).
[4] R. G. Brewer and J. R. Lifsitz, Phys. Lett. **23**, 79 (1966).
[5] F. Shimizu, Phys. Rev. Lett. **19**, 1097 (1967).
[6] G. M. Zverev et al., ZhETF Pis. Red. **5**, 391 (1967) [JETP Lett. **5**, 319 (1967)]; G. M. Zverev et al., ibid. **9**, 108 (1969) [**9**, 61 (1969)].
[7] G. A. Askar'yan, Zh. Eksp. Teor. Fiz. **42**, 1567 (1962) [Sov. Phys.-JETP **15**, 1088 (1962)]; P. Y. Chiao et al., Phys. Rev. Lett. **13**, 479 (1964).
[8] A. L. Dyshko et al., ZhETF Pis. Red. **6**, 655 (1967) [JETP Lett. **6**, 146 (1967)]; V. N. Lugovoĭ and A. M. Prokhorov, ibid. **7**, 153 (1968) [**7**, 117 (1968)].
[9] V. V. Korobkin and A. J. Alcock, Phys. Rev. Lett. **21**, 1433 (1968).
[10] M. M. T. Loy and Y. R. Shen, ibid. a) **22**, 994 (1969); b) **25**, 1333 (1970); c) Appl. Phys. Lett. **19**, 285 (1971).
[11] V. V. Korobkin et al., ZhETF Pis. Red. **11**, 153 (1970) [JETP Lett. **11**, 94 (1970)].
[12] N. I. Lipatov et al., ibid. **11**, 444 (1970) [**11**, 300 (1970)].
[13] C. R. Giuliano and J. H. Marburger, Phys. Rev. Lett. **27**, 905 (1971).
[14] R. Cubeddu and F. Zaraga, Optics Comm. **3**, 310 (1971).

V. I. Talanov. Certain Problems in the Theory of Self-Focusing. The description of stationary self-focusing in the case of nonlinearity of the Kerr type is usually based on the parabolic equation[1]