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Meetings and Conferences

SCIENTIFIC SESSION OF THE DIVISION OF GENERAL PHYSICS AND ASTRONOMY OF THE USSR ACADEMY OF SCIENCES (19–20 January 1972)

A scientific session of the division of General Physics and Astronomy of the USSR Academy of Sciences was held on January 19 and 20, 1972, at the conference hall of the P. N. Lebedev Physics Institute. The following papers were delivered:

1. G. A. Askar'yan, Self-Focusing Effect.
2. V. E. Zakharov, Theory of Self-Focusing.
3. V. N. Lugovoĭ, Theory of Propagation of Giant Laser Pulses in a Nonlinear Media.
4. V. V. Korobkin, Experimental Investigation of the Propagation of Powerful Radiation in Nonlinear Media.
5. V. I. Talanov, Certain Problems of the Theory of Self-Focusing.
6. A. G. Litvak, Self-Focusing and Wave Propagation in a Plasma.
7. V. M. Eleonskiĭ, L. G. Oganes'yants and V. P. Silin, Vector Structure of Electromagnetic Fields in Self-Focused Waveguides.
8. E. R. Mustel', Identification of the Spectra of Supernovas of Type 1 and the Problem of Transmutation of Elements in Supernova Explosions.
9. V. M. Kuvshinov, N. S. Nikulin, and A. B. Severnyĭ, Circular Polarization of Optical Radiation of x Ray Sources in the Galaxy.

We publish below brief contents of some of the papers.

G. A. Askaryan. Self-Focusing Effect. The self-focusing effect[1a] consists in a decrease of the divergence (or, equivalently, to an increase in the convergence) of powerful radiation in a medium, owing to different nonlinear processes. All the varieties of self focusing are the consequences of such a change in the divergence. The spatial distribution of the self-focusing is analogous to the appearance of a dielectric waveguide; as is well known[2], waveguides come in different shapes, compositions, and variable cross sections (e.g., tapered waveguides for field amplification have been known for a long time). The waveguide concept of self-focusing is therefore the most complete one, if waveguide propagation is taken to mean a decrease in the divergence and in the cross section of the beam.

Two aspects of self-focusing are of greatest practical interest—long waveguides (for the transmission of concentrated energy over large distances) and strong contraction of the beam (to obtain maximum flux densities).

Self-consistent radiation propagation without divergences was considered by Talanov[3] and by Townes and co-workers[4], and was observed in many experiments, e.g., in the experiment of Townes (see[5]), where a strong decrease of the divergence and of the beam cross section was observed.

An extended filament can be obtained also by contraction or focusing of the beam. This was first observed by Pilipetskiĭ and co-workers (see[6]). His experiments were the first purposeful experiments on self-focusing. Such experiments were later performed on a larger scale[7], new data were obtained on the influence of the proximity of the focus to the surface, and it was shown that the divergence of filaments is much smaller than the diffraction value.

It is noted in a number of recent papers (see[8]) that at powers much above threshold a so-called multifocus structure is produced as a result of nonlinear absorption in the foci, and the power flowing into each focus is close to the so-called threshold power $P_{thr} \sim \lambda^2 c/n_2$ (which is determined from the compensation of the diffraction divergence by the nonlinear refraction[4]. Such a breakdown of the beam into near-threshold components was first noted by Townes et al. (see[4]), where it is stated that "a beam whose power is much higher than the threshold value probably breaks up into several beams of threshold power." This process was considered also by Bespalov and Talanov[9].

It should be noted that the calculations in[8] were performed for a special type of instantaneous nonlinearity, and the regions of their applicability was not determined. Indeed, as shown by Zakharov et al.[10], the form of the solution depends significantly on the small deviation of the nonlinearity from the n_2E^2 form. This deviation may be due to relaxation, saturation, or other types of nonlinearity, including those connected with absorption, something very difficult to take into account in dynamics because of the very short time during which the strong field of the moving focus acts on the medium. This time is $t \approx z_{foc}/v_{foc} \approx 10^{-11}-10^{-12}$ sec at a focus velocity $v_{foc} \approx 3 \times 10^9$ cm/sec and at a focal-spot length $z_{foc} \approx 10^{-2}$ cm. But this time, however, it is commensurate with the molecule orientation relaxation, i.e., one cannot assume that $\delta n = n_2E^2$ near the focus. Multiphoton absorption cannot take place within a short time. In the case of strong stimulated Raman scattering, one can likewise not assume that $\delta n = n_2E^2$, owing to the change of the refractive index by the vibrationally-excited molecules, which have different polarizability[12]. All this shows that it is incorrect to treat the processes near the focus on the basis of a solution of the problem with nonlinearity of the type n_2E^2 and without testing the applicability of this theory to experiment.

Possible solutions in pulsating-waveguide form[10] make the interpretation of the experiments[11] on the multifocus structure ambiguous.

Thus, the question whether the beam collapses into a filament or into a system of foci cannot be regarded as solved. It is quite probable that in a definite range of conditions there is collapse into a filament, and in another range (e.g., at low velocities of the focus) one gets a multifocus structure, and it is possible that behind each focus there is a waveguide segment of filament resulting of relaxation or perturbation of the medium.

We note that the dispute "filament or multifocus structure" does not affect the question of waveguide limitation of the beam divergence, which was observed in many experiments both in the optical band and in the radio band in a plasma (such experiments were performed recently by Litvak and co-workers[12]).

The multifocus structure is highly inefficient in practice, since it distributes the energy over a large volume and does not carry it over large distances, since the power is absorbed and scattered in the foci, and only a power close to the threshold value, i.e., the same power that is incident on one focus, reaches the receiver. Therefore calculations for the multifocus structure can be useful only insofar as they determine the range of conditions in which one should not operate.

The energy fed to a single focus or to the waveguide can be increased by setting an initial beam divergence $\theta \gg \theta_{\text{diff}}$, so that the trapping conditions are $\theta^2 \sim n_2E^2 \gg n_2E^2_{\text{thr}}$. The problem of gathering energy into one focus is quite interesting in practice.

Self-focusing of powerful beams can be used to obtain pre-thermonuclear temperatures. The fast motion of the focus[13] makes it possible to use concentrated field regions for particle acceleration[14].

It is possible that meandering of the focus in the target leads to the appearance of an overheated group of particles and to hard x-ray or neutron emission.

Intensive studies have been made recently of self-focusing of acoustic waves with allowance for strong nonlinearity of acoustic waves in dense media as a result of heating[1b], cavitation[1c], changes in the compressibility, change in the carrier density[15], etc.

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[1] G. L. Askar'yan, a) Zh. Eksp. Teor. Fiz. **42**, 1567 (1962) [Sov. Phys.-JETP **15**, 1088 (1962)]; ZhETF Pis. Red.: b) **4**, 144 (1966); c) **13**, 395 (1971); d) **4**, 400 (1966) [JETP Letters, b) **4**, 99 (1966) c) **13**, 283 (1971) d) **4**, 270 (1966)].

[2] Physics Dictionary (in Russian), vol. 1, entry "Waveguide," G. V. Kisun'ko et al., Soviet encyclopedia, 1960, p. 302.

[3] V. I. Talanov, Izv. vuzov (Radiofizika) **7**, 564 (1964).

[4] R. Chiao et al., Phys. Rev. Lett. **14**, 479 (1964).

[5] E. Carmire et al., ibid. **16**, 347 (1966).

[6] H. F. Pilipetskiĭ and A. R. Rustamov, ZhETF Pis. Red. **2**, 88 (1965) [JETP Lett. **2**, 55 (1965)].

[7] G. A. Askar'yan et al., ibid. **14**, 452 (1971) [JETP Lett. **14**, 308 (1971)].

[8] A. L. Dyshko et al., ibid. **6**, 655 (1967); **7**, 153 (1968); [JETP Lett. **6**, 146 (1967); **7**, 117 (1968)]; Zh. Eksp. Teor. Fiz. **61**, 2305 (1971) [Sov. Phys.-JETP **34**, 1235 (1972)].

[9] V. M. Bespalov and V. I. Talanov, ZhETF Pis. Red. **3**, 471 (1966) [JETP Lett. **3**, 307 (1966)].

[10] V. E. Zakharov et al., ZhETF Pis. Red. **14**, 564 (1971) [JETP Lett. **14**, 390 (1971)]; Zh. Eksp. Teor. Fiz. **60**, 136 (1971) [Sov. Phys.-JETP **33**, 77 (1971)].

[11] 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)].

[12] Yu. Ya. Brodskiĭ et al., ibid. **13**, 136 (1971) [**13**, 95 (1971)]; B. G. Eremin and A. G. Litvak, ibid. **13**, 603 (1971) [**13**, 430 (1971)].

[13] P. D. McWane, Nature **211**, 1081 (1966).

[14] G. A. Askar'yan and S. D. Manukyan, Zh. Eksp. Teor. Fiz. **62**, 2156 (1972) [Sov. Phys.-JETP **35**, 1127 (1972)].

[15] G. A. Askar'yan and V. I. Pustovoĭt, Zh. Eksp. Teor. Fiz. **58**, 647 (1970) [Sov. Phys.-JETP **31**, 346 (1970)].

V. E. Zakharov. Theory of Self-Focusing. Stationary self-focusing[1] of waves of nonlinear media, including self-focusing of electromagnetic waves in a nonlinear dielectric, is described by the equation for the complex envelope of the wave[2,3]

$$2i\frac{\partial\Psi}{\partial z}+\Delta_{\perp}\Psi+|\Psi|^2\Psi=0. \tag{1}$$

This equation describes, in particular, beams (waveguides) that are homogeneous along the propagation axis: plane[2] $\Psi = \sqrt{2}\eta e^{4i\eta^2x}/\text{ch}\, 2\eta x$, and cylindrical[3] $\Psi = e^{iz/\lambda^2}\lambda^{-1}R(r/\lambda)$. The functions $R(\xi)$ were calculated in this case with a computer.

The problem of the theory is to determine what happens to a wave with transverse distribution $\Psi_0(r)$ at $z = 0$ incident on a nonlinear half-space $z > 0$, and in particular determine the feasibility of trapping the wave energy in a waveguide propagation mode, and also the possibility of the formation of singularities (foci) at finite values of z.

The theory is entirely different for two-dimensional (x, z) and three-dimensional (x, y, z) beams. In the two-dimensional case the beam energy is trapped in the waveguide propagation mode[4]. As $z \to \infty$, a finite number of planar waveguides is produced, which generally speaking are inclined to the axis. The waveguide parameters can be calculated from the initial distribution of the field $\Psi_0(x)$. To this end it is necessary to solve the eigenvalue problem

$$\begin{bmatrix} id/dx & -\Psi_0/\sqrt{2} \\ \Psi_0^*/\sqrt{2} & -id/dx \end{bmatrix}\begin{bmatrix}\chi_1\\ \chi_2\end{bmatrix}=\zeta\begin{bmatrix}\chi_1\\ \chi_2\end{bmatrix}.$$

As $z \to \infty$, each complex eigenvalue $\zeta_i = \xi_i + i\eta_i$ corresponds to a waveguide with amplitude η_i and slope (relative to the axis) $\tan\varphi_i = 4\xi_i$.

Actually, however, such two-dimensional waveguide propagation can be realized only in a strongly anisotropic medium (e.g., in a plasma with propagation transverse to the magnetic field), since a planar waveguide in an isotropic medium is unstable to transverse modulation.

In the three-dimensional case, the description of the nonlinear medium with the aid of Eq. (1) is not accurate enough, for in the case of sufficiently intense beams it leads to the formation of a singularity of a pointlike focus[5]. Near the focus, the field behaves like[6a]

$$\Psi \approx \lambda^{-1}(z)\, R\,(r/\lambda(z)) \exp\left\{ i \int \lambda^{-2}(z)\, dz + [ir^2\lambda'_z/2\lambda(z)]\right\} + A_0;$$

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*The articles by V. N. Lugovoi and by V. M. Eleonskii, L. G. Oganes'yants, and V. P. Silin abstracted below contain the erroneous statement that self focusing is described in the paper by T. F. Volkov (in the collection "Fizika plasmy i problema upravlyaemykh termoyadernykh reaktsiĭ" [Plasma Physics and the Problem of Controlled Thermonuclear Reactions], Vol. 3, AN SSSR, 1958, p. 336). That paper deals with longitudinal redistribution of the field and plasma in plane waves, and the question of the change of divergence as a result of the appearance of transverse gradients was neither posed nor considered. The article by T. F. Volkov therefore does not deal with self-focusing.