An analysis has shown that there exist two phase trajectories, one of which (0abc0) corresponds to the possible existence of a spatially localized solution, which has in the limit of small k_z/k the form

$$E_z = \frac{|\epsilon_0|}{\sqrt{2\Delta}} kx, \quad E_x^2 = -\frac{\epsilon_0}{\Delta}\left[1 + \frac{1}{2}\epsilon_0 (kx)^2\right], \quad x \leqslant \frac{\sqrt{2}}{k\sqrt{-\epsilon_0}};$$

$$E_z = \sqrt{-\frac{2\epsilon_0}{\Delta}}\,\mathrm{sign}\,x / \mathrm{ch}\left[\sqrt{-\epsilon_0}\, k\,|x| - \sqrt{2} + \ln(1+\sqrt{2})\right], \quad E_x = 0,$$

$$x \geqslant \frac{\sqrt{2}}{k\sqrt{-\epsilon_0}},$$

and the other corresponds to a spatially periodic solution with a period $4[\sqrt{2} + \ln(1 + \sqrt{2})]/k\sqrt{-\varepsilon_0}$ (Fig. 2). We emphasize that the presence of a small k_z decreases the maximum value of the self-focused field by a factor $\sqrt{2}$ compared with the solution of the scalar-field theory. In the case of a spatially periodic solution, there is alternation of the regions of the transverse field with the regions in which there is a longitudinal field. As follows from Fig. 2, the vector of the electric field rotates in this case.

[1] T.F. Volkov, Fizika plazmy i problema uprovlyaemykh termoyadernykh reaktsii (Plasma Physics and the Problem of Controlled Thermonuclear Reactions), AN SSSR 3, 336 (1958).
[2] V.P. Silin, Zh. Eksp. Teor. Fiz. 53, 1662 (1967) [Sov. Phys.-JETP 26, 955 (1968)].
[3] S.A. Akhmanov, A.P. Sukhorukov, and R.V. Khokhlov, Usp. Fiz. Nauk 93, 19 (1967) [Sov. Phys.-Usp. 10, 609 (1968)].

CONCERNING THE NATURE OF THE NONLINEARITY OF THE NaCl CRYSTAL

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The nonlinearities of condensed media, which lead to self-action of intense laser radiation in them, are usually attributed to the following mechanisms: the Kerr effect [1], striction [2], thermal [3], and SRS [4]. We wish to show that in the case of alkali-halide crystals such as NaCl there is one more possibility, which plays an important role in self-action processes. The presence of such processes (self-focusing, self-bending) in NaCl crystals is evidenced by the results of our earlier investigations [5, 6].

Back in [7] we have already shown that color centers appear in the region where the NaCl crystal is damaged by ruby-laser radiation. They correspond to absorption bands located in the visible region of the spectrum, on the side of the laser-emission line, and leading to an increase of the dispersion at the frequency of this line. This raises naturally the question of whether these centers appear already during the action of the laser pulse, and consequently have a bearing on the nonlinearity, as was assumed by us earlier [8], or whether they arise after the action of the laser pulse and have no direct bearing on the self-action processes.

To answer this question it was necessary to obtain the absorption spectrum of the NaCl crystal during the time of action of the laser pulse ($\sim 10^{-8}$

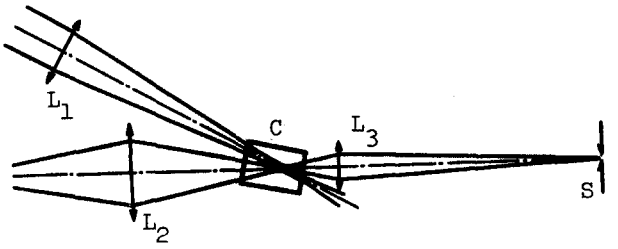

Fig. 1. Experimental setup for obtaining the absorption spectrum of a crystal exposed to a laser pulse. C - investigated crystal, S - slit of spectral instrument.

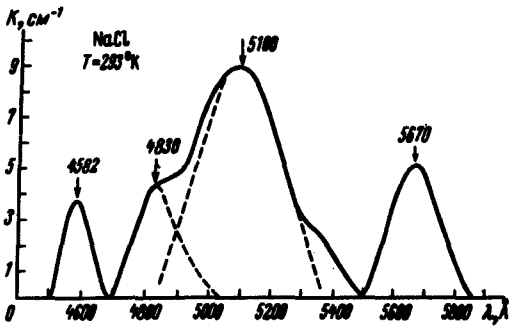

Fig. 2. Absorption spectrum of NaCl crystal during the time it is irradiated with the laser pulse.

sec). Such spectra were obtained in this investigation with the aid of a procedure developed by us earlier [9]. In this procedure, a pulse of probing radiation with a continuous spectrum, having a duration approximately equal to the duration of the reference laser beam, was made to coincide with the latter while passing through the investigated crystal. The measurement results have confirmed the correctness of our assumptions concerning the occurrence of color centers in the crystal during the time its irradiation with a monopulse ruby laser, and have shown that the nonlinearity of the NaCl crystal is connected in the main with this circumstance.

We used in the experiment a single-mode ruby laser with passive Q switching. The laser radiation was focused by lens L_1 into the investigated crystal. Lens L_2 transmitted the image of the point-like pulsed sounding source with continuous spectrum in such a way that it overlapped in the crysjal the focal region of the lens L_1 (see Fig. 1). The sounding beam and the image of the focal region of the lens L_1 were projected by the optical system L_3 on the spectrograph slit with a 50-fold magnification. The alignment of the focus of lens L_1 and of the image of the sounding source focused by lens L_2 in the crystal was verified experimentally. The measurements were made at room temperature. The absorption spectra were photographed at a beam density somewhat lower than the damage threshold value. The threshold for damaging the investigated NaCl crystal by the ruby-laser radiation was 2.5×10^9 W/cm^2, in agreement with the published data [10, 11].

The measurements have shown that in the absence of a laser pulse the crystal is practically transparent in the visible region. When the laser pulse is applied, absorption bands appear in the crystal; a typical absorption spectrum is shown in Fig. 2.

Using a formula of the Sellmeyer type and starting from the measurement data, we can estimate the contribution of the resultant bands to the change in the refractive index at the ruby-laser frequency. Let n_0 be the refractive index of the initial crystal, and n the refractive index of the irradiated crystal, and let the nonlinear change of n be $\Delta n = n - n_0$. Considering one band with a maximum at ν_0, we can write down for its contribution to $n(\nu_L)$ at the frequency ν_L the expression

$$n^2(\nu_L) = n_0^2 + \frac{B}{\nu_0^2 - \nu_L^2}, \qquad (1)$$

where $B = (Nf)(e^2/\pi mc^2)$; here N is the number of color centers per cm^3, f is the oscillator strength of the band, e and m are the charge and mass of the electron respectively, and c is the velocity of light in vacuum. From (1) we

obtain

$$(n^2 - n_0^2) = \frac{B}{\nu_0^2 - \nu_L^2} = (n + n_0)(n - n_0) \cong 2n_0\Delta n,$$

since $(n + n_0) \simeq 2n_0$ and $(n - n_0) = \Delta n$. Hence

$$\Delta n = \frac{B}{2n_0(\nu_0^2 - \nu_L^2)} = (Nf)\frac{(e^2/\pi mc^2)}{2n_0(\nu_0^2 - \nu_L^2)}. \quad (2)$$

The unknown quantity here is the product (Nf), which we determine from the formula [12]

$$(Nf) = 5{,}24 \cdot 10^{17} \frac{n_0}{(n_0^2 + 2)^2} K_{max}\Delta H, \quad (3)$$

where K_{max} is the coefficient of absorption at the maximum of the absorption band in cm^{-1}, and H is the half-width of the absorption band in electron volts. Taking the values of K_{max} and ΔH, respectively, for the bands 4582, 4830, 5100, and 5670 Å, we calculate for them the values of (Nf) by means of formula (3), and substituting them in (2) we obtain $(\Delta n)_1 = 1.04 \times 10^{-6}$, $(\Delta n)_2 = 1.85 \times 10^{-6}$, $(\Delta n)_3 = 9.42 \times 10^{-6}$, and $(\Delta n)_4 = 4.23 \times 10^{-6}$. The total change in the refractive index at the frequency ν_L is equal to their sum, i.e., $\Delta n = 1.65 \times 10^{-5}$.

The obtained value of Δn agrees in sign and in order of magnitude with the value of the nonlinearity calculated earlier [6] from the angle of self-bending of an inhomogeneous ruby-laser beam in a NaCl crystal. Thus, the color centers produced in this crystal are responsible, in the main, for the observed self-actions.

[1] Y. Shen, Phys. Rev. Lett. 20, 378 (1966); G. Mayer and F. Gires, Compt. Rend. 258, 2039 (1964).
[2] Y. Shen, Phys. Rev. Lett. 20, 378 (1966); R. Chiao, E. Garmire, and C. Townes, Phys. Rev. Lett. 13, 479 (1964); Phys. Rev. Lett. 14, 1056 (1965).
[3] Yu.P. Raizer, ZhETF Pis. Red. 4, 286 and 124 (1966) [JETP Lett. 4, 193 and 85 (1966)]. A.G. Litvak, ibid. 4, 341 (1966) [4, 230 (1966)]. Yu.P. Raizer, Zh. Eksp. Teor. Fiz. 52, 470 (1967) [Sov. Phys.-JETP 25, 308 (1967)].
[4] V.S. Butylkin, A.E. Kaplan, and Yu.G. Khronopulo, Izv. Vuzov Radiofizika 12, 1792 (1969).
[5] M.S. Brodin and A.M. Kamuz, Ukr. Fiz. Zh. 10, 1151 (1966).
[6] M.S. Brodin and A.M. Kamuz, ZhETF Pis. Red. 9, 577 (1969) [JETP Lett. 9, 351 (1969)].
[7] M.S. Brodin, V.N. Vatulev, S.V. Zakrevskii, and A.M. Kamuz, Kvantovaya elektronika. Trudy respublikanskogo seminara po kvantovoi elektronike (Quantum Electronics, Proceedings of Seminar on Quantum Electronics), Kiev, Naukova dumka, 1965.
[8] M.S. Brodin and A.M. Kamuz, Ukr. Fiz. Zh. 14, 1978 (1969).
[9] M.S. Brodin and A.M. Kamuz, ibid. 14, 517 (1969).
[10] D. Olness, Appl. Phys. Lett. 8, 283 (1966).
[11] N.V. Karlov, G.P. Kuz'min, and A.M. Prokhorov, ZhETF Pis. Red. 12, 363 (1970) [JETP Lett. 12, 248 (1970)].
[12] D. St. James, Color Centers (Russian translation), Moscow, 1958, p. 84.