[3] Yu.A. Aleksandrov, JINR Preprint R3-4784, Dubna, 1969; Elem. Chast. i Atomn. Yad. (Elementary Particles and Atomic Nuclei), Atomizdat 1, 547 (1971).
[4] T.S. Zimin, I.R. Karpovich, A.N. Kshnyakina, S.D. Prokudin, R.P. Ozerov, N.V. Ranev, S.V. Kiselev, and I.D. Datt. Apparatura i metody rentgenovskogo analiza (Apparatus and Methods of X-ray Analysis), SKB RA, Leningrad, 1969, p. 14.
[5] Yu.A. Aleksandrov, A.M. Balagurov, G.S. Samosvat, and L.E. Fykin, JINR Preprint R14-5358, Dubna, 1970.
[6] International Tables of X-ray Crystallography, The Kynoch Press, Birmingham, England, 3, 202 (1962).

OBSERVATION OF FINE STRUCTURE WITHIN THE LIMITS OF HOMOGENEOUS LINE WIDTH

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It has been shown in a number of theoretical papers for the case of gaseous, liquid, and solid media [1 - 4] that in a strong resonant optical field the frequency dependence of the gain (absorption) of a weak field in a saturable transition has a dip that is narrower than the homogeneous line width. The dip width is determined by the lifetimes of the transition levels [2]. A study of these structures is useful, first, for the understanding of the physical processes in a laser [1, 5] and, second, can yield an effective method of determining the lifetimes and other level characteristics.

We report here observation and a qualitative analsyis of the fine structure in the 3.3912-μ saturated line $5s'[1/2]_1^0 \rightarrow 4p'[3/2]_2$.

It follows from the experimental data below that the influence of the atomic collisions on the fine structure of the saturated line cannot be explained without taking level degeneracy into account. Allowance for degeneracy in the presence of collisions was carried out only in [3] for the $J = 1 \rightarrow J = 0$ transition. Since we used here the transition $J = 1 \rightarrow J = 2$, we calculated the saturated gain line in third order of perturbation theory with allowance for the depolarizing collisions for the indicated transition. In the case of unidirectional motion of linearly polarized waves in a strong and weak field, the frequency dependence of the gain $f(\Omega)$ of the weak field, in the limiting case of inhomogeneous and homogeneous broadening, is given by

$$f(\Omega) \backsim \begin{cases} \exp\left[-\left(\frac{\Omega}{kv}\right)^2\right] - \frac{E^2 d^2}{1800} L_{2\gamma}[B + b(\Omega)]; \quad kv >> \gamma, & (1) \\ L_\gamma\left(1 - \frac{E^2 d^2}{900}[B + b(\Omega) L_\gamma]\right); \quad kv << \gamma, & (2) \end{cases}$$

where Ω is the frequency deviation of the weak or strong field, the latter being tuned to the center of the line (ω_0); $L_x = x^2/(\Omega^2 + x^2)$, E^2 is the strong-field intensity, d the modulus of the reduced matrix element of the transition, 2γ the homogeneous width of the transition, k the wave vector and v the average thermal velocity of the atom:

$$B = \begin{cases} B^{\uparrow\uparrow} = 100/\gamma_a^{(0)} + 2/\gamma_a^{(2)} + 60/\gamma_b^{(0)} + 42/\gamma_b^{(2)} & (3) \\ B^{\uparrow\rightarrow} = 100/\gamma_a^{(0)} - 1/\gamma_a^{(2)} + 60/\gamma_b^{(0)} - 21/\gamma_b^{(2)} & (4) \end{cases}$$

$$
b(\Omega) = \begin{cases} b^{\uparrow\uparrow}(\Omega) = L_{\gamma_a^{0}}\, 100/\gamma_a^{(0)} + L_{\gamma_a^{(2)}}\, 2/\gamma_a^{(2)} + L_{\gamma_b^{(0)}} 60/\gamma_b^{(0)} + L_{\gamma_b^{(2)}} 42/\gamma_b^{(2)}, & (5) \\ b^{\uparrow\rightarrow}(\Omega) = L_{\gamma_a^{(1)}}\, 37{,}5/\gamma_a^{(1)} + L_{\gamma_a^{(2)}} 1{,}5/\gamma_a^{(2)} + L_{\gamma_b^{(1)}} 67{,}5/\gamma_b^{(1)} + & (6) \\ \quad + L_{\gamma_b^{(2)}}\, 31{,}5/\gamma_b^{(2)}\ . & \end{cases}
$$

The symbols $\uparrow\uparrow$ and $\uparrow\rightarrow$ indicate the mutual positions of the planes of polarization of the fields, $\gamma_a^{(0)}$ and $\gamma_b^{(0)}$ are the decay rates of the upper and lower levels, respectively, and $\gamma_a^{(1)}$, $\gamma_a^{(2)}$, $\gamma_b^{(1)}$, and $\gamma_b^{(2)}$ are constants that take the depolarizing collisions into account [6]. In the absence of collisions $\gamma_{a,b}^{(1,2)} = \gamma_{a,b}^{(0)}$ and the constants $\gamma_{a,b}^{(1,2)}$ increase with increasing pressure [7, 8]. Formulas (1) and (2) are written out under the assumption that $2\gamma >> \min \gamma_a^{(0)}, \gamma_b^{(0)}$, which is usual for lasers.

The terms proportional to B in (1) and (2) describe known saturation effects, viz., the Bennet hole (the term $L_{2\gamma}$) in an inhomogeneous line and a similar decrease of the gain contour of the homogeneous line (2); in addition, (1) and (2) have a narrow dip (the term $b(\Omega)$) containing Lorentzians with width narrower than 2γ.

If the waves move in opposite directions, the fine structure exists if $2kv << \min \gamma_a^{(0)}, \gamma_b^{(0)}$, which is possible in solids and liquids [4], but has little probability in gases. In our case, the $f(\Omega)$ dependence for opposing wave motion can be obtained from (1) and (2) by putting $B(\Omega) = 0$ and by substituting B/2 for B. The latter means that in the case of opposing wave motion the weak-field gain becomes saturated more slowly than in the case of motion in the same direction; this agrees with the conclusions of [9].

The fine structure in question was observed with the aid of the setup illustrated in Fig. 1.

The gain line of the laser amplifier 1 was saturated by linearly-polarized radiation of frequency $\approx\omega_0$ for laser 2 and was investigated by the weak field for another laser 3. The frequency of laser 3 was varied in the range $\approx\omega_0 \pm$ 225 MHz at a constant power, and therefore the amplified signal of laser 3, registered by the system 4, is the frequency form of the amplifier gain laser. The polarizationplane of laser 3 was switched over periodically. The lasers were decoupled.

Fig. 2 shows to the appropriate scales, oscillograms of the unsaturated gain line of the laser amplifier at two pressures inside the amplifier 1 (Figs. 2a and 2b), and of the saturated line in the case of opposing motion (Figs. 2c and 2d) and motion of the fields in the same direction (Figs. 2e and 2f). The curves in Figs. 2c, 2d, 2e, and 2f agree well with (1) and (2).

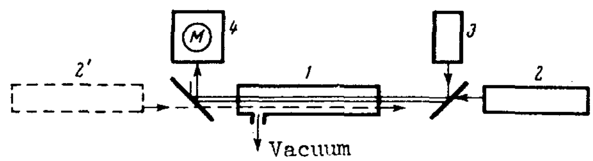

Fig. 1. Experimental setup: 1) laser amplifier, 2, 2') saturating laser, 3) weak-signal laser, 4) recording system with oscilloscope.

First, the curves of Figs. 2c and 2d lie higher than the corresponding curves of Figs. 2e and 2f, as indicated above, the weak-field gain becomes less saturated for opposing wave motion than for motion in the same direction.

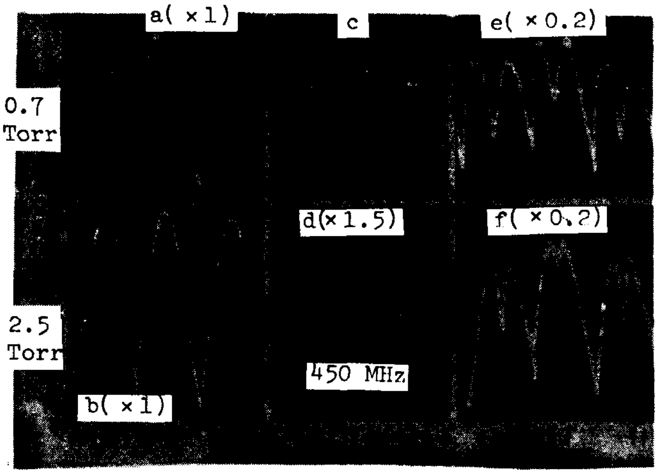

Fig. 2. Dependence of the gain of the weak field on its frequency in the presence of a strong saturated field at the line center: a, b) in the absence of a saturating field, c,d) opposing motion of fields. The symbols $\uparrow\uparrow$ and $\uparrow\rightarrow$ show the mutual orientations of the weak and strong field polarization planes. The gas pressure inside the quantum amplifier is indicated, as are the numerical coefficients by which the ordinates of the oscillograms are to be multiplied for comparison with one another.

Second, in the case of opposing wave motion, only a broad Bennet hole is observed in the saturated line (Fig. 2c). This hole vanishes, as a result of broadening, with increasing pressure (Fig. 2d). Finally, fourth, a dip (Figs. 2e, 2f) much narrower than the Bennet hole (Figs. 2c, 2d) is observed in the gain line when the waves move in the same direction. It is interesting to note that with increasing pressure the fine structure at parallel polarizations narrows down from 90 to 40 MHz (Figs. 2e, 2f$\uparrow\uparrow$). The explanation of this fact is as follows: It is known that the decay rates $\gamma^{(0)}_{a,b}$ depend on the pressure much less than $\gamma^{(2)}_{a,b}$ [7, 8]. As a result, whereas at low pressures one can see in $b_{\uparrow\uparrow}(\Omega)$ a contribution of the broadened terms $L_{\gamma^{(2)}_a}$ and $L_{\gamma^{(2)}_b}$ (Fig. 2e$\uparrow\uparrow$), with increasing pressures this decreases like $1/\gamma^{(2)}_a$ and $1/\gamma^{(2)}_b$, the terms $L_{\gamma^{(0)}_a}$ and $L_{\gamma^{(0)}_b}$ are broadened little, and on the whole the structure $b_{\uparrow\uparrow}(\Omega)$ narrows down (Fig. 2f$\uparrow\uparrow$) to a value determined by the widths of the levels $\gamma^{(0)}_a$ and $\gamma^{(0)}_b$.

In the case of perpendicular polarizations of the fields, the fine structure becomes less contrasty with increasing pressure, since $b_{\uparrow\rightarrow}(\Omega)$ contains only pressure-dependent terms.

[1] S.G. Rautian, Trudy FIAN 43, 3 (1968).
[2] E.V. Baklanov and V.P. Chebotaev, Zh. Eksp. Teor. Fiz. 61, 922 (1971) [Sov. Phys.-JETP 34, 490 (1972)].
[3] A.I. Alekseev, ibid. 58, 2064 (1970) [31, 1112 (1970)].
[4] C.V. Shank and S.E. Schwarz, Appl. Phys. Lett. 13, 113 (1968).
[5] M.A. Gubin, A.I. Popov, E.D. Protsenko, Kvantovaya elektronika (Quantum Electronics), No. 4, p. 34, Soviet Radio.
[6] M.I. D'yakonov and V.I. Perel', Zh. Eksp. Teor. Fiz. 48, 345 (1965) [Sov. Phys.-JETP 21, 227 (1965)].
[7] B. Decomps and M. Dumont, IEEE QE-4, 916 (1968).
[8] E. Kotlikov, G. Todorov, and M. Chaika, Opt. Spektr. 30, 185 (1971).
[9] E.V. Baklanov and V.P. Chebotaev, Zh. Eksp. Teor. Fiz. 60, 552 (1971) [Sov. Phys.-JETP 33, 300 (1971)].