particular, that for a given sample such a coupling will be much stronger for the second group of domains than for the first.

The experiments were performed on single-crystal disks of yttrium garnet with parameters $4\pi M = 1750$ G and $|K/M| = 43$ Oe. The results of the experiment for a disk with 2 mm diameter and 0.2 mm thickness are shown in Fig. 2 (similar results were obtained for disks with other dimensions). As follows from Fig. 2, besides the branches AC, AB, and NN, corresponding to magnetization precession, there were obtained two additional branches GF and KL. The resonance-absorption curves of the latter occur only for antisymmetrical excitation relative to domains 2 - 4 (h_y) for the GF branch and relative to domains 1 - 3 (h_x) for KL. Such excitation conditions give grounds for assuming that the branches GF and KL correspond to the resonant domain-boundary displacement frequencies. In the field range $4.6 < H' < 5.2$ there is good agreement between the experimental (sections AE and MS) and the theoretical curves. It can consequently be assumed that the domain structure in the sample is close to the theoretically chosen model. For fields $H' < 4.6$ the experimental deviate from the theoretical curve for $\omega'_{\perp 1}$ (section EC), apparently because of coupling with the strongly pronounced boundary-displacement boundary (branch GF) in this field region. As indicated above, the coupling of the magnetization oscillations in the domains with the boundary displacement is strongest for the domains 2 - 4. Therefore, taking only this coupling into account, we can estimate the parameter ℓ^2 by the procedure proposed in [1]. Using the experimental and theoretical values of the frequencies of the EC branch, we calculated the values of the parameter ℓ^2 and used **two formulas** for the frequencies of the coupled oscillations to determine the resonant boundary-oscillation frequencies for the group of domains 2 - 4. The results of this calculation are presented by the dashed line GF. The same values of the parameter ℓ^2 were used to calculate the resonant frequencies of the domain group 1 - 3 without allowance for the coupling (the dashed line KL).

It should be noted that the values of the parameter ℓ^2 for the disk agree with the values obtained for a sphere [1]. The strong difference between the experimental values of the resonant frequencies of boundary oscillations of the first and second domain groups show that, at least for yttrium garnet, the demagnetizing field of the sample is the main "elastic force" determining the resonant frequency of the domain-boundary displacement.

[1] V.I. Dudkin and A.I. Pil'shchikov, Zh. Eksp. Teor. Fiz. 52, 677 (1967) [Sov. Phys.-JETP 25, 444 (1967)].
[2] V.I. Dudkin and A.I. Pil'shchikov, ibid. 53, 56 (1967) [26, 38 (1968)].

DYNAMICS OF CLEARING CLOUDS WITH A LASER BEAM

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1. Much importance is being attached in meteorology to the artificial creation of transparency "windows" in fogs and clouds. One of the effective means is to evaporate the drops with powerful laser radiation [1, 2]. Under laboratory conditions, the clearing of clouds was investigated in [3, 4]; the corresponding theory was developed for plane homogeneous waves in [3 - 5].

We report here the results of a theoretical analysis of the formation of a cleared channel in a cloud by passage of a bounded laser beam. We trace the dynamics of the expansion of the channel cross section and the rate of its growth. We discuss the influence exerted on the clearing process by the motion of the cloud (wind) and by diffusion blurring of the channel.

2. A cloud (or fog) consists of minute drops with radius $r_d = 5$ μ. For CO_2 laser radiation with $\lambda = 10.6$ μ (the relation $r_d \lesssim \lambda$ is satisfied) the cross sections for the scattering and absorption of individual drops is proportional to their volume, and the transport equation for the wave intensity takes the form

$$\frac{\partial I}{\partial z} + \frac{1}{c}\frac{\partial I}{\partial t} + (\alpha_s + \alpha_a)\rho I = 0, \tag{1}$$

where c is the speed of light, α_s and α_a are the scattering and absorption mass coefficients, with values $\sim 10^3$ cm^2/g, $\rho(g/cm^3)$ is the water content of the cloud, characterizing the mass of the drops per unit volume. Under the influence of sufficiently strong radiation, the volume of the drop decreases exponentially with time [1 - 5]. The change of the water content of the cloud under such action is described by the equation

$$\frac{\partial \rho}{\partial t} + v\frac{\partial \rho}{\partial x} + \rho\frac{I}{W_c} = D\left(\frac{\partial^2 \rho}{\partial x^2} + \frac{\partial^2 \rho}{\partial y^2}\right), \tag{2}$$

where x and y are the transverse coordinates of the beam, v is the velocity of the lateral wind (the motion of the cloud along the beam hardly changes the picture; the z axis of the beam need not necessarily be directed vertically), and D is the coefficient of the Brownian or turbulent diffusion, depending on the state of the atmospheric air. The energy lost to evaporation of the drops is characterized by the parameter

$$W_c = \rho_w h_v / \alpha_w, \tag{3}$$

where $\rho_w = 1$ g/cm^3 is the density of water, $h_v = 540$ cal/g is the specific heat of vapor formation, and α_w is the coefficient of absorption of water; for the CO_2 laser radiation $\alpha_w = 1.2 \times 10^3$ cm^{-1} [4]. Taking the foregoing quantities into account, the critical energy density is $W_c = 1.89$ J/cm^2.

The transparency of the cloud is characterized by its optical thickness

$$\tau(x, y, z, t) = (\alpha_s + \alpha_a) \times \int_0^z \rho\left(x, y, z', t - \frac{z}{c} + \frac{z'}{c}\right) dz', \tag{4}$$

for which we can obtain from (1) and (2) one equation in the form

$$\frac{\partial \tau}{\partial t} + v\frac{\partial \tau}{\partial x} - D\left(\frac{\partial^2 \tau}{\partial x^2} + \frac{\partial^2 \tau}{\partial y^2}\right) = -\frac{I_0(x, y, t - z/c)[1 - \exp(-\tau)]}{W_c}. \tag{5}$$

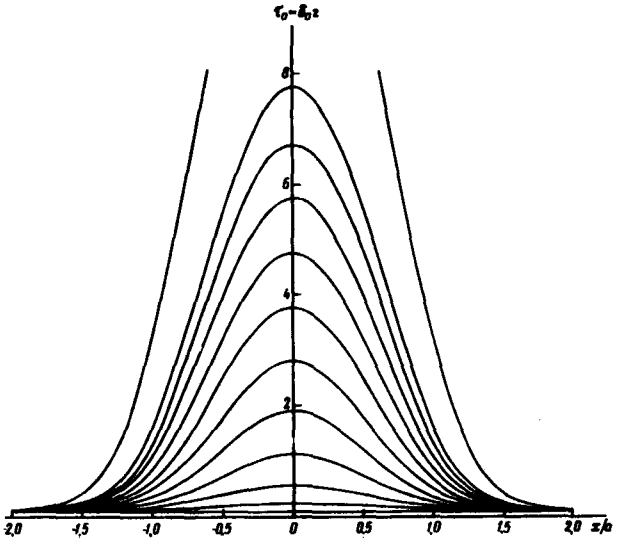

Fig. 1. Dynamics of clearing of a channel in a cloud by a Gaussian beam of a pulsed laser. The picture shows the motion of the transparency front $\tau_{tr} = 0.1$ with increasing pulse energy $W_0/W_c = 0.1, 1, 2, 3, \ldots, 10, 15$.

Here $I_0(x, y, t)$ is the intensity of the wave on entering the cloud at $z = 0$. The initial state of the transparency is characterized by the function $\tau_0(x, y, z)$; it can be usually assumed that the cloud is homogeneous, i.e., $\tau_0 = \delta_0 a$.

3. The optical thickness of the cloud varies under the influence of short pulses ($T_p \ll T_w, T_d$) in the following manner (see also [3 - 5]):

$$\tau = \ln\left\{1 + [\exp\tau_0(x, y, z) - 1]\exp\left(-\frac{W_0\left(x, y, t - \frac{z}{c}\right)}{W_c}\right)\right\}, \tag{6}$$

where

$$W_0\left(x, y, t - \frac{z}{c}\right) = \int_{-\infty}^{t-\frac{z}{c}} I_0(x, y, t')\,dt'$$

is the energy density of the laser pulse. It follows from (6) that to obtain the specified degree of transparency $\tau = \tau_{tr}$ the required energy is

$$W_0 = W_c \ln\left(\frac{\exp\tau_0 - 1}{\exp\tau_a - 1}\right). \tag{7}$$

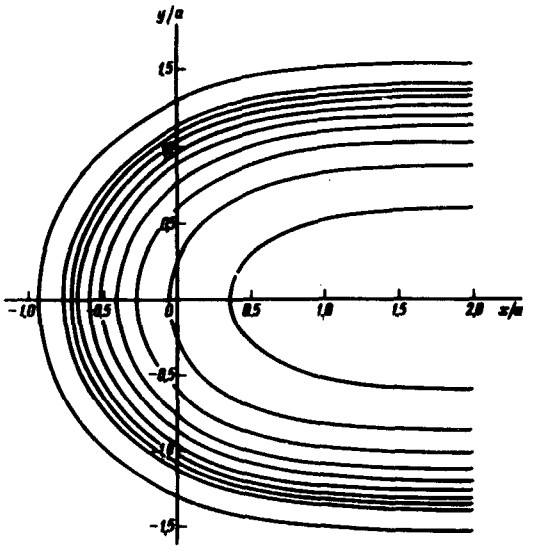

Fig. 2a. Stationary form of clear channel produced by a Gaussian beam in the presence of a strong lateral wind. The transparency fronts $\tau_{tr} = 0.1$ are shown in the section $\tau_0 = 0$ for different wind velocities (or for different values of $W_v = (\sqrt{\pi/2})I_0 a/v$: $W_v/W_c = 2, 3, 4, \ldots, 10, 15$.

The greatest transparency is reached at the end of the pulse on the beam axis. In a Gaussian beam, $I_0(r, t) = I_0(t)\exp(-r^2/a^2)$ the transparency channel at the level τ_{tr} narrows down gradually in the cloud (Fig. 1). The radius of the channel reaches a value R at the cross section z at which the initial optical thickness is

$$\tau_0(z) = \frac{W_0\exp(-R^2/a^2)}{W_c} + \ln\tau_{tr} \tag{8}$$

(we put in (8) $\tau_0 \gg 1$ and $\tau_{tr} \ll 1$). The formation of a channel with radius equal to the laser-beam radius calls for an energy e times larger than for clearing the cloud on the beam axis. The energy needed to clear the cloud increases in direct proportion to its optical thickness ($\tau_0 = (\alpha_s + \alpha_a)\rho_0 z$).

The transparency front $\tau_{tr} = \text{const}$ moves in the cloud with velocity v_{tr}:

$$v_a = \frac{c\,v_d}{c + v_d}, \quad v_c = \frac{I_0(t - z/c)[1 - \exp(-\tau_0)]}{\delta_0 W_c}. \tag{9}$$

Obviously, the rate of growth of the channel is smaller than the speed of light. Usually $v_d \ll c$ and $v_{tr} \approx v_d$ - the velocity of the transparency front is determined by the rates of evaporation of the drops in the cloud.

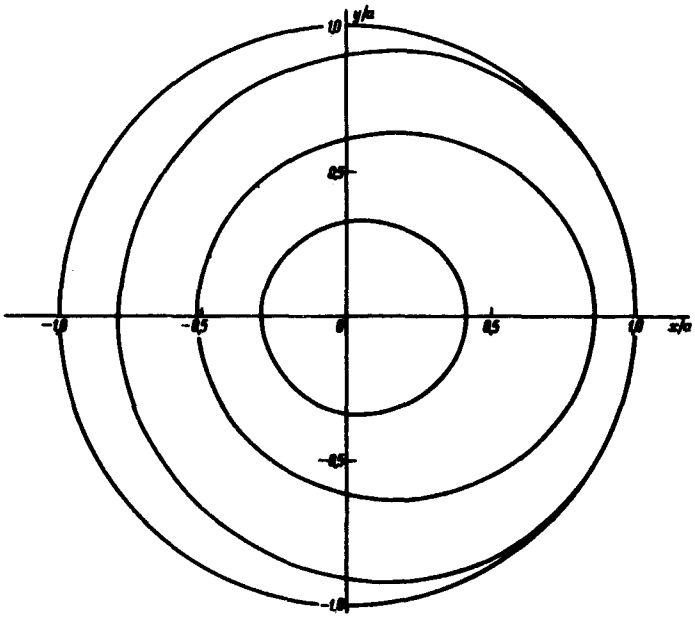

Fig. 2b. Curves of equal intensity at the level $I = I_0/a$ in the same cross section $\tau_0 = 1$ at different lateral-wind velocities: $W_v/W_c = 0$ (origin of coordinates); 0.2, 1.5, ∞.

4. The clear channel produced after the termination of a short pulse will be carried with the moving cloud and become blurred by diffusion. When sufficiently long pulses act on the cloud, these effects can influence the clearing process itself. Convective motions in the cloud can be either induced (as a result of the wind) or free (owing to the convection produced in the gravitational field). The initial stage of clearing $t \ll T_w$ is the same as in a cloud at rest. After a time $t \gtrsim T_w$ the clearing regime becomes stationary within the confines of the laser beam. The channel ceases to grow in length and is expanded by the wind along the wind direction (Fig. 2a). Formula (6) retains the same form if the energy density W_0 is replaced by the quantity

$$W_{0,w} = \int_{-\infty}^{t} I_0\left(x - vt + vt';\ y,\ t' - \frac{z}{c}\right) dt'. \tag{10}$$

Thus, the "effective" pulse duration decreases from T_p to T_w. The length of the clearing channel is determined now not by the entire pulse energy, but by part of it, $W_{0,w} \simeq I_0 T_w \simeq I_0 a/v$. The remainder of the energy goes to broadening of the channel. The velocities of atmospheric clouds are usually $v \simeq 10$ m/sec, and for a beam with radius $a \simeq 1$ m we have $T_w \simeq 0.1$ sec.

5. The formation of the transparency "window" can be influenced by drop-transport diffusion processes. In the atmosphere there is usually turbulent diffusion, $D_t \simeq 1 - 10$ m^2/sec, and in laboratory chambers we have Brownian diffusion with $D_B \simeq 10^{-7}$ cm^2/sec [6] (the latter is hindered by free convection). The start of formation of a transparency channel ($\tau \gtrsim 1$) by a Gaussian beam in the presence of diffusion, in accordance with Eq. (5), is described by the formula

$$r = r_0 - \int_0^t \frac{I_0(t - z/c - t')\exp\left[-\dfrac{r^2}{a^2(1 + t'/T_d)}\right]}{W_c(1 + t'/T_d)}\, dt'. \tag{11}$$

On the beam axis ($\tau = 0$) at $I_0 = \text{const}$ we have

$$r = r_0 - \frac{I_0 T_d}{W_c} \ln\left(1 + \frac{t}{T_d}\right) . \qquad (12)$$

Obviously, the duration of that part of the pulse which clears the channel effectively is equal to the diffusion time T_d. In the case of turbulent diffusion we have $T_d \approx 1$ sec for a beam with a = 1 m. With decreasing cross section of the high-power beam, the role of diffusion blurring of the channel increases ($T_d/T_W \approx av/D$).

6. Using the foregoing formulas it is possible to trace also the passage of the laser beam itself (Fig. 2b). In this case there is an analogy with the passage of a laser beam through a self-bleaching medium with inertial absorption mechanism. We note also that after clearing the cloud can act on the beam like a thermal lens and make it nonlinearly divergent [7, 8].

[1] F.A. Williams, Int. J. Heat and Mass Transfer 8, 575 (1965).
[2] V.E. Zuev, Rasprostranenie vidimykh i infrakrasnykh voln v atmosfere (Propagation of Visible and Infrared Waves in the Atmosphere), Sov. Radio, 1970.
[3] G.L. Lamb and R.B. Kinney, J. Appl. Phys. 40, 416 (1969).
[4] G.I. Mullaney, W.H. Christiansen, and D.A. Russel, Appl. Phys. Lett. 13, 145 (1970).
[5] S.L. Glickler, Appl. Optics 10, 644 (1971).
[6] L.T. Matveev, Osnovy obshchei meteorologii (Principles of General Meteorology), Gidromet. izd., 1965.
[7] A.P. Sukhorukov, Usp. Fiz. Nauk 103, 81 (1970).
[8] J. Wallace and M. Camac, J. Optical Soc. Am. 60, 1587 (1970).

STIMULATION OF CHEMICAL PROCESSES BY INFRARED LASER RADIATION

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In [1] we have observed the photochemical action of infrared radiation, wherein the vibrationally-excited molecules take direct part in a chemical reaction. The conclusion that vibrationally-excited molecules take part in the reaction follows also from the results of [2].

We have investigated the behavior of several inorganic chemical nonreacting systems under the influence of IR radiation of a CO_2 laser. The radiation intensity ranged from 20 to 50 W in a beam of approximate diameter 9 mm. The irradiation time was shorter than 0.5 sec. The reactions were produced in cells 20 mm in diameter and 100 mm long, with windows of AgCl. The substances absorbing the IR radiation of 10.6 μ wavelength were N_2F_4 (valent vibrations of the N-F bond $\nu_2 = 934$ cm^{-1} and $\nu_8 = 958$ cm^{-1}), BCl_3 (valent vibrations $\nu_3 = 958$ cm^{-1}), SF_6 (deformation vibration $\nu_3 = 943$ cm^{-1}), SiH_4 (deformation vibration range 910 - 1000 cm^{-1}, frequency 914 cm^{-1}), and PF_5 (valent vibration 948 cm^{-1}).

We investigated the following systems:

N_2F_4; $N_2F_4 - NO$; $N_2F_4 - NO - N_2$; $N_2F_4 - NO - CF_4$, $N_2F_4 - NO - NF_3$;
$N_2F_4 - NO - Xe$; $N_2F_4 - N_2O$; $N_2F_4 - H_2$; $N_2F_4 - CH_4$; $N_2F_4 - BCl_3$;
BCl_3; SiH_4; $SiH_4 - BCl_3$; $SF_6 - NO$; $SiH_4 - SF_6$.