

$$\frac{1 - \beta^2}{\beta} \frac{J_\nu(\nu\beta)}{J'_\nu(\nu\beta)} < \frac{3}{2\nu} \beta^2, \quad (4)$$

we have as a net result stimulated emission ($W_\nu > 1$). The stimulated emission can prevail over absorption in the ultrarelativistic case $\beta \rightarrow 1$, starting with the fundamental harmonic. Using for this case the known asymptotic formulas for the Bessel function and its derivative [5], we obtain

$$W_\nu = 1.013\nu^{-4/3} \frac{e^2 g^2 \tau}{m_0} \frac{m_0 c^2}{E} \left(1 - 0.726\nu^{4/3} \left(\frac{m_0 c^2}{E} \right)^2 \right). \quad (5)$$

We see therefore that stimulated emission will prevail over absorption up to the harmonics

$$\nu < \sqrt{\nu_{\max}}, \quad (6)$$

and that the harmonic

$$\nu_{\max} \sim (E/m_0 c^2)^3$$

gives a maximum intensity of spontaneous emission.

In particular, for an accelerator with $E \sim 50$ MeV the intensification of the emission is possible up to harmonics $\nu < \sqrt{\nu_{\max}} \sim 1000$. When $\nu > \sqrt{\nu_{\max}}$, to the contrary, the absorption energy begins to exceed the emission energy. This method (in the case of absorption) can also be used to accelerate relativistic electrons in cyclic accelerators.

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THE PHOTOREDUCTION $\text{TR}^{3+} \rightarrow \text{TR}^{2+}$ IN FLUORITE CRYSTALS

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The effect of reduction of trivalent rare-earth ions (TR^{3+}) serving as activators in CaF_2 to the divalent state has been observed so far only under the influence of hard radiation (γ , neutrons, deuterons, fast electrons), in chemical reactions, or in electrolysis. The valent transition $\text{TR}^{3+} \rightarrow \text{TR}^{2+}$ is accompanied by a crystal coloration characteristic of

the particular ion involved [1-3].

We describe in this letter the photoreduction of Nd^{3+} ions in CaF_2 crystals (type 1) to the divalent state under the influence of powerful light flashes.

The investigations were carried out with CaF_2 crystals with 0.5 wt.% Nd^{3+} (type 1) at 300°K. The crystals were synthesized by a procedure described in [4]. In addition to $\text{CaF}_2:\text{Nd}^{3+}$, we investigated crystals containing, besides neodymium, small amounts of oxygen (O^{2-}) and cerium (Ce^{3+}). The investigated CaF_2 samples were cylindrical rods ~75 mm long and ~6.5 mm in diameter. The powerful light flashes were produced by IFP-800 xenon lamps placed in an elliptical illuminator. It must be noted that the experimental setup and the processing of the crystals made it possible to obtain stimulated emission.

The effect of photoreduction was investigated by the following procedure: The absorption and luminescence spectra of the crystals were obtained prior to illumination at 77 and 300°K, using the SP-700 and DFS-12 instruments, for the purpose of comparison with the spectra of the illuminated crystals. The samples were then placed in an illumination chamber, where they were exposed to strong light flashes, and their optical spectra were again investigated after illumination.

The exposure to light colored the $\text{CaF}_2:\text{Nd}^{3+}$ (type 1) crystals light brown. A detailed analysis of the optical spectra of these crystals has disclosed the appearance of absorption bands characteristic of the Nd^{2+} ions in CaF_2 [2], and no noticeable change in the intensities of the components of the initial Stark spectrum of the Nd^{3+} ions.

Figure 1 shows the absorption spectra of $\text{CaF}_2:\text{Nd}^{3+}$ (type 1) crystals taken with the SP-700 spectrometer at 300°K before and after illumination. Figure 1a shows the spectrum of the unexposed $\text{CaF}_2:\text{Nd}^{3+}$ (type 1) crystal, while Fig. 1b shows the spectrum of the identical crystal after 1000 flashes of light (total spectrum of the IFP-800 lamp) with 500 J energy per flash. It is seen that the exposure to light gave rise to strong absorption in the ultraviolet and to several bands in the visible and infrared regions. Figure 1c shows the difference spectrum of these crystals, obtained by placing an unexposed crystal in one channel of the SP-700 and an exposed one in the other. It is seen that the difference spectrum is the absorption spectrum of the divalent neodymium ion. Figure 1d shows for comparison the absorption spectrum of a CaF_2 crystal (type 1) in which the Nd^{3+} has been reduced by gamma rays from Co^{60} .

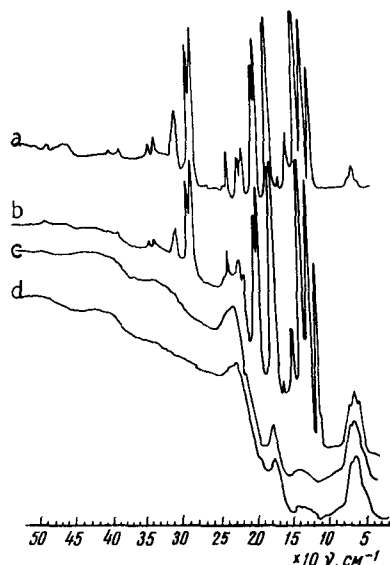


Fig. 1

The experimental results thus show that when $\text{CaF}_2:\text{Nd}^{3+}$ (type 1) crystals are exposed to powerful light flashes the Nd^{3+} is reduced to Nd^{2+} .

A more detailed report of the study of the photoreduction in $\text{CaF}_2:\text{TR}^{3+}$ crystals will be published in a separate paper; some preliminary conclusions can, nevertheless, probably al-

ready be drawn. When the crystals are exposed to flashes of light, free electrons and holes are produced in the energy bands. Since the width of the forbidden band of CaF_2 is ~ 10.6 eV [1], this ionization process is apparently connected either with a two-photon mechanism or with ionization of the impurity levels with energy < 6.2 eV (2000 \AA). The free electrons captured by the Nd^{3+} ions produce the Nd^{2+} ions and thus cause the observed effect.

It turns out further that the photoreduction is influenced also by some extraneous impurities. Thus, for example, O^{2-} and Ce^{3+} impurities enhance the valent transition of the neodymium. Crystals containing these impurities contain more Nd^{2+} , other conditions being equal, than "pure" $\text{CaF}_2:\text{Nd}^{3+}$ crystals. We believe that this is due to the fact that the O^{2-} and Ce^{3+} impurity ions may produce additional levels of hole localization, and by the same token increase the stability of the produced Nd^{2+} ions, which usually have low stability in "pure" crystals.

The observed effect explains the nature of "aging" of $\text{CaF}_2:\text{Nd}^{3+}$ crystals (type 1) under stimulated emission conditions, as observed by A. A. Kaminskii, L. S. Kornienko, and A. M. Prokhorov [5].

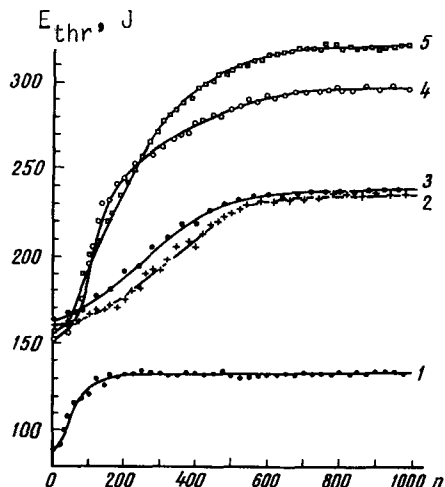


Fig. 2. "Aging" curves of "pure" $\text{CaF}_2:\text{Nd}^{3+}$ crystals (curve 1) and of crystals with O^{2-} and Ce^{3+} impurities (curves 2 - 5) in the generation mode. $E_{\text{exc}} = 500$ J (1), 330 J (2, 3), 500 J (4), and 800 J (5).

Figure 2 shows plots of the threshold generation energy of the $\text{CaF}_2:\text{Nd}^{3+}$ crystals. It turns out that the thresholds for generation and for accumulation of Nd^{2+} ions rise in parallel fashion. The concentration of the Nd^{2+} ions at the given light-flash energies exhibits saturation. The dependence of the limiting concentration of Nd^{2+} on the flash energy is apparently connected with different de-excitation action of the exciting light.

In this connection, we can explain the "aging" of $\text{CaF}_2:\text{Nd}^{3+}$ crystals as follows: The appearance of the Nd^{2+} ions in the crystals leads to parasitic absorption at the frequencies of the working pump bands of Nd^{3+} . In other words, a filter tuned to the excitation frequencies is produced. In addition, noticeable absorption at the generation wavelength 10461 \AA (9559 cm^{-1}) appears, and this also raises the threshold and lowers the efficiency. It was also observed earlier [5] that filtering of the UV band from the radiation spectrum of the excitation lamp eliminates the harmful "aging" effect. Our investigations

of the photoreduction phenomenon under analogous conditions also shows that no Nd^{2+} is observed in this case.

Further investigations of the photoreduction of Nd^{3+} in crystals of the fluorite type will apparently lead to methods for eliminating "aging" in the generation mode. Thus, for example, this effect can be eliminated by introducing additional optically-active impurities which have a larger electron capture cross section than the working ions.

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CONCERNING ONE METHOD OF ANALYZING MAGNETIC BREAKDOWN IN METALS

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As is well known [1], magnetic breakdown, which is observed in many metals placed in a constant and homogeneous magnetic field $\vec{H} = \{0, 0, H\}$, is due to quantum tunneling of a charged quasiparticle (conduction electron) between closely-lying trajectories $\epsilon_s(\vec{p}) = E$, $p_z = p_{z0}$ ($\epsilon_s(\vec{p})$ = dispersion law, \vec{p} = quasimomentum, s = number of band; the energy E and the projection of the momentum on the z axis are conserved), which determine the classical motion of the electron in \vec{p} -space. In constructing a quantitative theory of magnetic breakdown, greatest interest is attached to the calculation of the probability of interband breakdown and the determination of the jump in phase of the quasiclassical wave function, a jump occurring when the electron goes from one trajectory to another. In the quasiclassical approximation, which is well satisfied in metals, these two quantities determine completely the energy spectrum and the wave function of the quasiparticle and enter in all the macroscopic electronic characteristics of the metal.

In this note we propose to analyze interband magnetic breakdown by a method which yields simple analytic expressions for the breakdown probability and the phase difference; these equations are valid in the entire interval of magnetic-field variation ¹⁾. In accord with the presently held view concerning charged quasiparticles as the carriers of conductivity in metals, the analysis is carried out in terms of an arbitrary dispersion law.

We shall carry out our investigation for a case when the points in \vec{p} -space, where the difference $\epsilon_1(\vec{p}) - \epsilon_2(\vec{p}) = \Delta(\vec{p})$ is small, are concentrated near a certain plane. (This situation is typical of metals.) For simplicity we can assume that at fixed p_x and p_z the minimum of $\Delta(\vec{p})$ ($\min \Delta(\vec{p}) \neq 0$) is reached on the plane $p_y = 0$.

In regions of \vec{p} -space that are sufficiently remote from the plane $p_y = 0$, we can neglect interband transitions and the wave function $G_s(\vec{P})$ of the electron in the \vec{p}, s representation (defined as the coefficients of the expansion in terms of the functions $\tilde{\psi}_{\vec{p}, s}$ = $u_{\vec{p}_x + eH_y/c, \vec{p}_y, \vec{p}_z}^{(s)}(\vec{r}) \exp(i\vec{p} \cdot \vec{r}/\hbar)$, where $u_{\vec{p}}^{(s)}(\vec{r})$ is the periodic multiplier in the Bloch function), written in the quasiclassical approximation, and is of the form