contraction in the normal and radial directions), the optical properties of the radially and normally polarized beams differ (see (1)). This means that a complicated and variable polarization of the light beam will be observed from the very beginning of the formation of the channel.

Thus, the results of [3] cannot describe even stationary self-focusing of light in solids via the electrostriction mechanism. An important factor is that if stationary self-focusing does take place in this case, then not all the light rays will be retained in the channel, but only those having a definite polarization.

[1] G. A. Askar'yan, JETP 42, 1567 (1962), Soviet Phys. JETP 15, 1088(1962).
[2] V. I. Talanov, Izv. Vuzov, Radiofizika 7, 564 (1964).
[3] R. I. Chiao, E. Garmire, and C. H. Townes, Phys. Rev. Lett. 13, 479 (1964).
[4] L. D. Landau and E. M. Lifshitz, Teoriya uprugosti (Theory of Elasticity), M., 1965.
[5] D. I. Abakarov, A. A. Akopyan, and S. I. Pekar, JETP 52, 463 (1967), Soviet Phys. JETP 25, in press.

COHERENT PHOTON DECAY IN A NONLINEAR MEDIUM

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The purpose of the present communciation is to estimate the possibility of observing a new type of light scattering, whereby the incident wave ("pump")

$$\frac{1}{2}\mathbf{E}_3 \exp[i(\omega_3 t - \mathbf{k}_3 r)] + \text{c.c.}$$

is transformed, as a result of the nonlinear polarizability of the medium, into a pair of waves

$$\frac{1}{2}\mathbf{E}_{1,2} \exp[i(\omega_{1,2} t - \mathbf{k}_{1,2} r)] + \text{c.c.},$$

satisfying the conditions $\omega_3 = \omega_1 + \omega_2$ and $\vec{k}_1 + \vec{k}_2 - \vec{k}_3 = \Delta = 0$. In the optical band, these conditions lead, as a result of the dispersion of the refractive index $n(\omega)$, to a practically single-valued (or doubly-valued) connection between the direction and the frequency of the scatterd radiation. This effect is similar to spontaneous Mandel'shtam-Brillouin scattering, the second electromagnetic wave playing here the role of the acoustic wave. We confine ourselves to the case when $t\omega_{1,2} >> kT$ and the medium is transparent at frequencies $\omega_{1,2}$, so that the scattering is connected only with quantum fluctuations [1]. These fluctuations determine the noise level of parametric light amplifiers and probably the efficiency of the existing pulsed parametric light generators, in which no stationary oscillation amplitude manages to establish itself.

In the case of low pump power (when the gain is $G \leq 1$ and the principal role is played by spontaneous decay) the scattered radiation can be called "parametric luminescence" with corresponding "parametric superluminescence" when $G > 1$. We present below formulas for the intensity S and the band $\Delta\omega$ of the frequencies emitted in a given direction in these two cases.

The spectrum of parametric luminescence ω is limited, besides the condition $\Delta = 0$, only by the condition that the crystal be transparent at the frequencies ω and $\omega_3 - \omega$.* For example, in the case of the $LiNbO_3$ crystal, at $\lambda_3 = 0.5\ \mu$, the luminescence spectrum spans the intervals $\lambda \sim 1.7 - 4\ \mu$ (these waves are scattered at angles $\nu \sim 0 - 30^\circ$) and $\lambda \sim 0.7 - 0.55\ \mu$ ($\nu \sim 0 - 5^\circ$). It is possible for backward waves ($\nu > \pi/2$) and radio waves to be emitted, too. Of course, the coherent directional emission is accompanied by diffuse scattering due to the fluctuations of the density and orientation of the scattering centers. Its observation in the optical band, however, is apparently impossible.

Assume that a wave with frequency ω_3 is incident on a uniaxial negative crystal perpendicularly to its face (the linear dimensions of the face are much larger than the layer thickness z), with a polarization vector $\vec{e}_3$ perpendicular to the optical axis and $\vec{e}_{1,2} \perp \vec{e}_3$. In the case when $G \leq 1$ we can obtain with the aid of perturbation theory the following expression for the luminescence intensity with frequency $\omega_1 \pm \Delta\omega_1/2$, radiated into a solid angle $d\Omega_1$ in the direction ν_1, ϕ_1:

$$\frac{dS_1}{d\Omega_1} = S_3 \frac{\hbar n_1 \omega_1^4 \omega_2 \, |e_1 \hat{\chi} e_2 e_3|^2 z}{c^5 n_2 n_3 |\cos\nu_1 \cos\nu_2|} (z\,\Delta\omega_1), \tag{1}$$

where $\hat{\chi}$ is the tensor of nonlinear polarizability of the crystal and $\Delta\omega_1$ is the effective band of the noise scattered in the given direction:

$$\Delta\omega_1 = 2\pi (z\,\partial\Delta_z/\partial\omega_1)^{-1} .$$

In the case of the $LiNbO_3$ crystal at $\lambda_3 = 0.5\ \mu$ it follows from the $n(\omega)$ relation that waves with $\lambda_1 = 0.7\ \mu$ and $\lambda_2 = 1.7\ \mu$ are emitted in the $\nu = 0$ direction, with $\Delta\omega_1/2\pi c = 9/z$ cm^{-1}. Putting in (1) $e_1\hat{\chi}e_2e_3 = 10^{-8}$ abs. units and $z = 1$ cm we get $dS_1/d\Omega_1 = 2\times10^{-7}S_3$.

This estimate demonstrate the feasibility of experimentally investigating this effect, for example with the aid of cw lasers**. Such experiments will make it possible, for example, to measure the absolute magnitude and dispersion of $\hat{\chi}$, determine the tuning characteristics of the parametric light generators and frequency converter. Of great interest are measurements of the mutual correlation of the radiation at the frequencies ω_1 and ω_2. [1-3]

When $G \gg 1$, the connection between S_1 and S_3 becomes nonlinear (making it possible to determine G by measuring the $S_1(S_3)$ relations). In this case the fluctuations cannot be calculated by probability methods and it becomes necessary to use, say, the three-dimensional analog of the method used in [1]. If we start from the limiting noise figure of an arbitrary amplifier, as defined by Heffner [4] on the basis of the uncertainty relation, then

$$\frac{dS_1}{d\Omega_1} = (2\pi)^{-3} \hbar\omega_1 k_1^2 (G_0 - 1)\, \Delta\omega_1\, \eta \quad , \tag{2}$$

where $G = 1 + \sinh^2(\beta z\sqrt{1 - \Delta_z^2/4\beta^2})/(1 - \Delta_z^2/4\beta^2)$ is the gain (without allowance for losses), $G_0 = \cosh^2\beta z$, $\beta^2 = (2\pi)^3\omega_1\omega_2|e_1\hat{\chi}e_2e_3|^2 S_3|c^3 n_1 n_2 n_3 \cos\nu_1 \cos\nu_2|^{-1}$, and η is a coefficient of order 1. When $\beta z \ll 1$, Eq. (2) goes over into (1).

In conclusion we note that it is of interest to obtain a more rigorous derivation of (2), and also to take into account the losses and the thermal fluctuations. We note that similar scattering of the type $\omega_1 + \omega_3 \rightarrow \omega_1 + \omega_2$ in liquids at $\omega_{1,2} \sim \omega_3$ can likewise probably reach an observable magnitude.

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[1] W. Lisell, A. Yariv, and A. Siegman, Phys. Rev. 124 1946 (1961).
[2] J. Gordon, W. Loisell, and L. Walker, Phys. Rev. 129, 481 (1963).
[3] B. R. Wollow and R. Glauber, Phys. Rev. (in press).
[4] H. Heffner, PIRE 50, 1604 (1962).
[5] S. E. Harris, M. K. Oshman, and R.L. Byer, Phys. Rev. Lett. (in press).
[6] S. A. Akhmanov, V. V. Fadeev, R. V. Khokhlov, and O. N. Chunaev, Symp. on Modern Optics, March 1967, USA; JETP Letters v.6, no. 3, in press.
[7] D. Magde and H. Mahr, Bull. Amer. Phys. Soc. 12, no. 3, 273 (1967).

*In the presence of absorption at one of the frequencies, the luminescence intensity $dS/d\Omega$ decreases by a factor az (a = absorption coefficient).

** Preliminary experiments by D. P.Krindach with an argon laser have shown that parametric luminescence can be readily observed with the unaided eye (private communication). Harris et al. [5] also observed luminescence of a lithium niobate crystal in the direction $\nu \sim 0^\circ$ upon excitation with an argon laser. Observation of the effect in LiNbO$_3$ and ADP crystals excited by pulsed laser is reported in [6] (λ_3 = 0.6/3 μ) and [7] (λ_3 = 0.69/2 μ).

NOTE

Concerning the article by B. N. Bogomolov et al., Vol. 5, No. 7

As pointed out by Sh. M. Kogan, the possibility of obtaining N-shaped current-voltage characteristics in Corbino discs placed in a magnetic field, which was experimentally demonstrated in our letter (JETP Letters 5, 212, 1967, transl. p.169), was theoretically predicted by F. G. Bass (JETP 48, 275, 1965, Soviet Phys. JETP 21, 181, 1965).

The authors express their apology for omitting a reference to this article.

ERRATUM

Article by A. M. Leontovich et al. Vol. 5, No. 9, transl. p. 259

Figure 2 should read "20 nsec" in lieu of "20 msec."