β, namely $|\zeta^2| = 1.9 \times 10^{-38}$ $g^2 cm^2/sec^2$, $\hbar\omega = 0.53$ eV, $\Delta = 0.29$ eV, $\kappa = 16$, $m_c = 0.037m$ [5], $\gamma_1 = 13.2\bar{\gamma} = 4.9$ [4], and $\epsilon_0 = 0.8$ eV (at room temperature), we obtained an estimate of the value of the coefficient of the two-photon absorption in germanium, namely $\beta_{theor} = 0.1$ cm/MW.

The discrepancy between the experimentally and theoretically obtained values of β can probably be attributed to two causes. First, in the experiment we were unable to determine the distribution of the intensity of light over the cross section of the beam. The non-equilibrium distribution of the light intensity over the cross section should lead only to an overestimate of β. Second, one cannot exclude the possibility of an appreciable contribution to β from indirect two-photon transitions. Both these factors call for further study.

In conclusion, we are grateful to N. A. Penin and T. I. Galkina for a discussion of the work and V. V. Kostin for help with the measurements.

[1] V. V. Kostin, L. A. Kulevskii, T. M. Murina, A. M. Prokhorov, and A. A. Tikhonov, ZhPS 6, 33 (1967).
[2] M. S. Bespalov, L. A. Kulevskii, V. P. Makarov, A. M. Prokhorov, and A. A. Tikhonov, Zh. Eksp. Teor. Fiz. 55, 144 (1968) [Sov. Phys.-JETP 28, 77 (1969)].
[3] G. Dresselhaus, A. F. Kip, and C. Kittel, Phys. Rev. 98, 368 (1955).
[4] J. M. Luttinger, ibid. 102, 1030 (1956).
[5] L. M. Roth, B. Lax, and S. Zwerdling, ibid. 114, 90 (1959).

SIMULTANEOUS GENERATION OF TWO WAVES OF DOUBLE FREQUENCY IN A NONLINEAR CRYSTAL

M. P. Golovei and G. I. Kosourov
Institute of Crystallography, USSR Academy of Sciences
Submitted 16 December 1968
ZhETF Pis. Red. 9, No. 4, 225-228 (20 February 1969)

The question of effective frequency conversion with satisfaction of the so-called condition of vector synchronism was considered in many papers, for example, as applied to the study of the generation of harmonics in focused beams [1-3] and to the generation of sum and difference frequencies [4,5]. In these studies, sight was lost of the fact that it is possible to satisfy the synchronism condition for several directions simultaneously. In the present paper we demonstrate such a possibility, using the KDP crystal as an example.

When two plane monochromatic electromagnetic waves with frequency ω and with wave vectors $\vec{k}_1$ and $\vec{k}_2$ making an angle Δ propagate in a nonlinear medium, a wave of quadratic polarization is produced and breaks up into three plane polarization waves of frequency 2ω and wave vectors $2\vec{k}_1$, $\vec{k}_1 + \vec{k}_2$, and $2\vec{k}_2$, propagating in the directions of the initial waves and in the direction of the bisector of the angle between their normals. For optically negative crystals such as KDP, the initial waves are ordinary waves and the moduli of the wave vectors of the polarization waves are respectively

$$2k = 2(\omega/c)n_1^o, \quad 2k\cos\frac{\Delta}{2} = 2(\omega/c)n_1^o\cos\frac{\Delta}{2}, \quad 2(\omega/c)n_1^o.$$

Each of these polarization waves can effectively radiate an electromagnetic harmonic wave of frequency 2ω, with the same normal, only if its propagation velocity is equal to the wave velocity of the extraordinary wave of the harmonic in the same direction. This leads to the synchronism conditions:

$$n_1^o = n_2^e\left(\theta - \frac{\Delta}{2}\right), \quad n_1^o \cos\frac{\Delta}{2} = n_2^e(\theta), \quad n_1^o = n_2^e\left(\theta + \frac{\Delta}{2}\right), \tag{1}$$

where θ is the angle between the bisector of the normals of the initial waves and the optical axis of the crystal.

Simultaneous satisfaction of all three synchronism conditions is impossible. Usually one of the conditions is satisfied. Either one of the waves proceeds in the synchronism direction

$$\theta \pm \frac{\Delta}{2} = \theta_o = \arcsin \frac{n_2^e}{n_1^o}\sqrt{(n_1^{o2} - n_1^{o2})(n_2^{o2} - n_2^{e2})}$$

and the second wave does not take part in the generation of the harmonic, or, if convenient, $\Delta = 0$ and the waves coincide, or else the condition of the so-called vector synchronism is satisfied and the harmonic is radiated in the bisector direction. However, it is possible to satisfy simultaneously two conditions, besides the trivial case when each wave proceeds in one of the two possible synchronism directions in the crystal and generates the harmonic independently.

From the equation for the surface of the wave normals of the extraordinary wave of the harmonic and from the synchronism condition (1) we have

$$\frac{\Delta}{2} = \arccos \frac{n_2^o}{n_1^o}\{[n_2^{o2}/n_2^{e2}) - 1]\sin^2\theta + 1\}^{-1/2}. \tag{2}$$

Plotting the angles $\varphi_1 = \theta - \Delta/2$ and $\varphi_2 = \theta + \Delta/2$ as functions of the angle θ of the direction of the harmonic radiation, we obtain a closed curve (φ_1 and φ_2 are regarded as one double-valued function $\varphi(\theta)$), part of which is shown in Fig. 1. It is seen from the plot that the angle $\varphi_1 = \theta_0$, which gives a harmonic in the synchronism direction, corresponds to $\varphi_2 = \theta_0 + \Delta_1$, which, together with φ_2, gives also a harmonic in the direction $\theta_0 + \Delta_1/2$. Δ_1 can be obtained from (2) with $\theta = \theta_0 + \Delta_1/2$. This yields:

$$\Delta_1 \cong 2\,\mathrm{arc\,tg}[(n_2^{o2} - n_2^{e2})\sin 2\theta_o/(n_2^{o2}n_2^{e2})/n_1^{o2}) - (n_2^{o2} - n_2^{e2})\cos 2\theta_o].$$

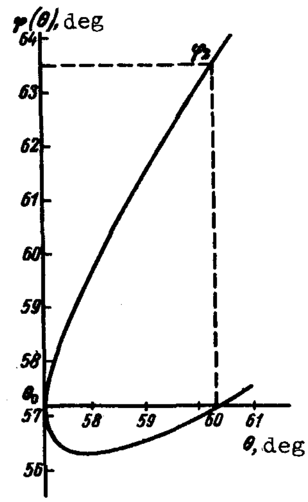

Fig. 1

The experiment was performed with a KDP crystal 40 mm long in the light of an LG-75 He-Ne laser. After passing through a 50% splitting mirror the light was directed to the crystal, which was installed in the synchronism direction. The second part of the beam was directed by means of an auxiliary mirror to the same

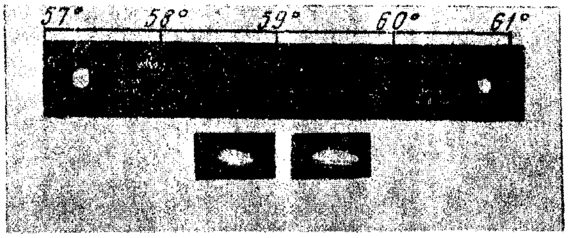

Fig. 2

crystal and the angle was chosen such as to produce a second-harmonic wave. The harmonic was separated from the fundamental radiation by means of filters and was photographed in the focal plane of a quartz lens with f = 150 mm. Figure 2 shows photographs of both harmonics and the traces of the laser beams in the focal plane of the indicated lens. For KDP, $\theta_0 = 57°8'$ and $\Delta_1 = 3°21'$.

Figure 2 shows clearly the difference in the angular distributions of the harmonic in the direction of the synchronism and of the harmonic connected with the interaction of the beams. This is due to the fact that a unique focusing of the harmonic is observed near the synchronism direction. As seen from Fig. 1, the (φ_1, φ_2) curve has a vertical tangent at the point θ_0. Therefore, at a finite aperture $\Delta\varphi$ of the laser beam, the angular dimensions of the harmonic will be quantities of second order of smallness relative to $\Delta\varphi$, and the radiation of the second wave has angular dimensions of the order of $\Delta\varphi$. For the same reason, the lateral maxima connected with the finite length of the crystal are seen clearly only in the synchronism direction.

Similar results were obtained with beams of two lasers, since the generation condition does not require coherence of the beams.

[1] P. D. Maher, R. W. Terhune, M. Nisenoff, and A. Savage, Phys. Rev. Lett. 8, 21 (1962).
[2] S. A. Akhmanov and R. V. Khokhlov, Problemy nelineinoi optiki (Problems of Nonlinear Optics), Inst. of Scient. Inform., USSR Acad. Sci., 1965.
[3] S. A. Akhmanov, A. I. Kovrigin, and N. K. Kulakova, Zh. Eksp. Teor. Fiz. 48, 1545 (1965) [Sov. Phys.- JETP 21, 1034 (1965)].
[4] Yu. A. Gol'din, V. G. Dmitriev, V. K. Tarasov, and N. V. Shkunov, Nelineinaya optika (Nonlinear Optics), Proc. 2nd All-union Symp. on Nonlinear Optics, Nauka, Siberian Div., Novosibirsk, 1968, p. 188.
[5] R. C. Miller and A. Savage, Phys. Rev. 128, 2175 (1962).

ANOMALOUS MAGNETIC SENFTLEBEN EFFECT

V. D. Borman, B. I. Nikolaev, and V. I. Troyan
Moscow Engineering Physics Institute
Submitted 23 December 1968
ZhETF Pis. Red. 9, No. 4, 229-231 (20 February 1969)

It was recently noted [1] that, unlike the observed effect in polar gases (the electric Senftleben effect) [2,3], the relative change of the thermal conductivity coefficient $(\epsilon = \Delta\kappa/\kappa_0)$ of the strongly polar gas CH_3CN (dipole moment d = 3.96 Debye) in an electric field has a strongly pronounced nonmonotonic character (the anomalous electric Senftleben effect): the quantity ϵ, which depends on the field E and on the pressure p via the ratio E/p, has a maximum $(\epsilon_{max} = 5 \times 10^{-4})$ at E/p = 180 V/cm-mm Hg, and reverses sign $(\epsilon = 0)$ at E/p = 350 V/cm-mm Hg. According to the theory presented in [4,5], the increase of the thermal conductivity coefficient is directly connected with the presence in the gas of collisions for which the detailed balancing principle is not satisfied, and therefore the anomalous effect is of considerable interest for further research. The precession of the