Thus, it is quite probable that no cosmic-ray showers are detected in Weber's experiment.

In conclusion, we are grateful to G.A. Askar'yan and E.S. Shmatko for valuable discussions, and to V.I. Kobizskii, G.L. Fursov, N.I. Mocheshnikov, and B.N. Strelkov for constant help. The authors are grateful to the crew of the accelerator of the Physico-technical Institute of the Ukrainian Academy of Sciences for consideration and hospitality.

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FEATURES OF SCATTERING OF LIGHT BY HYPERSONIC WAVES IN UNIAXIAL CRYSTALS

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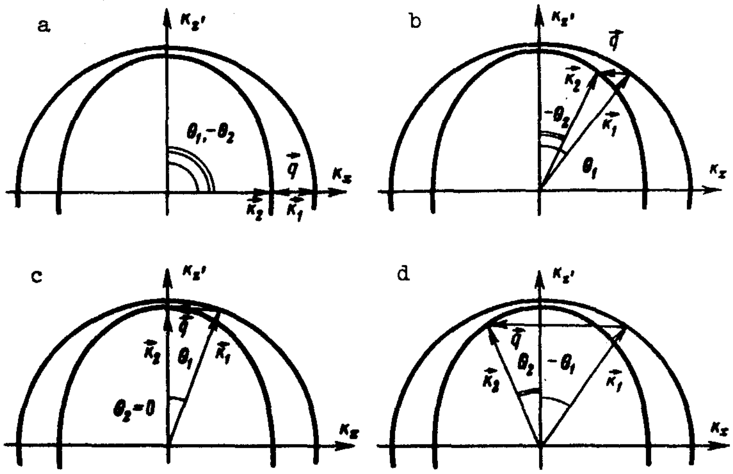
The scattering of light by elastic waves in crystals is a subtle means of investigating the characteristics of propagation of elastic waves. In this connection, it is of interest to study the features of the scattering phenomenon itself. These features can appear in optically anisotropic crystals when the plane of polarization of the light is rotated during the course of the scattering. They are well known for scattering of light by thermal phonons (see [1] and the references therein). In scattering (diffraction) of light by coherent elastic waves with lower frequency and with strictly specified propagation direction and polarization, these features become manifest more distinctly and uniquely. Scattering of light by coherent elastic waves in uniaxial crystals was first considered in [2], where only one case was investigated, wherein the plane of scattering coincided with the xy plane (z is the optical axis). Using quartz crystals as an example, it was shown that if the scattering of light is accompanied by rotation of the plane of polarization, then the geometry of the scattering differs from the normal so-called Bragg geometry in that the angles of incidence and diffraction of the light are not equal, and collinear interaction is possible when the wave vectors of the elastic waves and of the incident and scattered radiation are parallel.

In the present paper we consider a more general case, when the plane of scattering makes an arbitrary angle with the optical axis. Then the optical anisotropy of the crystal leads to such interesting effects as the appearance, at a given frequency, of elastic waves of two possible angles of incidence, and accordingly two diffraction angles.

To study the singularities of the scattering of light in an optically anisotropic crystal, it is convenient to use the wave-vector surface [3], the radius vector of which defines the value of the wave vector of the light propagating in a given direction. For uniaxial crystals this is a two-cavity surface consisting of a sphere and an ellipsoid, which are tangent to each other at two points lying on the k_z axis ($\vec{k}$ is the wave vector). During the scattering process, there should be satisfied the law of momentum conservation $\vec{k}_2 = \vec{k}_1 + \vec{q}$, where 1 and 2 pertain to the incident and scattered light, respectively, and $\vec{q}$ is the wave vector of the elastic waves. Therefore, to determine the possible scattering geometry and its dependence of the frequency of the elastic

Fig. 1. Intersections of the surfaces of the wave vectors with the scattering plane, and vector triangles of scattering. The wave vector of the elastic waves is parallel to the x axis (for clarity, the difference between k_1 and k_2 has been greatly exaggerated).



waves, it is necessary to take the intersection of the wave-vector surface with the plane of scattering, and to construct in this section all the possible vector triangles that express the momentum conservation law.

Let us consider the case when the wave vector of the elastic waves is parallel to the x axis, and the scattering occurs in the plane z'x', where z' makes an angle α with the optical axis z. We assume for concreteness that the refractive index $n_0 > n_e$ (the sphere lies outside the ellipsoid [3]) and that the incident light is ordinary, i.e., $k_1 > k_2$.

Figure 1 shows parts of the intersection of the wave-vector surface with the z'x plane (the total cross sections are a circle and an ellipse), and also several possible vector triangles. The angles of incidence (θ_1) and diffraction (θ_2) of the light are defined in the usual manner as the angles between the wave vector of the light and the normal to the wave vector of the elastic waves in the scattering plane. We introduce for the signs of the angles a definition whose purpose it is to emphasize the distinction from the normal Bragg geometry ($k_1 = k_2$, $\theta_1 = \theta_2$), for which it is assumed that θ_1 and θ_2 are both larger than zero. Using Fig. 1, we can easily obtain expressions for the angles θ_1 and θ_2 and their dependence on the frequency of the elastic waves and on the angle α. In the general case of arbitrary α, the formulas turn out to be quite cumbersome, and we confine ourselves only to a qualitative discussion.

At $\alpha = 0$ (zx scattering plane) the sections of the wave-vector surface have a point of tangency on the k_z axis. It is easily seen that in this case the scattering of the light is possible, starting with zero values of q (zero frequencies of the elastic waves) and with zero values of the angles θ. With increasing q, there can be realized either a geometry similar to Fig. 1b or a geometry of Fig. 1d. In the former case, when the frequency of the elastic waves is increased, the angles increase in absolute magnitude from 0 to 90°, with $\theta_1 > 0$ and $\theta_2 < 0$. In the latter case, the angles also increase to 90°, but both remain positive. In both cases $|\theta_1| > |\theta_2|$, with the exception of extremely high frequency ν_{max}, when $\theta_1 = \theta_2 = 90°$ (back scattering), and the collinear-scattering frequency ν_0 (Fig. 1a), where $\theta_1 = -\theta_2 = 90°$. It follows from Fig. 1 that $\nu_{max} = (v/\lambda_0)(n_0 + n_e)$, and $\nu_0 = (v/\lambda_0)(n_0 - n_e)$, where v is the velocity of the elastic waves and λ_0 is the wavelength of the light. Thus, in the case of scattering in the zx plane, at elastic-wave frequencies below ν_0, two scattering geometries are possible, i.e., two angles θ_1 and accordingly two angles θ_2.

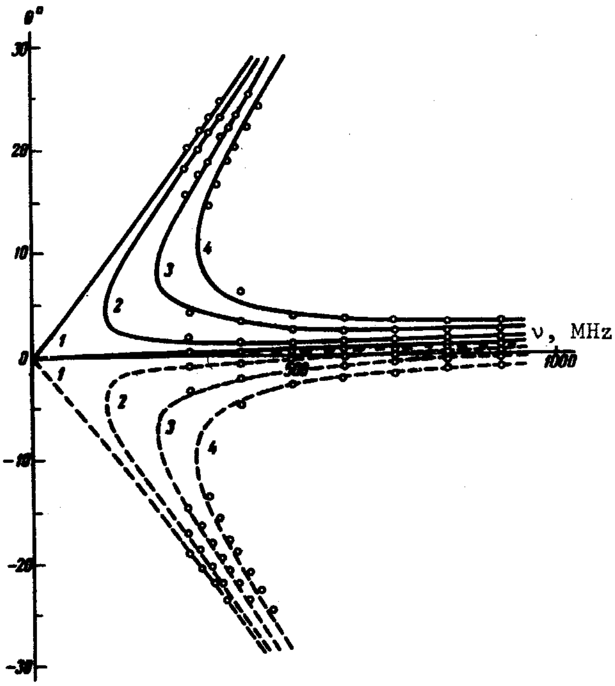


Fig. 2. Internal angles θ_1 and θ_2 vs. the frequency of the longitudinal elastic waves in a $LiNbO_3$ crystal. The elastic waves propagate along the x axis, the scattering plane is xz', where z' makes an angle α with the z axis. α: 1 - 0°, 2 - 5°, 3 - 7.5°, 4 - 10°. Solid (θ_1) and dashed (θ_2) curves - calculation.

When $\alpha \neq 0$, the circle and the ellipse cease to be tangent to each other (Fig. 1), and their splitting along the k'_z axis increases with increasing α. As seen from Fig. 1, in this case the scattering is possible starting only with a certain nonzero value q_{min} (ν_{min}), which will be the larger the larger the angle α. In all other respects, at small α, this case is analogous to scattering in the zx plane, i.e., as before, two scattering geometries are possible. Starting with a certain value of α, at which ν_{min} becomes larger than ν_0, there remains only one possible scattering geometry. This value of α depends on the refractive indices of the crystal and usually amounts to about 45°. At larger α, the geometry of the scattering turns out to be essentially similar to the geometry of the scattering in the xy plane [2], into which it goes over smoothly as $\alpha \to 90°$.

The foregoing conclusions were verified experimentally for the case of trigonal crystals of lithium niobate. We used a procedure analogous to that in [4]. The elastic waves were excited with the aid of the piezoeffect, the light source was an LG-75 laser with λ_0 = 6328 Å. To measure the dependence of the scattering geometry on the angle α, we used a sample in the form of a cylinder with a polished lateral surface.

The results of the experiment are given in Fig. 2, which shows the dependence of the internal angles θ_1 and θ_2 on the frequency of the longitudinal elastic waves at different values of α. The figure does not show points corresponding to the angles $\theta_1 = -\theta_2 = 90°$ (collinear interaction), which were observed experimentally at 935 MHz. We note that in fact one measures in the experiments the angles not of the wave vector of the light, but of the ray [3], but the corresponding corrections amount to less than 10% and were therefore disregarded.

As seen from Fig. 2, the results of the experiment agree well with calculations carried out within the framework of the concepts developed above.

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EXPERIMENTS ON THE STABILIZATION OF FLUTE INSTABILITY WITH THE AID OF AN INTEGRATING FEEDBACK SYSTEM

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In a number of experiments aimed at the study of the influence of feedback at the m = 1 mode of flute instability in the Phoenix II installation [1], it was shown that there always exists a residual instability connected with the frequency characteristic of the feedback loop. The increment of these oscillations is proportional to the upper limiting frequency of the stabilizing system, and their occurrence limits the possibility of employing such systems for plasma stabilization. To overcome this difficulty, it was proposed [2] to decrease the increment of the residual oscillations by limiting the frequency characteristic of the feedback system from above, i.e., by using an integrating amplifier. The resultant phase shift can be compensated for by measuring not the fluctuations of the electric potential, as was done in [1] and [3], but the fluctuations of the azimuthal electric field or (for a given azimuthal oscillation mode m) as the result of the azimuthal displacement of the pickup used for the fluctuations of the potential relative to the stabilizing electrode, by an angle $\pi/2m$.

Experiments aimed at verifying the foregoing idea were made with the Phoenix II installation. We used the same stabilizing electrode as in [1], and the oscillations of the potential with azimuthal mode m = 1 were measured with an electrostatic probe displaced in azimuth by 90°. The integrating amplifier ensured a feedback-loop transfer coefficient δ in the form

$$\delta(\omega) = \frac{\alpha\beta}{\tau\omega} \qquad (1)$$

up to very low frequencies $\omega \ll \omega^*$. Here α is the sensitivity of the pickup, β the gain, τ the integration constant, and ω^* the frequency of the precession of the ions about the axis of the apparatus in an inhomogeneous magnetic field. The frequency of the flute oscillations in the system without feedback was ω^* [2].

Introduction of such a feedback system led to a significant change in the behavior of the plasma. The threshold of appearance of the plasma loss increased to a certain density n, which depended on δ. At densities below threshold, just as in [1], we observed low-frequency oscillations, but unlike in [1], where the amplitude of the oscillations decreased when the feedback system was turned on by only a factor of 2, in this case introduction of the feedback was accompanied by a decrease of the oscillation amplitude by a factor of at least 30. When the new threshold density n was exceeded, flute oscillations again appeared and decreased the density to the natural threshold of the flute instability n_0. (In these experiments, carried out with injection of 8-keV atoms, the threshold density was $n_0 \simeq 1 \times 10^8$ cm^{-3}.)

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