Experimental observation of the linear polarization of parametric x-ray emission

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It has been established experimentally for the first time that parametric *x* radiation is highly linearly polarized. The position of the plane of the maximum linear polarization is found to depend on the azimuthal angle of the photon emission relative to the Bragg direction.

In 1985 a new type of electromagnetic radiation was discovered in experimental studies at the Tomsk synchrotron. This electromagnetic radiation, detected in the passage of ultrarelativistic electrons through crystals,[1,2] was called parametric x-ray emission. Parametric x-ray emission was subsequently observed experimentally in the

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electron beams of the Erevan synchrotron[3] and the synchrotron of the Khar'kov Physicotechnical Institute.[4] In Refs. 1–6 it was shown that parametric x-ray emission is characterized by a line spectrum with n-fold values of the photon energy and with a high spectral-angular density in the direction of the Bragg angles of reflection from the crystal planes.

Parametric x-ray-emission mechanism can be viewed as a dynamic diffraction of the intrinsic field of relativistic electrons from the crystallographic planes of the crystal. If the intrinsic field of an electron is though of as a set of pseudophotons,[7] we should expect that the parametric x-ray-emission photons corresponding to the Bragg reflection would be linearly polarized. The linear polarization of these photons would amount approximately to

$$P = \sin^2 2\theta_B (2 - \sin^2 2\theta_B) \qquad (1)$$

and the polarization plane would be perpendicular to the scattering plane. If, on the other hand, one considers photons which are emitted in a given direction near the Bragg angle, then dependence of the degree of polarization and the orientation of the plane of the maximum linear polarization on the observation angle would be, according to theoretical estimates, more complex and the degree of polarization of the x rays would reach unity, depending on the geometry of the experiment.

In this letter we report the first results of an experimental study of the linear polarization of parametric x radiation. The experiment was carried out with a silicon single crystal of thickness $t = 0.35$ mm for the (220) reflection. The angle of incidence of the relativistic electrons with an energy $E = 900$ MeV on the (110) plane of a silicon crystal was $\theta_B = 9°$ and the energy of the γ rays being studied was in the range $E_\gamma = 19.5$–21.5 keV (depending on the angle of detection relative to the Bragg direction). The overall experimental arrangement is similar to that in Ref. 6. To measure the polarization, we used a Compton polarimeter consisting of two detectors [based on NaI(Tl) crystals measuring $\phi 19 \times 1$ mm] and a scatterer (Plexiglas with a thickness of 1 mm). The detectors were positioned in a plane perpendicular to the Bragg direction at an azimuthal angle of 90° with respect to each other, at a distance of 50 mm from the scatterer. The axis of rotation of the polarimeter was brought into coincidence, by means of a laser, with the Bragg direction within 0.5°. The photon beam to be analyzed was shaped by a collimator, $\phi 4$ mm, which was situated a distance of 2100 mm from the crystal (corresponding to an angular capture $\Delta\theta_x = \Delta\theta_y = 0.5$ mrad), coaxially matching the axis of rotation of the polarimeter.

The polarimeter, along with the collimator, could be moved in two mutually perpendicular directions (along the x and y axes; Fig. 1a). The analyzing capability of the polarimeter for the given geometry of the experiment, calculated analytically, was $R = 0.96$. The angular distribution of the reflection relative to the Bragg direction was measured in an independent experiment in which the polarimeter, along with the collimator, was moved along the x and y axes. A PS-16 proportional counter, instead of a scatterer, was used in the experiment in this case. The results of the measurements are shown in Fig. 1b.

The labels I, II, and III in Fig. 1a indicate the regions of the reflection of parametrix x-ray emission, in which the linear polarization of the x radiation was studied. In

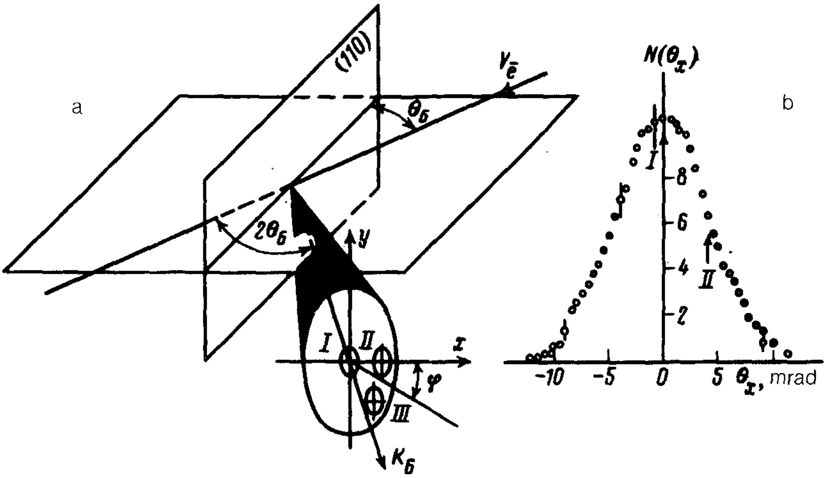

FIG. 1. (a) Experimental geometry; v_e—velocity of the initial electron, k_B—Bragg direction; (b) angular distribution of the reflection in the horizontal direction.

the experiment we measured the azimuthal dependence $N(\varphi_i)$ of the yield of the scattered quanta of the parametrix x-ray emission in the variation range of the azimuthal angle $0°\leqslant\varphi_i < 360°$. Such measurements make it possible to determine the two polarization parameters which characterize the linear polarization of the radiation (for example, the degree of polarization P and the slope φ_0 of the plane of the maximum linear polarization). The unknown quantities are incorporated in the measured dependence in the following way:

$$N(\varphi_i) = N_0\,[1 + PR\cos 2\,(\varphi_i - \varphi_0)]. \qquad (2)$$

Figure 2a shows the results of the measurement of the spectrum of scattered photons (with and without a scatterer) for region II in the case of a horizontal orientation ($\varphi = 0°$) and vertical orientation ($\varphi = 90°$) of the detectors. The degree of linear polarization P, the slope of the polarization plane φ_0, and their errors were determined by the method of least squares. The results are presented in Table I.

Figure 2b shows the measured dependence $[N(\varphi_i) - N_0]/N_0$ for region II (the solid curve is the result of fitting). As follows from the results of the experiment, the minimum polarization occurs in the Bragg direction (region I) and the slope of the polarization plane corresponds to the slope of the polarization plane for ordinary x-ray diffraction. Away from the Bragg direction the degree of linear polarization is high ($P = 0.8$), in good agreement with the conclusions of the theory.[7] In the regions II and III the polarization plane coincides with the plane that passes through the photon momentum and the vector corresponding to the Bragg direction; i.e., the polarization characteristic of parametric x-ray emission is completely analogous to that of Čerenkov (Čerenkov-Vavilov) radiation.[8] This circumstance is direct proof of the fact that at electron energies $E\sim 1$ GeV and for the chosen geometry the contribution from the

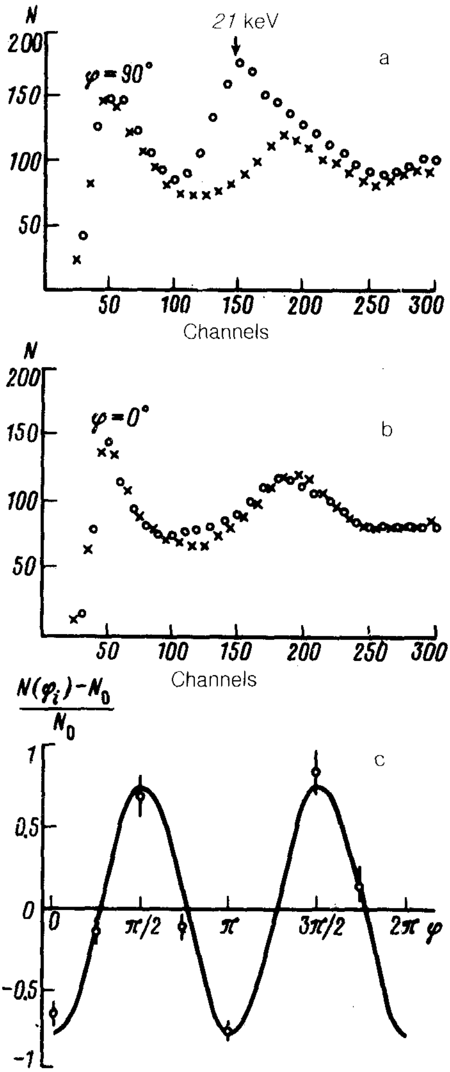

FIG. 2. (a) Spectrum of scattered photons with a scatterer (points) and without a scatterer (crosses); (b) azimuthal dependence of the scattered-photon yield for region II (points—experimental; solid curve—data fitting for $P = 0.80$).

TABLE I.

Reflection region	Angular coordinates of the collimator		P	φ_0, mrad
	θ_x, mrad	θ_y, mrad		
I	0 ± 0.5	0 ± 0.5	0.14 ± 0.06	90.5 ± 3.7
II	4.0 ± 0.5	0 ± 0.5	0.80 ± 0.08	3 ± 2.7
III	3.0 ± 0.5	− 3 ± 0.5	0.82 ± 0.12	− 51.5 ± 5.5

diffracted photons of the bremsstrahlung and from transition radiation is very small in comparison with the contribution from parametric x radiation.

A source of x radiation with a high degree of polarization and with a given direction of the polarization plane can thus be obtained by off-axis collimation of the parametric x-ray beam. In contrast with x-ray diffraction, where the Bragg angle uniquely determines the energy of the scattered photons and their polarization [see Eq. (1)], no such correlation is observed in the case of parametric x-ray emission. A high degree of polarization can be obtained even in the case of small values of θ_B (i.e., for inelastically scattered photons) by choosing a certain region of the reflections.

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