Quasi-Čerenkov radiation from 4.5-GeV electrons in diamond (experimental)

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A quasi-Čerenkov x-ray radiation by 4.5-GeV electrons from (110) planes in a diamond crystal has been observed. The photon yield increases with the thickness of the crystal.

The possible production of x radiation by a relativistic charged particle in uniform rectilinear motion in a single crystal at Bragg angles and at Bragg frequencies (quasi-Čerenkov radiation) was first pointed out in Refs. 1–3. Since then, the theory of quasi-Čerenkov (parametric) radiation has been developed for perfect crystals[4–7] and also for liquids[8] and mosaic crystals.[9] First reports[10,11] of experimental observations of this radiation have recently appeared.

In this letter we report an experimental study of quasi-Čerenkov radiation in the extracted 4.5-GeV electron beam of the Erevan synchrotron.

The use of an extracted beam in experiments of this sort results in a more reliable determination of the absolute cross section for the process.

Figure 1 shows the experimental layout. The electron beam, with a divergence of 10^{-5} rad, is incident on the target crystal in a direction making an angle of 35° with the (110) plane. The radiation from the electrons is detected at an angle $2\theta_B = 70°$ from the initial direction of the electron beam. The target crystal (0.2 or 1 mm thick) is held in a goniometer arrangement which provides remote control over the angular position of the crystal target in two mutually perpendicular directions, within an error of 4×10^{-5} rad. To orient the crystal with respect to the direction of the electron beam, we make use of the known orientation dependence of the emission of high-energy electrons as they are channeled in a single crystal. The emitted photons are detected with a proportional counter with a beryllium entrance window 0.15 mm thick, filled with the gas mixture Xe + 10%CH_4. The photons are detected in a solid angle of 2×10^{-4} sr. As a monitor procedure, we measure the number of electrons which have emitted hard bremsstrahlung photons in the crystal.

Figure 2 shows the experimental results on the observation of the emission of 4.5-GeV electrons in a diamond crystal of thickness $l = 0.2$ mm at an angle $2\theta_B = 70°$. In the experiment, we observed a peak structure in the emission at a photon energy of 8.9 ± 1 keV ($l = 1$ mm) or 9.2 ± 1.1 keV ($l = 0.2$ mm). The peak disappeared from the emission spectrum when the crystal was rotated 50 mrad around the vertical. When the angle between the (110) plane and the direction of the electron beam was changed from 35° to 30°, and the photon detection angle was correspondingly changed

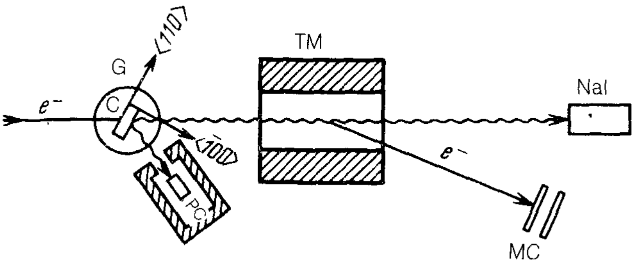

FIG. 1. The experimental layout. C—Crystal radiator; G—goniometer apparatus; PC—proportional counter; TM—turning magnet; NaI—total-absorption spectrometer; MC—monitor counters.

from 70° to 60°, the peak in the emission spectrum shifted to an energy $E_\gamma = 11.3 \pm 1.3$ (Fig. 3), in satisfactory agreement with the theoretical value $E_\gamma = 9.8$ keV found from the formula

$$\omega_B = \frac{\pi n}{a\,|\cos\theta_B\,|},$$

where ω_B is the Bragg frequency of the emission, θ_B is the angle between the momentum of the electron and the reciprocal lattice vector, a is the lattice constant, and $n = 1,2,3$ is the order of diffraction.

Table I shows the experimental results after subtraction of the background radiation on the basis of the results of measurements with an unoriented target.

In the case of a target 1 mm thick we can clearly see, at $\theta_B = 35°$, a second peak,

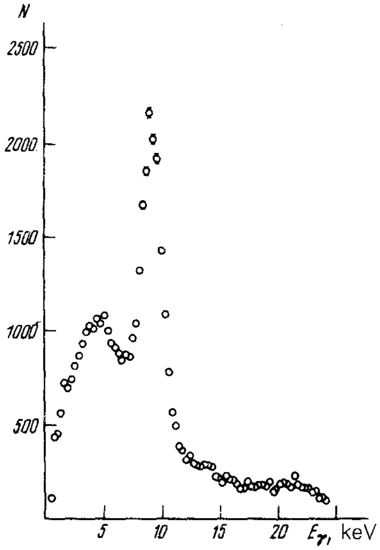

FIG. 2. Spectrum of x rays emitted at an angle $2\theta_B = 70°$ for the crystal $l = 0.2$ mm thick.

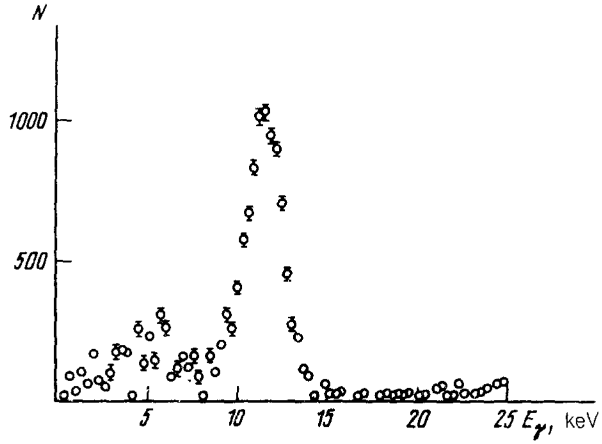

FIG. 3. Spectrum of the x rays emitted at an angle $2\theta_B = 60°$ after subtraction of the emission from an oriented crystal.

$E_\gamma = 21 \pm 1.8$ keV (the theoretical value is 19.1 keV), with a yield of $2.62 \pm 1.2 \times 10^{-7}$ photon/electron.

It can be seen from this table that for the crystal 0.2 mm thick the theoretical and experimental values of the number of emitted photons agree fairly well. In the case of the crystal 1 mm thick, in contrast, the theoretical value is substantially higher than the experimental value. A possible explanation is the imperfections of the crystal used in the experiment; the theory was derived for a perfect single crystal.

Could emission of other types contribute to this effect? In particular, the bremsstrahlung produced by a particle in a crystal might be reflected from crystallographic planes and escape from the crystal at the same angle (twice the Bragg angle) from the projectory of the particle, with the same Bragg frequency.

The number of bremsstrahlung photons formed over a distance a in the frequency

TABLE I.

θ_B	Target thickness	E_γ (keV)	Number of photons per electron	
			Experimental	Theoretical
35^0	1 mm	8,9 ± 1	$(1.1 \pm 0.1) \times 10^{-6}$	$1,38 \times 10^{-5}$
35^0	0,2 mm	9,2 ± 1,1	$(6,61 \pm 0,8) \times 10^{-7}$	1.2×10^{-6}
30^0	0,2 mm	1.13 ± 1.3	$(1.0 \pm 0.17) \times 10^{-6}$	$9,3 \times 10^{-7}$

interval $(\omega, \omega + d\omega)$ can be estimated from[1]

$$dN_{\mathrm{brem}} = \frac{a\,d\omega}{L_{\mathrm{rad}}\,\omega}\left[1 + \left(\frac{\omega_0}{\omega}\gamma\right)^2\right]^{-1} \times 2.7,$$

where ω_0 and L_{rad} are the plasma frequency and radiation length of the medium, and γ is the Lorentz factor of the particle. With $\hbar\omega = 8.5$ keV, $\gamma = 9000$ and $\hbar\omega_0 = 36$ eV (diamond) we would have $(\omega_0\gamma/\omega^2) \approx 1500$.

This result means that in the region studied we would have $dN_{\mathrm{brem}} \propto \gamma^{-2}$. If we assume that we have $d\omega/\omega \sim 10^{-2}$ in the case of Bragg reflection (in agreement with the calculated[7] spectra width of quasi-Čerenkov radiation), then for diamond 0.2 mm thick the number of reflected bremsstrahlung photons would not exceed 4×10^{-8} per particle.

For diamond of the same thickness the calculated number of quasi-Čerenkov-radiation photons [the (2,2,0) reflection; $\hbar\omega_B = 8.5$ keV; $\theta_B = 35.3°$] would be 1.2×10^{-6}, i.e., two orders of magnitude greater than the bremsstrahlung component. The intensity of the quasi-Čerenkov radiation would be essentially independent of[12] γ.

We made an attempt to experimentally estimate a possible component of ordinary bremsstrahlung. For this purpose we placed an aluminum plate 3 mm thick in front of a diamond radiator with a dimension of 0.2 mm. Within the experimental errors, we observed no increase in the emission yield due to the diffraction of real bremsstrahlung photons from the aluminum target.

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