Radiation by 28-GeV electrons in a thick tungsten crystal

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The radiation energy loss of electrons has been measured as a function of the angle between the beam axis and the $\langle 111 \rangle$ axis in a tungsten single crystal 1 mm thick at room temperature.

This letter reports measurements of the radiation by electrons in tungsten which were carried out as part of a program of research on quantum electrodynamic processes in strong fields in oriented crystals.[1] The measurements were carried out on the Kaskad experimental apparatus[2] at the Serpukhov accelerator. An electron beam with a momentum of 28 ± 1 GeV/c, an intensity of 10^4 e^-/cycle, and a divergence at the base no greater than ± 1 mrad was directed to a crystal mounted in a goniometer. This goniometer had two rotation axes, with rotation steps of 17 and 48 μrad. Beam proportional chambers determined the track of each electron within 0.1 mrad. In the crystal, the electrons emitted bremsstrahlung γ rays and were turned by the field of a magnet behind the goniometer. The γ rays passed through a helium duct to a total-absorption Čerenkov spectrometer, which determined their energy. The radiation was detected in a solid angle of 1.3×10^{-4} sr.

The target was a tungsten single crystal at room temperature. The $\langle 111 \rangle$ axis of this crystal, which has the highest potential, was oriented at a small angle with respect to the normal to the surface of the crystal. A preliminary orientation of the $\langle 111 \rangle$ axis along the beam axis was carried out on the linear accelerator at the Khar'kov Physicotechnical Institute. The angle between the $\langle 111 \rangle$ axis and the normal to the crystal surface was determined with the help of a reflected laser beam. The laser beam was used to bring the crystal into an approximately coaxial orientation with the beam on the Kaskad apparatus. Further fine adjustments were carried out on the basis of the bremsstrahlung spectrum detected by the spectrometer.

If the angle between the $\langle 111 \rangle$ axis and the electron momentum satisfies $\theta \ll \theta_v = v_0/m$ [m is the mass of an electron, and for tungsten we have $v_0(\langle 111 \rangle) = 420$ eV], the properties of the radiation, which is a magnetobremsstrahlung, are determined by the parameter $\chi_s = v_0 \epsilon / \alpha_s \mathrm{m}^3$, where ϵ is the energy of the electron, and α_s the screening radius.[3,4] With $\epsilon = 28$ GeV we have $\chi_s \approx 0.8$, and the radiation is of a substantially quantum nature. The radiation by electrons moving along the $\langle 110 \rangle$ axis had been measured previously in Ge at $\epsilon = 150$ GeV (Ref. 5) and in Ge and also Si at a different energy, $\epsilon = 170$ GeV (Ref. 6). The values found for the

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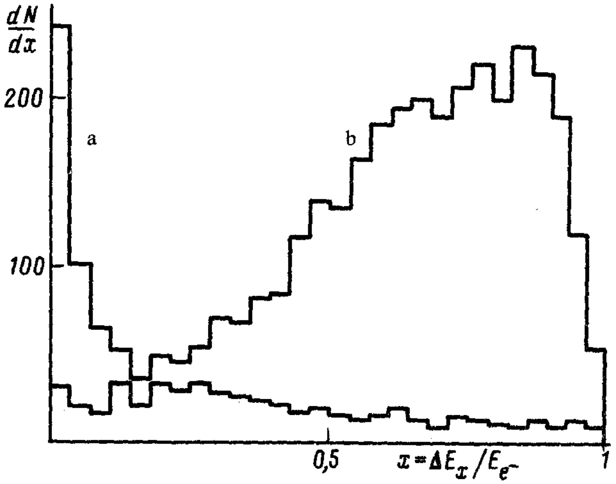

FIG. 1. Spectra radiated by electrons. a—Disoriented crystal; b—crystal oriented with its $\langle 111 \rangle$ axis along the beam direction.

parameter χ_s were $\chi_s \approx 0.8, \chi_s \approx 0.9$ (Ge), and $\chi_s \approx 0.5$ (Si), respectively. The use of tungsten thus made it possible to study the quantum properties of the radiation at substantially lower energies.

Figure 1 shows the spectra radiated by electrons in tungsten; for spectrum a the crystal was "disoriented" (the electrons moved far from axes or planes), while for spectrum b the crystal was oriented along the $\langle 111 \rangle$ axis. The spectrum in the disoriented crystal is similar to the spectrum radiated in a thick amorphous target. The average value of the γ rays in the spectrum is $\langle \Delta E_\gamma \rangle = 7.7 \pm 0.1$ GeV. The background radiation loss of electrons inthe matter before the electrons reached the crystal contributes $\langle \Delta E_{\gamma b} \rangle = 1.3 \pm 0.1$ GeV. The spectrum radiated by electrons which have passed through a crystal in a strong field has a quite different shape. Essentially all of the electrons lose some of their energy; the average value of the energy in the spectrum is $\langle \Delta E_\gamma \rangle = 18.9 \pm 0.2$ GeV.

Figure 2 shows the orientation dependence of the radiation after the background has been subtracted. The beam divergence at the base is $|\theta| < 0.3$ mrad for each point; the errors are statistical. The motion away from the $\langle 111 \rangle$ axis along the angle θ was in the direction perpendicular to the $(\bar{1}10)$ plane. The spectrum contains three regions: a strong-field region, in which magnetobremsstrahlung is the primary radiation mechanism; an intermediate region $(\theta \sim \theta_v)$; and a coherent-radiation region $(\theta \gg \theta_v)$.[3,4] The curves in Fig. 2 were calculated for three cases: 1—the orientation dependence of the radition under ideal conditions (the tungsten crystal is ideal, and all of the radiation is detected by the spectrometer); 2—the same as for case 1, but the absorption of photons in the crystal was taken into account; 3—the orientation dependence of the radiation for the actual experimental conditions (the absorption of photons, multiple scattering, the imperfections of the crystal, and the beam divergence were all taken into account). The measured energy loss thus agrees within 10% with the theoretical predictions over the entire range of angles θ studied.

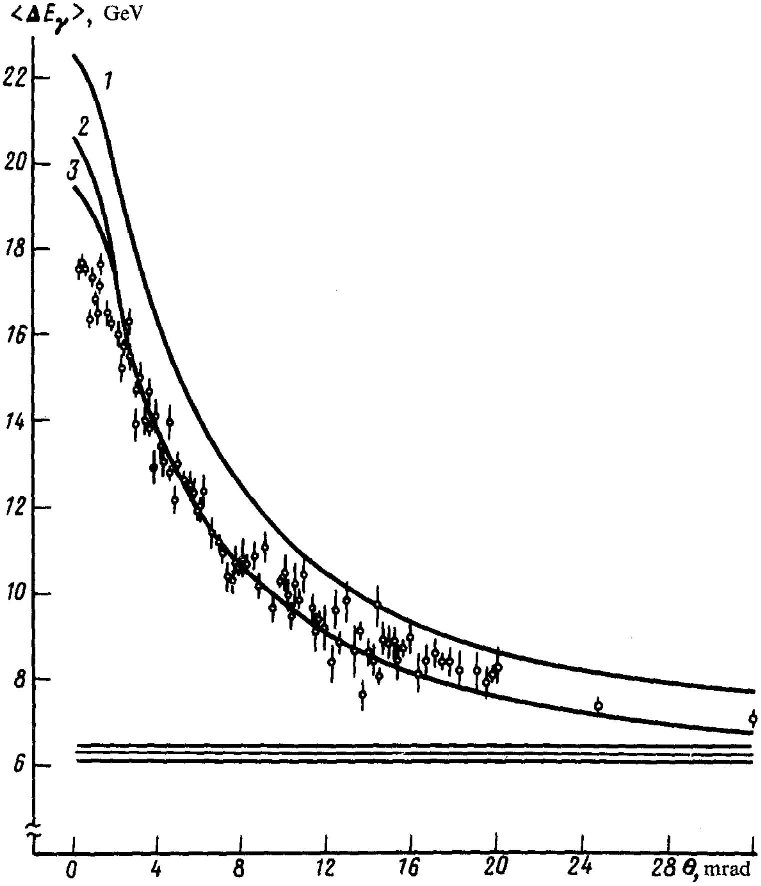

FIG. 2. Orientation dependence of the radiation by the electrons. Here θ is the angle between the $\langle 111 \rangle$ axis and the electron momentum. The solid lines show the radiation in a disoriented crystal.

The radiation length of amorphous tungsten is 3.5 mm and is essentially constant for high-energy electrons. The radiation length of a tungsten crystal depends on several factors and may be substantially smaller. In the present study the radiation length for the tungsten crystal for electrons with a momentum of 28 GeV/c, moving in the strong field along the $\langle 111 \rangle$ axis, was 0.86 ± 0.05 mm, where absorption has been taken into account (see the difference between curves 1 and 2 in Fig. 2). When the increase in the energy is taken into account, the radiation loss should decrease, to a minimum value $L_{ch} \approx 0.30$ mm at $\epsilon \sim 200$ GeV (Ref. 4). A decrease in the radiation length was also observed in Refs. 5 and 6.

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[1] V. N. Baĭer, V. A. Baskov, V. B. Ganenko *et al.*, Preprint No. 204, P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow, 1988.
[2] V. A. Baskov, V. V. Kim, V. I. Sergienko *et al.*, Preprint No. 50, P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow, 1988.
[3] V. N. Vaier, V. M. Katkov, and V. M. Strakhovenko, Phys. Lett. A **11**, 251 (1986).
[4] V. N. Baĭer, V. M. Kotkov, and V. M. Strakhovenko, Zh. Eksp. Teor. Fiz. **92**, 1228 (1987) [Sov. Phys. JETP **65**, 686 (1987)].
[5] A. Belkasem *et al.*, Phys. Lett. B **177**, 211 (1986).
[6] J. F. Bak *et al.*, Phys. Lett. B **213**, 242 (1988).

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