Study of the electromagnetic shower produced by electrons in a tungsten single crystal

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The spectra and orientation dependence of the positrons in a shower produced by a 700 MeV electron beam in a tungsten single crystal of thickness 1740 μm have been measured. The results of a study of the scattering of a 1000 MeV electron beam in this single crystal are reported. It is observed that the periodicity of the structure of the target appreciably influences the spectral distributions of the positrons in a shower.

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The interaction of electrons and positrons with thick single crystals, as well as with amorphous targets, leads to the production of an electromagnetic shower. While showers in amorphous targets have been studied rather completely both theoretically and experimentally (see for example Refs. 1–3), showers in single crystals have not been studied at all. At the same time studies of the elementary electromagnetic processes (scattering, bremsstrahlung, annihilation)[4–6] in thin single crystals have revealed appreciable orientation effects which can influence some characteristics of a shower in thick crystals. The lack of theoretical and experimental results and also the possibility of practical application of the results make it important to investigate showers in single crystals.

The purpose of the present work is to study experimentally the effect of the crystal structure on the yield of positrons formed as the result of development of an electromagnetic shower in tungsten. The positrons can be channeled, and a maximum in the direction of the single-crystal axis will be observed in the angular distribution of the positrons leaving the crystal. The width and intensity of this maximum should depend to a great extent on the value of the critical channeling angle ψ_c for relativistic particles, which according to Lindhard's theory[7] is determined from the expression

$$\psi_c=(4Ze^2/Ed)^{1/2},$$

where Z is the atomic number of the crystal, e is the charge of the electron, E is the positron energy, and d is the distance between atoms along a string.

If the channeling effect is important, use of a single crystal as an electron-positron converter can lead to an increase in the conversion coefficient and can improve the emittance of the accelerated positron beam.

The work was carried out in the electron linear accelerator at our institute. A diagram of the experiment is shown in Fig. 1. A beam of accelerated electrons with initial divergence ~10^{-4} rad hit a target 1 mounted on a goniometer 2. The spectra and orientation dependence of the electrons and positrons of a given energy were measured by means of a magnetic spectrometer 3 and an ionization chamber 4 in a solid angle ~10^{-6} sr at zero angle with respect to the beam axis. The error in determination of the positron or electron energy did not exceed ±2 MeV. The relative errors in measurement of the electron or positron intensity did not exceed 5% for a fixed particle energy. All curves were obtained in the continuous recording mode in a two-coordinate recording potentiometer. The experimental technique has been described in more detail previously.[8,9] The targets were plates of single-crystal and amorphous tungsten of thickness 1740 μm (≈0.5 radiation length). The crystal was cut perpendicular to the [111] axis. It was feared that with this crystal thickness coherent effects would be greatly decreased as the result of multiple scattering and that it would not be possible to orient the crystal in the usual manner. However, collimation of the bremsstrahlung in a solid angle ~10^{-6} sr permitted reliable orientation of the crystal (Fig. 2a) (ϑ is the angle between the beam axis and the [111] axis of the crystal).

In Fig. 2b (curve 1) we have shown the orientation dependence of the yield of 40-MeV positrons from the investigated crystal at an incident-electron energy E_0 = 700 MeV. The shape of the curve favors the idea suggested above that the shower positrons are channeled; however, this same shape of the dependence of the yield of 40-MeV electrons (curve 2) and the dependence of the yield of 600-MeV positrons on the angle ϑ (Fig. 2c) indicate that the channeling effect is unimpor-

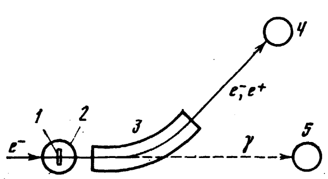

FIG. 1.

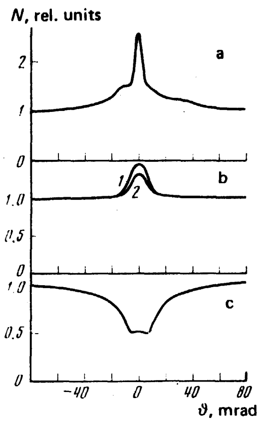

FIG. 2.

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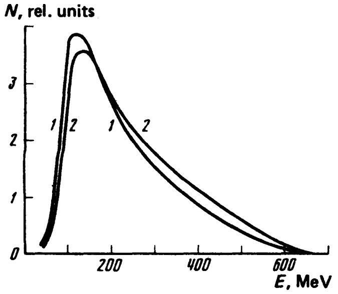

FIG. 3.

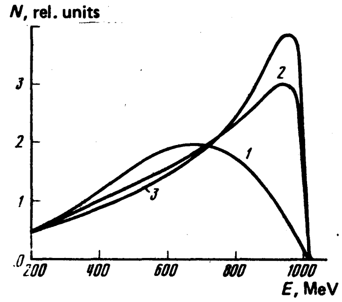

FIG. 4.

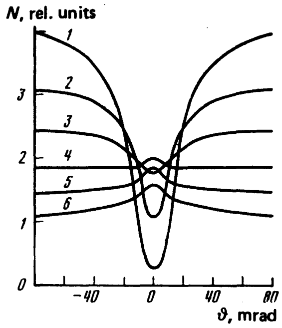

FIG. 5.

tant or is suppressed by other effects. The increase in the yield of positrons and electrons at small crystal-orientation angles is apparently due to coherent bremsstrahlung of the electron beam.

In Fig. 3 we have shown the spectra of shower positrons at orientation angles $\vartheta=0$ (curve 1) and $\vartheta=0.1$ rad (curve 2) at an incident-electron energy $E_0=700$ MeV. The spectrum of positrons from the amorphous target coincides with curve 2 within experimental error.

The rapid drop in positron yield at energies below ~150 MeV can be partially explained by the rapid removal of these particles from a given solid angle as the result of the increase of their initial angular distribution and multiple scattering in the target. A similar result was obtained by Grishaev *et al.*[10] The observed difference in the spectra for the two crystal orientations cannot be explained just by the occurrence of coherent bremsstrahlung, which increases the contribution of low-energy photons. The decrease of the yield of high-energy positrons at $\vartheta=0$ in this solid angle may be the consequence of anomalously high scattering of the beam by a string of atoms.[4] To clarify this question we measured the spectra of electrons which had passed through the crystal (Fig. 4) at orientation angles $\vartheta=0$ (curve 1), $\vartheta=33$ mrad (curve 2), and $\vartheta=66$ mrad (curve 3). The electron beam energy was $E_0=1000$ MeV. Analysis of the results shows that the contribution of electron scattering by strings of atoms may be significant. This is confirmed also by the family of orientation dependences (Fig. 5) of the yield of secondary electrons with energies 1000, 900, 800, 700, 600, 500 MeV (respectively curves 1 2, 3, 4, 5, and 6) from the single crystal.

Thus, on the basis of the experimental results we can conclude that the target structure appreciably affects the development of the shower and, in particular, the positron yield.

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[1]H. H. Nagel, Z. Phys. **186**, 319 (1965).
[2]I. P. Ivanenko, Élektromagnitnye kaskadnye protsessy (Electromagnetic Cascade Processes), Moscow State University, 1972.
[3]O. A. Zaĭmidoroga, Yu. D. Prokoshkin, and V. P. Tsupko-Sytnikov, Zh. Eksp. Teor. Fiz. **51**, 749 (1966) [Sov. Phys. JETP **24**, 498 (1967)].
[4]I. A. Grishaev, V. L. Morokhovskiĭ, and B. I. Shramenko, Tr. V. Vsesoyuznogo soveshchanya po fizike vzaimodeĭstviya zaryazhennykh chastits s monokristallami (Proceedings of the Fifth All-Union Conf. on the Physics of Interaction of Charged Particles with Single Crystals), Moscow State University, 1974, p. 282.
[5]I. A. Grishaev, G. D. Kovalenko, and B. I. Shramenko, Zh. Eksp. Teor. Fiz. **72**, 437 (1977) [Sov. Phys. JETP **45**, 229 (1977)].
[6]G. L. Bochek, V. I. Vit'ko, I. A. Grishaev, G. D. Kovalenko, V. I. Kulibaba, V. L. Morokhovskiĭ, and B. I. Shramenko, Pis'ma Zh. Eksp. Teor. Fiz. **24**, 103 (1976) [JETP Lett. **24**, 90 (1976)].
[7]J. Lindhard, Influence of Crystal Lattice on Motion of Energetic Charged Particles, Mat.-Fys. Medd. Dan. Vid. Selsk. **34**, No. 14 (1965). Russ. transl., Usp. Fiz. Nauk **99**, 249 (1969).
[8]G. L. Bochek, I. A. Grishaev, N. P. Kalashnikov, G. D. Kovalenko, V. L. Morokhovskiĭ, and A. N. Fisun, Zh. Eksp. Teor. Fiz. **67**, 808 (1974) [Sov. Phys. JETP **40**, 400 (1975)].
[9]V. L. Morokhovskiĭ, V. I. Kasilov, G. D. Kovalenko, and A. N. Fisun, Prib. Tekh. Eksp., No. 3, 36 (1973) [Instrum. Exper. Tech.].
[10]I. A. Grishaev, V. P. Efimov, V. I. Kasilov, and A. N. Fisun, Ukr. Fiz. Zh. **13**, 1927 (1968) [Ukr. Phys. J.].

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