The orientation relation in the emission of nuclear fission fragments from a single crystal

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The emission of nuclear fission fragments from a tungsten single crystal induced by 1200-MeV electrons is studied. The charged particles are recorded by means of a background-free technique using track detectors. We found an orientation relation between the emission of photo- and electro-nuclear fission fragments of tungsten and the position of the crystallographic axes relative to the direction of the electron beam.

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Current extensive studies of the interaction of ultrarelativistic charged particles with single crystals have led to the discovery and qualitative explanation of coherent interaction[1,2] and channeling and shadowing effects.[3,4] The influence of these effects on nuclear reaction cross sections has not been studied previously.

In this work we report on the experimental determination of the orientation relation in the emission of fission fragments from a tungsten single crystal as it interacts with ultrarelativistic electrons. This work was carried out with a 2-GeV electron beam of the KhFTI linear accelerator. A diagram of the experiment is given in Fig. 1. A beam of electrons with energies of 1200 MeV and a divergence of 2×10^{-4} rad was directed to a tungsten single crystal located in a goniometer vacuum chamber. Using the goniometer, the crystal was rotated around three axes with a rotation angle accuracy of 5×10^{-5} rad. The crystal was prepared in the shape of a plate 1 mm thick, whose goniometric area made an angle of $\sim3°$ with the crystallographic plane (111). The orienting of the crystal relative to the electron beam was done according to the technique of Ref. 5 in which the $\langle 111\rangle$ crystal axis was set along the beam axis. The orientation relations for the emission of the fission fragments were obtained by rotating the crystals around an axis perpendicular to the direction of the electron beam.

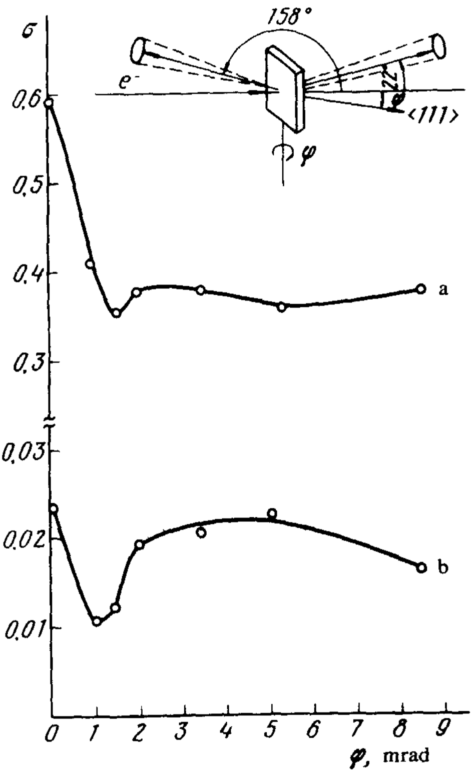

FIG. 1. The orientation relation for the emission of nuclear fission fragments by a tungsten single crystal: a) at an angle of 22° and b) at an angle of 158° relative of the direction of the electron beam.

The fission fragments were recorded on a mylar film located 50 mm from the single crystal at angles of 22 and 158° to the direction of the incident beam. The film position allowed the particles to penetrate at an angle of 60° relative to its surface. Identification of the fission fragments was done from tracks in the mylar film, which were measured with a MBI-3 microscope after the film had been dipped in a KOH solution.

The statistical error in measuring the emission of the tungsten nuclear fission fragments did not exceed 3%.

Figure 1 shows the orientation relations for the emission of tungsten nuclear fission fragments which are measured at an angle of (a) 22° and (b) 158° relative to the direction of the electron beam.

The angle between the crystal axis $\langle 111 \rangle$ and the beam direction in mrad is plotted along the horizontal axis; the number of particles per unit solid angle for a single incident electron σ is plotted along the verticle axis.

Since the bremsstrahlung radiation for high-energy electrons has a sharp directional dependence, and the paths of the fission fragments in tungsten ($\sim 3\ \mu$m) are much less than the thickness of the crystal (1000 μm), the emission of nuclear fragments at an angle of 22° is primarily due to the process of photofission, while that at 158° is due to electrofission. The contribution to nuclear fission made by neutrons formed along the entire thickness of the crystal is negligibly small.

According to Fig. 1, the most important change in the emission of nuclear particles as a function of crystal orientation occurs at angles of 1 mrad. This value is significantly less than the critical channeling angle for particles in the crystal and the detector trapping angle, but is of the same order of magnitude as the Lindhard angle for electrons incident on the crystal. The region of less strongly varying angles in the fission particle orientation relation is of the same order of magnitude as the critical angle for particle channeling and the characteristic angle for the coherent interaction of electrons with the crystal.

We have thus shown that the coherent interaction of high-energy charged particles with a single crystal and the channeling and shadowing effects have an important effect on the cross sections of nuclear reactions in the crystal. Our results indicate a possibility of controlling the emission products of nuclear reactions; this may be applicable to the physics of the atomic nucleus and the physics of radiation damage in crystals.

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