Observation of an interference of coherent bremsstrahlung and parametric mechanisms for radiation by relativistic electrons in a crystal

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Coherent emission of radiation by electrons with energies of 15 and 25 MeV at the (220) system of atomic planes in a silicon crystal 30 μm thick has been studied experimentally. The interference of the mechanisms of coherent bremsstrahlung and parametric radiation, recently predicted theoretically, has been observed for the first time.

1. The ordered arrangement of atoms in a crystal lattice is the reason for the coherent components of the bremsstrahlung and polarization bremsstrahlung of a fast charged particle moving through a crystal. Coherent bremsstrahlung[1] has been studied in detail, and it is in fact widely used to generate linearly polarized high-energy γ rays.[1,2] Coherent polarization bremsstrahlung, usually called "parametric x radiation,"[3,4] is currently the subject of intense theoretical and experimental research[5–7] because of its unique characteristics (its narrow spectrum, its high degree of polarization, its high collimation, and the possibility of gradually changing the photon energy).

Until recently, the mechanisms of coherent bremsstrahlung and parametric x radiation have been studied separately. It was demonstrated theoretically in Refs. 8 and 9 that there can be an effective interference between coherent bremsstrahlung and parametric x radiation, and that this interference would substantially change the characteristics of the total radiation by a fast particle (in particular, the total radiation would become dependent on the sign of the particle's charge).

In this letter we are reporting a direct experimental observation of this interference effect.

2. The best conditions for observing an interference of parametric x radiation and coherent bremsstrahlung—conditions under which the amplitudes for the two processes are approximately the same in absolute value—for a given observation angle can be realized by adjusting the energy of the incident charged particles and also by choosing the appropriate system of atomic planes at which the coherent radiation is to be formed. In the present experiments we used an electron beam with an energy of 15 and 25 MeV. We used an existing apparatus for studying the parametric x radiation; the basic characteristics of the apparatus are given in Ref. 10. In this apparatus the angle at which the emitted photons are detected (ψ) is rigidly fixed by the photon measurement channel at 0.31 rad. Analysis shows that under these conditions the (220) crystallographic plane is the most convenient one for observing an interference of parametric x radiation and coherent bremsstrahlung when a silicon crystal is used

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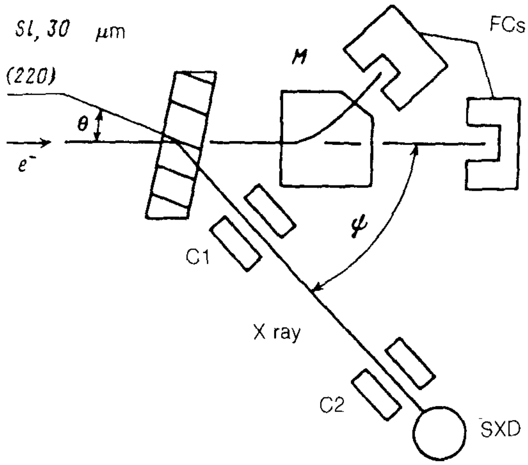

FIG. 1. Experimental layout. C1, C2—Collimators; FCs—Faraday cups; M—turning magnet; SXD—semiconductor x-ray detector.

as target. In the experiments we accordingly used a Si crystal 30 μm thick, cut appropriately.

We measured the intensity of the coherent emission into a given measurement channel, with a solid angle $\Delta\Omega = 1.23 \times 10^{-6}$ sr, as a function of the angle θ, between the (220) plane and the direction of the fast-electron beam (Fig. 1). The results of these measurements are shown in Fig. 2a for the 25-MeV electrons and in Fig. 2b for the 15-MeV electrons. Also shown here are theoretical predictions of parametric x radiation (curve 1) and of the total radiation, i.e., the parametric x radiation plus the coherent bremsstrahlung (curve 2).

Calculations were carried out for an electron beam with a divergence of $0.75/\gamma$, where γ is the Lorentz factor of the electron. Analysis showed that a divergence of the electron beam on the order of $1/\gamma$ causes essentially no change in the ratio of the intensities at the peaks on the orientation curve.

3. The discrepancy between the experimental points in Fig. 2a confirms the theoretical conclusion[8,9] that parametric x radiation makes up the bulk of the coherent radiation by the 25-MeV electrons under these experimental conditions. In the coherent emission of the 15-MeV electrons, on the other hand, a significant interference of the mechanisms of coherent bremsstrahlung and parametric x radiation is predicted. This interference is manifested as a significant change in the spectrum and angular distribution of the radiation and in the orientation dependence. The set of experimental points in Fig. 2b confirms these theoretical predictions very convincingly.

In summary, the coherent emission of fast electrons under conditions corresponding to an interference of the mechanisms of coherent bremsstrahlung and parametric x radiation has been studied experimentally for the first time. An interference effect has been observed in the orientation dependence of the emission intensity. This effect confirms the theoretical predictions of Refs. 8 and 9, and it demonstrates that the calculations based on that theory agree well with the experimental results.

The effect observed here significantly distorts the characteristics of the coherent

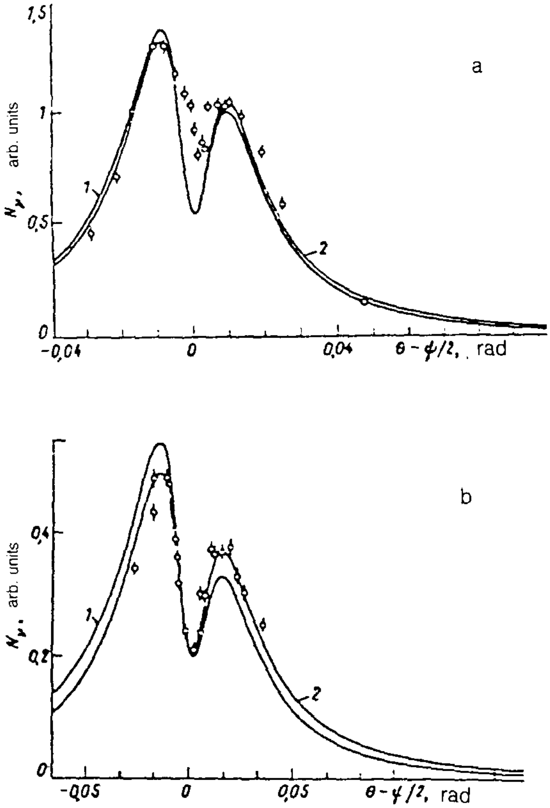

FIG. 2. Orientation dependence of the x-radiation yield. a: 25-MeV electrons. b: 15-MeV electrons. Points—Experimental; curve 1—theoretical yield of parametric x radiation if interference is ignored; 2—theoretical total radiation yield in the case of an interference between parametric and bremsstrahlung radiation.

emission of relativistic charged particles in a crystal at detection angles on the order of a few times γ^{-1}. It may therefore be important to take this effect into account when practical use is made of this coherent emission.

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