Observation of resonant transition x radiation excited by 900-MeV electrons in a layered target

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Quasimonochromatic x radiation with a photon energy of about 20 keV has been found during the passage of 900-MeV electrons through a periodic target consisting of layers of the polyester Lavsan. Analysis of the experimental spectra and angular distributions of the emission shows that a resonant transition radiation in the x-ray part of the spectrum is being observed.

Transition x-ray emission has been studied in detail theoretically and experimentally[1,2] and is widely used in detectors for relativistic particles in high-energy physics.[3] It has been pointed out[2,3] that we do not have detailed experimental results on resonant transition x radiation for beams of high-energy particles. The characteristics of resonant transition x radiation have been studied at electron energies below 100 MeV. Such electrons are capable of generating a soft x radiation with a photon energy of about[4] $E_\gamma \approx 2$ keV.

The resonant transition x radiation which results from an interference of radiation in periodic structures[1,2] is distinguished from ordinary transition radiation by its high monochromaticity and its high spectral-angular density, which is proportional to the square of the number (N) of layers in the radiator: $dN_\gamma/dE_\gamma d\Omega \propto N^2$. The energy which the photons of resonant transition x radiation can have is proportional to the particle energy E, while the spectral-angular density satisfies the proportionality $dN_\gamma/dE_\gamma d\Omega \propto E^2$.

In this letter we are reporting the first experimental results obtained at the Tomsk synchrotron. The experimental layout is shown in Fig. 1. A beam of electrons with an energy $E = 900$ MeV, an angular divergence of about 10^{-4} rad, and a monochromaticity of 0.5% is dumped on a target for a time $\tau = 2\times 10^{-2}$ s. The target, installed in the accelerator chamber, consists of ten films of thickness $l_1 = 12\ \mu$m of the polyester Lavsan, which are separated by vacuum gaps of width $l_2 = 24\ \mu$m. The angle between

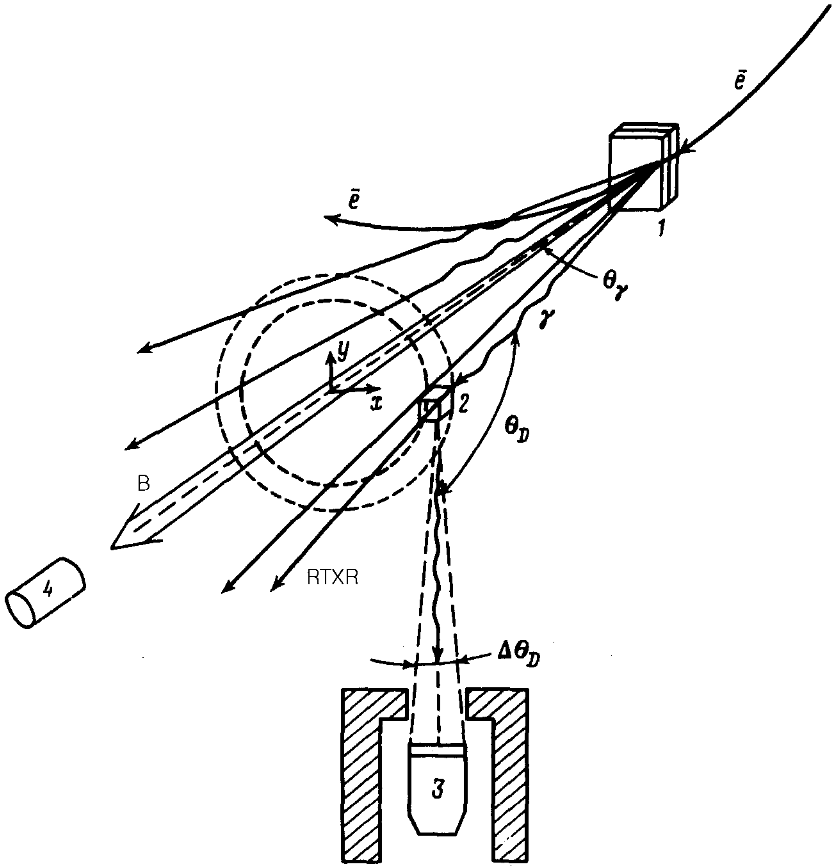

FIG. 1. The experimental layout. 1—Layered target; 2—graphite scatterer of the x radiation; 3—detector; 4—quantometer. B) Bremsstrahlung; RTXR) resonant transition x radiation.

the plane of the films and the beam axis is 70°. The target was designed to produce resonant radiation with an energy of about 20 keV at an angle $\theta_\gamma \approx 3\gamma^{-1}$ from the electron beam.

The x-ray beam generated in the target escapes from the vacuum chamber of the synchrotron through a beryllium flange 200 μm thick. A graphite scatterer with dimensions of $4\times4\times4$ mm is positioned 630 cm from the target. A special mechanical system with stepping motors can move the scatterer in two mutually perpendicular directions (x, y) and put it in a selected part of the radiation cone.

The x radiation is detected by a scintillation counter using a NaI(Tl) crystal 1 mm thick with a beryllium entrance window. The energy resolution at the Co^{57} line with $E_\gamma = 14$ keV is 50%, and that at the Am^{134} line with $E_\gamma = 59.6$ keV is 25%. This spectrometer is oriented at an angle $\theta_D = 90°$ from the axis of the x-ray beam. Structurally, it is attached rigidly to the scatterer and is moved along with it. The solid

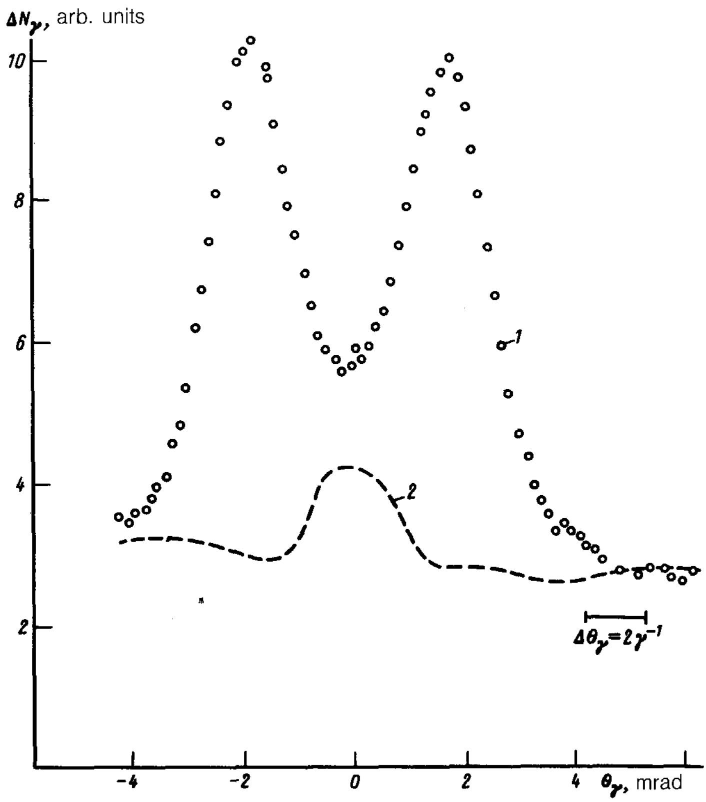

FIG. 2. Angular distribution of the x radiation with x-ray energies (1) $E_\gamma = 10$–40 keV and (2) $E_\gamma > 60$ keV.

angle monitored by the detector is fixed at $\Delta\theta_D = 2.2 \times 10^{-2}$ sr. The procedure for detecting spectrometric information is described in Ref. 6.

Figure 2 shows angular distributions of the x radiation generated in the layered target. These distributions were found by moving the scatterer along the direction perpendicular to the beam axis in the horizontal plane. Curve *1* shows the angular distribution of the x rays with energies in the interval $E_\gamma = 10$–40 keV; curve *2* shows the corresponding distribution for x rays with $E_\gamma > 60$ keV. In the former case the energies of the x rays that are detected lie in an interval which overlaps the range in which the presumed resonant frequency of the resonant transition x radiation lies (when the energy resolution of the detector is taken into account). The shape of curve *1* indicates that the fraction of the radiation which is detected in this case is distributed spatially near a conical surface with a vertex angle $\theta_\gamma = 3\gamma^{-1}$, where $\gamma^{-1} = m_0c^2/E = 0.57$ rad. The *nonresonant* transition x radiation is emitted for the most part at an angle $\theta_\gamma \approx \gamma^{-1}$ from the direction of the electron beam.

In the latter case, most of the radiation that is detected is bremsstrahlung directed along the beam axis, concentrated in a cone $\theta_\gamma = \gamma^{-1}$.

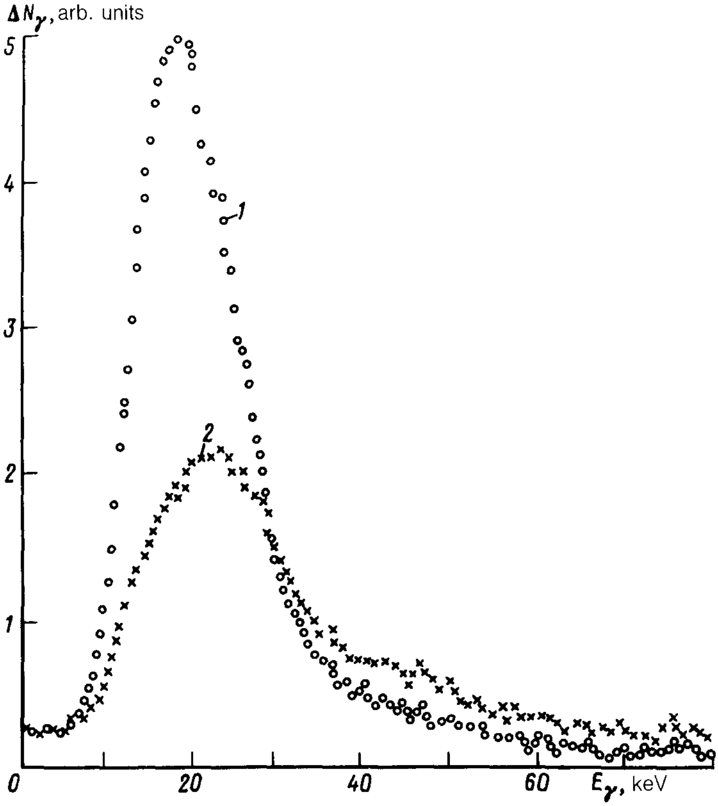

FIG. 3. Spectra of the x radiation scattered through an angle of about 90° with respect to the direction of the electron beam. 1—Measured with the graphite scatterer positioned at an angle $\theta_\gamma = 3\gamma^{-1}$ with respect to the direction of the electron beam; 2—at an angle $\theta_\gamma = 2.3\gamma^{-1}$.

Figure 3 shows emission spectra measured when the graphite scatterer was positioned at an angle $\theta_\gamma = 3\gamma^{-1}$ (points *1*) or $\theta_\gamma = 2.3\gamma^{-1}$ (points *2*). When the scatterer is positioned at the maximum of curve *1* in Fig. 2, a peak is observed in the scattered-radiation spectrum at a photon energy $E_\gamma = 18$ keV. When the Compton effect is taken into account, this energy is found to correspond to an energy $E_\gamma = 18.7$ keV of the emitted photons. The emission angle θ_γ is related to the photon energy E_γ of the resonant transition x radiation by[5]

$$\theta_\gamma^2 = \frac{2r\lambda_\gamma}{l_1 + l_2} - \gamma^{-2} - \frac{l_1}{l_1 + l_2}\left(\frac{E_p}{E_\gamma}\right)^2, \quad r = 1, 2, \ldots; \tag{1}$$

Here λ_γ is the wavelength of the radiation, and E_p is the energy of a plasmon of the medium. This relation follows from the condition for a resonance[1] of the x radiation generated in the plates of the radiator. The calculated value of $\theta_\gamma (r = 1)$ for a photon energy $E_\gamma = 18.7$ keV is 1.6 mrad, in satisfactory agreement with the actual angular position of the scatterer, $\theta_\gamma = 1.7$ mrad.

When the scatterer is placed at the position $\theta_\gamma = 2.3\gamma^{-1}$, the peak in the emission spectrum shifts rightward, and its intensity decreases sharply, demonstrating that this peak is of a resonant nature.

An estimate of the yield of those x rays in the spectral peak which are emitted into the aperture of the scatterer yields $\Delta N_\gamma \approx 10^{-3}$ photon/e^-, where the absorption (in the target, in the exit flange of the synchrotron chamber, and along the path in air) and the efficiencies of the scatterer and the spectrometer are taken into account. This figure corresponds to an angular density of about 5×10^3 photon/($e^-\cdot$sr) for the resonant transition x radiation. A comparison with the experiments of Refs. 7–9 shows that this figure is substantially higher than the corresponding figure for emission accompanying channeling or that for parametric x-ray emission. The relative angular densities of the resonant transition x radiation, the emission accompanying channeling, and the parametric x-ray emission are $\approx 1:10^{-3}:10^{-6}$, respectively, at photon energies of tens of kiloelectron volts. These figures suggest that it might be possible to utilize resonant transition x-ray emission to develop an intense source of quasimonochromatic x radiation in which the photon energies might reach several hundred kiloelectron volts, if electron beams with electron energies in the gigaelectron volt range were used.

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