Recording the transition radiation from cosmic-ray electrons

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A transition-radiation detector was used as part of the equipment installed aboard the artificial earth satellite "Intercosmos-17," to investigate cosmic-ray electrons. It is shown that the experimentally observed energy release from the transition radiation is in good agreement with the theoretical predictions.

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The x-ray transition radiation detectors (XTR) are now used successfully to separate electrons from the flux of cosmic-ray protons which exceeds them by 2–3 orders of magnitude.[1]

In this paper, we give the results of measuring and comparing with the theoretical effect the transition radiation of cosmic-ray electrons. The measurements were conducted using a device installed aboard the satellite "Intercosmos-17".[2] The device contained three XTR detectors, each of which consisted of an emitter and a proportional counter. The emitter consisted of one hundred 12.5-μm-thick mylar films
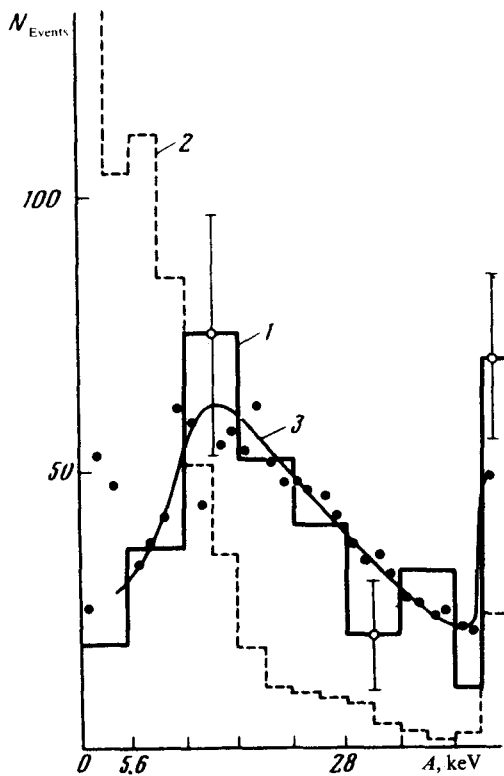
FIG. 1. The distribution of ionization in the XTR counter produced as a result of transmission through the XTR detector of a proton with $E_p = 1$ GeV-curve 2 and of electrons with $E_c \geqslant 1$ GeV-curve 1; calculated distribution for the electron with $E \geqslant 11$ GeV-curve 3.

spaced 750 μm apart. A proportional counter, which had a 250-μm-thick beryllium inlet window, was placed behind the emitter. The thickness of the active volume of the counter was 1.5 cm; it was filled with 95% xenon and 5% methane at a pressure of 0.95 atm. The counter recorded the total ionization from the charged particle and the XTR quanta.

In the described experiment the total energy release in the proportional counter was measured by a sixteen-channel differential amplitude analyzer. The analyzer was controlled by a telescope, an integral part of the device, which consisted of a scintillation and a Cerenkov counter and a shower calorimeter. The telescope recorded individual, single-charge relativistic particles with an energy release in the calorimeter exceeding 1 GeV. The telescope was periodically covered by a lead filter $3t$ units in thickness, as a result of which it recorded either the total flux of relativistic protons and electrons or only the relativistic protons. A full description of the device and of the method of isolating an individual, singly charged relativistic particle is given elsewhere.[2]

According to the location of the filter, two pulse-height distributions of the energy release were constructed in the proportional counter for the total flux $N^{\mathrm{open}}(\epsilon_{\mathrm{counter}})$ and for the protons $N^{\mathrm{closed}}(\epsilon_{\mathrm{counter}})$. The distribution of the energy release for the electrons $N_e(\epsilon_{\mathrm{counter}})$ was determined as the difference
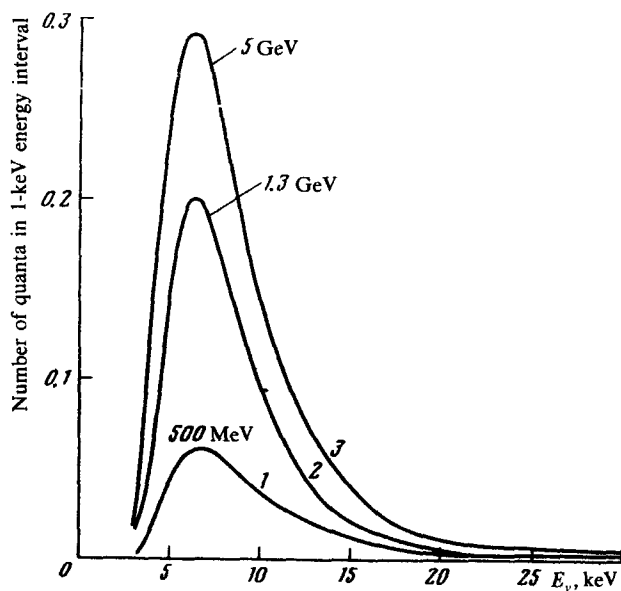
FIG. 2. Differential energy spectra of XTR quanta emitted from the mylar radiator and absorbed in 8.85 mg/cm^2 xenon as a result of transmission through the XTR detector of a 0.5-GeV electron-curve 1, of a 1.3-GeV electron-curve 2, and of a 5-GeV electron-curve 3.

$$N_e(\epsilon_{\text{counter}}) = N^{\text{open}}(\epsilon_{\text{counter}}) - 1.08 N^{\text{closed}}(\epsilon_{\text{counter}}).$$ (1)

Here $\epsilon_{\text{counter}}$ has values corresponding to the analyzer's channels. The scale factor of one channel is equal to 2.8 ± 0.56 keV. The coefficient 1.08 takes into account the reduction of the proton flux in the lead filter.[3] The histograms of the electron and proton distributions, which are normalized to the same number of events, are shown in Fig. 1 (curves 1 and 2, respectively). The error for the proton distribution is negligibly small. The electron distribution evidently corresponds to a large average energy release (it comprises $26 \pm^4_{1.5}$ keV) compared to the average energy release from the protons (comprising 8.3 ± 1.0 keV). If we assume that because of relativistic increase the ionization losses of electrons exceed by a factor of 1.5 those of the protons,[4] then the average energy release of the XTR quanta is $26 - 1.5 \times 8.3 = 13.5 \pm^{4.3}_{2}$ keV. The differential spectrum of XTR quanta from the layered radiator, which consists of n foils of t g/cm^2 thickness from a particle with Lorentz factor γ, according to Garibyan,[5] is given by

$$\frac{dN}{dE} = \frac{\alpha}{\pi \hbar \omega} \left(\frac{2 + \frac{\omega_p^2}{\omega^2} \gamma^2}{\frac{\omega_p^2 \gamma^2}{\omega^2}} \ln\left(1 + \frac{\omega_p^2}{\omega^2} \gamma^2\right) - 2 \right)$$

$$\times \left(1 + \exp - \mu(E) t\right) \frac{1 - \exp(-n\mu(E)t)}{1 - \exp(-\mu(E)t)},$$

where $\alpha = (1/137)$, ω_p is the plasma frequency of the medium, ω is the frequency of the XTR quanta, and $\mu(E)$ is the coefficient of absorption of quanta in the emitter.

Figure 2 shows the spectra of XTR quanta, which emerged from the emitter and were absorbed in the active volume of the counter, for three energies of the electrons. The spectra were calculated from Eq. (2) for the design of the detector described above. The coefficients of absorption of the XTR quanta in mylar were determined from Ref. 6 and in xenon from Ref. 7. The average energy of the XTR quantum, which depends weakly on the energy of the emitting particle, is equal to 9.2 keV. The saturation of the energy release from XTR occurs at electron energy of 3 GeV (Lorentz factor 6×10^3). We determined from Eq. (2) the average number of XTR quanta $\bar{n}(E)$ absorbed in the counter from the electron with energy E_e.

The theoretical calculation of the distribution of ionization in the counter from the electron with energy > 1 GeV was carried out by the Monte Carlo method according to a scheme used by Zatsepin.[4]

1. We examined 10^4 electron events with energy > 1 GeV and assumed that the differential electron spectrum has the form $(dN/dE) = AE^{-\gamma}$ where γ varied from 2.5 to 3.5. The range of electron energies was broken down into intervals of 0.15-GeV for energy of 1-3 GeV and a half-interval $\geqslant 1$ GeV.

2. The following processes were examined for each energy of the electron E_e: a) ionization in the counter ϵ^{ioniz}; b) the true number of quanta absorbed in the counter [distributed according to the Poisson law at $\bar{n}(E_e)$]; c) energy of each quantum (distribution of the energy release of the XTR quanta corresponds to the curves in Fig. 2).

3. We determined the total energy release in the counter. The results of the calculation are shown in Fig. 1 (curve 3).

It can be seen that the calculated distribution (Fig. 1, curve 3) is in good agreement with the experimental distributions (Fig. 1, curve 1). The calculated and experimental distribution for electrons differ noticeably from the experimental distribution for protons. The average ionization in the calculated distribution is equal to 25.5 keV. The average number of XTR quanta per electron with an energy > 1 GeV is equal to 1.3 ± 0.1. The average calculated energy release from XTR quanta per electron is equal to 12.3 ± 1.0 keV. The conducted calculation indicates that the experimental results are in good agreement with the predictions of the XTR theory for a layered detector.

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