# Registration of electrons of energy ~100 MeV trapped by the earth's magnetic field

R. N. Basilova, N. L. Grigorov, E. I. Kogan-Laskina, and G. I. Pugacheva

*Nuclear Physics Institute of the Moscow State University*
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Streams of electrons of energy ~100 MeV, quasi-trapped by the earth's magnetic field, were observed in the region of the equator at heights 200–250 km.

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In the first experiments on the registration of high-energy electrons in outer space near the earth, using satellites,[1,2] streams of electrons with energies of dozens to hundreds of MeV were observed. The high intensity of these streams (on the order of the intensity of the primary cosmic rays) gave grounds for suggesting the possibility of capture of the electrons emerging from the atmosphere by the geomagnetic field.[2]

Subsequent experiments, performed with various types of apparatus, have refined the absolute values of the electron fluxes at different geomagnetic latitudes and the form of the energy spectrum in the energy interval 100–1000 Mev.[3,4]

It was demonstrated in some published theoretical papers that the primary cosmic rays can produce a belt of high-energy electrons trapped by the geomagnetic field at heights where the longitudinal drift does not cause them to vanish in the atmosphere, i.e., at heights $\gtrsim$ 1000 km. At smaller heights, on the other hand, there can exist electron streams that are quasi-trapped by the geomagnetic field.[5,6]

However, no experimental evidence has been obtained so far for the existence in the outer space next to the earth of trapped or quasi-trapped high-energy electrons.

(We shall henceforth use the term "quasi-trapped" for particles which cross the equatorial plane at least more than twice as they move in outer space from one hemisphere to the other).

To observe quasi-trapped particles it is necessary to carry out measurements under conditions such that it is impossible to register the particles of the direct albedo, i.e., the particles emerging from the atmosphere on the same magnetic-field force lines on which the recording apparatus is located.

Electrons with energies $\sim$100 MeV will conserve their magnetic moments as they move at heights 100–1000 km, i.e., the condition $B/\sin^2\alpha=\text{const}$ is satisfied at each point of their trajectory ($B$ is the magnetic field intensity and $\alpha$ is the pitch angle). It follows therefore that if the electron has left the atmosphere with a pitch angle $\alpha(\lambda)=\pi/2$ at a latitude $\lambda$, where the intensity was $B(\lambda)$, then in the region with the minimal value of the field $B_0$ (the region of the equator) it will have a pitch angle $\alpha_{\max}$:

$$\alpha_{max} = \arcsin\sqrt{B_0/B(\lambda)}\ldots \quad (1)$$

On the other hand, if $\alpha(\lambda)<\pi/2$ at the point of emergence from the atmosphere, then $\alpha<\alpha_{\max}$ in the region of the equator.

Consequently, all the albedo electrons in the regions of space near the geomagnetic equator will make angles $\epsilon=\pi/2-\alpha\geqslant\pi/2-\alpha_{\max}$ with the normal to the force line of the earth's magnetic field.

Therefore, if measurements are made with a narrow-angle telescope with angle aperture $\theta_0<\epsilon$ in directions perpendicular to the force lines of the earth's magnetic field, then under these conditions the albedo particles will not be registered by the telescope.

If the telescope axis is aimed on the zenith, then a condition must be satisfied such that the minimal angle $\theta_{\min}$ between the particle-velocity vector and the vertical be larger than the angular aperture $\theta_0$ of the telescope.

We denote the magnetic dip angle at the measurement point by $\psi$. Then $\theta_{\min}=\epsilon-\psi\geqslant\pi/2-(\alpha_{\max}+\psi)$ and the condition for not registering the albedo particles takes the form

$$\pi/2 - (\alpha_{max} + \psi) \geqslant \theta_0 \ldots \quad (2)$$

For an experimental observation of the quasi-trapped electrons we used the results of measurements with the artificial satellite "Kosmos-490"[7] on those sections of the satellite trajectory on which $0\leqslant|\psi|\leqslant7°$.

For each such section we determine the largest of the possible angles $\alpha_{\max}$, starting from the condition that the albedo electrons that turned up on the selected sections

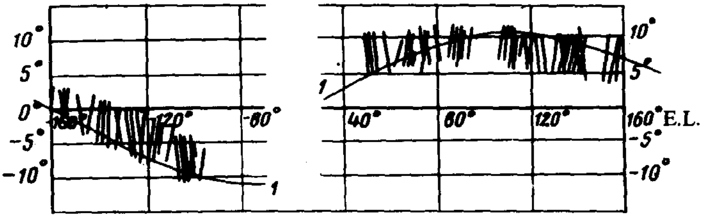


FIG. 1. Arrangement of the segments of the trajectories, on which the measurements were performed, in the western and eastern hemispheres: 1—geomagnetic equator.

of the trajectory leave the atmosphere at heights 30 km with pitch angles $\alpha(\lambda)=90°$. We selected also sections for which $65° \leqslant \alpha_{max} \leqslant 75°$. All are shown in Fig. 1. These sections were next broken up into two groups of $\alpha_{max}$. In one group $65° \leqslant \alpha_{max} \leqslant 70°$, and in the other $70° < \alpha_{max} \leqslant 75°$.

The results of the measurement of the electron fluxes on the chosen sections in the eastern and western hemispheres are given in Table I.

The first line of Table I shows the average value of $\alpha_{max}$ on the trajectory sections contained in the corresponding group. $T$ is the total measurement time. $N_f$ and $N_{nf}$ are the numbers of the particles registered with and without a filter, respectively. The last line shows the flux of electrons with energy $E \geqslant 80$ MeV, which was determined from the formula

$$J_e = \frac{(N_{nf} - 1.07N_f)}{\Gamma_0 T} 10^4 \text{m}^{-2} \text{sec}^{-1} \text{sr}^{-1} \cdot \Gamma_0 = 4.1 \text{ cm}^2 \text{ sr}.$$

The 25% difference between the intensities of the primary cosmic rays in the western and eastern hemispheres, due to the different magnetic rigidities (13 and 15 GV, respectively), can lead to a variation of 25% in the quasi-trapped electrons produced by the cosmic rays in the upper part of the atmosphere.

Let us estimate the contribution of the albedo electrons to the measured fluxes.

TABLE I.

| | Western hemisphere | | Eastern hemisphere | |
|---|---|---|---|---|
| | $65° \leqslant \alpha_{max} < 70°$ | $70° < \alpha_{max} \leqslant 75°$ | $65° \leqslant \alpha_{max} \leqslant 70°$ | $70° < \alpha_{max} \leqslant 7$ |
| $< \alpha_{max} >$ | 68.1° | 71.7° | 68.1° | 72.1° |
| $T$,sec | 1020 | 1643 | 1108 | 2260 |
| $N_f$ | 72 | 119 | 64 | 131 |
| $N_{nf}$ | 135 | 227 | 97 | 235 |
| $J_e(E \geqslant 80$ MeV) $\text{m}^{-2}\text{sec}^{-1}\text{cm}^{-1}$ | 139 ±35 | 148 ±28 | 63 ±28 | 102 ±21 |

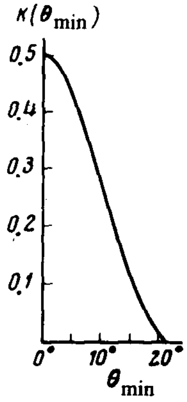


FIG. 2. Dependence of the relative "aperture" of the apparatus for the albedo particles on the minimal angle $\theta_{min}$ between the axis of the instrument and the particle-velocity vector.

The albedo particles on a trajectory section with a magnetic dip angle $\psi$ makes angles $\theta > \theta_{min} = 90° - (\alpha_{max} \pm \psi)$ with the vertical. (The different signs of $\psi$ mark particles from different hemispheres.)

For particles making angles $\theta \geqslant \theta_{min}$ with the vertical, the geometric apparatus factor $\Gamma(\theta_{min})$ constitutes a certain fraction of the total geometric factor $\Gamma_0$, i.e., $\Gamma(\theta_{min}) = \Gamma_0 K(\theta_{min})$. The dependence of $K$ on $\theta_{min}$ is shown in Fig. 2. It was calculated from the geometric parameters of our apparatus with allowance for the fact that the albedo particles are registered by the instrument in a limited interval of azimuth angles $0 \leqslant \phi \lesssim 2\alpha_{max}$. (In the calculation of $\Gamma_0$, the value of $\phi$ is varied in the interval $0 \leqslant \phi \leqslant 2\pi$.)

Using the data of Fig. 2 and assuming that over the lengths of the chosen trajectory sections the magnetic dip varies linearly from $-\psi_{max}$ to $+\psi_{max}$, we can obtain the mean value of the geometric factors for the registration of the albedo particles as a function of the quantity

$$\alpha_{max}: \langle \Gamma_a \rangle = \left(\frac{\Gamma_0}{2\psi_{max}}\right) \int_0^{\psi_{max}} K[\theta_{min}(\psi)]\, d\psi.$$

Thus, for $\alpha_{max} = 70°$ we have $\langle \Gamma_a \rangle = 0.09\ \Gamma_0$ and for $\alpha_{max} = 75°$ we have $\langle \Gamma_a \rangle = 0.32\ \Gamma_0$.

We assume for the flux of the albedo electrons the largest of the measured electron fluxes on the equator, $\sim 75\ m^{-2}\ sec^{-1}\ sr^{-1}$, in the measurements of the global (averaged over all directions) intensity of the electrons on the satellite "Proton-4".[3] At this flux of the albedo electrons, their contribution to the measured fluxes is: $J_{alb} \leqslant 0.09 \times 75 = 7\ m^{-2}\ sec^{-1}\ sr^{-1}$ on trajectories with $\alpha_{max} \leqslant 70°$ and $J_{alb} \leqslant 0.32 \times 75 = 24\ m^{-2}\ sec^{-1}\ sr^{-1}$ on trajectories with $70° < \alpha_{max} \leqslant 75°$. After subtracting these fluxes from the measured ones we obtain the fluxes of the electrons that are not due to the albedo: on the trajectories where $65° \leqslant \alpha_{max} \leqslant 70°$ we have $I = J_e - J_{alb} \geqslant 139 \pm 35 - 7 = 132 \pm 35\ m^{-2}\ sec^{-1}\ sr^{-1}$ (in the western hemisphere) and $J_e - J_{alb} = 63 \pm 28 - 7 = 54 \pm 28\ m^{-2}\ sec^{-1}\ sr^{-1}$ (in the eastern hemisphere). On trajectories where

$70° < \alpha_{max} \leqslant 75°$ we have respectively $I \geqslant 148 \pm 28 - 24 = 124 \pm 28$ m$^{-2}$ sec$^{-1}$ sr$^{-1}$ and $I \geqslant 102 \pm 21 - 24 = 78 \pm 21$ m$^{-2}$ sec$^{-1}$ sr$^{-1}$.

The mean values of the intensity for $65° \leqslant \alpha_{max} \leqslant 75°$ are $\langle I \rangle = 128 \pm 22$ m$^{-2}$ sec$^{-1}$ sr$^{-1}$ and $\langle I \rangle = 70 \pm 17$ m$^{-2}$ sec$^{-1}$ sr$^{-1}$ in the western and eastern hemispheres, respectively.

Inasmuch as in accordance with the registration conditions these fluxes cannot be due to albedo electrons, their pitch angles should be $\alpha > \alpha_{max}$. At these pitch angles the mirror points for these electrons on the trajectories on which they were registered will lie above the atmosphere regions from which the albedo electrons come. Therefore these electrons should experience several reflections at the mirror points before they lose their energy. Consequently, they should be classified as quasi-trapped particles.

Thus, our experimental data allow us to state that at heights 200–250 km in the equator region we have observed fluxes of electrons with energies $\sim 100$ MeV that are quasi-trapped by the magnetic field of the earth. The intensities of these fluxes are close of primary cosmic rays in the corresponding hemispheres.

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