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CLOUD CHAMBER INVESTIGATION OF THE ELECTRON-PHOTON COMPONENT OF EXTENSIVE AIR SHOWERS AT SEA LEVEL

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The energy spectra of the electronic component of extensive air showers containing various numbers of particles were measured at different distances from the axis. No dependence of the energy spectrum on the number of particles in the shower was detected. The energy spectrum becomes softer with increasing distance from shower axis. A significant discrepancy was found to exist between the fraction of high-energy electrons observed experimentally and that computed from cascade theory for various distances from the axis. The lateral distribution of the energy carried by the electronic component can be approximated by the function r^{-n}, where $n = 2 \pm 0.5$ for distances between 2 and 10 meters.

It was demonstrated[1] that, in the central region of extensive air showers, nuclear-active particles of more than 10^{11} ev can generate, by means of π-mesons, the electronic component near the observation level. This conclusion was reached as the result of a study of the lateral distribution of the electronic component in the central region of extensive showers. As a further study of the generation mechanism of electronic component we investigated its energy characteristics, which should depend more strongly on the production mechanism than the lateral distribution. The energy spectra of the electronic component at various distances from the shower axis were measured in course of the present work for showers containing different numbers of particles.

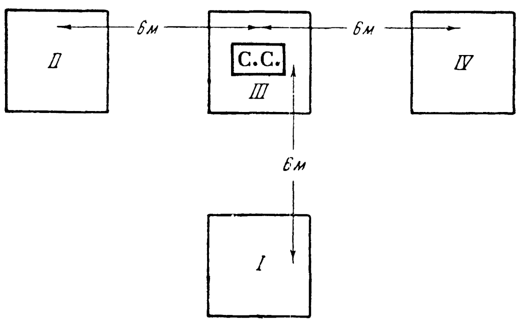

FIG. 1. Arrangement of hodoscope counter trays and the cloud chamber (C.C.)

The experimental arrangement consisted of a rectangular cloud chamber[2] with dimensions 60 × 60 × 30 cm and four groups of hodoscoped counters. A diagram of the positions of the hodoscope counter trays and the cloud chamber is shown in Fig. 1. The cloud chamber and the hodoscope were triggered by a system of counters discharged by the extensive air showers.* 2175 showers were recorded during 1189 hours of operation.

* A detailed description of the triggering system and of the hodoscope arrangement will published in Ref. 3, where the effects connected with the innacuracy in the determination of the distance from axis will be discussed as well. A possible shift of the axis position towards smaller distances cannot evidently cause a substantial change in the results of the present work.

The position of axis r and the number of particles N in a shower were determined by the usual method[3,4] from the value of particle flux density ρ, recorded by three counter trays (II, III, and IV, Fig. 1) of the hodoscope. The distribution of all recorded showers with respect to intervals of r is shown in Fig. 2 (histogram).

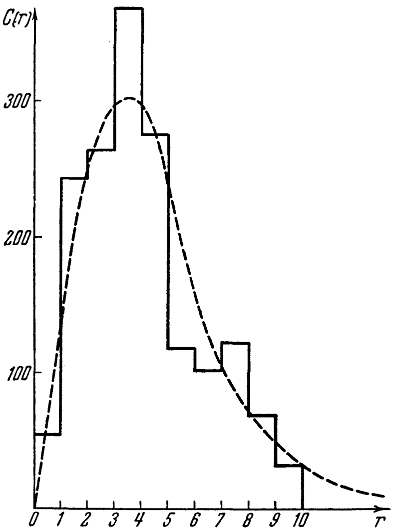

FIG. 2. Distance distribution of extensive air showers.

The energy of the electrons and photons was determined by means of a cloud chamber containing 7 lead plates, 0.5, 1.5, 2, 2, 2.5, 2, and 2.5 cm thick respectively, using cascade curves for lead calculated by Ivanenko[5] with allowance for scattering. Since the cascade curves[5] yield the total number of particles in a cascade shower and since the evaluation of shower photographs only the particles traveling forwards (within an angle < 180°) can be counted, we determined the fraction of the particles traveling forwards by using the angular distribution function of shower particles.[6] Data on the total number of particles which should have been observed between all plates of the cloud chamber, originating from a primary electron or photon of a given energy, are given in Table I.

The energy of electrons and photons in the energy range $10^8 - 10^9$ ev was determined from the total number of particles between the plates. This value, for a given primary energy, is subject to less fluctuations than any other characteristic of the cascade shower (number of particles at the maximum, position of the maximum) and represents therefore the best characteristic of the primary energy.

It was shown in Ref. 7 that the error of such a method of energy determination is close to statistical, and is therefore determined by the number of particles in the shower, i.e., it amounts to 20 — 30% for the investigated energy region. The above method of determination of the electronic shower energy was recently used in a number of investigations.[7-9] In the region of energies $\geq 2 \times 10^9$ ev the energy of electrons and photons was determined from the number of particles present at 11.5, 16.5, and 20.5 radiation units since it was difficult to count the number of particles at the maximum due to high density there. The accuracy of the energy determination in that region was also on the order of 30%.

TABLE I

Energy of the primary particle ($\times 10^8$ ev)	Electron	Photon	Energy of the primary particle ($\times 10^8$ ev)	Electron	Photon
1	3.2	2.7	9	24.9	21.5
2	6.0	5.1	10	27.3	24.0
3	8.9	7.4	20	51.3	48.0
4	11.6	9.5	40	100.0	96.0
5	14.7	12.0	60	150.0	147.0
6	17.8	14.0	80	200.0	198.0
7	20.3	16.5	100	250.0	250.0
8	22.6	19.0			

In order to avoid an uncertainty in the effective area of the chamber we considered only those electrons and photons that passed through the lid of the chamber. We also took into account the decrease in the effective area for inclined showers due to the fact that a part of the particles was outside the illuminated region of the chamber. The effective recording area varied between 0.12 and 0.10 m^2 for energy variation from 10^8 to 3×10^9 ev (for vertical showers the effective chamber area was equal to 0.15 m^2).

Three integral energy spectra of electrons and photons for three groups of extensive showers with $10^4 - 5 \times 10^4$, $5.1 \times 10^4 - 10^5$, and $1.1 \times 10^5 - 5 \times 10^5$ particles and for three intervals of distance from shower axis: $r \leq 3$, $3 < r \leq 6$, and $6 < r \leq 10$ m, were plotted to study the dependence of the energy spectrum of the electronic component on the number of particles and on the distance from axis. The results are showin in Fig. 3 (a, b, c).*

It can be seen from Fig. 3 that within the limits of statistical accuracy the energy spectrum at a given distance from the shower axis is independent of the number of particles in the shower. In Fig. 4, therefore, the spectra for the three distance intervals are averaged over all showers with number of particles between 10^4 and 5×10^5. It can be seen from the curves that the energy spectrum of electrons and photons depends on the distance from shower axis — the spectrum becomes softer with increasing distance.

From the obtained spectra we have determined what fraction of the total number of particles in ex-

*Average values, equal to n+1 (where n < 10), are shown in Figs. 3 and 4 for Π_{exp} (>E) = n. The errors $\pm \Delta n$ are determined from the Poisson distribution.

tensive air showers comprises high-energy electrons and photons. We have found the following relation:

$$R(r_1, r_2) = \int_{r_1}^{r_2} \rho_1(r)\, C(r)\, dr \Big/ \int_{r_1}^{r_2} \rho_0(r)\, C(r)\, dr,$$

where $\rho_1(r)$ is the density over 1 m^2 of electrons and photons with energy larger than 10^9 ev at the distance r from the axis, $\rho_0(r)$ is the density per square meter of all particles recorded by the counters at the same distance from axis, and C(r) is the number of extensive air showers recorded in the given distance interval (cf. Fig. 2). The value of this relation for showers with different N and for different distance intervals is given in the first three columns of Table II.

TABLE II

	Experimental results			Theoretical results	
N	10^4–$5\cdot10^4$	$5.1\cdot10^4$–10^5	$1.1\cdot10^5$–$5\cdot10^5$	$s=1$	$s=1.5$
$R(0.3)$	(1.82±0.25)%	(1.50±0.35)%	(1.45±0.26)%	34%	12.5%
$R(3.6)$	—	(0.17±0.13)%	(0.45±0.11)%	5.3%	4.3%
$R(6.10)$	—	—	(0.09±0.09)%	1.7%	2.0%

The experimental data made it possible to estimate the energy flux carried by the electronic component of extensive air showers at various distances from axis. In calculating the energy flux we took into the account, besides the electrons and photons which underwent a multiplication in the lead plates of the cloud chamber, also the electrons and photons of comparatively low energy which were absorbed in the first or in the second plate. If the electron was absorbed in the first plate, which was 0.5 cm thick, its energy was assumed to be 10^7 ev; if the absorption of the particle took place in the second plate, 1.5 cm in thickness, its energy was estimated as 3×10^7 ev. These estimates are based on ionization losses only. Electrons and photons which produced pairs in the chamber were ascribed an energy of 5×10^7 ev. The contribution of all these particles to the energy flux is very small at distances less than 6 m from the shower axis and becomes noticeable only at distances > 6 m from the axis.

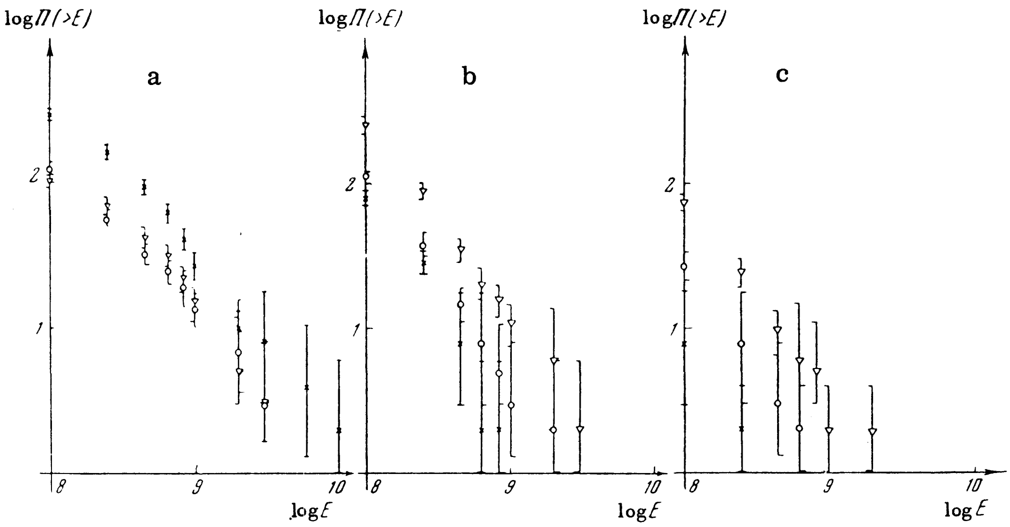

FIG. 3. Integral energy spectra of the electron-photon component for three groups of extensive air showers with the number of particles: × — 10^4 — 5×10^4, ⊙ — 5.1×10^4 — 10^5, ∇ — 1.1×10^5 — 5×10^5, a — for $r \leq 3$ m, b — for $3 < r \leq 6$ m, c — for $6 < r \leq 10$ m. П (>E) — number of particles with energy >E, recorded by the cloud chamber in all showers, the axes of which fell in the corresponding distance interval.

The lateral distribution of energy flux of the electronic component is represented in a log-log scale in Fig. 5 for three groups of showers with different number of particles.* It can be seen that within the limits of accuracy of the measurements the lateral distribution of energy flux is independent of the number of particles in the shower. If we approximate the dependence of the energy flux density on distance by the function r^{-n}, then $n = 2 \pm 0.5$.

We compared the experimentally obtained energy spectra and fraction of high-energy particles with the corresponding values calculated from cascade theory in order to find how does the production

*The effect of the mixing of the showers from different intervals due to the innacuracy of distance determination, described in Ref. 3, was taken into account in the calculations of the energy flux density at various distances from the axis.

mechanism of the electronic component influence its energy characteristics. It should be noted that, while the experimental high-energy spectra and fractions of high-energy particles were obtained by us for the electrons and photons together, calculations of the cascade theory refer to electrons only.

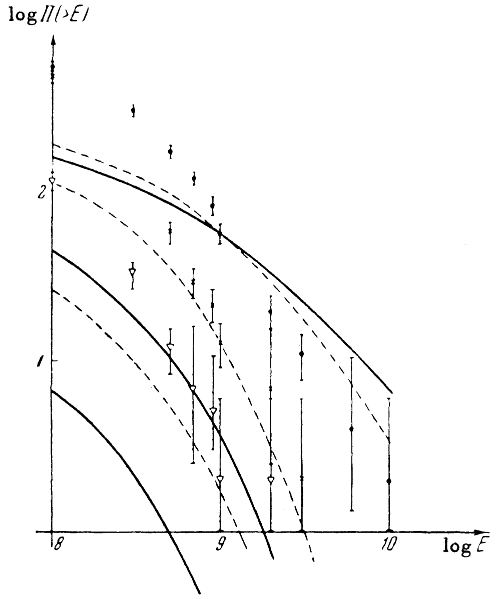

FIG. 4. Integral energy spectra of the electron-photon component of extensive air showers with the number of particles $10^4 - 5 \times 10^5$ for the distance intervals: ● — $r \leq 3$; × — $3 \leq r \leq 6$; ∇ — $6 < r \leq 10$ m; Electron spectra according to cascade theory are shown by the solid curve for $s = 1$, dotted — for $s = 1.5$. The experimental and the theoretical spectra are normalized for the energy 10^9 ev and $r \leq 3$ m.

We computed the energy spectra at various distances from the shower axis using the distance distribution of electrons with energy E calculated in Ref. 10. This distribution function was calculated in that reference for different values of the cascade parameter s and for distances down to zero.* Since our experimental spectra refer to distance intervals, we averaged the theoretical spectra over corresponding distance intervals using the experimental distance distribution of showers approximated by the solid curve in Fig. 2.

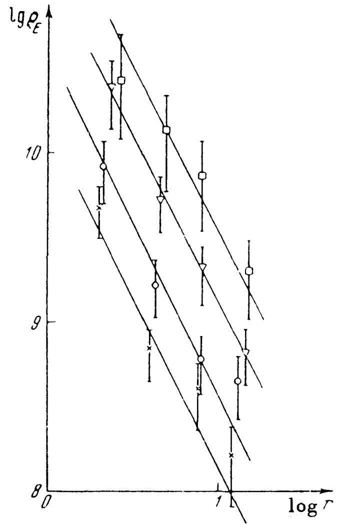

FIG. 5. Lateral distribution of the energy flux carried by the electronic component of extensive air showers. Energy flux density ρ_E is expressed in ev/m². Values of N: × — $10^4 - 5 \times 10^4$; ○ — $5.1 \times 10^4 - 10^5$; ∇ — $1.1 \times 10^5 - 5.1 \times 10^5$; □ — $5.1 \times 10^5 - 10^6$.

The integral energy spectra for $s = 1$ (solid curve) and $s = 1.5$ (dotted curve) are shown in Fig. 4. The experimental and the theoretical spectra are normalized for the energy 10^9 ev and $r \leq 3$. It can be seen that the experimental spectra are softer than the theoretical and are in better agreement with the value $s = 1.5$ than with $s = 1$. This fact is especially noticeable for small distances from the axis.

The fraction of high-energy electrons ($> 10^9$ ev) at various distances from shower axis was calculated by us in the following way: The total number of electrons in showers with $s = 1$ and $s = 1.5$ was determined from the cascade curves for air.[12] Their lateral distribution was calculated according to the approximation formula given by Greisen.[13] The number of electrons with energy $> 10^9$ ev in showers with $s = 1$ and $s = 1.5$ was determined from the well-known formula of cascade theory, without accounting for ionization losses. The lateral distribution of these electrons was obtained by means of calculations contained in Ref. 10. The fraction of high-energy electrons for showers with $s = 1$ and $s = 1.5$ averaged over distance intervals, are given in the two last columns of Table II.†

It can be seen from Table II that the value of the ratio $R(r_1, r_2)$ for showers recorded at sea level is considerably smaller than that computed from cascade theory. It is difficult to explain this fact on the basis of our present knowledge.

It is possible that in the central region of extensive air showers there is a large number of photons of

*The distribution functions given in Ref. 10 for $s = 1$ agree within 10% with the corresponding functions of Ref. 11, and for $s = 1.5$ exceed them by 50% in the whole distance range.

†Analogous calculations of the fraction of high-energy electrons at various distances from the axis were carried out by Hazen[14] by means of cascade theory for the altitude of 3260 m. The ratio ρ_1/ρ_0 was calculated. The values obtained for $s = 1$ are in agreement with our data if one accounts for the difference between the values of the radiation unit for 3260 m and sea level.

comparatively low energy which are in equlibrium with high-energy electrons. These photons, undergoing a conversion in the dense covers placed above the counters (amounting, according to a crude estimate to ~ 1/3 t-units) and in the counter walls increase the flux density of low-energy particles. Nor can we exclude the possibility that the electronic component of extensive air showers recorded by us is generated by means of π-mesons possessing a very soft energy spectrum.

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