NUCLEAR-ACTIVE PARTICLES IN ATMOSPHERIC SHOWERS

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Submitted to JETP editor December 20, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 13-21 (July, 1961)

Extensive and "young" air showers were studied at sea level with an array of 128 ionization chambers covering an area of 10 m^2. The energy of the nuclear-active particles near the axes of the extensive showers was found to be less than 50 percent of the energy of the electron-photon component. The mean inelasticity coefficient of the nuclear-active particles of the extensive showers exceeds 0.6 — 0.75. There is practically no nuclear-active component in a large fraction of the "young" atmospheric showers.

INTRODUCTION

THE opinion that the extensive air shower (EAS) is an electronic cascade in equilibrium with a nuclear avalanche, which in turn serves so to speak as a base for the shower,[1] has for a long time been regarded as suitably founded and not subject to doubt.

Many recent investigations, however, have shown, on the one hand, that the arguments used to prove the important role played by the nuclear-active component in the development of the EAS deep in the atmosphere is not unequivocal.[2] Models have been proposed, on the other hand, by which all the average characteristics of the EAS are explained without stipulating that the nuclear-active particles play a decisive role in the development of the EAS.[3]

It seems to us, in this connection, that the question of the characteristics of the elementary processes that underlie the formation of EAS has now again become timely. It is possible that a study of the nuclear-active particles in an EAS will help answer this important question. We deemed it advisable, therefore, with an aim toward obtaining information on nuclear-active particles in air showers, to carry out a suitable reduction of the experimental data obtained with the apparatus[4] used to study ionization bursts at sea level.

The apparatus used to carry out this research was described elsewhere.[4] The same reference contains data on the threshold for the registration of ionization with chambers in various rows, and on the system used to trigger the signal control in the case of registration of an air shower.

1. NUCLEAR-ACTIVE PARTICLES IN EXTENSIVE AIR SHOWERS

In the case when an EAS strikes the array, the summary ionization in chamber rows III and IV (see[4], Fig. 1) served as an indication of the energy $E_{e\text{-}ph}$ of the electron-photon component of the EAS striking the array. If nuclear-active particles were simultaneously incident on the array from the EAS, they interacted with the graphite block in the array and transferred part of their energy to the π^0 mesons. The energy transferred to the π^0 mesons was determined from the summary ionization in chamber rows I or II.

If we measure the ionization J_{max} produced by all the particles of the electron-photon cascade during the maximum of its development, then the energy of the cascade is $E = kJ_{max}$, where k is practically constant.

In the real conditions of our array, when the ionization was determined only at two cascade-development depths (in rows III and IV or I and II), it was impossible to locate the maximum of the shower or to determine J_{max}. In order to minimize the error, we took for J_{max} each time the ionization in that pair of rows (III or IV and I or II), in which the ionization was greater. We shall henceforth use the notation $J_{1,2}$ and $J_{3,4}$, bearing in mind that we took the greater of the two possible values of the overall ionization obtained from rows I and II or III and IV, respectively.

If it is true that $J_{max} = J_{1,2}$ (for the lower rows) or $J_{max} = J_{3,4}$ (for the upper rows), then

$$E_{e\text{-}ph} = kJ_{3,4} \text{ and } E_{\pi^0} = kJ_{1,2},$$

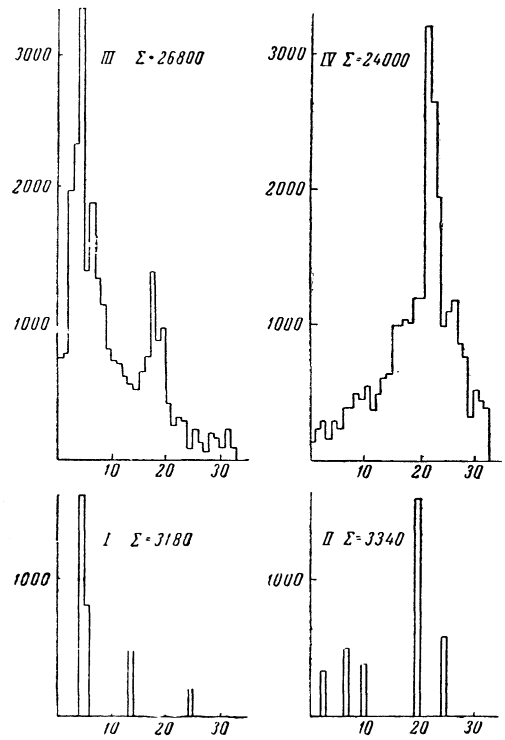

FIG. 1. Example of distribution of ionization over chambers of rows III and IV in the case when the axis of the EAS goes through the array. Abscissas—number of the chambers in a given row; ordinates—ionization in a given chamber, expressed in terms of relativistic particles passing through the the central chord. The lower part of the figure shows the distribution of the ionization, due to nuclear-active particles, in rows I and II.

i.e.,

$$E_{\pi^0} / E_{\text{e-ph}} = J_{1,2} / J_{3,4}.$$

It must be noted that the determination of the absolute value of $E_{\text{e-ph}}$ or of E_{π^0} from the measured values of $J_{3,4}$ or $J_{1,2}$ is subject to considerable errors, since the coefficient k depends on corrections for the transition effect, on constructive features of the chambers, and on the spatial and angular distributions of the particles, factors that do not lend themselves to accurate evaluation. This coefficient does not enter into the ratio $E_{\pi^0}/E_{\text{e-ph}}$ (if the chambers of the upper and lower rows are identical, as was the case in our array); it is therefore methodologically more correct to measure this ratio rather than $E_{\text{e-ph}}$ and E_{π^0} separately. Thus, the ratio of the summary ionization (summed over the row), measured by the lower rows of chambers, to the ionization measured in the upper rows of the chamber, will yield the energy transferred by the π^0 mesons to the nuclear-active particles of the EAS, referred to the energy of the electron-photon component of the EAS at the shower location where the nuclear active particles were located.

Since we did not use any special systems to determine the position of the shower axis in the registration of the EAS, the average $\overline{(J_{1,2}/J_{3,4})}$ is essentially equal to the ratio $\overline{(E_{\pi^0}/E_{\text{e-ph}})}$, averaged over showers with different numbers of particles (of different "powers") and over different portions of the shower. In those cases when the distribution of the ionization over the chambers of rows III and IV had a maximum at the central part of the layout and decreased monotonically towards the edges in both rows, III and IV, we assumed that the shower axis passed through the array.

An example of one such case is shown in Fig. 1. When the ionization distribution had no maximum or when the ionization increased monotonically from one edge of the array to the opposite one, or finally, when the ionization had a maximum in one row in the central part of the array, while the other row had no maximum, it was assumed in all these cases that the shower axis did not pass through the array.

We have singled out from among all EAS registered by the array those cases for which $J_{3,4} \geq 1.2 \times 10^4$ relativistic particles, i.e., cases for which $E_{\text{e-ph}} \gtrsim 2 \times 10^{12}$ ev. During the 1842 hours that the array was in operation, 284 EAS with $J_{3,4} \geq 1.2 \times 10^4$ were registered. The distribution of the number of cases of incidence of the axes of EAS of various "powers" is listed in Table I.

Table I

Size of registered EAS	Number of showers with axis over array	Number of showers with axis outside array
$1.2\cdot10^4 \leqslant J_{3,4} < 2,4\cdot10^4$	68±8	83±9
$2.4\cdot10^4 \leqslant J_{3,4} < 6\cdot10^4$	47±7	54±7.7
$6\cdot10^4 \leqslant J_{3,4} < 1.2\cdot10^5$	13±3.6	11±3.3

As can be seen from Table I, the EAS axis passes through the array in approximately 50 percent of the cases. In those cases when the axis passes outside the array, the EAS region registered is close to the shower axis. Consequently the ratio $\overline{E_{\pi^0}/E_{\text{e-ph}}}$ pertains to the central regions of the EAS.

Starting from the frequency of the registered EAS and from the energy of the electron-photon component of the showers ($J_{3,4} \geq 1.2 \times 10^4$ corresponds to $E_{\text{e-ph}} \gtrsim 2 \times 10^{12}$ ev), we can conclude that by picking out the showers with $J_{3,4} \geq 1.2 \times 10^4$ we automatically pick out the EAS with $\gtrsim 10^5$ particles. The average for these showers is $\overline{(J_{1,2}/J_{3,4})} = 0.130 \pm 0.047$. The distribution of the

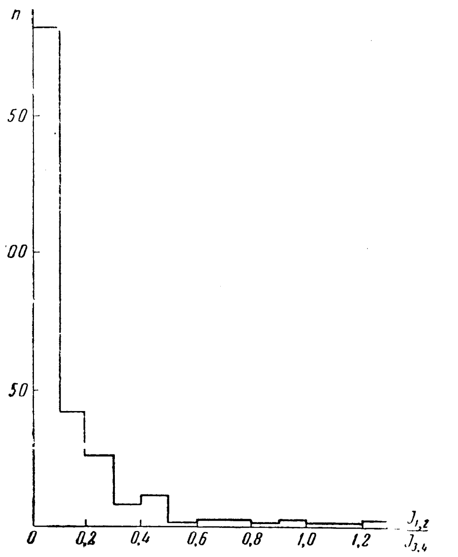

FIG. 2. Distribution of EAS based on the ratio $J_{1,2}/J_{3,4}$, (abscissas). The ordinates represent the number of showers with given ratio $J_{1,2}/J_{3,4}$.

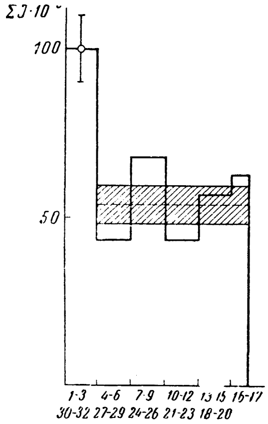

FIG. 3. Distribution of ionization over the chambers of the first row in all the registered EAS. Abscissas—number of chambers connected in one group; ordinates—values of the summary ionization registered by the given group of chambers in all the showers. The width of the shaded region is equal to twice the mean-square error.

values of $J_{1,2}/J_{3,4}$ over all 284 showers is shown in Fig. 2.

For the showers whose axes passed through the array, we obtained $\overline{(J_{1,2}/J_{3,4})} = 0.128 \pm 0.036$. The distribution of the ratios $J_{1,2}/J_{3,4}$ does not differ in this case from the one shown in Fig. 2.

In order for $\overline{(J_{1,2}/J_{3,4})}$ to be equal to $\overline{(E_{\pi^0}/E_{e\text{-}ph})}$ it is necessary that rows I and II of the array, which are under graphite, register only the electron-photon component generated by the nuclear-active particles in the array. However, because the EAS have a definite angular distribution, part of the electron-photon component of the air shower will pass through the side surfaces of the graphite absorber, multiply in the lead, and simulate the nuclear component in the EAS. This effect will cause the summary ionization recorded in all EAS in the outermost chambers of rows I and II to be greater than that recorded in the central chambers of the array.

In order to estimate the contribution of the electron-photon component of the EAS to the ionization registered by the chambers under the graphite layer, we plotted the distribution, over the chambers of row I, of the summary ionization registered in all 284 EAS.

To increase the accuracy we interconnected the chambers in groups of three, and additionally interconnected the groups that were symmetrical about the vertical plane passing through the center of the array. The result was the summary-ionization distribution shown in Fig. 3. This distribution shows that the three outermost chambers, taken together, registered in all the EAS an ionization 1.86 ± 0.26 times greater than registered on the average by the like three-chamber groups remote from the edge of the array. Assuming that the ionization produced in the chambers by the nuclear-active particles is independent of the location of the chamber in the array, we deduce from Fig. 3 that the electron-photon component of the EAS increases the ionization in row I by $30 \pm 7.5\%$. Therefore $\overline{(E_{\pi^0}/E_{e\text{-}ph})} = (0.130 \pm 0.047) \times (0.70 \pm 0.075) = 0.091 \pm 0.031$.

The nuclear-active particles can leave through the side surfaces of the array and thereby reduce E_{π^0}. By taking account of the angular distribution of the EAS, we can calculate the magnitude of this effect. It decreases E_{π^0} by 6 percent. We therefore have finally $E_{\pi^0}/E_{e\text{-}ph} = 0.097 \pm 0.036$.

Since the lateral distribution of the energy flux of the nuclear-active component is not broader than the lateral distribution of the energy flux of the electron-photon component of the shower, the average $\overline{(E_{\pi^0}/E_{e\text{-}ph})}$ over the entire shower will not exceed 0.097 ± 0.036.

A characteristic feature is that the value of $\overline{(E_{\pi^0}/E_{e\text{-}ph})}$ is determined to a considerable degree by a small number of showers having a

Table II

Size of shower $J_{3,4}$	Shower axes over array $\overline{(J_{1,2}/J_{3,4})}$	Shower axes outside array $\overline{(J_{1,2}/J_{3,4})}$	Average value of $J_{1,2}/J_{3,4}$ for given group of showers
$1.2\cdot10^4$—$2.4\cdot10^4$	0.062±0.011	0.092±0.023	0.078±0.014
$2.4\cdot10^4$—$6\cdot10^4$	0.202±0.046	0.182±0.041	0.191±0.031
$6\cdot10^4$—$1.2\cdot10^5$	—	—	0.178±0.068
$>1.2\cdot10^5$	—	—	0.150±0.046

nuclear-active component of anomalously high energy. As can be seen from Fig. 2, $E_{\pi^0}/E_{e\text{-}ph} < 0.10$ in 65 percent of the registered EAS.

It should be noted that, within the limits of experimental error, we observed no relation between the ratio $\overline{(J_{1,2}/J_{3,4})}$ and the value of $J_{3,4}$, except in the smallest of the registered showers.

The value of $\overline{(J_{1,2}/J_{3,4})}$ for different shower groups is listed in Table II.

It is possible that the low value of $\overline{(J_{1,2}/J_{3,4})}$ for showers with $J_{3,4} < 2.4 \times 10^4$ was due to the apparatus effect, since the ionization chambers in the lower rows (I and II) had an ionization-registration threshold of 200 — 300 relativistic particles. If this is so, it is more correct to take for the average $\overline{(J_{1,2}/J_{3,4})}$ the value corresponding to showers with $J_{3,4} \geq 2.4 \times 10^4$, namely 0.186 ± 0.027. Consequently, taking the foregoing corrections into account, we have in this case $\overline{(E_{\pi^0}/E_{e\text{-}ph})} = (0.186 \pm 0.027) \times (0.70 \pm 0.075) \times 1.06 = 0.138 \pm 0.024$.

2. "YOUNG" AIR SHOWERS

a) Intensity and spectrum of "young" air showers. In 1900 hours of operation, the array registered 52 "young" atmospheric showers (YAS),[3] which produced in rows III and IV an ionization $J_{3,4} \geq 1.2 \times 10^4$ relativistic particles. We classified showers as "young" if the bursts in rows III and IV were such that $\geq 60\%$ of all the ionization was produced in four or less chambers, i.e., in a circle of radius ~ 20 cm. Cases when the chamber with maximum ionization was on the edge of the array were excluded. This caused the area of the array effective in the registration of the "young" showers to decrease from 10 to 8 m^2. With account of this correction, the intensity of the YAS is $(0.95 \pm 0.13) \times 10^{-10}$ cm^{-2} sec^{-1}.

The requirement $J_{3,4} \geq 1.2 \times 10^4$ is tantamount to stating that the energy of the electron-photon cascade in the YAS be not less than 2×10^{12} ev. In all the YAS, the summary ionization in the third row of chambers was 1.5 or 2 times greater than the summary ionization in the fourth row. It follows therefore that YAS are highly collimated streams of the electron-photon component contained in the high-energy photons and electrons.

It is easy to show that the main part of the bursts in rows III and IV, which we attribute to the incidence of a narrow electron-photon shower from the air onto the array, cannot be simulated by electromagnetic interactions of high-energy muons in the lead absorbers of the array.

In fact, the number of bursts due to muons in the third row of chambers should not exceed the number of bursts registered by the second row. The intensity of single bursts in the second row, with $J_2 \geq 1.2 \times 10^4$ (the muons cannot produce structural bursts) is 2×10^{-11} cm^{-2} sec^{-1}. It is obvious that not all single bursts are produced by muons. Some are produced also by single nuclear-active particles. But if all the single bursts in the second row are attributed to electromagnetic muon interactions, even then their fraction in the "young" air showers will be merely 20 percent.

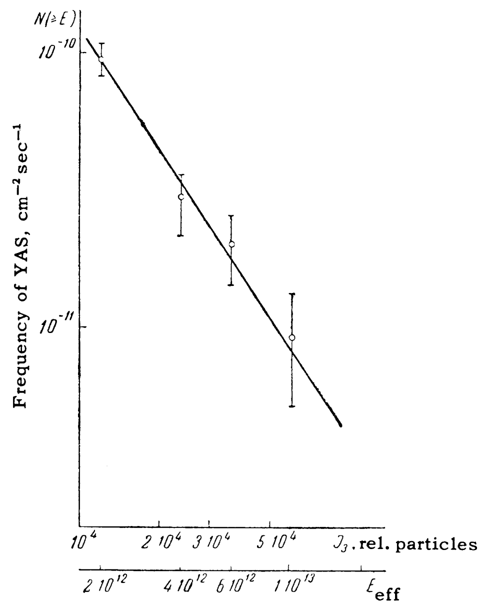

FIG. 4. Integral energy spectrum of YAS. Abscissas—summary ionization in the third row of chambers, produced by the YAS (the second scale shows the energy of the electron-photon component of the YAS). Ordinates—number of showers with $E_{e\text{-}ph}$ (or J_3) greater than a given value.

We have determined the energy of the electron-photon component of the YAS from the summary ionization in the third row of chambers.

Figure 4 shows the integral distribution of YAS relative to the value of J_3 (or $E_{e\text{-}ph}$, the energy of the electron-photon component of the YAS). This distribution can be approximated by a power law of the type $N(\geq J_3) = AJ_3^{-\gamma}$, where $\gamma = 1.5 \pm 0.4$.

As can be seen from Fig. 4, several YAS with energy $E_{e\text{-}ph} \geq 10^{13}$ ev were recorded during the time of operation. Were the young electron-photon showers of such high energy to move further through the atmosphere (had they been observed not at sea level, but some 3000 — 4000 m above sea level), they would develop into a cascade with $\sim 10^4$ particles at the maximum, i.e., they would develop into an ordinary extensive air shower.

Thus, "young" air showers are the forerunners of extensive air showers with at least $N \sim 10^4$ particles.

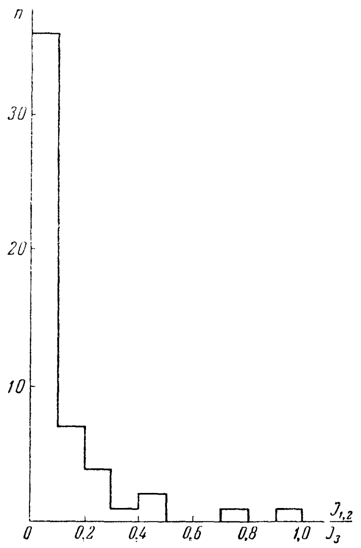

FIG. 5. Distribution of value of $J_{1,2}/J_3$ in "young" showers. Abscissas—$J_{1,2}/J_3$, ordinates—number of YAS with given value of $J_{1,2}/J_3$.

b) Nuclear-active particles in "young" air showers. The role of nuclear-active particles in the development of extensive air showers deep in the atmosphere is difficult to assay, for a number of reasons. First, the point where the EAS is registered is separated from the point where the shower is produced by a considerable layer of atmosphere, in which the nuclear-active particles can, in principle, expend the greater part of their energy on the formation of the electron-photon component of the EAS. The low energy of the EAS nuclear-active component, found at the observation level of a large fraction of the showers (see Fig. 2) cannot serve as a decisive argument against attributing a decisive role to the nuclear-active particles in the development of the EAS. Second, the appreciable development of the nuclear cascade within the layer of the atmosphere causes only a part of the nuclear-active particles contained in a given air shower to fall on an array of limited area. The natural fluctuations in the number and energy of the nuclear-active particles in a shower of given number of particles will become aggravated by fluctuations due to the small dimensions of the array used to register the nuclear-active particles. The most direct answer to this question could therefore be obtained by studying the nuclear-active particles in the acts of generation of extensive air showers.

Inasmuch as "young" air showers are cases wherein the electron-photon component is generated directly above the array (calculations show that at sea level the effective layer within which YAS with $E_{e\text{-}ph} \approx 10^{12}$ ev are produced is three cascade units thick), the majority of the secondary nuclear-active particles generated in the same act in which the electron-photon component of the YAS was generated should strike an array of the size we used. Since YAS involve cases wherein the energy transferred to the electron-photon component is large enough for an extensive air shower to develop upon passage of this component through the atmosphere, a study of the nuclear-active component in YAS can help answer the question raised above.

We therefore examined, in 52 incidences of YAS with $E_{e\text{-}ph} \geq 2 \times 10^{12}$ ev, the ratio $J_{1,2}/J_3 = E_{\pi^0}/E_{YAS}$, which characterizes the energy transferred by the neutral pions to the nuclear-active particles of the YAS in 60 g/cm^2 of graphite, referred to the energy of the electron-photon component of the YAS. The distribution of $J_{1,2}/J_3$ is shown in Fig. 5.

This distribution calls for two clarifications. First, the interval $0 \leq J_{1,2}/J_{3,4} \leq 0.1$ contains 24 cases when $J_{1,2} = 0$. Second, a structural burst was observed in an overwhelming number of cases when $J_{1,2} \neq 0$ (~ 70%), demonstrating the presence of several nuclear-active particles in the YAS. We can therefore state that the cases $J_{1,2} = 0$ signify a practically total lack of nuclear-active component in a "young" air shower.

The mean value $\overline{(J_{1,2}/J_{3,4})}$ in all 52 YAS was 0.11 ± 0.03, i.e., its value is practically the same in YAS as in EAS with $J_3 \geq 1.2 \times 10^4$. It is curious that the distribution of the ratios $J_{1,2}/J_3$ is practically the same in YAS as in EAS.

3. DISCUSSION OF RESULTS

The question of the fraction of the energy of nuclear-active particles in EAS is of great interest because of the role that nuclear-active particles play in the development of EAS deep in the atmosphere. The energy of the nuclear-active particles contained in an EAS is usually (see, e.g.,[5]) estimated by measuring the energy transferred to the neutral pions in a thick layer of light matter, and the mean summary energy $\overline{E}_{n\text{-}a}$ of the nuclear-active particles in the EAS is determined by assigning an arbitrary mean inelasticity coefficient $\overline{K} \sim 0.3$ to these nuclear-active particles. Whereas an inelasticity coefficient $\overline{K} \sim 3$ can be justified in the case of nucleons, (a low inelasticity coefficient was in fact obtained[6] for nucleons in the energy region $\sim 10^{10}$ ev), this is not the case for the nuclear-active particles of an EAS. In fact, if it assumed that the electron-photon component of the shower deep in the atmosphere (in particular, at sea level) is in equilibrium with the nuclear component and if it is assumed that the nucleons and mesons have different mean inelasticity coefficients, $\bar{K}_n$ and $\bar{K}_\pi$ respectively, then the change in the summary energy flux due to the nucleon and pion components in the shower can be described by the following equations (neglecting the decay of the $\pi^\pm$ mesons):

$$dE_n/dX = -\bar{K}_n E_n(X)/L; \quad (1)$$

$$dE_\pi/dX = -\bar{K}_\pi E_\pi(X)/3L + 2\bar{K}_n E_n(X)\,3L, \quad (2)$$

where $E_n(X)$ and $E_\pi(X)$ is the summary energy of the nucleon and meson components at a depth X g/cm^2 from the top of the atmosphere.

From these equations it follows that:

a) If $\bar{K}_n = 1/3$ and $\bar{K}_\pi = 1$, then for a depth 1000 g/cm^2 and an interaction range $L = 70$ g/cm^2 the nucleon energy flux will amount to 25 percent of the total energy flux of all the nuclear-active particles. The contribution to the electron-photon component of an EAS in a thin layer of the atmosphere, made by the nucleon component, will be one-ninth the contribution of the $\pi^\pm$ mesons, i.e., the effective value of $\bar{K}$ will be close to 1.

b) If $\bar{K}_n = \bar{K}_\pi = 1/3$, then the nucleon energy flux at a depth 1000 g/cm^2 will in this case be merely 5 percent of the total energy flux of the nuclear-active shower component. This case, however, is apparently impossible, for it corresponds to too small an absorption coefficient for the nuclear-active component, $\mu_{n-a} = (630 \text{ g/cm}^2)^{-1}$. This absorption coefficient does not correspond to the mean absorption coefficient of the particles in the shower, $\mu_N = (200 \text{ g/cm}^2)^{-1}$. Consequently, an effective value $\bar{K} \approx 0.3$ can hardly be assumed for the nuclear-active particles with any justification.

It seems to us that a more logical way to determine the energy of the nuclear-active particles in the EAS will be one in which the inelasticity coefficient K is not stipulated a priori.

From our data we can estimate the mean fraction of the energy of the nuclear-active component of an EAS in the following fashion:

We know that the mean fraction of particles absorbed in a shower (averaged over different showers with a given number of particles) has a value $\mu_N = (200 \text{ g/cm}^2)^{-1}$ and is practically independent of the "power" of the shower N.

If the independence of μ_N of the depth of the level of observation of the EAS in the atmosphere is attributed to the role of the nuclear-active component, then the absorption of the energy flux of this component will be determined by the range $\Lambda = 1/\mu_N = 200$ g/cm^2.

The fact that μ_N is independent of the number of particles N over a wide range of values of N indicates that the $\pi^\pm$-meson decay plays an insignificant role in the dissipation of the energy of the nuclear-active component of the EAS in the atmosphere. Consequently, the value of Λ is determined by the singularities of the nuclear-interaction processes, and primarily by the transfer of energy to the neutral pions. Neglecting the decay of the $\pi^\pm$ mesons, we can easily relate the energy $E_{\pi^0 C}(X)$, transferred to the neutral pions in a layer of graphite X g/cm^2 thick, to the energy flux E^0_{n-a} of the nuclear-active component of the EAS.

We denote by $E_C(X)$ and $E_a(X)$ the energy fluxes of the nuclear active components under a layer of graphite and air of thickness X, respectively. Then

$$E_{\pi^0 C}(X) = E^0_{n-a} - E_C(X) = E^0_{n-a} - E_a(X) = E^0_{n-a} - E^0_{n-a}\, e^{-X/\Lambda} = E^0_{n-a}\left(1 - e^{-X/\Lambda}\right); \quad (3)$$

on the other hand, we can readily ascertain that under the same assumptions

$$E_{\pi^0 C}(X) = \frac{\bar{\alpha}_{\pi^0}}{L}\int_0^X E_C(X)\,dX = \frac{\bar{\alpha}_{\pi^0}}{L}\int_0^X E_a(X)\,dX = \frac{\bar{\alpha}_{\pi^0}\Lambda}{L}\left(1 - e^{-X/\Lambda}\right). \quad (4)$$

Here $\overline{\alpha_{\pi^0}}$ is the mean fraction of energy transferred to the neutral pions by the nuclear-active particles of the EAS in one interaction. Comparing (3) and (4), we can readily note that $\overline{\alpha_{\pi^0}} = L/\Lambda$.

If we take for L and Λ the customary values $L = 70$ g/cm^2 and $\Lambda = 200$ g/cm^2, we obtain $\overline{\alpha_{\pi^0}} \approx 1/3$, i.e., the effective inelasticity coefficient for nuclear-active particles of an EAS is $\bar{K} = 3\overline{\alpha_{\pi^0}} \approx 1$.

The ratio of the energy transferred to the neutral pions in a given layer of graphite to the energy of the electron-photon component of the EAS, E_{e-ph}, is

$$E_{\pi^0 C}(X)/E_{e-ph} = (E^0_{n-a}/E_{e-ph})\,(1 - e^{-X/\Lambda}). \quad (5)$$

According to our data, we have for 60 g/cm^2 of graphite

$$\overline{E_{\pi^0 C}\,(60 \text{ g/cm}^2)/E_{e-ph}} = 0.10 \pm 0.036$$

and if $\Lambda = 200$ g/cm^2, then $E_{n-a}/E_{e-ph} = 0.40 \pm 0.14$.

On the other hand if we assume, with account of the remarks made earlier, that

$$\overline{[E_{\pi^0 C}\,(60 \text{ g/cm}^2)/E_{e-ph}]} = 0.138 \pm 0.024,$$

then

$$\overline{E_{n-a}/E_{e-ph}} = 0.53 \pm 0.09.$$

The foregoing estimate of the ratio of the energy of the nuclear-active particles to the energy of the electron-photon component of the shower yields a value some 2 — 2.5 times smaller than previously obtained by some workers,[5] who assumed an inelasticity coefficient ~ 0.3 for the nuclear active particles in the EAS.

This discrepancy signifies that the true inelasticity coefficient of the nuclear-active particles in an EAS is not 0.3, but at least 2.5 or 2 times greater, i.e., $\overline{K} \cong 0.75 - 0.6$.

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