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Spatial Distribution of the Particles of Extensive Air Showers Produced by Primary Cosmic Rays of Various Energies

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The spatial distribution of charged particles in the central region of extensive air showers produced by primary cosmic ray particles of various energies was experimentally investigated. It has been found that, within the limits of experimental error, the spatial distribution is independent of the energy of the primary particle producing the shower in the energy region of 10^{13} –6×10^{15} ev.

EARLIER experiments[1] have determined the spatial distribution of charged particles near the core of extensive air showers for primary energies between 6×10^{13} ev and 10^{15} ev. In the summer of 1954, we carried out experiments which had the purpose of widening the energy interval of the investigated extensive air showers. The spatial distribution of particles in showers of primary energy lower than 6×10^{13} and higher than 10^{15} ev was studied at 3860 m above sea-level.

The experimental arrangement described in Ref. 1 was used for the investigation of the spatial distribution of the flux of charged particles in showers produced by primaries with energy > 10^{15} ev. Groups of hodoscoped counters, each 16 cm^2 in area, were used to ensure accurate measurements of high density particle flux. The methods of particle flux density determination, of core selection, and of the counting of the number of particles, used in each case of an air shower detection, were identical with those described in Ref. 1. The resulting average spatial distribution of particles in showers consisting of 1.2×10^6 particles is shown in Fig. 1 (curve 1). The x-axis represents the distance from the core in meters, the y-axis the flux density of shower particles, expressed in number of particles per square meter.

A difficulty connected with the small number of particles in showers arises in the investigation of showers with less than 10^4 particles. We studied showers which discharged 4–7 counters out of the 456 counters, with the area of each equal to 100 cm^2 , present in our arrangement (Fig. 2). The cores of such showers were selected by groups of hodoscoped counters shielded with 2 cm and, in some of the measurements, with 4 cm of lead. The cascade multiplication of the electron-photon component in lead increases with the proximity of the core to the shielded group of counters. The determination of the core location

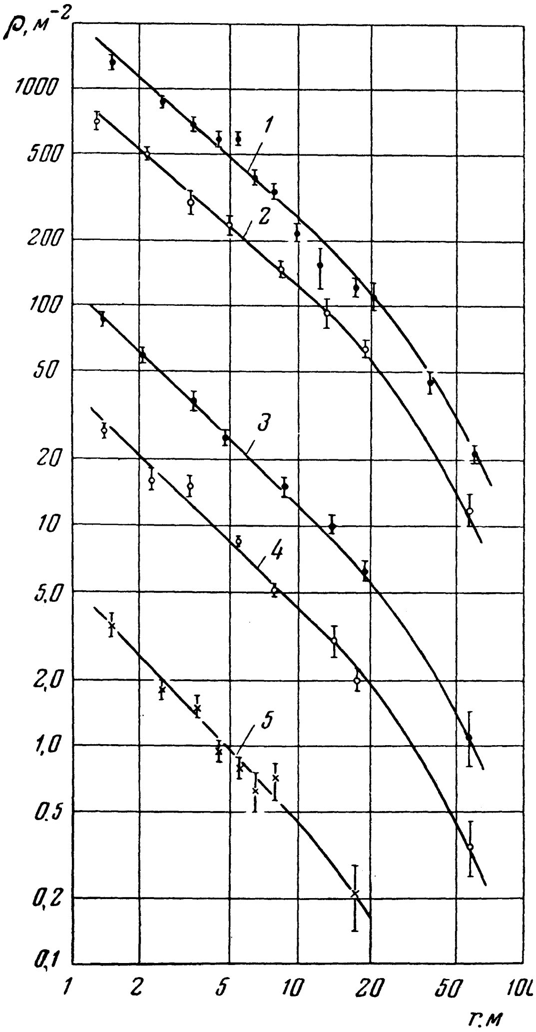

FIG. 1. Spatial distribution of the flux density of charged particles in extensive air showers with different numbers of particles: curve *1*–1.25×10^6 ; *2*–5.7×10^5 *3*–6.3×10^4 ; *4*–2.1×10^4 ; *5*–2.5×10^3.

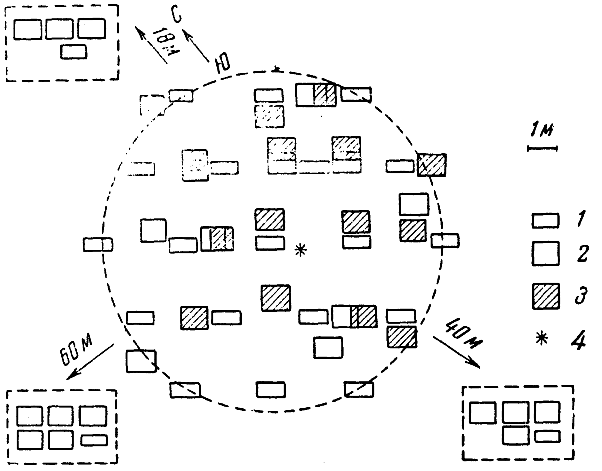

FIG. 2. Position diagram of hodoscope counters: *1*—nonshielded counters: 100 × 24 = 2400 cm^2; *2*—nonshielded counters: 330 × 12 = 3960 cm^2. *3*—shielded counters: 330 × 12 = 3960 cm^2; *4*—group of master counters.

by means of the shielded hodoscoped counters was effected without any difficulty.*

For the showers with total number of particles between 10^3 and 4×10^3 ($\overline{N} = 2.5 \times 10^3$), the difference between the actual number of particles in individual showers was disregarded, since the error of the determination of the number of particles in an individual shower amounted to 50% in each case. We measured the ratio of the total number of counters to the number of counters recording the passage of a shower particle, at a given distance from the core, for all the investigated showers. The margin of each measured distance from the core amounted to one meter, which was similar to the error of the determination of the core position for an individual shower. The resulting spatial distribution of particles is shown in Fig. 1 (curve 5). The results of Ref. 1 are included for comparison in the same figure (curves 2,3 and 4). The slopes of the linear portions of the curves were analyzed by means of least-square method. The values of the exponent n of the spatial distribution function $\rho(r) \sim 1/r^n$ corresponding to a straight line in a log-log plot, for showers with different numbers of particles and, consequently, of various primary energies are given in the Table. It can be seen both from Fig. 1 and the Table that the experimental results of Ref. 1 are in good agreement with the present work.

The normalized spatial distribution of particles in showers produced by primaries of different energies is shown in Fig. 3.

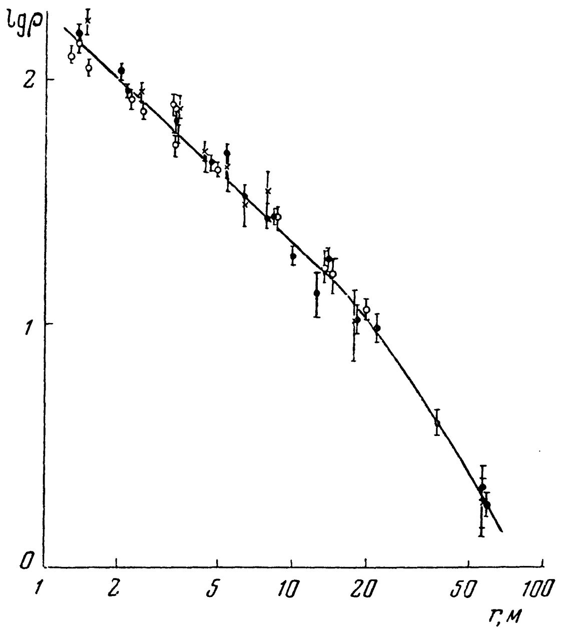

FIG. 3. Normalized spatial distribution of the flux density of charged particles in extensive air showers of different primary energies. The densities are normalized at the distance of 10 m.

Total number of particles $\overline{N}$	Energy of the primary particle $E_0 = 5 \times 10^9 N$	n
$1.25 \cdot 10^6$	$6.2 \cdot 10^{15}$	0.93 ± 0.06
$5.7 \cdot 10^5$	$2.9 \cdot 10^{15}$	0.90 ± 0.02
$6{,}3 \cdot 10^4$	$3.2 \cdot 10^{14}$	1.03 ± 0.03
$2{,}1 \cdot 10^4$	$1.0 \cdot 10^{14}$	1.00 ± 0.06
$2.5 \cdot 10^3$	$1{,}2 \cdot 10^{13}$	1.11 ± 0.08

It should be noted that, in order to determine the total number of particles in a shower, it is necessary to make use of the distribution function up to distances of the order of several hundred meters from the core. We used the results of Ref. 2, assuming the independence of the spatial distribution from the primary energy, which, as it can be seen from the Table, is fully ascertained for the central part of the shower.

Theoretical considerations, based on the electron-photon cascade theory[3] as well as on the nuclear cascade theory of shower development with an account of the angular distribution of particles produced in the elementary processes of nuclear interaction[4] show that, with the decrease of the primary energy, one should expect a steeper slope of the spatial distribution function near the core of an extensive air shower. It can be seen from the Table

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*This method was proposed by G. T. Zatsepin.

that the expected change in the spatial distribution function is not observed experimentally.**

The experimental results obtained can be explained under the assumption of the presence of a single, energetically distinct nuclear-active particle in the core of the extensive air shower having a primary energy less than 10^{15} ev. This particle produces then the high-energy electron-photon component in the depth of the atmosphere.[6]

This conclusion can be illustrated by the comparison of our results on the spatial distribution with the angular distribution of particles in the nucleon-nucleon interaction processes observed in photographic emulsions. Under the assumption that the extensive air showers, recorded by us, which are produced by primary nucleons of 1.2×10^{13} ev, are formed at ~ 15 km, it follows from the experimentally observed spatial distribution that the greater part of the energy released in the primary interaction is carried away by particles within a solid angle equal to $\sim 10^{-4}$ sterad.. In Ref. 7, only one particle was found within the angle of 10^{-4} sterad in a nucleon–nucleon interaction at $\sim 10^{13}$ ev primary energy, the single particle evidently carrying away the greater part of the energy of the primary particle.

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**The tendency of the spectral distribution function for showers of 10^{15} ev to be steeper, which may possibly be connected with the change of the nature of the primary nuclear interaction process for particles of 10^{15} ev[5] needs an additional investigation.

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Nuclear Disintegrations Produced by 660 mev Protons in Photographic Emulsions

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We present experimental material from an investigation of nuclear disintegrations produced in photographic emulsion by 660 mev protons. The general features of the disintegration, the magnitude of the cross section for inelastic processes, and the distributions in energy and angle of secondary protons and alpha particles are presented. The yield of charged π-mesons per disintegration is obtained, and an approximate value is suggested for the lower limit of the cross section for emission of two charged π-mesons in a disintegration.

AT the present time there has been accumulated a large amount of experimental material from investigation of nuclear disintegrations occurring through the action of particles with energies of some hundreds of mev.

Experiments on stars in photographic emulsion, radiochemical investigations of reaction products, and experiments on scattering and absorption of particles have enabled us to establish the quantitative features of some aspects of the process of interaction of high energy particles with nuclei, and to compare the experimental data with various pictures of the nuclear model and the mechanism of interaction. However, a detailed analysis of the experimental data is made difficult by the great variety of the processes which occur, and also by the lack