

COMPOSITION OF NUCLEAR-ACTIVE PARTICLES WITH MOMENTUM  $>1.8 \text{ BeV}/c$  IN COSMIC RADIATION AT 3250 m ABOVE SEA LEVEL . I

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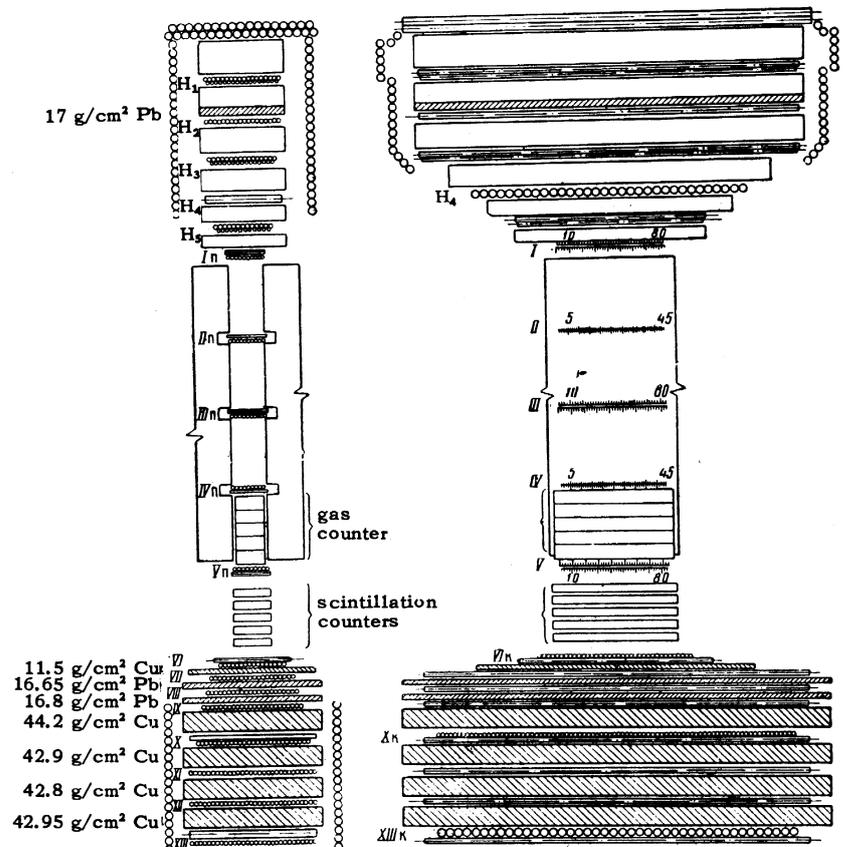
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The nature and the momentum spectrum of nuclear-active cosmic-ray particles in the atmosphere were investigated at 3250 m above sea level using a magnetic mass spectrometer and a five-layer proportional counter. In the momentum range 100–720 MeV/c, a ratio  $N_{\pi^+}/N_{\pi^-} = 0.90 \pm 0.15$  has been obtained for the cosmic-ray nuclear-active particle flux.  $\pi$  mesons comprise about 5% of all particles in the 1.8–22 BeV/c momentum range, and not more than 10% of the particles with momentum  $\geq 1.8 \text{ BeV}/c$ .

IN experiments devoted to the study of the nature and of the energy spectrum of particles produced by cosmic rays, the nature and the energy of the primary particles remains, strictly speaking, unknown in the majority of cases. However, when using cosmic-ray particles for a study of the interactions at energies not accessible to accelerators, it is necessary to know the composition of the primary-particle flux.

At mountain altitudes, the star-producing particles with low-energies are mainly nucleons. Low-energy  $\pi$  mesons produced in stars decay before interacting, not far from the place of production. In the high-energy range ( $\sim 10 \text{ BeV}$ ), the mean free path of the  $\pi$  mesons before decay is of the order of the nuclear mean free path, and in the production processes the contribution of  $\pi$  mesons to the secondary particle production should there-

FIG. 1. Diagram of the apparatus in two perpendicular sections.



Character of Passage of Nuclear-Active Particles with  
Momentum 1.8–22 BeV/c through the Absorbers of the  
Apparatus

Method of selection of nuclear-active particles and the series of measurements	Character of interaction of particles in the absorbers							
	Products which did not traverse tray XIII, $N_{stop}$		Products which traversed tray XIII; large stars ( $n \geq 5, m \geq 2$ ), $N_{star}$		$N_{stop} + N_{star}$		Remaining events of passage through absorbers	
	+	-	+	-	+	-	+	-
1. Interactions in the absorbers of the apparatus: Series A Series B	188 13	3 2	5* 15	1* 0	193 28	4 2	Cannot be distinguished from $\mu$ mesons	
Total:	201	5	20	1	221	6		
2. Production of particles above the apparatus in nuclear interactions. Measurements under 25 cm Pb [17]	5	1	1	2	6	3	20	5

\*Anticoincidences (I + II + III + IV + V - XIII).

fore increase with increasing energy.

The purpose of the present experiment was to determine the relative number of  $\pi$  mesons in the flux of nuclear-active particles of cosmic radiation in the energy range  $> 1.8$  BeV/c.

## 1. INSTRUMENTATION

The experiment was carried out at 3250 m above sea level (Mount Aragats, Armenia) using a magnetic mass spectrometer.

A cross section of the instrument is shown in Fig. 1. The apparatus consists of a mass spectrometer (magnetic field intensity 6850 Oe), a hodoscope placed above the spectrometer, [1] a five-layer thin-wall gas proportional counter, [2] and five scintillation counters. [3] The design enables us to measure the momentum and the specific ionization for particles traversing the magnetic field, and to determine the character of their passage through lead and copper absorbers placed below the spectrometer.

The root-mean-square errors of the momentum measurement at 2 and 20 BeV/c amount to 10 and 80% respectively. The specific ionization was determined for individual particles with an average error of  $\pm 14\%$  using the gas counter, and  $\pm 10\%$  using the five scintillation counters.

The amount of matter above the instruments (roof of the building) amounted to not more than  $5 \text{ g/cm}^2$  of wood and  $1 \text{ g/cm}^2$  of steel.

## 2. SEPARATION OF NUCLEAR-ACTIVE PARTICLES OF THE AIR FLUX FROM ELECTRONS, $\mu$ MESONS, AND PARTICLES PRODUCED IN THE APPARATUS

Exclusion of electrons. A lead plate  $17 \text{ g/cm}^2$  thick was placed above the tray  $H_2$  of the hodoscope (Fig. 1) to decrease the background of electrons.

A hodoscope surrounding the first three absorbers [ $11.5 \text{ g/cm}^2 \text{ Cu} + (16.65 + 16.8) \text{ g/cm}^2 \text{ Pb}$ , i.e.,  $0.87 + 3.2 + 3.24$  cascade units] was used as a detector of the electrons that traversed the magnetic field. To exclude the electrons, all particles which produced in these three absorbers showers with particles that did not penetrate into the following copper absorber ( $44.2 \text{ g/cm}^2$ ) were excluded from the analysis.

Exclusion of particles produced in the apparatus. All particles produced by neutral radiation or in stars in the hodoscope above the magnet were excluded.

Exclusion of  $\mu$  mesons. The problem of distinguishing between nuclear-active particles and  $\mu$  mesons was studied by G. V. Khrimyan, [4] who showed that events of stopping not due to ionization, scattering at an angle greater than two-root-mean-square multiple scattering angles, and "large" stars (of the type  $n \geq 5, m \geq 2$ ),\* are

\*Stars produced in the hodoscope sandwiched between absorbers are characterized by the numbers  $m$  and  $n$ , where  $m$  is the number of trays penetrated by not less than two particles of the star, and  $n$  is the number of observed secondary particles of the star. [4]

due exclusively to nuclear-active particles.

Other types of interactions of nuclear-active particles cannot be distinguished from electron cascades produced by  $\mu$  mesons. Nuclear-active particles were separated from  $\mu$  mesons using the method proposed in [4] (large-angle scattering events were not taken into account because of selection difficulties).

### 3. $\pi$ MESONS IN THE FLUX OF NUCLEAR-ACTIVE PARTICLES AT 3250 m ABOVE SEA LEVEL

According to experimental results, [5-15] the cross sections for the inelastic nuclear interactions of  $\pi^\pm$  mesons and nucleons with nuclei are equal within the limits of statistical error ( $\leq 15\%$ ), and are independent of the particle momentum in the range  $\geq 2$  BeV/c.\* The fraction of  $\pi$  mesons in the flux of nuclear-active particles of cosmic radiation can therefore be determined from the number of positively and negatively charged particles that undergo inelastic nuclear interactions. In the present experiment, we have used the results of two series of measurements: Series A (coincidences of I + II + III + IV + V - XIII), in which the apparatus recorded mainly the particles absorbed together with their secondary products in the absorbers, and Series B (coincidences I + II + III + IV + V), in which the apparatus recorded all particles.

Detailed data on the character of the passage of positive and negative "primary" particles through the absorbers in the two series of measurements A and B are given in the table. The data show that the ratio  $N^+/N^-$ , within the limits of the statistical errors of the experiment, is identical for primary particles producing large stars with penetrating secondaries and for particles which undergo other types of nuclear interactions. This means that we can use the data of both series of measurements to determine the relative number of  $\pi$  mesons in the cosmic-ray flux in air.

The momentum spectra of positive and negative particles with momentum  $\geq 1.8$  BeV/c observed in Series A are shown in Fig. 2a. Analogous spectra obtained from Series B are shown in Fig. 2b. In addition to particles shown in Figs. 2a and 2b, we observed five particles with momenta  $> 22$  BeV/c whose sign of charge could not be determined.

\*The investigations [5-9] refer to photographic emulsions, and [10-15] to C, Cu, and Pb. In [5-9, 11, 15], the cross sections are given for the momentum range  $> 20$  BeV/c.

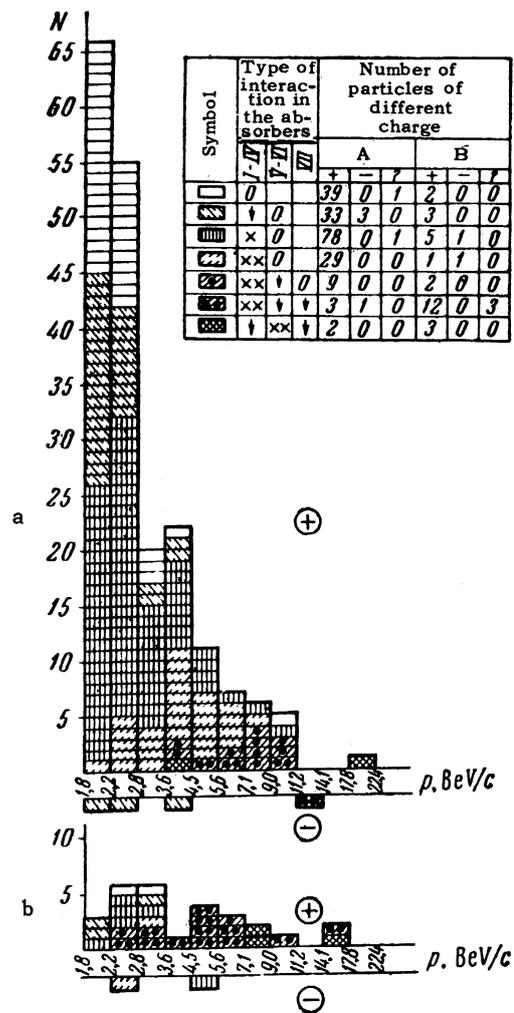


FIG. 2. Momentum spectra of nuclear-active particles of cosmic radiation at 3250 m altitude: a - spectrum of particles observed in the series of measurements A, b - spectrum of particles observed in the series of measurement B. Notation: o - stopping, ↓ - passing without interaction, x - production of a weak star, xx - production of a large star ( $m \geq 2$ ,  $n \geq 5$ ),  $\gamma$  - particles with momenta greater than 22 BeV/c, whose sign of charge could not be determined.

According to the data of both series of measurements, 232 particles were observed in the momentum range  $> 1.8$  BeV/c, of which 6 were negative, 221 positive, and 5 of unknown sign.

Thus, in the 1.8-22 BeV/c energy range, which contains 95-98% of the particles with momenta  $\geq 1.8$  BeV/c, the number of negative particles amounts to  $\sim 3\%$ .

We investigated the ratio  $N_{\pi^+}/N_{\pi^-}$  in the momentum range up to 720 MeV/c, where particles can be identified by momentum and ionization. [16, 17] Using the apparatus described (Fig. 1), we obtained  $N_{\pi^+}/N_{\pi^-} = 17/15$ . According to the data of an earlier experiment "without generators," [16]

$N_{\pi^+}/N_{\pi^-} = 47/56$ .<sup>\*</sup> Thus, for air  $N_{\pi^+}/N_{\pi^-} = 0.90 \pm 0.15$ .

If the ratio  $N_{\pi^+}/N_{\pi^-}$  does not differ greatly in the momentum range  $> 1.8$  BeV/c from that observed in the energy range up to 720 MeV/c, then it follows from the data given in Figs. 2a and 2b that  $\pi$  mesons amount to  $(6 \pm 2)\%$  of all nuclear-active particles in the momentum range 1.8–22 BeV/c.

If we assume that all five particles of unknown sign are also  $\pi$  mesons, then, in the momentum range  $> 1.8$  BeV/c, the maximum number of  $\pi$  mesons amounts to not more than 10% of the flux of cosmic-ray nuclear-active particles at 3250 m altitude.

There are no direct experimental data in the literature on the fraction of  $\pi$  mesons among the nuclear-active particles in the atmosphere. All we have is the spectrum of the  $\pi$  mesons, calculated from experimental spectra of the  $\mu$  mesons assuming that all the  $\mu$  mesons are the decay products of  $\pi$  mesons produced in air,<sup>[18]</sup> in addition to the data on the ratio  $(N_{in}^+ - N_{in}^-)/W_{na}N_{\mu}$  in the cosmic-ray flux.<sup>[11]</sup> ( $N_{\mu}$  is the number of  $\mu$  mesons,  $N_{in}$  is the number of particles interacting in the absorbers of the apparatus, and  $W_{na}$  the probability of interaction of nuclear-active particles.<sup>†</sup>)

In order to compare our data with the results of<sup>[11]</sup> and<sup>[18]</sup>, it is necessary to determine the total number of nuclear-active particles which traversed our setup. The spectrum in Fig. 2 and the table give the number  $N_{stop}$  of particles which stopped, and the number  $N_{star}$  producing stars in absorbers. The remaining particles, which traversed the absorbers without interaction or which produced small stars on passing through them, were excluded by the anticoincidence system (-XIII) and by the selection criteria of nuclear-active particles.

In order to determine the detection efficiency  $W$  of the nuclear-active particles, we have studied the passage through the apparatus absorbers of nuclear-active particles with momentum  $\geq 1.8$  BeV/c produced by neutrons or originating in large stars ( $n \geq 5$ ,  $m \geq 2$ ) in the series of measurements under 25 cm Pb.<sup>[17]</sup> These data are also given in the table. According to the data of Series B, also obtained under 25 cm Pb, we have  $W$

$= 0.31 \pm 0.09$ . In Series B, the number of  $\mu$  mesons with momenta  $\geq 1.8$  BeV/c was equal to 1088. Hence, we obtain  $N_{\pi}/N_{\mu} = (4.6 \pm 2.3) \times 10^{-3}$ ;  $(N_{na}^+ - N_{na}^-)/WN_{\mu} = (8 \pm 3) \times 10^{-2}$ . The values obtained agree within the limits of the experimental errors with the calculations of<sup>[18]</sup>;  $N_{\pi}/N_{\mu} = 3.5 \times 10^{-3}$  (in the range 2–4 BeV/c), and with the data of<sup>[11]</sup>:  $(N_{in}^+ - N_{in}^-)/W_{na}N_{\mu} = (6.1 \pm 0.6) \times 10^{-2}$ .

The flux of charged nuclear-active particles in cosmic rays in the atmosphere consists of protons,  $\pi$  mesons, deuterons,<sup>[17]</sup> and possibly K mesons.\* The present data refer to the relative number of  $\pi$  mesons. The relative number of K mesons, protons, and deuterons in the momentum range  $\geq 2$  BeV/c cannot be determined by measuring the ionization and momentum or by the method used in the present experiment. This problem requires other experimental methods and lies outside the scope of the present article.

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\*These data are published here for the first time.

<sup>†</sup>The selection criteria of the  $N_{in}$  events, used in<sup>[11]</sup>, do not exclude the background  $\delta N_{\mu}$  of  $\mu$  mesons producing electron showers (see<sup>[4]</sup>), i.e., in<sup>[11]</sup>, in fact,  $N_{in} = N_{na} + \delta N_{\mu}$  and therefore,  $N_{in} \neq N_{\pi^-}$ , but  $N_{in}^+ - N_{in}^- = N_{na}^+ - N_{na}^-$  since  $\delta N_{\mu}^+ \approx \delta N_{\mu}^-$ .

\*In the energy range 100–720 MeV/c, not a single K meson was observed among more than 500 nuclear-active particles in the series of measurements A and B.

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Translated by H. Kasha

108