Multiply charged particles of the primary cosmic rays with energies $\geqslant$2 TeV

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The results of measurements of the energy spectra and the charge composition of the primary cosmic-ray nuclei with $z \geqslant 2$ at energies > 2 TeV are presented. The experiment was carried out with the apparatus "Sokol" aboard the artificial earth satellite "Kosmos-1543."

In 1984, the apparatus "Sokol" on board the artificial earth satellite "Kosmos-1543" was used to measure the energy spectra and charge composition of particles of the primary cosmic rays with energies $\gtrsim 2$ TeV. The energy of the particles was measured with a sectioned ionization calorimeter with an absorber thickness of about 5.5 mean free paths for proton interaction ($\lambda^{p}_{\rm int}$). Two types of Čerenkov detectors, placed directly above the ionization calorimeter, were used to measure the charge of the particles. The upper detector (DZ-2), which consisted of four 1-cm-thick Plexiglas counters, was used for measuring charges with $5 \lesssim z \lesssim 50$. Eleven 5-cm-thick Plexiglas directional counters (DZ-1), used for measurements in the range $1 \lesssim z \lesssim 5$, were placed below this detector. The apparatus is described in detail in Ref. 1.

During the experiment, the longitudinal axis of the apparatus was oriented vertically. The events satisfying the following conditions were recorded: a) At least in one of the DZ-1 counters the amplitude of the pulse was 0.3 greater than the probable amplitude produced by a singly charged relativistic particle; b) the total energy evolved in the calorimeter was greater than 1 TeV; c) the energy evolved in the adjacent layer of the adsorber was greater than 35 GeV in any eight of the ten controlled levels in the ionization calorimeter. The amplitudes of the pulses were measured in all 95 sensors of the apparatus when these three requirements were satisifed simultaneously. Under these conditions the net operating time was 257 hours. The geometric factor was equal to 325 $\text{cm}^2\cdot\text{sr}$. In excess of 10 000 events were recorded by the apparatus. About 2000 of them were caused by the particles that passed within the solid angle of the apparatus. These events were further analyzed.

The cases in which the readings of the counters of detectors DZ-1 and DZ-2 situated in the path of the primary particles agreed with each other were selected in the analysis. The energy of the primary particle was determined with allowance for the correction for the energy lost through the lower base of the ionization calorimeter ($\sim 15\%$) and for the energy released due to the splitting of the nucleus.

The distribution of the selected events according to the charge z of the primary particle in Ref. 2 showed that the protons and α particles can be distinguished quite reliably. The fraction of protons among the detected α particles was no greater than several percent. With increasing charge, the accuracy of singling out nuclei with a given charge decreases. Among the nuclei of carbon and oxygen atoms, for example, the admixture of nuclei with approximately the same values of z can be as high as 10–20%. For $z \geqslant 10$ the nuclei with a fixed value of z can no longer be singled out unambiguously. The nuclei in this case can be safely divided into groups (H, MH, VH).

The measured differential energy spectrum of the α particles is shown by the filled circles in Fig. 1. Also shown in this figure are the results of other studies. The results of experiments in which the energy was measured by an ionization calorimeter are denoted by dark symbols and the results of indirect measurements with x-ray emulsion chambers, $0.5\lambda^{p}_{\rm int}$ thick, are represented by light symbols. The measured spectra of group M nuclei ($5 < z \leqslant 9$) and of group VH nuclei ($21 \leqslant z \leqslant 30$) are shown in Figs. 2 and 3. The light symbols are the results obtained with use of an ionization calorimeter of small thickness (to $\sim 2\lambda^{p}_{\rm int}$).

To determine the charge composition, we used nuclei with an energy greater than 2 TeV. In addition to the groups of nuclei which we considered here (α, M, VH), we have also singled out the H group ($9 < z < 21$).

In the second column in Table I we list the nuclei that strike the apparatus within the limits of the solid angle. This number of nuclei was obtained taking into account the recording efficiency and the redistribution of the events among the charge groups.

Table I shows that as we go to energies $\geqslant 2$ TeV, the charge composition of the primary nuclei with $z \geqslant 2$ does not change substantially in comparison with the data obtained at energies[6,7] $\gtrsim 1$–10 GeV/nucleon.

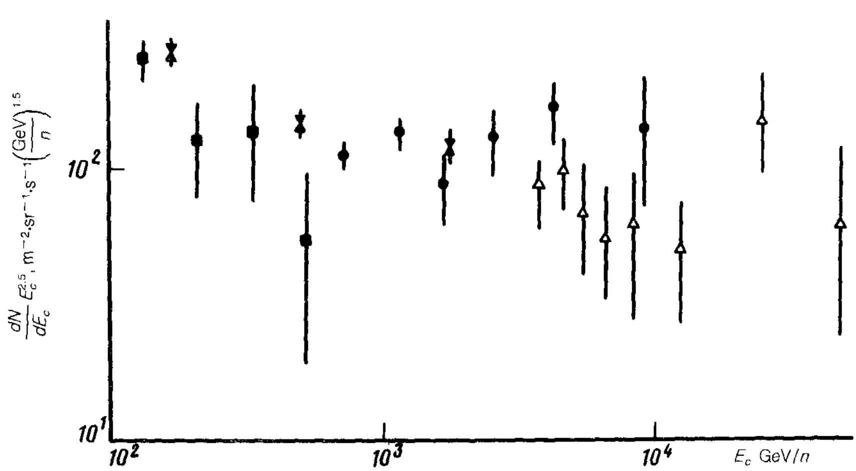

FIG. 1. Differential energy spectrum of α particles ⧗—Ref. 3; △—Ref. 4; ■—Ref. 5; ●—the present study.

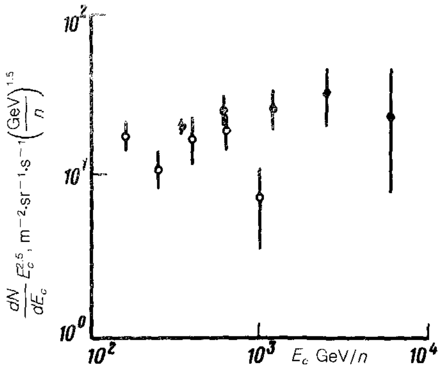

FIG. 2. Differential energy spectrum of the nuclei of group *M*. ○—Ref. 5; ●—the present study.

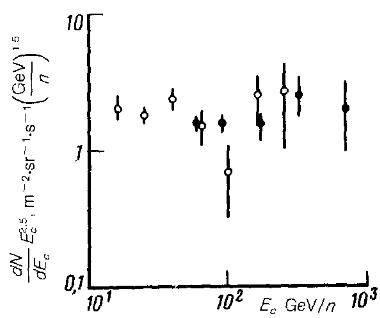

FIG. 3. Differential energy spectrum of the nuclei of group *VH*. ○—Ref. 5; ●—the present study.

TABLE I.

Group of nuclei	Number of nuclei	Normalized number of nuclei, %	Data from Ref. 6	Data from Ref. 7
α	196 ± 20	172 ± 26	~ 220	239 ± 5
M	114 ± 11	100	100	100
H	87 ± 9	76 ± 11	77 ± 5	73 ± 1
VH	66 ± 9	58 ± 10	66 ± 7	59 ± 2

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