Collisions of relativistic nuclei of the iron group with heavy emulsion nuclei at small impact parameters, and the phenomenon of nuclear pionization

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The individual characteristics of mesons and protons in a shower are obtained as functions of the energy of the incident relativistic nuclei in interactions of relativistic nuclei with nuclei at a high degree of overlap of the geometric cross sections. Agreement is observed with calculation by the model of the collective mechanism of interaction of nucleus–nucleus pionization.

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One of the principal causes of the increased interest in the study of relativistic nuclei is the possibility of investigating the nature of strong interactions in new conditions that are not attainable by other means. It is natural to expect new qualitative effects, determined for example by the collective character of the interaction, to manifest themselves with highest probability in the interaction of appreciable masses of nuclear matter, i.e., in collisions of heavy nuclei with the smallest impact parameter. To understand the mechanism of interaction, the most information can be obtained from the characteristics of the emitted shower particles (the meson and the proton components separately) and their measurements in a wide range of the energy of the incident nuclei. Such experimental data for interactions of incident nuclei with a charge $Z \geqslant 20$ and energy $E_{\rm kin} > 2$ GeV/nucleon are practically nonexistent at present.

The purpose of the present study was to investigate the characteristics of shower particles in interactions of nuclei of the iron group in cosmic rays ($Z = 20$–26, $E_{\rm kin} = 1$–20 GeV/nucleon) with the Ag and Br emulsion nuclei with almost complete overlap of their geometric cross sections, i.e., in events with a maximum number of interacting nucleons of the incident nucleus $n_{\rm int}$. We selected 32 events with $n_{\rm int} \geqslant 40$. The events were selected in accordance with criteria[1,2] $N_b + N_g = N_h \geqslant 28$ and $N_b \leqslant 10$ (N_b and N_g are the numbers of strongly ionizing charged particles with energies $E_{\rm kin} < 31$ MeV/nucleon and $31 \leqslant E_{\rm kin} \leqslant 450$ MeV/nucleon, respectively).

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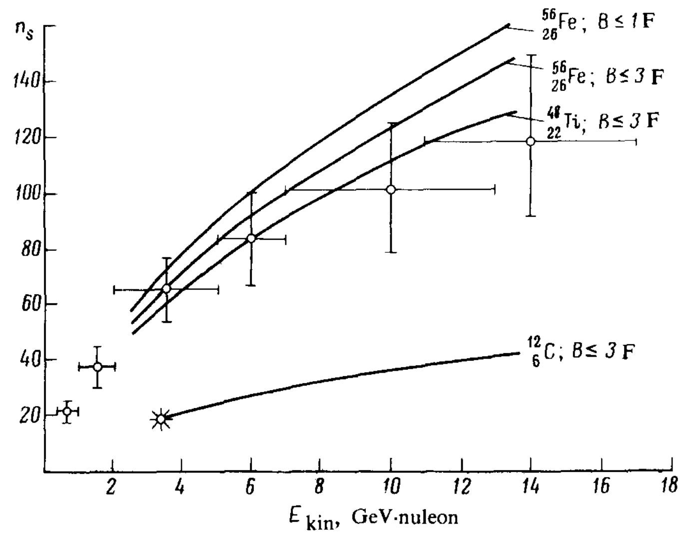

FIG. 1. Dependence of the average multiplicity n_s of the shower particles on the kinetic energy of the incident nucleus: ●—experimental data for incident nuclei of the iron group; *—the interactions of the carbon nuclei with the Ag and Br nuclei[6]; curves—calculation for the interaction of the nuclei C^{12}, Ti^{48}, and Fe^{56} with Ag and Br at different values of the impact parameter B.

The following characteristics were obtained for the shower particles as functions of the energy of the incident nucleus: multiplicity (Fig. 1), differential angular distributions in the coordinates $x = \log \tan\theta$ separately for the meson component ($E_\pi > 68$

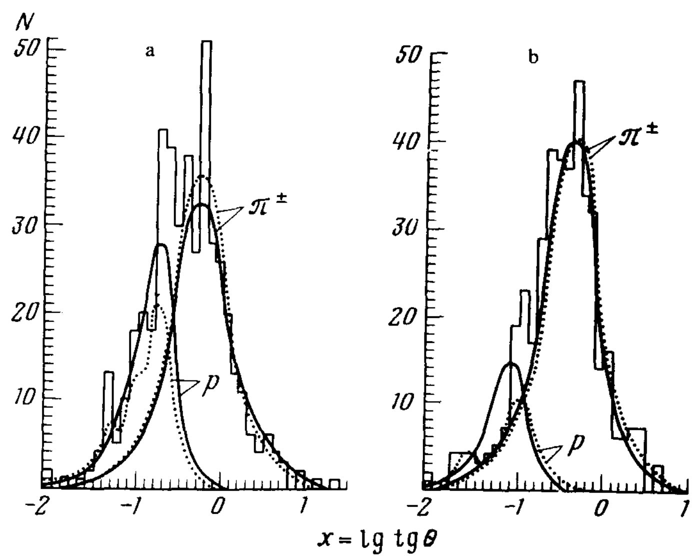

FIG. 2. Angular distributions of shower particles in coordinates $x = \log \tan\theta$ as a function of the energy of the incident nuclei of the iron group: a) $E_{kin} = 2$–5 GeV/nucleon, 454 particles; b) $E_{kin} = 7$–13 GeV/nucleon, 420 particles. Histograms—experiment; dotted curves—contributions of the proton and meson components to the experimental distributions; solid curved—calculation in accordance with the model of Ref. 3.

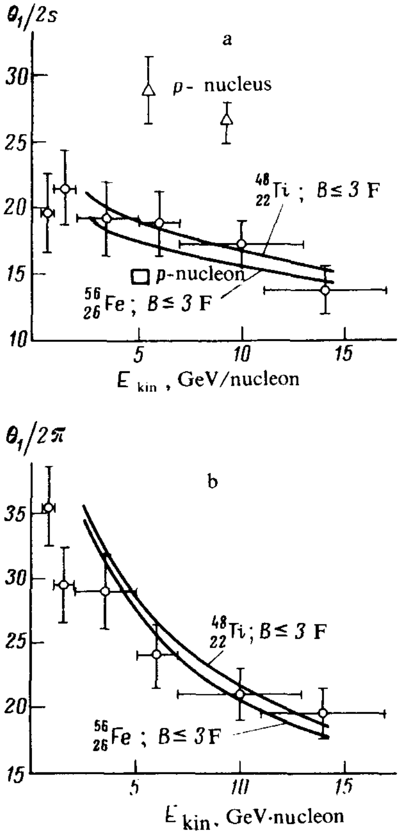

FIG. 3. Dependence of the half-value angle of emission of the shower particles $\theta_{(1/2)s}$(a) and of the $\pi^{\pm}$ mesons $\theta_{(1/2)\pi}$ (b) on the kinetic energy of the incident nucleus: ●—experiment, interactions of incident iron-group nuclei with the Ag and Br nuclei; curves—calculation by the model of Ref. 3 for the incident Ti^{48} and Fe^{56} nuclei. In the calculation and in the experiment, the half-value angle is determined from the distribution with respect to $x = \log \tan\theta$.

MeV) and the proton component ($E_p > 450$ MeV) (Fig. 2) and the half-values of the emission angles of all the shower particles and $\pi^{\pm}$ mesons (Fig. 3). The separation of the meson component was based on the balance of the charges before and after the interaction in events with total disintegration of the interacting nuclei (the criterion $N_h \geqslant 28$) and on the best agreement between the curve of the normal distribution of the mesons with the right-hand slope of the experimental distribution of the shower particles.

The experimental characteristics are compared with calculation in accordance with the model of central interactions of the nuclei[3] which is based on the phenomenon of the collective stripping of the "meson fields" [3)] of the colliding nuclei. This mechanism is realized in the course of successive interaction of the incident nucleus, which is a Lorentz-contracted disk, with layers of the target-nucleus material. After the end of the interaction of the relativistic nuclei, there are produced three dynamically and spatially separated, independently decaying objects: the excited incident nucleus, which decays principally into relativistic nucleons; a cluster of excited hydronic matter produced by the stripped fields and decaying mainly into mesons; and the excited part of the target nucleus overlapped by the incident nucleus and serving as a source of h-

particles.[4)] Their decay is described by using a thermodynamic model with a single parameter $T=\mu=0.14$ GeV, which makes it possible to determine the multiplicity and the spectral angular characteristics of the emitted particles.

In Fig. 1–3 the calculated data are represented by the solid lines. Satisfactory agreement is observed between the results of the calculation and experiment. Variation, in the calculation, of the limiting value of the impact parameter B_{max} when the averaging in the region $0\leqslant B\leqslant B_{max}$ does not lead to a substantial deviation of the results (Fig. 1). The calculated curve for the ^{12}C nuclei agrees with the experimental value of the multiplicity n_s at an energy $E_{kin}=3.4$ GeV/nucleon.[6] For events with $n_{int}\geqslant 40$, the larger statistics have confirmed the previously noted[2] singularities in the behavior of the half-value angle in nucleus–nucleus interactions, namely the difference from the value of $\theta_{(1/2)s}$ in p-nucleus[7] collisions and the proximity to the value $\theta_{(1/2)s}$ in p-nucleon[8] collisions (Fig. 3a).[5)] This fact is a simple qualitative consequence of the model of Ref. 3: as the masses of the colliding nuclei approach each other, the Lorentz factor of the pionization cluster, which is the source of the greater part of the s particles, approaches the Lorentz factor of the c.m.s. of the two colliding nucleons.

The comparison of the different characteristics of shower particles produced in central collisions of heavy relativistic nuclei with the calculation results offer evidence in favor of the hypothesis that the nucleus-nucleus pionization, which is the basis of the model of the collective interaction mechanism, has been realized.

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[3)]The "meson field" can be taken to be the gluon matter in the quark–gluon model[4] or the soft part of the proton spectrum in the parton model.[5]
[4)]The experimentally observed h-particles are emitted both directly from the target-nucleus volume covered by the incident nucleus, and by its uncovered part.
[5)]In events with $E_{kin}>2$ GeV/nucleon, at a large number of produced mesons, the presence of a small number of noninteracting protons of the incident nucleus has little effect on the value of $\theta_{(1/2)s}$ (underestimate of $\theta_{(1/2)s}<2°$). This makes it possible to compare our data with those of Refs. 7 and 8.

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