Multiple generation of particles in collisions of nuclei of energy higher than 10^{12} eV

A. Szomodyi, S. Sugar, B. Chadraa, Yu. Basina, S. Brikker, N. Grigorov, L. Grigor'eva, M. Kondrat'eva, L. Mishchenko, R. Nummik, L. Papina, L. Podgurskaya, L. Poperekova, I. Raporport, V. Sokolov, Ch. Tret'yakova, L. Chikova, V. Shestoperov, Zh. Shopenberg, B. Batskan, D. Neachu, M. Haidue, T. Visky, J. Dubinski, and L. Just

Budapest–Ulan-Bator–Moscow–Bucharest–Kosice Collaboration

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The average multiplicity in the interaction of primary cosmic-ray particle nuclei with emulsion nuclei, referred to one interacting nucleon, measured in an emulsion stack exposed on the "Interkosmos-6"satellite, turned out to be less than the value expected for expected for indpendent nucleon-nuclear collisions.

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An analysis of the interaction of nuclei of primary cosmic rays with nuclei in an emulsion stack (of volume ~45 liter), exposed on the satellite "Interkosmos-6",[1] has enabled the authors to determine some features of these interactions at energies 10^2—10^3 GeV/nucleon. The acts of the interactions in the stack were revealed by the readings of track spark chambers that monitored the passage of the particles and operating when the energy release in the ionization calorimeter (of small thickness, ~1.3 the range for the nucleon interaction) exceeded 10^{12} eV.

From among the events found in this manner we reduced the interactions of 17 nuclei with charge ≥ 6. In a number of events, several successive interactions are produced by a single primary nucleus, owing to its fragmentation. For each interaction event in the emulsion the following were determined: the charge Z_0 of the nucleus inducing the event, the charge Z_1 of the produced heavy fragment (the charges were determined by counting the slow δ electrons), the number of fragmentation α particles and protons n_α and n_p, respectively, and also the number n_{s0} of the shower particles and their angular distribution.

The energy of the Z_0 nucleus was determined from the angle between the scattered α particles (if they were produced) or from the Castagnoli formula. The lower bound of the primary-nucleus energy was estimated from the energy released in the ionization calorimeter.

The physical characteristic of the nuclear interaction process was taken to be the quantity $m = (n_s - n_p)/\nu$, which is the number of particles generated in the event per interacting nucleon (ν is the number of the incident-nucleus nucleons that take part in the inelastic interaction). The number ν was determined from the equation

$$\nu = 2\{ Z_o - (Z_1 + 2n_\alpha + n_p) \} . \qquad (1)$$

We assume here that all the particle fragments (the heavy fragment of the nucleus, the evaporated protons, and the α particles) do not participate in the generation of the secondary particles, and the incident-nucleus nucleons that do take part in this process are protons and neutrons in equal numbers on the average (when expression (1) vanished, we put $\nu = 1$).

The least definite procedure is the separation of the fragmentation protons n_p. If the evaporation protons in the system of the incident nucleus have an energy E_p and respectively a velocity β_p, then they can be emitted in the laboratory system at angles in the range $\leq \theta_{\max}$, defined by the equality $\tan\theta_{\max} = (1/\gamma_0)(\beta_p/\sqrt{1-\beta_p^2})$. Assuming $E_p = 20$ MeV, we ascribe to the fragmentation protons all the particles with emission angles $\theta \leq \theta_{\max}$. This procedure can only overestimate n_p (on acccount of the particles produced with small emission angles), and consequently undervalue ν.

We considered first events in which it was possible to observe in at least one of the successive interaction the fragmentation α particles, which made it possible to estimate the Lorentz factor γ_0 of the primary nucleus.

In five events of this type, initiated by primary nuclei with charge Z from 6 to 23 and with energy from 180 to 550 GeV/nucleon, we registered 10 interactions in the emulsion with a total number of shower particles $\Sigma n_s = 233$. After subtracting the fragmentation protons, this left $\Sigma(n_s - n_p) = 218$ generated secondary particles. We determined also the summary number of nucleons interacting in these events, namely $\Sigma\nu = 57$.

It follows therefore that the average multiplicity of generation of secondary particles per interacting nucleon amounts in these events to $m = [\Sigma(n_s - n_p)/\Sigma\nu] = 3.8 \pm 0.9$.

This value is approximately one-third the result expected assuming independent superposition of $\Sigma\nu$ nucleon-nucleon collisions, and approximately half the result expected assuming independent nucleon-nucleon interaction (in the latter case, with account taken of the energy of the incident nucleons, one should expect $m = 8.6 \pm 0.6$ per interacting nucleon).

To decrease the possible influence of the sampling, we took into consideration also the remaining registered events, with the exception of two of the 17 primary nuclei, for which the multiplicity of the produced particles greatly exceeds 10^2 and does not contradict the hypothesis of independently interacting nucleons. In 20 interacting nuclei we observed 570 generated particles at a total number of 127 interacting nucleons, meaning $m = 4.6 \pm 0.7$ as against the 8.7 ± 0.4 expected for the independent nucleon-nucleon interactions.

It turns out that the obtained value of m depends little on the value of E_p assumed in the calculation. If we put, in particular, $E_p = 100$ MeV, then the average number of produced particles per interacting nucleon becomes $m = 4.5$ in place of the $m = 3.8$ cited above.

The results allow us to conclude that in a number of cases the inelastic interactions of the nucleons packed in the nucleus have a non-additive, "collegiate," character in collisions with another nucleus. This process is realized with high probability in interactions of nuclei.

[1] S. I. Brikker, Yu. V. Vaĭsberg, N. L. Grigorov *et al.*, Izv. Akad. Nauk SSSR Ser. Fiz. **38**, 930 (1974).