INELASTIC INTERACTIONS OF NUCLEONS AND NUCLEI AT HIGH ENERGY

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Our information concerning the elementary act of collision and interaction of nucleons and pions of energy $>10^{13}$ eV have been obtained essentially by analyzing the experimental data on different phenomena in extensive air showers (EAS) and by comparing them with some model of the elementary act.

From among the elementary-act models investigated to date, the best agreement between the calculated and observed characteristics of EAS is obtained for the two-fireball model [1] with account of the possible excitation of the nucleon to the isobar state at an average inelasticity coefficient of 0.5 for nucleons. Such a model apparently describes well the most common features of inelastic collisions of nucleons and pions with the nuclei of air atoms over a wide energy interval.

However, the agreement between calculation and experiment is far from complete. Thus, for example, the observed number of muons in the shower yields a smaller multiplicity of generation of secondary particles than is assumed in this model, yet to explain the high intensity of the showers in the stratosphere [2] it is necessary to increase the multiplicity greatly. The two-fireball model explains neither the nonmonotonic dependence of the total number of nuclear-active particles on the number of electrons in the shower at mountain altitudes [3], nor the difference in the role of the nuclear-active component in large and small showers [4]. On the basis of the variation of the particle-number spectrum of the showers, it is concluded that the energy spectrum of the primary cosmic radiation is variable [5]. However, when account is taken of the fluctuations in the development of showers, and of the complicated composition of the primary cosmic radiation, it is difficult to explain the extremely rapid variation of the particle-number spectrum of the showers, and there is no explanation at all for the shift in the location of the "break" in the shower particle-number spectrum in the region of smaller showers on going from sea level to mountain altitudes [3,5] when the characteristics of the elementary act do not depend on the energy. These and many other "strange" results cannot be explained within the framework of a single picture of the elementary act with monotonic energy dependence. Calculations and estimates show that the entire aggregate of the experimental data on the phenomena occurring in cosmic rays of energy higher than 10^{13} eV, including "breaks" and "strange" results, can be explained under two assumptions.

1. When nucleons and nuclei of ultrahigh energy collide there exists, besides the known multiple pion-production process occurring in the 10^{10} - 10^{13} eV region, also a process wherein a large fraction (~70%) of the nucleon energy is transferred to the electron-photon component, bypassing pionization. The effective cross section of such "gammanization" is $\sigma < 1$ mb/nucleon for incident-nucleon energy $E_0 \leq 10^{13}$ eV and $\sigma = 10 - 20$ mb/nucleon for $E_0 \geq 10^{14}$ eV. This process is apparently characterized by a high degree of energy dissipation.

2. In the same energy interval (10^{13} - 10^{14} eV/nucleon), the exponent of the energy spectrum of the primary cosmic radiation changes by an amount $\Delta\gamma \simeq 0.5$. It is possible that this change is connected with a decrease in the average lifetime of the cosmic rays in the universe prior to the nuclear interaction, owing to the increase in the summary effective cross section for inelastic collisions between protons and nuclei with energy above 4×10^{13} eV/nucleon. Then the change in γ is the consequence of the proposed process.

It is easy to see how inclusion of these assumptions simplifies the interpretation of many "strange" observational results. The presence along with the ordinary pionization of acts with predominant energy dissipation in the electron-photon component increases on the one hand the total flux of particles in the EAS in the stratosphere, and on the other hand decreases the relative number of muons in the shower. The energy threshold for the additional "gammanization" process leads to violation of the monotonic dependence of the number of nuclear-active particles in the shower on the total number of electrons, starting with showers produced by primary protons with energy $\sim 4 \times 10^{13}$ eV, and ending with showers produced by complex nuclei with energy $\sim 4 \times 10^{14}$ eV/nucleon.

The fact that in the same energy interval the change in the energy spectrum coincides with the appearance of an additional process wherein energy is transferred to the electron-photon component makes it possible to explain the break in the particle-number spectrum of the showers, as well as the shift of this break into the region of higher energies on going over from mountain altitudes to sea level.

The most characteristic detail of the new process is a rapid increase in the effective cross section in the energy interval 10^{13} - 10^{14} eV. The resultant ~30% increase in the summary cross section for the inelastic interaction can hardly correspond to the prediction of the theory of complex orbital angular momenta, since the additional process differs from ordinary pionization. If the energy threshold for the process under consideration is related with some new particle, then its mass should be $\sim 10^{11}$ eV/c^2 and its lifetime $< 10^{-11}$ sec, but the absence of a noticeable number of $\pi^{\pm}$ mesons from the decay differentiates this particle from the already-known baryons. The high inelasticity coefficient indicates that such interactions have a peripheral character. From the point of view of the structure of the nucleon, an energy $\gtrsim 4 \times 10^{13}$ corresponds to a length $< 10^{-15}$ cm, which is interesting from the point of view of weak interactions.

All the foregoing possibilities are equally interesting and strikingly surprising. Unfortunately, our choice between these possibilities cannot be verified experimentally until enough direct data are obtained on the properties of the elementary interact act at energies $\sim 10^{14}$ eV.

[1] L. G. Dedenko, Izv. AN SSSR ser. fiz. 29, 1725 (1965), transl. Bull Acad. Sci. Phys. Ser., in press.

[2] R. A. Antonov, Yu. A. Smorodin, and Z. I. Tulinova, Trudy FIAN (Phys. Inst. Acad. Sci.) 26, 142 (1964).

[3] T. V. Danilova, E. V. Denisov, and S. I. Nikol'skii, JETP 46, 1561 (1964), Soviet Phys. JETP 19, 1056 (1964).

[4] S. I. Nikol'skii and A. A. Pomanskii, JETP 35, 618 (1958), Soviet Phys. JETP 8, 430 (1958).

[5] Yu. A. Fomin and G. B. Khristiansen, JETP 46, 2141 (1964), Soviet Phys. JETP 19, 1512 (1964).