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Below we present summaries of three papers that were read at the session of the Division of General Physics and Astronomy and the Division of Nuclear Physics on 21–22 November 1979, the materials of which were published in Usp. Fiz. Nauk 131, 511 (1980) [Sov. Phys. Usp. 23, 418 (1980)].

S. I. Nikol'skiĭ. *Study of hadron interactions in cosmic rays*. The results of a large number of experiments performed to study hadron interactions in cosmic rays seem to imply approximate scale invariance in inelastic collisions of nucleons and nuclei up to incident-nucleon energies of about 100 TeV. Significant deviations from the scale-invariance extrapolations of hadron multiple-production characteristics at high energy and certain unusual experimental data force us to consider an essential change in the multiple-production picture. This statement requires clarification and citations of experimental data.

The approximate nature of the scale invariance reflects the absence of strict scale invariance even in the accelerator range of energies. Various manifestations of the scale-invariance property for the fragmentation parts of secondary hadrons in multiple-production events were observed in cosmic rays before the concepts of scaling, self-similarity, and scale invariance were enunciated. The constancy of the coefficient of inelasticity of the nucleons in nucleon-nucleus collisions and the proportionality of the energy of the leading pions to the energy of the incident nucleon up to energies ~1TeV were established in cosmic-ray experiments as far back as 1950–1960.

Analysis of recent experimental data on the energy spectra of muons, hadrons, and γ quanta at mountain elevations indicates that the scaling properties of the fragmentation part of the secondary-particle energy spectrum are preserved in inelastic collisions of hadrons up to 50–500 TeV.[1-3] Studies of the energy dependence of the inelasticity coefficient in collisions of nucleons with lead nuclei in the 1–30-TeV energy range have not contradicted this conclusion.[4] Nor are any significant changes observed in this energy range in studies of transverse momenta of secondary particles of their composition.

Consistent with the clarity of our general picture of inelastic nucleon-nucleus collisions up to ~100 TeV, all methods used to determine the energy spectrum of the primary cosmic-ray particles produce results that are in good internal agreement. In the range of primary-particle energies above 1000 TeV, different methodological approaches to determining the primary energy spectrum give quantitatively different results. The explanations may be found in a strong influence of changes in the multiple-production process in this energy range, which are not usually taken into account, on the particle-number spectrum of the showers.

Serious contradictions also come up in multiplicity estimates for inelastic hadron-nucleus collisions based on the development of various extensive-shower components in the atmosphere. The secondary-pion multiplicities in nucleon-nucleus interactions at energies above 10^3 TeV would have to be assumed several times larger to account for the height of maximum development of the electron-photon shower component, as compared to the multiplicities that explain the numbers of muons in the shower. This disproportion among the secondary particles, which has been called "gammanization," implies an energetically conspicuous change in secondary-particle composition.

Experiments performed to study the absorption of nuclear-cascade avalanches in lead[5] attest to a change in secondary-particle composition, and one that is apparently of threshold nature. Given a predominantly pionic secondary-particle composition, the averaged absorption of the avalanche should be no slower than three times the mean free path for an inelastic collision of pions, and this is borne out by observations for initial energy values below 50 TeV. At a total hadron-avalanche energy of $\gtrsim 100$ TeV, however, the absorption is slowed by nearly a factor of two, which implies the appearance of some type of particle among the secondary hadrons that is not a pion or a nucleon and, on the basis of its total energy, removes more than 20% of the energy of the primary hadron.

Extensive showers reveal features of the development of the avalanche down through the atmosphere. Showers with primary energies of $\sim 3 \cdot 10^3$ TeV have maximum development at much smaller depths in the atmosphere than would follow from any "approximate scaling" model, including models in which the multiplicity has a $\sim E^{1/4}$-type dependence on energy. At a primary energy $\gtrsim 5 \cdot 10^4$ TeV, the depth at which the maximum occurs is near the depth expected on the basis of certain "approximate scaling" variants. To characterize the sharpness of the change in the depth of shower maximum on only a tenfold increase in primary energy, it is sufficient to say that this change corresponds to a change in primary-particle composition from heavy nuclei (iron only) to pure protonic over this power-of-ten energy range. This explanation was proposed by Thornton and Clay.[6]

To interpret experimental data indicating a rapid shift of the height of the shower-development maximum, it is more helpful to assume the generation, with an energetically significant effective cross section, of new particles that protract absorption in the calorimeter for hadron avalanches with energies above 100 TeV. If we assume that the new particles have properties similar to those of charmed particles, their formation at energies above 100 TeV in the atmosphere will change the picture of the development of extensive air showers as follows. At energies of 10^2 to 10^3 TeV, their formation and decay in the hadron channels accelerate the development of the shower in the upper atmosphere as though they increased the multiplicity in inelastic hadron-nucleus collision events. The lepton decay channels show a change in the ratio of the fluxes of the electron-photon and low-energy-muon components in the flux in favor of the former ("gammanization"), since high-energy muons do not contribute quantitatively to the total muon flux. As the energy of the primary particles and the Lorentz factor of the new secondary particles increase, the decay paths of the latter are lengthened, so that the maximum of shower development shifts quickly deeper into the atmosphere. A lifetime of 10^{-11} to 10^{-12} sec for the particle would be consistent with all available data on "long" avalanches in the calorimeter and the rapid shift of the development maximum of extensive showers in the atmosphere.

During the next few years, accelerators will be used in detailed analysis of the characteristics of inelastic nucleon-nucleon collisions in the 10^2–10^3-TeV energy range. The goal of cosmic-ray experiments should be investigation of the higher energies in the hope of determining whether it is enough to take into account new processes detected at ~100 TeV to explain the experimental data for energies of 10^3–10^6 TeV or whether the change in the inelastic hadron collision picture continues as the energies increase.

[1]L. V. Volkova and G. T. Zatspein, Izv. Akad. Nauk SSSR Ser. Fiz. 38, 1066 (1074).

[2]E. A. Kanevskaya, Yu. A. Smotodin, and L. T. Baradzei, Fifteenth Intl. Cosmic Ray Conf., Vol. 7, 1977, p. 453.

[3]S. I. Nikolsky, in: IX Intl. Symp. on Mult. Proc. G-19, Tabor, 1978.

[4]V. P. Pavlyuchenko, R. A. Nam, S. I. Nikol'skiĭ, A. P. Chubenko, and V. I. Yakovlev, Trudy Fiz. Inst. Akad. Nauk 109, 30 (1979).

[5]V. I. Yakovlev *et al.*, Fifteenth Intl. Cosmic Ray Conf., Vol. 7, 1977, p. 115.

[6]C. J. Thornton and R. W. Clay, Phys. Rev. Lett. 43, 1622 (1979).