EXPERIMENTAL BASIS FOR THE MODELS OF CASCADE PROPAGATION IN ATMOSPHERE

Strugalski Z.

Institute of Physics of the Warsaw Technical University
ul. Koszykowa 75
00-662 Warsaw, Poland
and
Joint Institute for Nuclear Research, High Energy Labor.
Dubna, USSR

ABSTRACT

The picture of the hadron-nucleus collision process is presented as emerged on the basis of newly obtained experimental data. The picture is applicable for models of cascade propagation in Earth atmosphere.

1. Introduction

Results from studies of cascades ond of their propagation in the Earth atmosphere form a basis for our knowledge about ultra-high energy cosmic ray particles; these results are fundamental for the cosmic ray astrophysics as well. But, the knowledge about the cascade propagation in a medium rests on the information about the hadron-nucleon, hadron-nucleus, and nucleus-nucleus collision processes first of all.

Now, various models of the hadron-nucleon and hadron-nucleus collision processes, and of the particle-producing reactions in them, are in use, based on different almost arbitrarily introduced physical processes assumed. The assumptions do not correspond in many cases to the reality - they are inadequate. The question: "Is an assumption adequate or not ?" should find its answer primarily in experiments.

We have studied experimentally the hadron-nucleus collisions at the conditions when the reaction outcome was almost totally identified, Strugalski Z. et al. (1981 a, b; 1982 a - c; 1983 a -e); experimental data have been obtained as well on the hadron-nucleon collision processes in their initial stages - before decays of produced resonances, using massive target nuclei as detectors, Strugalski Z. (1981 a,b; 1982; 1984 a-d; 1985). The results are crucial for any model of the hadron-nucleon, hadron-nucleus, and nucleus-nucleus collisions and, therefore, for a more adequate model of the cascade propagation in media - in the Earth atmosphere in particular.

2. Experimental procedure

In experiments, the 26 and 180 litre xenon bubble chambers, Kanarek T. et al. (1959), Kuznetsov E. V. et al. (1970), were used. The smaller chamber was exposed to beams of pions with 2.34, 5, and 9 GeV/c momentum from the synchrophasotron of the Joint Institute for Nuclear Research in Dubna; the bigger chamber was exposed to pion beam at 3.5 GeV/c momentum from the accelerator of the Institute of Experimental and Theoretical Physics in Moscow.

General experimental information about the pion-xenon nucleus collisions is contained in series of Communications of the JINR: Strugalski Z. et al. (1981, 1982, 1983, 1984, 1985). Additional appropriate information has been found in various emulsion works: Andersson B. et al. (1978), Babecki J. and Nowak G. (1978), Bannik B.P. et al. (1980), Gurtu A. et al. (1979), Meyer H. et al. (1963), Otterlund I. et al. (1978), Tsai-Chü et al. (1977), Winzeler H. (1965); the accelerator data there are at energies up to about 400 GeV in the lab, the cosmic ray data are up to a few thousands GeV.

3. Results

Four main phenomena are usually observed, when hadrons collide with atomic nuclei: a) The emission of nucleons with energies from about 20 up to about 400 MeV; b) The production of particles; c) The evaporation of target fragments; d) The fission of residual target nucleus.

3.1. Nucleon Emission. Any hadron with kinetic energy higher than the pion production threshold may pass through some layer of nuclear matter before to come into particle - producing reaction in it; there are events in which incident hadrons with energies of a few GeV traverse nuclei or are stopped in them without causing particle production. In any case, are the particles produced or not, any hadron causes emission of nucleons in passing through atomic nucleus. The number n_N of the emitted nucleons equals the number of nucleons contained within the volume $v = \pi D_o^2 \lambda$ centered on the hadron path λ in nuclear matter, where D_o is the diameter of the nucleon. The particle production process does not effect an influence on the nucleon emission.

Any hadron loses its kinetic energy monotonically along its path in nuclear matter, by nucleon emission. Energy spectra and angular distributions of emitted nucleons are practically the same in pion-xenon nucleus collisions with and without particle production; they do not depend neither on the multiplicity of emitted protons nor on the multiplicity of produced pions. The spectra and distributions are the same for pion-xenon collisions at 3.5 GeV/c momentum and for the proton-nucleus collisions in emulsions at 400 GeV/c.

3.2. Particle Production. Particles are produced via intermediate objects, we have called them "generons", created firstly in 2 ⟶ 2 type endoergic reactions and decaying after the lifetimes $\tau \approx 10^{-22}$ s into particles and resonances. Generons behave themselves in passage through nuclear matter as usual hadrons do it - in particular, they can produce new generons in colliding with the downstream nucleons. A quasilinear cascade of generons may develop in nuclear matter, therefore. This way, the outcomes in hadron-nucleus collisions at an energy E are the compositions of m outcomes in hadron-nucleon collisions at energies in average E/m, where m is the number of particle-producing collisions of the incident hadron.

The nucleon emission process does not depend on the particle production process. The region of the particle production process in the target nucleus is not larger than the region of the nucleon emission, therefore; it is rather almost linear and situated collinearly with the incident hadron course in predominant number of collisions.

3.3. Evaporation of Target Fragments. Relation between the multiplicity of the emitted protons and the mean multiplicity of the charged fragments in collisions with a given proton multiplicity allows to determine the size and localization of the fragment evaporation region, Strugalski Z. (1984). Nuclear fragments are evaporated from the surface of the damaged part of the target nucleus; the damage is due to the nucleon emission process accompanying the passage of any hadron through nuclear matter.

3.4. Fission of the Residual Target Nucleus. In any hadron-nucleus collision the target nucleus is damaged, and relatively large part of it is removed, as it may be concluded from experimental results on the nucleon emission and target fragment evaporation. Obviously, such damaged nucleus is instable and it must decay into stable smaller nuclei in the final state.

More information about the experimental picture of the hadron-nucleus and hadron-nucleon collision processes can be found in series of works: Strugalski Z. (1982, 1984, 1985).

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