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THE NUCLEO-CASCADE PROCESS AND ITS ROLE IN THE DEVELOPMENT OF WIDE ATMOSPHERIC SHOWERS

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The results of the work directed by Academician D. V. Skobel'tsyn of the Physics Institute imeni P. N. Lebedev, force one to conclude that wide atmospheric showers cannot be identified with electron-photon showers from primary electrons. Analysis of this data shows the importance of high-energy "nucleo-active" particles and unique "nucleo-cascade" processes creating these particles in both the mechanism of atmospheric shower formation and the process of its development. Experimental data recently obtained from the study of primary particles in cosmic rays also forces one to repudiate the notion that a wide atmospheric shower arises from one primary particle.

It is firmly established at present that most particles in primary cosmic radiation are heavy nucleo-interacting particles (1, 2) -- mainly protons and some heavier atomic nuclei (3) -- and now there is no reason to assume that there are high-energy electrons in primary radiation.

The results of the work, which exposed definite anomalies in the phenomenon of wide showers, may be summed up as follows:

1. The dependence of altitude function upon shower density does not agree with the cascade theory (4).

2. The showers are anomalously wide (5).

3. The high-energy electron-photon component is not focused in the narrow region of the shower "column," but has a distribution width actually exceeding the theoretical (6).

4. The showers contain a considerable number of penetrating particles. This fact is neither explained nor considered by the cascade theory. The current density of such particles in atmospheric showers at average altitudes (approximately 4 kilometers) is of the order of 1 - 2 percent (7) of the current density of electrons in

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central (R approximately 100 meters) regions of the shower. The spatial distribution of penetrating particles is wider (6) than that for electrons. Taking this into consideration, the total number of penetrating particles constitutes an even greater part of the total number of all particles of the shower.

5. High-energy nucleo-active particles, which generate "special" showers, are contained in wide showers (8) (at an altitude of approximately 4 kilometers, their number may be roughly evaluated as 1/2 - 1/4 of the number of "nonactive" penetrating particles in the shower).

6. The energy borne by penetrating and nucleo-active particles, due to the large average energy per particle, is high and makes up (at an altitude of approximately 4 kilometers) at least tens of percents of the total energy of the shower particles.

Any theory of wide atmospheric showers which satisfies experimental data must describe the formation and development of a complex shower which includes the three components just mentioned (electron-photon, penetrating, and nucleo-active), starting from the premise that the primary particle generating the shower is a heavy "nuclear" particle and not a high-speed electron. Until recently, there had been no data on processes which could form the foundation for erecting such a theory. Now, however, such data has been provided by the discovery of the so-called "special" showers in 1945 - 1946 (9, 10).

Works relating to the study of special showers (both at Mt Pamir and in the stratosphere) reduce to the following conclusions:

1. High-energy nucleo-active particles interact with nuclei having an effective cross section close to the geometric nuclear cross section, thus generating "special" explosive showers in the process.

2. When the special shower is created, both penetrating particles and high-energy electron-photon component are generated (10) (possibly through the agency of decay of extremely short-lived mesons into photons).

3. At 4- to 5-kilometers altitudes, a considerable number of the particles (apparently the majority of them) which generate special showers are secondary particles. This is apparent from the fact that there is a neutral generating component (11) at these altitudes and, moreover, this part of the generating particles makes up one of the components of wide showers (10).

4. Showers generated by particles known to be primary (observations in the stratosphere) have the same character as the special showers generated by secondary particles. Thus the generation of special showers is a very common process characteristic of high-energy nucleo-active particles.

Having considered these facts, we deem it possible to make certain hypotheses as the basis for interpreting wide showers.

1. Wide atmospheric showers are generated by heavy (nucleo-active) particles in primary cosmic radiation.

2. The initial act causing such a shower in the stratosphere is the emergence of the special shower (in the collision of a primary particle with an atomic nucleus).

3. Three components are generated in this special shower: a soft (electron-photon), a penetrating (nu mesons, which probably emerge through the decay of pi mesons rather than in the initial act of generation), and a nucleo-active component.

4. The cascade process which leads to the emergence of an avalanche of particles forming a wide shower as an end result consists, then, of the usual cascade multiplication of the electron-photon component and another very important nucleo-cascade process. The latter cascade process emerges because the nucleo-active particles formed in the special shower containing rather high energy can again generate special showers during collisions with the nucleons of atmospheric nuclei and thus provoke a repetition of the primary nuclear process which generated the given wide shower.

The rejection of that premise of the cascade theory of showers which assumed the presence of a "ready" electron on the periphery of the atmosphere is thus due not only to the fact that the generation process occurs at various atmospheric levels according to the exponential absorption of primary "nuclear" particles. The experimentally established fact of the existence of particles generating special showers as a component of wide showers (their number in the "average" shower is possibly 10^4 - 10^5) leads to the conclusion that, for sufficiently high energy in the special shower new nucleo-active high-energy particles are created. Thus, we are forced to acknowledge the existence of the nucleo-cascade process just mentioned. The absence of a maximum curve for showers generated by nucleo-active particles (12) does not contradict the existence of the nucleo-cascade process, since the average energy of primary particles necessary to create secondary particles capable of generating special showers must be much greated than the maximum energy spectrum of primary particles (approximately 3.10^9 eV).

The basic properties of showers may be qualitatively explained by making certain natural assumptions relative to the origin of special high-energy showers.

1. The given hypothesis is not contradicted by the fact that most particles in a shower are electrons. The "critical" energy is much higher (3.10^9 - 10^{10} eV) for the nucleo-cascade process than for electrons (approximately 10^8 ev). Thus, even in the shower's initial phase of development, when the main energy is probably included in the "nuclear" component, the shower particles are predominantly electrons since, in cascade multiplication of particles, their number is inversely proportional to "critical" energy. In the nucleo-cascade process, the energy apparently transfers irreversibly from the nuclear component into the electron-photon and "nucleo-inactive" mu-meson components. Moreover, it should be assumed that many particles are created in one act of generation of a special shower of very high energy. Both of these factors may lead to rapid energy degradation of nuclear particles, since the shower's energy may be mainly included in the electron-photon component and mu mesons at great depths.

2. The anomalously wide distribution of particles in a shower is due to the large angles of separation of the initial directions for both penetrating particles and particles of the electron-photon component in special showers (these angles are so small as to be disregarded in an electron-photon shower). The spatial distribution is also wide because of the long paths of penetrating-type particles. Since the electron-photon component is created in the depths of the shower, its spatial distribution is determined not only by the angular separation of the initial directions and scattering but also by the spatial distribution of its generating component. The separation of the generating component must be very great since the path of the particles in air cannot be less than one kilometer. The mu mesons have the greatest width of separation.

3. The formation of special showers in wide showers and the nuclear fissions connected with them are explained by the emergence of strongly ionizing particles and neutrons (13).

It follows from the above discussion that: (1) the nuclear aspects of a shower should be observed more clearly with increase in altitude; (2) in wide showers, especially in the initial phase of their development, it is possible to observe a structure connected with the presence of special showers emerging in air; and (3) "young" showers (low energy) may be observed not only in the stratosphere, but also at average altitudes. Since energy not less than 10^{13} - 10^{14} eV is necessary to form a wide atmospheric shower dense enough to be observed, while 10^{10} eV is necessary to form secondary nucleo-active particles, then such particles for the most part are observed as "solitary" only for small densities of the atmospheric shower accompanying them. The special showers generated by those particles in air containing a limited number of particles may be observed only short distances from the place of emergence before the particles scatter over a large area. This condition holds in the case of "narrow" showers. It is possible to eliminate difficulties encountered in some cosmic ray phenomena connected with nuclear particles ("stars," special showers, etc.) by considering the existence of the nucleo-cascade process.

In this article it has been impossible to discuss the afore-mentioned hypotheses and variations of the nucleo-cascade process or to consider employing this process to explain other phenomena. Study of wide showers from the standpoint set forth will have fresh interest, since further detailed study of wide showers will reveal the characteristics of nuclear interaction of particles of very high energies (10^{14} - 10^{18} eV). Direct observations of such particles is not possible.

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