ALTITUDE DEPENDENCE OF EXTENSIVE AIR SHOWERS

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The altitude dependence of extensive air showers is studied assuming that the absolute amount of energy transferred to π mesons in collisions between nucleons with energies $E \gtrsim 10^{12}$ ev and nuclei is constant (in the c.m.s.). As is shown, in order to have the results of the calculation agree with the experimental data, we must assume that, in secondary interactions of particles (other than π mesons) which carry away most of the energy in the nucleon-nucleus collisions, a constant fraction of the incident-particle energy is imparted to the π mesons.

FROM the experiments of the Bristol group[1] we can conclude that, in collisions of nucleons with energy $E_N \gtrsim 10^3$ Bev with nuclei, the absolute amount of energy ~ 50 Bev imparted to π mesons remains constant in the c.m.s. Moreover, the total inelasticity factor varies little because of the increase of the energy transferred to other particles, which we shall henceforth refer to as X particles.

In the present article, the altitude dependence of extensive air showers is discussed, taking this feature of nucleon-nucleus collisions into account. We shall assume that, in collisions of π mesons and nucleons with $E_N < E_p$ ($E_p = 5 \times 10^3$ Bev is the threshold energy) with nuclei, π mesons carry away a constant fraction of the energy of the incident particle.

With respect to the character of the interaction of the X particles with nuclei, we shall make either one of the following two assumptions:

1. In the collision of an X particle with a nucleus, an amount of energy whose absolute value remains constant is transferred to π mesons in the c.m.s. whenever $E_X > E_p$, while a constant fraction of the energy of the incident particle is transferred whenever $E_X < E_p$.

2. In the collision of an X particle with a nucleus, a constant fraction of the energy of the incident particle is transferred to π mesons (for any E_X).

We shall also assume that the spectrum of the secondary particles in nuclear interactions at high energies is given by a power law, $dn/dE \sim E^{-1-\delta}$, where δ is a constant parameter. According to the data of the Bristol group, $\delta = 1/2$ for π mesons. We shall assume the same value $\delta = 1/2$ for the spectra of nucleons and X particles. Neglecting particle decay, we then obtain the following expression for the number of electrons in extensive air showers:

$$\Gamma_e = A \exp\{y_0 s + \lambda (x - x_0)\}$$

for $a^{-2} y_0 \ll x - x_0 < y_0$, and where $y_0 = \ln(E_0/\epsilon)$. E_0 is the primary energy, $\epsilon = 0.07$ is the critical energy for electromagnetic cascade processes, x_0 is the depth of shower initiation, and $a = 2.3$ is the ratio of the nuclear mean free path (for a single interaction) to the radiation length.

Under the assumption 1, we have $s_1 = 0.7$, $\lambda_1 = +0.2$ for $E_0 \gtrsim 10^5$ Bev, i.e., an extensive air shower does not attain the maximum, which contradicts the experimental data[2] ($s_{exp} = 1.2 - 1.4$, $\lambda_{exp} = -0.4$). Under the assumption 2, we have $s_2 = 1.4$, $\lambda_2 = -0.4$. Moreover, the existence of a single interacting X particle produced in one of the first collisions between the nucleon and nuclei is sufficient to obtain these values. This means that, regardless of the fact that the number of produced X particles may be small in each single collision, they may play a considerable role in the development of extensive air showers.

Thus, if in the collision of nucleons with nuclei a constant (in its absolute value) amount of energy is transferred to π mesons in the c.m.s., then, in order to explain the altitude dependence of extensive air showers, it is necessary to assume that the X particles produced in these collisions together with π mesons (the majority of the X particles being most probably K mesons) carry away a large part of the energy imparted to secondary particles, and that, in each of the consecutive collisions, they transfer a constant fraction of it to π mesons.

This conclusion is in good agreement with the results of Hayakawa and Ogita[3] who, assuming that the spectrum of X particles in the showers is similar to that of π mesons at energies $< 10^3$ Bev, and that it remains constant for energies higher than 10^3 Bev (this assumption is equivalent to our assumption 2), found that the theoretical curve of altitude dependence of extensive air showers agrees satisfactorily with the experimental one.

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[1] Duthie, Fisher, Fowler, Kaddoura, Perkins, and Pinkau, Proceedings of the 1959 Moscow International Conference on Cosmic Rays 1, 1960.

[2] K. Greisen, Progress in Cosmic Ray Physics (North-Holland Publishing Co., Amsterdam, 1956), vol. III.

[3] S. Hayakawa and N. Ogita, Proceedings of the 1959 Moscow International Conference on Cosmic Rays **2**, 1960.

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