An Interpretation of Mixed Showers

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A REMARKABLE experiment on mixed showers carried out by Chao[1] forces us to add some considerations to our previous note.[2] In *I* we emphasized that there had been few cases where multiple cascade showers had been found in a mixed shower. Chao's experiment, however, shows that such cases are rather more frequent than the cases of single core.

First we should remark the following characteristic features of the results of (A). Firstly, the smaller the size of the cascade shower, the lower is its initiating position in the cloud chamber. This seems to mean that his apparatus is selective and records more showers of larger size, because the considerable part of single cascade showers, which are supposed to have small size and initiate from upper lead plates, may be missed from the observation. The observed ratio of single and multiple cores in (A) may not represent the actual value. Secondly, initiating particles are almost all ionizing. This fact is not only in contradiction with experiments hitherto carried out,[3] but also very difficult to understand in view of the symmetry between charged and neutral particles in nuclear events, although some dissymmetry can be expected if some electromagnetic interaction between an incident ionizing particle and a matter nucleus might be effective for producing mixed showers.

In spite of the above unclear points, it is certain that more cases of multiple cores are occurring than expected in *I*. Now we must consider once more the possibility of these showers with multiple cores by the decay process of neutral nuclear mesons or of C-mesons which are expected to be produced by a nuclear collision if we adopt the hypothesis of Sakata[4] and Pais.[5] Taketani remarks that C-meson may be produced by incident heavy charged particles with a rather large cross section though smaller than that of charge acceleration.[6] The most predominant diverging angle of produced C-mesons is estimated as

$$\theta_c=[(\mu c/k)^2+(\mathrm{M}c/p)^2]^{\frac{1}{2}} \qquad (1)$$

where M and μ are the masses of nucleon and C-meson and p and k their momenta respectively. In most cases $k\sim 5$ Bev/c and p may be about a few tens of Bev/c, since we may consider that a half or less of the incident energy of nucleon is lost by a nuclear encounter. For such cases (1) is approximated by $\theta_c\gtrsim \mathrm{M}c/p$. This angle may not be inconsistent with the observation of (A), in which at least one cascade shower has almost the same direction as the incident one. On the other hand, the explanation in terms of the decay of neutral nuclear mesons is very difficult because they are emitted with so large angular divergence that the above feature can hardly be accounted for. Now the produced C-meson should immediately disintegrate into a pair of an electron and a positron. One of the pair particles with energy ϵ_1 has the angle θ_1 with the parent if the latter has energy E:

$$\theta_1\approx\mu c^2/(\epsilon_1 E)^{\frac{1}{2}}. \qquad (2)$$

This leads to a relation between the diverging angle and the energy for two disintegration particles:

$$\theta_1/\theta_2=(\epsilon_2/\epsilon_1)^{\frac{1}{2}}. \qquad (3)$$

Now the energy of a disintegration ray is estimated from the size of its initiating cascade shower. Then it is seen that this relation is satisfied in few cases of (A). The result of (A) shows that the cascade showers with larger angular divergences have not so small sizes as expected by (3). This discussion is also valid to the case of nuclear neutral mesons.

The above consideration seems still to rule out the role of decay process in mixed showers. As for angular distribution, our charge acceleration process discussed in *I* may be consistent with the new experimental result. The angular distribution of emitted photons by this process is given by[7]

$$d(\cos\theta)u^2(1-\cos^2\theta)/(1-u\cos\theta)^2,$$

which results in the most predominate angle

$$\theta_a\sim \mathrm{M}c/p. \qquad (4)$$

This may approximately explain the observed angular divergences for the momentum of a few tens of Bev/c. But the probability of accompanying the emission of a photon by a nuclear encounter, about 20 percent for the energy under consideration, may be too small to explain the rather frequent occurrence of two or more cores, even if the first remark above is taken into consideration. Furthermore, the large angular divergence taking place in the case of multiple cores cannot be explained by the charge acceleration of the incident fast nucleon, too. Thus it is suggested to introduce the charge acceleration process of produced charged mesons, which are believed to be emitted with large angle. This process may be considerably reduced by interference effect as mentioned in *I*, but in convenient circumstances such a process may be possible, for example when one of the produced mesons has a larger velocity or a larger angle than the others. This possibility, however, appears to contradict with Williams' conclusion,[8] that there is only a single core in an extensive air shower which would be caused by the same mechanism. Such a difficulty might be avoided by considering that in extreme high energy region as that met with in the case of air showers, too many mesons are produced to emit photons without interference, or subcores do not contribute to his experiment because of too large emitted angles. It is very regrettable that our semi-classical and intuitive theory prevents further progression to such problems.

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Cosmic-Ray Underground

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IN a previous note[1] one of the authors (S.H.) pointed out that the remarkable bend of the intensity-depth curve of the underground cosmic-rays can be accounted for by pi-mu decay and on this basis a rough estimation of the life of pi-mesons was made.[2] In the meanwhile the life of pi-mesons was determined at Berkeley for artificially produced mesons and we found that our estimated life agrees well with this result. It becomes thus of interest to treat the problem in a more precise manner. According to the current picture pi-mesons are produced by the primary cosmic-ray particles, presumably protons or heavier nuclei, on colliding with air nuclei and these mesons disintegrate into mu-mesons on falling down through the atmosphere. In this decay process almost all of pi-mesons of lower energies are transformed into mu-mesons at sea level, whereas only a little part of pi-mesons of higher energies are converted into mu-mesons. This results in that the energy spectrum of mu-mesons at sea level has a bend which manifests itself as the bend of the intensity-depth curve of the