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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-4-29. Extensive Air Showers at Their Maximum Development

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In the ordinary sessions several papers were presented which described observations of air showers near their maximum development. The improvements over earlier work have been not only in the greater sizes of the showers recorded, but, more importantly, in the more exact specification of the characteristics of the individual showers observed. As a consequence it is now possible to take better advantage of the special situation at the maximum where the experimentally observed quantities are more simply related to fundamental ideas and where they can therefore provide sharper tests of theory.

The quantities of fundamental interest are $N(E, x)$ which we call the average size of a cascade shower at depth x initiated by a primary of energy E, and $J(E)$ which we call the intensity of primaries with energy greater than E.

Above $E=10^{15}$ ev the intensity of primaries is so low that we must rely on air shower experiments for information about these quantities. But air shower experiments can only give us information on the quantity $S(N, x)$ which we may call the absolute intensity of shower events at depth x with size greater than N. With appropriate experimental facilities, one can, of course, specify other parameters such as μ meson content, nucleonic content, etc. At best, however, there remains a difficult problem in deducing N and J from S, a problem that is complicated by fluctuations in the longitudinal development. However, we can hope for a simplification of this problem near the maximum where the electronic size should be nearly proportional to the primary energy.

One observes a statistical sample of showers which can be analyzed in various ways. If, for example, the size and arrival direction of each shower is well determined and the effective area of the apparatus for detecting showers of any given size is known, then one can determine directly the integral size spectrum $S(N, x)$ for various values of x. For vertical showers at sea level ($x\approx1000$ g cm^{-2}) it is well known that the spectrum can be well described by a power law from $N=10^6$ to the largest sizes so far observed. This spectrum, *i.e.* S versus N at constant x, is represented by the straight line labeled 1000 g cm^{-2} in the schematic plot in Fig. 1. At smaller atmospheric depths we expect that the intensity of small showers which are beyond their maxima will increase, while that of large showers which have not had the chance to develop to full size will decrease. Therefore we can expect the size spectra a various depths to cross one another as shown in Fig. 1.

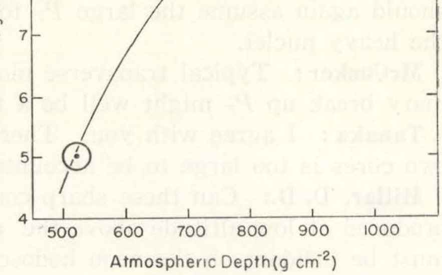

Fig. 1. Schematic plot of integral shower size spectra at various atmospheric depths.

The slope of a size spectrum is $(N/S)(\partial S/\partial N)_x$. If we draw a horizontal line across Fig. 1 and note the variation in N with x at constant S, we can determine $(1/N)(\partial N/\partial x)_S$. Finally we can draw a vertical line and from the intersections determine $(1/S)(\partial S/\partial x)_N$, which amounts to a determination of the altitude variation of the shower intensity. Between these three quantities there obviously exists to the identity relation:

$$-(1/N)(\partial N/\partial x)_S \equiv \frac{(1/S)(\partial S/\partial x)_N}{(N/S)(\partial S/\partial N)_x} . \quad (1)$$

In the absence of fluctuations it is clear that

$$(1/N)(\partial N/\partial x)_S = (1/N)(\partial N/\partial x)_E , \quad (2)$$

since the integral intensity would then serve to identify showers of a given primary energy at various depths in the atmosphere. This would make possible a direct relation between observed data and the fundamental quantity N. Also, at the depth of maximum development, we would have a simple relation between the size spectrum and the primary energy spectrum, namely:

$$J(E) = S(E/k) , \quad (3)$$

where k is about 2 Bev for all models of shower development. Even with fluctuations, we can expect equations (2) and (3) to be fairly accurate near maximum. For this reason it is worthwhile to summarize the present experimental knowledge of the atmospheric depths at which $(\partial N/\partial x)_S=0$ for various values of N.

Beginning at small shower sizes, Dr. Kamata reported on a measurement of the zenith angle distribution of extensive air showers with about 10^5 particles carried out with a spark chamber in an airliner at altitudes near 7000 meters. He found a maximum intensity not in the vertical direction, but rather at an angle of about 40° for which the corresponding atmospheric depth is 500-550 g cm^{-2}. Although he did not determine precisely the size of each shower or the sensitive area of the detector, this depth must be close to the depth at which the numerator of Eq. 1 goes to zero for $N=10^5$.

Juan Hersil and Professor Escobar of the University at La Paz and a group of us at M.I.T. have observed showers at 630 g cm^{-2} with the same equipment used previously at sea level. The method permits rather precise determinations of the size, core, position and arrival direction of each shower. For large showers we found, firstly, a steeper average lateral distribution function than at sea level which indicates already that the showers were detected at an earlier stage of development. Secondly, the zenith angle distribution for showers with more than 5×10^8 particles shows a hole in the vertical direction as in the observations of Dr. Kamata for smaller showers at greater altitude. Thirdly, the integral intensity S, when plotted for showers in various intervals of zenith angle shows the cross-over effect illustrated schematically in Fig. 2. The analysis indicates that $(\partial N/\partial x)_S=0$ for $N=10^8$ at an atmospheric depth near 650 g cm^{-2}.

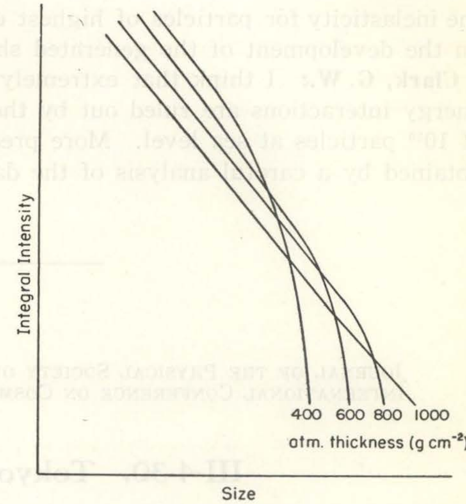

Fig. 2. Plot of experimental values of the shower size versus the atmospheric depth at which $(\partial N/\partial x)_s=0$.

Dr. Linsley reported similar measurements with a very much larger detector array at 820 g cm^{-2}, in New Mexico. Again in this experiment, the properties of each shower were precisely determined and the integral spectra at various zenith angles could be determined. A similar analysis showed that $(\partial N/\partial x)_S=0$ for $N=5\times10^8$ at about 840 g cm^{-2}.

Finally, Professor Greisen has measured the barometric coefficient and zenith angle distributions of the shower rates observed in the Cornell experiment. This gives a measure of $(\partial S/\partial x)_N$, and he combines this with his knowledge of $(\partial S/\partial N)_x$ to give $(\partial N/\partial x)_S$. He concludes that this quantity is approaching zero for $N=10^{10}$ at sea level (1040 g cm^{-2}).

At this point it is possible to construct a plot of N versus x for $(\partial N/\partial x)_S=0$ (Fig. 2). As we have argued above, this plot indicates roughly the average position of maximum development versus the size at maximum development. It can therefore provide a test of nucleon cascade theories.

As for $J(E)$, the quantity of astrophysical interest, it is clear that our most reliable absolute values will come from the intensity measurements made at these points of average maximum development. Certainly the question of kinks and fine structure in the primary energy spectrum can best be answered from such data.

Discussion

Wataghin, G.: I would like to raise the question whether one could derive some conclusions concerning the interaction mean free path of the primary particle and on the inelasticity for particles of highest energy, starting from the analysis of the data on the development of the generated showers in the atmosphere.

Clark, G. W.: I think that extremely small values of inelasticity for very high energy interactions are ruled out by the observation that showers can attain the size of 10^{10} particles at sea level. More precise limits on inelasticity can undoubtedly be obtained by a careful analysis of the data I discussed.

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III-4-30. Tokyo Air Shower Project

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Studies on the structure of EAS by Tokyo Air Shower Project were summarized.*

First, energy partition among various components of EAS was discussed and various quantities were related each other: such as the energy flow carried by electron-photon component as well as nuclear active component, nuclear mean free path at extremely high energy and the attenuation length of EAS. And the implication of the value of the attenuation length of EAS in the atmosphere was discussed.

Consistency among experimentally estimated values of various quantities suggests rather modest picture of EAS which is essentially consistent with what was postulated in calculations by N. Ogita. However this does not yet mean to reject such an abrupt change of the nature of nuclear interaction of the existence of radical deviation of the nature of EAS from the average, as discussed by Ueda and McCusker before, Miyake, Kameda and others in this conference. In fact we saw an indication of the necessity of some radical explanation in the study of the structure of individual core.

We should not forget that Kameda and Toyoda have given somewhat less importance to the role of nuclear active component than we did based upon their analysis of cloud chamber pictures. .

N-n_μ diagram was often used in this study. The basic idea is that by this diagram we may essentially avoid the confusion because of the fluctuation of the starting point of EAS in the atmosphere. There was an argument by Sreekantan. The argument is based upon his observation of fluctuation of nuclear active particles and mu-mesons. The both appeared to be related each other showing similar magnitude of fluctuation. The implication of this fact is that, since attenuation of the both must be different, only the fluctuation of the starting point of the shower can not show this sort of related fluctuation.

High energy nuclear active particles and high energy gamma rays were observed in

* The contents of most part of this article are in III-4-1 and III-4-28 and only the part which is related to other contributions will be presented here.