to the emitted power $\varepsilon \sim (e\nu/cR)\sqrt{\omega\Delta\omega} \sim 30\mu V/$ metre which in many times exceeds the level of natural noises of standard receiver $\varepsilon_T \sim 0.1 - 1\,\mu V$/metr (see, for example ref. 3, p. 88).

It should be noticed that the volume dimensions of rocks in which acts of interaction can be recorded are of same order of magnitude as radiation length for a μ-meson in dense medium (kilometres). This increases radiation efficiency of μ-mesons in electron-photon showers generated by them. The absence of outer radio-disturbances gives a possibility to use amplifiers with low levels of thermal noises and record outbursts of radioemission from meson groups of the shower produced in the atmosphere, or from single mesons.

It should be emphasized that the generation of radiowaves by cosmic particles and showers in the ground would be more intensive on the Moon which has no magnetic field and no atmosphere and which permits any cosmic particles of any energies come to its surface, and the absorption of radiowaves in the moon ground should be small even near the very surface because of the absence of moisture. This fact makes easier the recording of outbursts of ground radioemission of showers by means of the apparatus thrown on to the moon.

In general, the ground radio communication will be of great importance on the moon due to the absence of ionosperic layer and the great curvature of the moon surface which makes impossible the outer radio communication between two far points on the lunar surface.

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JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-4-23. An Analysis of Extensive Air Showers in Connection with the Primary Energy Spectrum and the High-Eenergy Nuclear Interactions

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Many reports[1,2,3] presented at this Conference and Moscow Conference show that a marked change in slope appears in the size spectrum of EAS both at sea level and at mountain altitude. Such a knick also appears in the energy spectrum of gamma-rays observed at balloon altitude[5,7] as well as at mountain altitude[4,6] (see Table).

Such anomalies could not be reproduced as far as we are concerning the usual model of pion production and nuclear cascade process together with a constant exponent of the energy spectrum of primary particles.

Thus we are led to the two standpoints. The first one is to assume a change in slope of the energy spectrum of primary particles.

If the exponent of the primary spectrum falls down above a certain primary energy, say, at several times 10^6 Bev, then a knick will appear in the size spectrum at about a few times 10^5 in the lower half atmosphere. As a model of nuclear interaction we adopt that used by Ueda and Ogita[8], in which a constant inelasticity and the equipartition of interaction energy to produced pions are assumed.

Table I.

Size Spectrum	Integral Exponent	N_{cri}
Mount.	$1.5 \rightarrow 2.0$	$4.5 \cdot 10^5$
S.L.	$1.4 \pm 0.2 \rightarrow 1.9 \pm 0.2$	$3 \cdot 10^5$
$E\gamma$ Spectrum		$E_{\gamma cri}$
High Alt.	$2.3 \pm 0.2 \rightarrow 2.8 \pm 0.3$	$1.5 \cdot 10^{12}$ ev
Mount.	$2.0 \pm 0.2 \rightarrow 2.5 \pm 0.2$	$\sim 10^{12}$ ev

The second standpoint is to assume a change in the character of nuclear interaction rather drastically in the very high energy region, say above 10^5 Bev. We take a model for nuclear interaction which is a slightly improved version of the model proposed by McCusker and Ueda[9]. In this model, above 10^5 Bev the majority of an incident energy is transferred to the secondary X-particles, including hyperons, excited states of nucleons with short life time, and so on. And the maximum energy of the directly produced pions is assumed to be limited to about 25 Bev in the C.M. system of the collision process. Due to the small inelasticity for the pionization in the very high energy region, the spectrum of π^0 and consequently the spectrum of gamma-rays falls down above a certain energy.

We should also notice, here, that both two standpoints are appropriate to explain the apparent constancy of observed attenuation of shower intensity in a fairly wide range.

The results of our calculations are shown in Figs. 1~7. Table shows the experimental data mentioned above. The exponent of the integral size spectrum at sea level changes from 1.4 to 1.9 at the size 3.10^5, and at mountain altitude it changes from 1.55 to 2.0 at the size $4.5.10^5$. The observed γ-ray spectrum changes its exponent from 2.0 to 2.5 at the γ-ray energy between 10^{12} ev and 10^{13} ev.

In Fig. 1 the calculated size spectrum at sea level are given. The dotted line is derived by the usual model. By the usual model we mean that the slope of the spectrum is constant and the character of nuclear interaction at lower energy region hold also at higher energy region without any change in the character. That is, i) the exponent of the primary spectrum $\gamma_p = 1.8$, ii) the production spectrum is similar to that of Landau's theory, iii) the inelasticity is taken as $\eta = 0.5$. Some quantities based on this model will be presented later on.

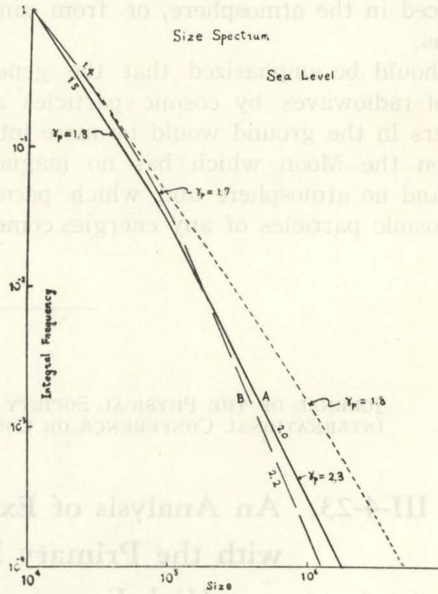

Fig. 1.

In all the cases the fluctuation in the depth of shower initiation was fully taken into account.

The curve A is the result calculated under the assumption that the primary energy spectrum changes its slope. As an integral exponent $\gamma_p = 1.8$ is employed below the primary energy of 5.10^{15} ev and $\gamma_p = 2.3$ above this energy. These values were chosen so as to fit the observed size spectrum at sea level.

The curve B represents the result calculated under the assumption that the nuclear interaction changes the character at high energies, and the exponent of the primary energy spectrum is constant $\gamma_p = 1.7$.

As one can see, the usual model of nuclear interaction mentioned before together with the constant slope of the primary energy spectrum can not reproduce the change in slope of the size spectrum.

A similar change in slope also appears at mountain altitude as shown in Fig. 2. In the both curves A and B, as can be seen the calculated positions where the slope changes do not shift appreciably by the difference of observation levels in the lower half atmosphere.

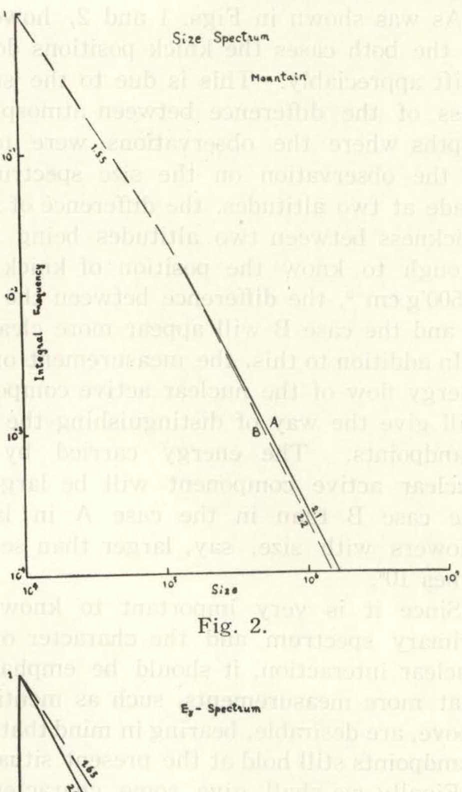

Fig. 2.

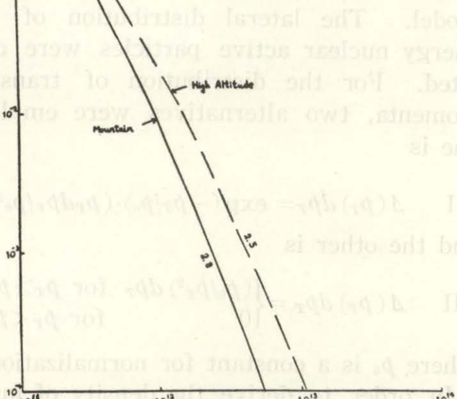

Fig. 3.

Fig. 3 shows the calculated γ-ray spectra of high altitude and at mountain altitude, based on the assumption B.

Fig. 4 shows the integral energy spectrum of π°-meson at mountain altitude, based on the assumption A. The integral exponent of the primary spectrum was taken as $\gamma_p=1.8$ below the primary energy of 10^{15} ev and 2.3 above this energy. The change in slope appears at $(4\sim5).10^{12}$ ev, the integral exponent being respectively 2.08 and 2.36 below and above the energy. If the primary energy spectrum has a knick at 5.10^{15} ev as in the case of the size spectrum (see Figs. 1 and 2), the change will appear at higher energy, say about 10^{13} ev. Though the change in slope appears at energy slightly higher than the observed one, it is not unreasonable to take the standpoint A at the present situation.

Thus as far as these two observed spectra are concerned, we can not decide which one of two standpoints mentioned above is more preferable. The difference between these two standpoints may appear if we investigate the properties of energy flow carried by the nuclear active component. Because the fraction of the energy carried by the nuclear active particles may differ in these two cases.

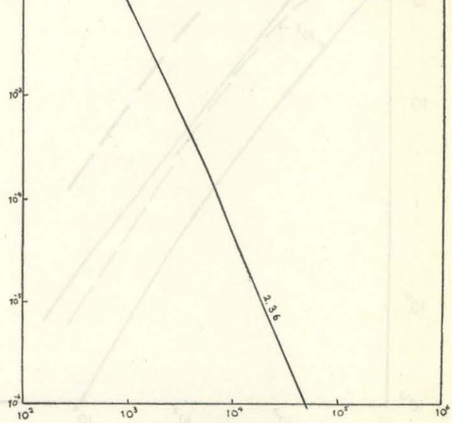

Fig. 4.

Figs. 5 and 6 show the energy spectra of the nuclear active component in showers of size 10^5 and 10^6. A some difference between two cases can be seen.

Comparing the above two standpoints with each other, we may say that both of these two standpoints can claim their validities as far as the present day data mentioned above are concerned.

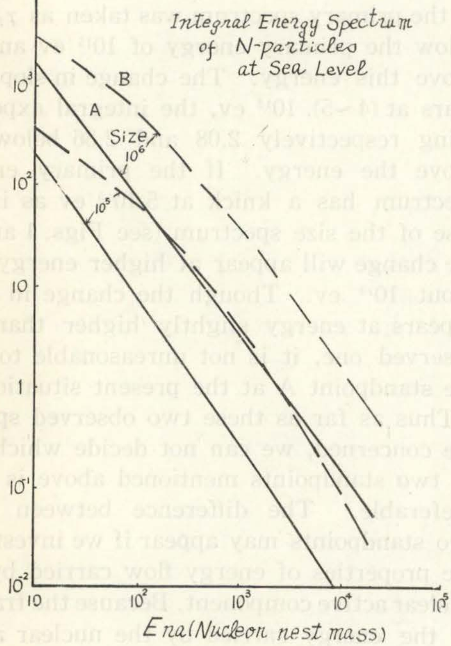

Fig. 5.

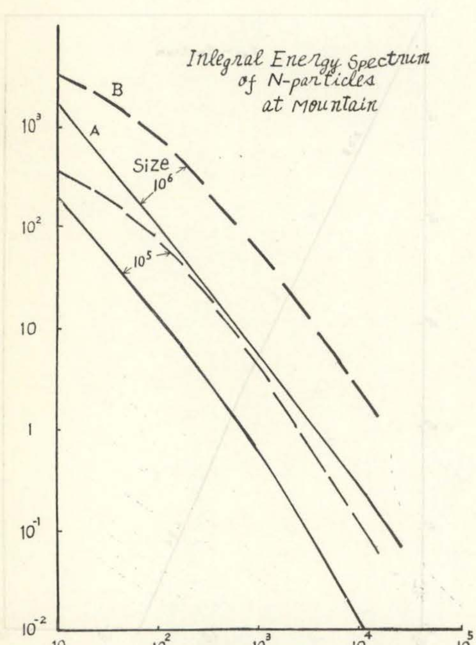

Fig. 6.

If the standpoint A is taken, one should expect that the position at which the slope of the size spectrum changes shifts toward lower value with increasing depth. On the other hand if the standpoint B is taken, the position of knick will not shift so much as expected in the case A.

As was shown in Figs. 1 and 2, however, in the both cases the knick positions do not shift appreciably. This is due to the smallness of the difference between atmospheric depths where the observations were made. If the observation on the size spectrum is made at two altitudes, the difference of mass thickness between two altitudes being good enough to know the position of knick, say $\gtrsim 500\,\mathrm{g\,cm^{-2}}$, the difference between the case A and the case B will appear more clearly.

In addition to this, the measurement of the energy flow of the nuclear active component will give the way of distinguishing the both standpoints. The energy carried by the nuclear active component will be larger in the case B than in the case A in larger showers with size, say, larger than several times 10^6.

Since it is very important to know the primary spectrum and the character of the nuclear interaction, it should be emphasized that more measurements, such as mentioned above, are desirable, bearing in mind that both standpoints still hold at the present situation.

Finally we shall give some characteristic feature of air showers derived by the usual model. The lateral distribution of high-energy nuclear active particles were calculated. For the distribution of transverse momenta, two alternatives were employed; one is

$$\text{I} \qquad \Delta(p_T)\,dp_T = \exp(-p_T/p_0)\cdot(p_T dp_T/p_0^2)$$

and the other is

$$\text{II} \qquad \Delta(p_T)\,dp_T = \begin{cases}(p_0/p_T^2)\,dp_T & \text{for } p_T \geq p_0\,, \\ 0 & \text{for } p_T < p_0\end{cases}$$

where p_0 is a constant for normalization.

In order to derive the density of nuclear active particles having energy greater than E, the nucleonic cascade theory developed by

Fukuda, Ogita and Ueda[10] was applied. The density at a depth x (in m.f.p. units) and at a distance r from the shower axis, as a function of primary energy E_0 is represented as follows.

For the case I

$$\rho_I(x,r,>E,E_0)=\frac{(1-\delta)\nu x}{2\pi r r_0}e^{-x}(E_0/E)^{\delta}\sum_{l=1}^{\infty}\frac{[(1-\delta)\nu x\ln(E_0/E)]^{l-1}}{[(l-1)!]^2}2\sqrt{\frac{lr}{r_0}}K_1\left(2\sqrt{\frac{lr}{r_0}}\right)$$

and for the case II

$$\rho_{II}(x,r,>E,E_0)=\frac{(1-\delta)\nu x}{2\pi r r_0}e^{-x}(E_0/E)^{\delta}\sum_{l=1}^{\infty}\frac{[(1-\delta)\nu x\ln(E_0/E)]^{l-1}}{[(l-1)!]^2}\left(\frac{lr}{r_0}\right)^2\left[1-\exp\{-(lr/r_0)\}\left(1+\frac{lr}{r_0}\right)\right]$$

where K_1 is the imaginary Bessel function and

$$r_0=(p_0/m_\pi c)\,10^3/E \text{ meters}$$

with E measured in Bev units. δ is the exponent of the production spectrum and ν is the fraction of charged secondary pions.

At small distances $(r\ll r_0)$

$$\rho_I\propto 1/r \quad\text{and}\quad \rho_{II}\propto 1/r$$

and at large distances $(r\gg r_0)$

$$\rho_I\propto r^{-3/4}\exp(-2\sqrt{r/r_0}),$$

$$\rho_{II}\propto r^{-3}.$$

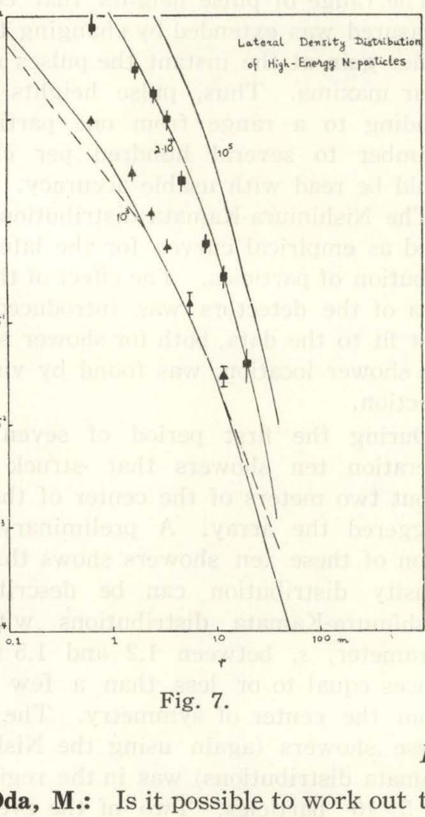

Fig. 7.

The calculated result is shown in Fig. 7 together with the experimental data[11]. The solid curves were derived with the P_T-distribution I and the broken curves with the P_T-distribution II. Figures attached on the curves show the ratios of primary energy to N-particles concerned. Though the difference between two cases may not be distinguished as far as the present data are concerned, a fairly good agreement with the data can be seen. This seems due to the constancy of the transverse momenta, nearly independently of other character of nuclear interactions.

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Discussion

Oda, M.: Is it possible to work out the break both on the N-spectrum and n_μ-spectrum?

Takagi, S.: Yes.

Ueda, A.: I would like to add a comment on Prof. Takagi's talk. If we choose the standpoint B, we can qualitatively reproduce the observed size dependence of nuclear active particles observed at mountain altitude which shows the dependence less weak below size of $\sim 10^5$ as compared with that in larger sizes.