STUDY OF ATMOSPHERIC SHOWERS*

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A system was constructed consisting of counters connected with neon tubes. This system was used for observing atmospheric showers at an altitude of 3250 m above sea level. The method used allowed us to make an estimation of the particle density in narrow showers and Auger showers. The investigation revealed also the existence of very dense penetrating showers.

In 1943 on Mt. Alagez we have observed [1,2] that besides the Auger showers there exist groups of correlated particles covering a small area, which are called by us "narrow showers" (formerly we have named them the showers of "a small radius"). The nature of these showers differs sharply from that of the ordinary showers and Auger ones. The observation of narrow showers meets with difficulties since the recording system records the Auger showers too.

The narrow showers are properly recorded when the separation between the counters becomes small. In this case the number of coincidences sharply increases and this increase cannot be accounted for by ordinary cascade showers. It would be also erroneous to explain this phenomenon by the influence of the core of the Auger showers. It can be easily shown that the recording probability of the shower's core by means of the ordinary arrangement of counters is negligibly small. However, the number of coincidences at small separations between the counters is 1.5—2 times larger than the corresponding number at large separations when apparently the Auger showers are observed.

From the above consideration it is seen that the number of narrow showers in air is very large and is in any case larger than the number of Auger showers. Actually the probability of recording the narrow showers is several hundred times smaller than that of the Auger showers. The Auger showers cover larger area and consist of a greater number of particles. Therefore, the counter arrangement situated in an arbitrary place will record the Auger showers.

As we have already noted above, the narrow showers besides their small transversal dimensions are characterized by a small density of the particles. Only a great number of narrow showers in air can explain the large effect caused by these showers in a counter system. Hence, by the way, it follows that the probability of the generation of narrow showers is also large. However, the mechanism of the generation is at the present time absolutely unknown. Moreover, up to now we do not know what kind of particles constitutes the narrow showers.

Recently, Alichanian and Alexandrian [3] by means of a special device have succeeded in diminishing the effect caused by extensive showers including the Auger showers. In this way they investigated the narrow showers in more pure conditions. Making use of this device, based on switching off the extensive showers by means of anticoincidence method, they showed that the

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penetrating power of the particles, constituting the narrow showers, is considerable.

By means of the same device the narrow showers were observed at an altitude of 960 m above sea level, and their number at this altitude appeared to be less than at an altitude of 3250 m.

Recently there appeared a number of papers presenting the results of the investigations of penetrating showers. Janossy and Rochester (4) by means of a very complicated device have observed at sea level showers with a very large penetrating power. Such showers were detected very seldom. However, it must be noted that their device was very disadvantageous for the detection of narrow showers possessing a small particle density. The transversal dimensions of these showers were not measured by these authors.

The penetrating showers at an altitude of 800 m above sea level were also observed by Watagin, Santos and Pompeia(5). The effect produced by the penetrating showers in this device was negligibly small. The authors came to the conclusion that the observed penetrating showers are the cores of the Auger showers, which contain penetrating particles (mesotrons). In the paper mentioned above the authors have paid principal attention to the penetrating power of showers. Strictly speaking only this feature enabled them to distinguish these showers from the usual cascade ones.

Our investigations have shown that the penetrating power is not the only characteristic feature of the showers which completely determines their nature. We have shown, for instance, that the narrow showers have a considerable penetrating power. However, there were observed in air penetrating showers having a radius much greater than that of the narrow showers. There is no doubt that the nature of the wide penetrating showers is completely different from the nature of narrow penetrating showers. Our experiments (3) have brought us to the conclusion that there exist at least three kinds of showers:

1. Cascade showers (Auger showers) with a radius of about 70—80 m.
2. Narrow showers with a radius of about several tens of centimetres having a large penetrating power.
3. Wide penetrating showers, consisting of a large number of particles. The radius of such showers is not determined up to now.

It is possible that the latter kind is connected with the Auger showers. This problem requires further investigation.

In the present work we have investigated the density of the particles in air showers using a new method developed by us. By means of this method we have been able to determine the density in narrow showers and in Auger ones and also to estimate the particle density in wide penetrating showers. Besides, we have performed experiments in order to examine the presence of uncharged particles in narrow showers.

These experiments were carried out on Mt. Alagez in 1945.

Experimental

The experimental arrangement used by us for the determination of particle density in narrow showers as well as in the Auger ones is shown schematically in Fig. 1. Three coun-

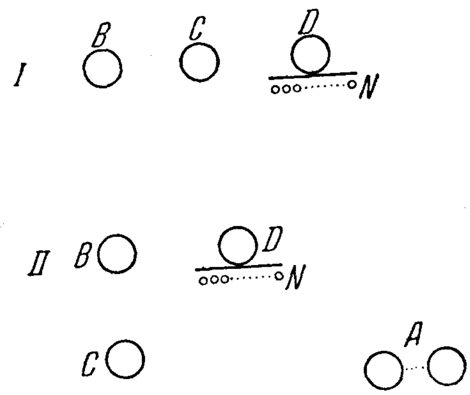

Fig. 1

ters B, C and D represented a usual system recording the Auger showers and at small separations the narrow showers too. Below the counter D there was placed a counter tray containing eleven small counters N covering almost completely all the surface occupied by the counter D. The impulses originated in each small counter were led to a separate circuit which included one neon tube*. This circuit

* The flashes of neon tubes for recording the transition of cosmic particles were suggested by Swan (6) and were used by him for the observation of the paths of particles.

is shown in Fig. 2. The impulse originated in a small counter was led to one of the grids of a double triode tube (A, Fig. 2); to the second grid was led the impulse caused by a triple coincidence ($B\ C\ D$), *i. e.* by the passage of a shower. Hence the system B, C, D was a master one. The tube A separated the coincidences between the master signal and that of one or several small counters. Only as a result of such a coincidence there appeared an impulse sufficient to open the closed multivibrator shown to the right of the tube A.

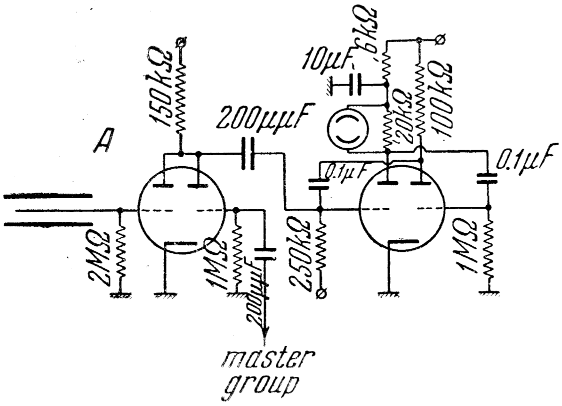

Fig. 2

Parallel to the anode of the multivibrator a neon tube was connected. It is clear from the foregoing that the neon tube flashed only when the impulse in a small counter appeared simultaneously with the master impulse. The duration of the flash was determined by the period of the multivibrator and was of the order of 0.01 sec. The flashes of the neon tubes were recorded on a sensitive film by means of a motion picture camera. The master impulses were led to a special high power cascade which governed the device, shifting the film by one frame. Detecting showers by the system B, C, D and noting simultaneously the number of flashed neon tubes one can obtain the data concerning the density of shower particles. It is obvious that the smaller are the counters N the better we can determine the density. The counters used by us were 8 cm long and 12 mm in diameter. Counters B and C were 20 cm long and 3 cm in diameter. The counter D consisted of two counters having the same dimensions. All the counters were filled with a mixture of argon at a pressure of 9 cm Hg and alcohol vapour at 1 cm Hg and have operated as self-quenching counters. The resolving power of the circuit separating the coincidences ($B\ C\ D$) was 1 μsec. The photographing of flashes was made by means of the camera with an objective 1 : 3.5 and a panchrom film (sensitivity about 1000).

In some experiments a new radio circuit was connected which permitted us to record, besides the coincidences ($B\ C\ D$), also the anti-coincidences (BCD-A). Investigation of the circuit shows that for the counting rate of the counter A up to 10^3 counts per minute, the number of omissions of anti-coincidences does not exceed 1.5 per cent.

Measurements and results

A. Auger showers

The method of investigation of particle density by means of neon tubes was applied firstly to the Auger showers. The Auger showers were recorded by counters B, C, D. The separation between B and D was about 3.5 m and the counter C was placed just in the middle between the two counters B and D. The tray containing eleven small counters N connected with neon tubes was placed under the counter D. The whole arrangement was placed inside a wooden house of a high-altitude station at Mt. Alagez (3250 m above sea level). The amount of wood above the arrangement did not exceed 3 g/cm^2. The results of measurements are given in Table 1. In the first column the number of simultaneously flashed tubes is given; in the second column is given

Table 1

Number of flashed neon tubes	Number of showers
1	34
2	24
3	13
4	11
5	7
6	3
7	2
8	6
9	3
10	0
11	0

the number of showers which caused the flashes of a corresponding number of neon tubes. Experimentally obtained curves can be used for the investigations of the spectrum of primary particles coming from the cosmic space. However, we shall not dwell upon this subject here. We note, by the way, that from the curve of the number of flashed neon tubes (Fig. 3) it is seen that among the Auger showers one can meet a considerable number of showers having a particle density exceeding 10^3 particles per 1 m^2. The number of showers with a particle density greater than 10^3 particles per 1 m^2 constitutes 2—4 per cent of the total number of showers with a density larger than 10^2 particles per 1 m^2. This result is in good agreement with the previously published data concerning the particle density in Auger showers (7).

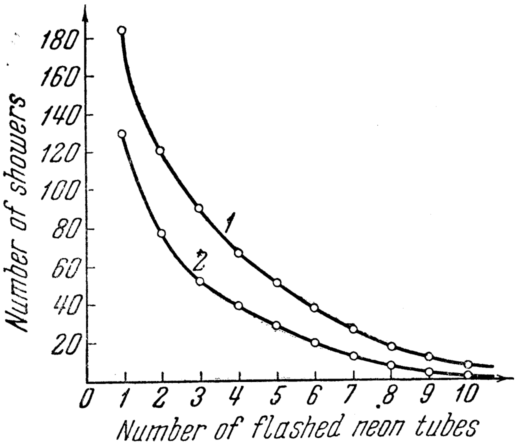

Fig. 3

We have obtained also a number of photographs by means of a telescopic arrangement shown in Fig. 1 with a separation between B and C equal to 3 m. The distribution curves in these two cases are very close. This could be expected, since in both cases the Auger showers were recorded.

B. Particle density in narrow showers

In order to obtain data concerning the particle density in narrow showers we have used the arrangement described above.

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Table 2

Number of flashed neon tubes	Number of showers
1	49
2	11
3	3
4	1
5	2
6	—
7	—
8	1
9	—
10	—
11	—

Besides, we have made use of the method permitting to switch off to a considerable extent the Auger showers. This was done with the help of a separate group of counters A separated by 1 m from the principal system and connected in anti-coincidence scheme. The effect of the Auger showers was 3 times smaller when the area covered by the counters A was equal to 360 cm^2. Hence, in the position II (Fig. 1) 70 per cent of anti-coincidences (B C D-A) are caused by narrow showers and the rest by the showers of different nature (Auger showers). It can be said that the anti-coincidences (B C D-A) are caused by narrow showers and partly by extensive showers with a small particle density. The counter tray N connected with the neon tubes was placed near the counter D. The results are given in Table 2.

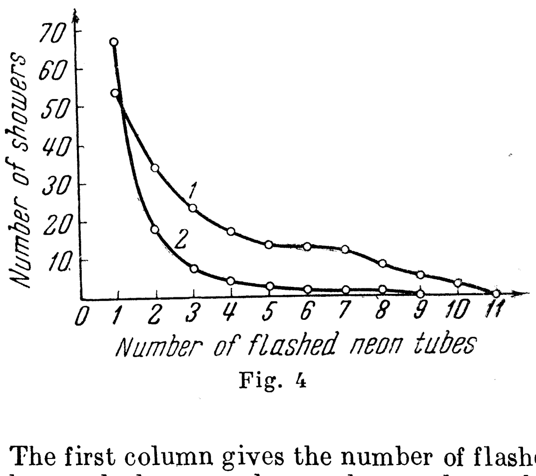

Fig. 4

The first column gives the number of flashed tubes and the second one the total number of the observed showers, which caused the corresponding number of flashes. As the table shows the number of showers which caused the flashes of more than two neon tubes is very small. The integral curve drawn according to the data of Table 2 is given in Fig. 4. Contrary to the case of the Auger showers the curve sharply falls off and the number of anticoincidences corresponding to the flashes of 3 or more tubes amounts only to 10 per cent of the total number of flashes. The corresponding figure for Auger showers was about 50 per cent of the total number.

C. Particle density in penetrating showers

Alichanian and Alexandrian [3] have shown, that, besides the penetrating narrow showers, there exist in air penetrating showers with a radius markedly exceeding the radius of the narrow showers. The transversal dimensions of these extensive penetrating showers are not measured up to now. Using the arrangement shown in Fig. 5 we

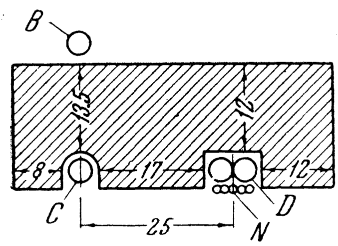

Fig. 5

tried to determine the density of the particles in penetrating showers. We have used again in these experiments a group of neon tubes connected with counters located under the counter D. The separations between the counters B, C and D (20 cm) were kept unchanged. The counters were covered by lead blocks as it is shown in Fig. 5. The minimum thickness the shower particle had to penetrate was equal to 12 cm. It is obvious that the arrangement shown in Fig. 5 detected not only the penetrating narrow showers but also the penetrating extensive ones. In order to separate both these types of showers from one another and to investigate the density of the particles in them separately, it was necessary to carry out the measurements at small distances as well as at large ones, exceeding the transversal dimensions of the narrow showers. However, owing to lack of time, we have not performed such measurements, but we hope to do this in the nearest future.

Using the arrangement mentioned above, we have been able to determine the particle density without separating the narrow showers from the broad ones. However, if there were in the air only the Auger showers and the narrow ones our measurements at $l = 20$ cm would give us a possibility to estimate the particle density in narrow showers, since the Auger showers consist mainly of electrons and photons that cannot penetrate 12 cm of lead. But the experiments have shown the existence of broad penetrating showers in air, besides the narrow ones. In Table 3 are given the results of measurements, which are to be considered as preliminary ones, since the total number of them is not large and, therefore, the statistical errors are considerable.

Table 3

Number of flashed neon tubes	Number of showers
1	20
2	10
3	6
4	4
5	1
6	1
7	3
8	3
9	2
10	3
11	—

From Table 3 and Fig. 4, where the integral curve *1* of the number of flashed neon tubes is given, it follows that among the penetrating showers there exist showers with an enormous density of the particles. For instance, we have observed six showers having the density larger than 1000 particles per 1 m^2. Since we have proved earlier that among the narrow showers there are no dense ones, it is natural to suppose that the dense penetrating showers possess a large extension which is in any case larger than that of the narrow ones. We cannot exclude at present the possibility that these penetrating showers constitute a part of the Auger showers. Howevers, in our opinion, the dense penetrating showers are not usual cascade showers and in any case consist of secondary penetrating particles.

D. Non-ionizing particles in narrow showers

The large atmospheric showers are described at present by the cascade theory, according to which high energy electrons or photons are multiplied in air, thus initiating a large shower which consists of electrons and photons. Such an explanation appears to be correct, though it is not excluded that the Auger showers contain such particles which arise at the same time but as a result of some other by-processes. As to the narrow showers we have no satisfactory explanation of their origin. Unfortunately, we even do not know what kind of particles constitutes these showers. It can only be stated that the narrow showers consist neither of electrons nor of photons. Our problem was to examine whether the narrow showers include any neutral particles. Such particles might have been photons, neutrons or, finally, hypothetical neutral mesons. The method used by us is easy to understand from Fig. 6. The

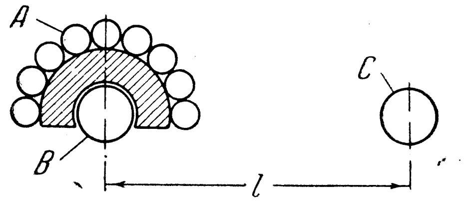

Fig. 6

counters B and C were connected in a coincidence scheme and the counters A connected in parallel anti-coincidence scheme. Charged particles which entered simultaneously the counters B and C could not cause a double coincidence, since these cases were switched off by the counters A. Only in those cases when a charged particle originated in a lead filter by some neutral particle entered the counter B and simultaneously a charged particle got into the counter C there occurred an anti-coincidence recorded by the arrangement. The thickness of the lead filter between the counters A and B was 10 mm. Group A consisted of 10 counters, 20 cm long, 20 mm in diameter connected in parallel. The counter B was 20 cm long and 3 cm in diameter. When the side counter C was separated by several metres from B the system detected about six anti-coincidences per hour. It is obvious that these anti-coincidences were caused by the entry of electrons in the side counter and of a phonon in the system B, A. If there were only Auger showers in the air it should be expected that the number of coincidences would remain constant, when the separation between the counters B and C would decrease. However, the experiments show that the number of coincidences increases when the counters are drawn together. The results are shown in Fig. 7. The increase observed at small l starts

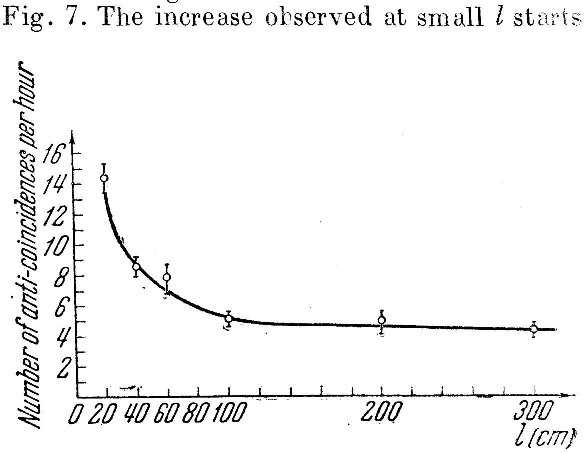

Fig. 7

at $l=1$ m and indicates that this increase is due to the action of narrow showers. If this supposition is correct, the neutral particles enter the narrow showers. These neutral particles are capable to generate the charged particles in the lead filter. Our experiments do not give us any possibility to draw conclusion concerning the nature of these neutral particles. Generally speaking, we may suppose that they are high energy photons. However, such a supposition seems to be unlikely, since the charged particles which constitute narrow showers are not electrons.

Discussion of results

The results of the investigations of the particle density of narrow showers show that in the majority of cases they consist of a small number of particles. Unfortunately, our data cannot give definite quantitative conclusions concerning the distribution of showers with respect to their density. This is due to the different sensitivity of our device to the showers of different density. In a limiting case a shower consisting of two particles (an electron pair) can put the arrangement into operation and we shall detect the flash of one neon tube. In order to obtain a clear picture of the shower structure, it would be desirable to cover with small counters the area equal to the transversal dimensions of a shower and then to observe the flashes of the neon tubes. Such a "carpet" is now in preparation. However, the data obtained in the present experiments give indications on the particle density in narrow showers, which put in operation our master system. From Figs. 3 and 4 it may be seen that the particle density in narrow showers is considerably smaller than that in Auger ones. When detecting the narrow showers in most of the cases the flashes of only one neon tube is observed. We must keep in mind that a part of the manyfold flashes (if not all of them) is due to Auger showers having a density not sufficient to be switched off by the counter A. If all cases given in Table 2 correspond to the narrow showers, the mean density becomes about 100 particles per 1 m^2. This figure is rather an upper limit of the particle density in narrow showers. It is very interesting to compare our data with those of Lewis ([8]), who observed using the coincidence method the ionization bursts in two chambers. His data obtained with one chamber are of a special interest. Lewis detected in these experiments about 100 bursts per 1 hour which corresponds to the crossing through the chamber of 80 relativistic particles and gives for the density the value about 1000 particles per 1 m^2. It seems that such a high density excludes the explanation of these bursts by narrow showers. On the other hand, the number of bursts sharply decreases with the increase of the separation between the chambers and just by this reason they cannot be considered as Auger showers. It is very probable that such bursts are due to the getting of several particles of a large ionization power into the chamber. Migdal ([9]) in his analysis of the ionization chamber data obtained at altidudes about 3—4 km has come to the conclusion that the great number of ionization bursts detected by different authors cannot be explained neither by the narrow showers nor by the Auger ones. It follows from calculations that the number of coincidences in the counter system would be 30—50 times larger than it had been observed experimentally, if the bursts were caused by relativistic particles.

The investigations outlined above revealed the presence of neutral particles in narrow showers. It is difficult to draw any conclusion concerning their nature. It would be most probable to suppose them to be photons. It is also possible that these neutral particles are neutrons although we cannot exclude the possibility of their being any unknown neutral particles.

Proceeding to the penetrating showers it is necessary to call attention to their enormous density. The large frequency of such showers brings us to the conclusion that these showers are generated in a different way and are probably not connected with Auger showers. The method of neon tubes appeared to be very useful and allowed to prove quite convincingly the existence of such dense penetrating showers. Independently of our investigation, Bell, Birger and Veksler ([10]) reported about their observation of dense showers at an altitude of 3250 m above sea level. Their method completely differs from ours and is based on the use of proportional counters. Up to the present time the scarce data concerning the dense penetrating showers does not permit us to make any definite conclusions on their properties and their nature remains unknown.

We are greatly obliged to Prof. A. Alichanow and Prof. L. Landau for a number of discussions concerning the air showers.

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