presence of fluid motions, and these questions are capable of a formal solution without the introduction of further hypothetical elements.

[1] P. Debye, Ann. d. Physik **30**, 57 (1909).
[2] J. A. Stratton, *Electromagnetic Theory* (McGraw-Hill Book Company, Inc., New York, 1941), pp. 559–560.
[3] W. R. Smythe, *Static and Dynamic Electricity* (McGraw-Hill Book Company, Inc., New York, 1939), Chap. 11.
[4] W. M. Elsasser, Phys. Rev. **69**, 106 (1946), quoted as I.
[5] W. M. Elsasser, Phys. Rev. **70**, 202 (1946), quoted as II.

Investigation of Auger Showers by the Proportional Counter Method

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THE main experimental results obtained by us in the fall of 1944 at 3860 m above sea level in the Pamir Mountains, U.S.S.R. (Middle Asia)* are set forth in this Note. Data on Auger showers which are available at present are based on the application of two complementary methods—the coincidence method[1] and ionization chamber method.[2]

This latter method (observation of ionization bursts) permits one to select showers exceeding a given size and this in turn yields (by means of the cascade theory) direct evidence concerning the energy spectrum of the primary shower-producing particles. However two essential limitations must be taken into account in this case.

First of all ionization bursts in thin-walled chambers can be produced not only by Auger showers but by heavily ionizing particles as well.

Secondly, when only a few particles of the observed showers pass through the cross section of the chamber, fluctuations of the number of particles can considerably distort the size distribution curve for bursts. Both of these factors can be overcome if instead of ionization pulses in one chamber we register coincidences caused by these pulses in two chambers arranged in a horizontal plane at a given distance from each other. Under these conditions heavy particles are not counted while fluctuations, as calculations show (D. Skobeltzyn), do not play any appreciable role (even when pulses caused by only two particles in each chamber are recorded).

In the present investigation which was carried out in the open air we employed instead of ionization chambers two trays of proportional counters, the latter being connected in parallel; the tube circuit and experimental method used by us was developed in this laboratory by Professor Veksler.

Each of the trays consisted of 6 proportional counters filled to atmospheric pressure with argon, the total area being $\sigma = 700$ cm^2 (the thickness of the aluminum counter walls was approximately 0.2 g/cm^2). Pulses from each of the trays were fed to a linear amplifier coupled to a multivibrator. The threshold of the multivibrator was regulated by negative bias on the grid of the first tube in each of the channels. The tubes which selected the double coincidences ($\tau = 2.85 \cdot 10^{-5}$ sec.) were placed after the multivibrator and therefore coincidences were recorded only when the linearly amplified pulses in each channel exceeded the multivibrator threshold. By keeping the latter constant and varying the amplification it was possible to vary the minimum amount of ionization in each of the counter trays necessary for registration of the pulses.

During the measurement the gas amplification factor remained constant. In order to determine this latter quantity, and thus to calibrate the apparatus, pulses due to α-particles from Po were used.

The magnitude of the ionization pulse (I) caused by a shower is proportional to the number of particles traversing the given counter tray: $n = I/i_0 l$, where l is the mean path of the particle in the counter (0.8 of the counter diameter) and i_0 is the "probable specific ionization" (75 ion pairs per cm of argon).

A definite particle density of the recorded Auger shower $\rho = n/\sigma$ and a definite average energy** of the primary particles correspond to this n.[4]

The dependence of the number of double coincidences per hour (after subtracting the accidental coincidences) on $n_{\min}$ or $\rho_{\min}$ are given by the curve in Fig. 1 (ν is the integral number of councident bursts of size exceeding $n_{\min}$). Within the investigated interval the dependence of ν on the sensitivity of the recording system (which is proportional to $1/n_{\min}$) turned out to be approximately linear.

The circles on the curve denote the results obtained by Auger[1] at an altitude of 3500 m by using a counter-controlled cloud chamber which is essentially equivalent to an ionization chamber in respect to registration of bursts due to showers (ν is the number of expansions per hour; n the number of tracks).[3]

Auger's cloud chamber data are in satisfactory agreement with our results obtained with proportional counters as concerns the order of magnitude of ν. On the other hand, it should be noted that there is a serious discrepancy between our results and those obtained by using ionization chambers (see the dotted lines, Fig. 1) not only in respect of the absolute number ν but also in respect of the dependence of ν on $n_{\min}$ ($\nu \sim (1/n^2_{\min})$ in the case of ionization chambers).

Calculations based on the cascade theory $(\rho \sim (1/r^{2-S}))^{5***}$ show that for a power energy spectrum of the primary particles of the form $dF = (A/E)(dE/E)$ (where dF is the

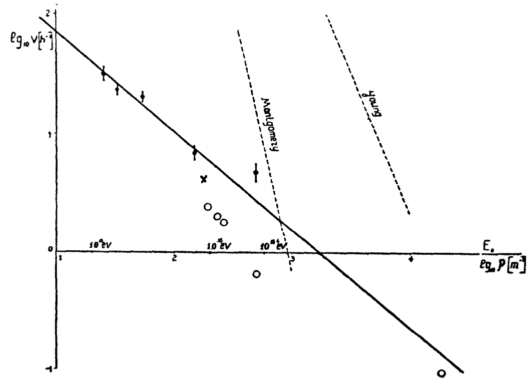

FIG. 1. Continuous curve—logarithm of frequency (ν) of Auger showers *versus* logarithm of density ($\rho_{\min}$) according to data of coincidences in two trays of proportional counters. Broken line—size-frequency curve of bursts in ionization chambers.

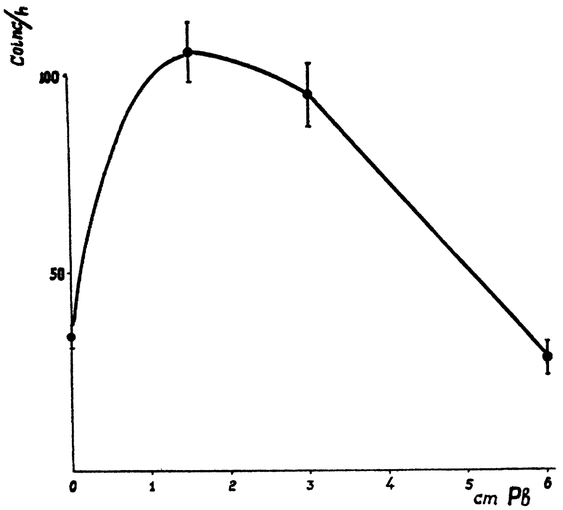

FIG. 2. Variation of coincidence rate with thickness of lead placed above each of two trays of proportional counters.

number of primary particles in the energy interval dE) one should expect a dependence close to $\nu \sim (1/n^{k}_{\min})$, where $k=\gamma/S$.[2] † For $\gamma=1.8$[2] (the value accepted by Euler in accordance with the spectrum of Millikan and Neher) we would obtain $k=1.5-1.6$.[3]

The value $k=1.3$, however, could be considered to be in accord with our experimental curve.

The cross in Fig. 1 indicates the result obtained with the sixfold coincidence circuit (of conventional Geiger counters —see the accompanying letter of D. Skobeltzyn).

The curve in Fig. 2 shows the influence of lead absorbers placed above each of the two trays of proportional counters (arranged in a horizontal plane) on the number of coincidences. This curve was measured at a sensitivity denoted as $n_{\min}=2$, the distance between the counter trays being 80 cm.

I wish to express my deep appreciation to Professor D. V. Skobeltzyn for suggesting this investigation and for his continual interest in its progress.

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* Near Mourgab.

** We assume that the showers originate only in the upper layers of the atmosphere. The conclusions may essentially change if this assumption is incorrect.

*** S is the parameter of the cascade theory.

† Relation (2) was noted by A. Migdal (in press). It also follows from formulas (11)-(15) of reference 4.

[1] Auger, Maze, Ehrenfest, and Fréon, J. de Physique **10**, 39 (1939).

[2] H. Euler, Zeits. f. Physik **116**, 73 (1940). R. Young, Phys. Rev. **52**, 559 (1937). C. Montgomery and D. Montgomery, Phys. Rev. **47**, 429 (1935); **56**, 640 (1939).

[3] D. Skobeltzyn, Comptes Rendus U.S.S.R. **44**, 203 (1944).

[4] D. Skobeltzyn, Comptes Rendus U.S.S.R. **44**, 154 (1944).

[5] S. Belenky, J. Phys. U.S.S.R. **8**, NI (1944).

Penetrating (Atmospheric) Showers in Cosmic Rays

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IN the preceding note (Lazareva) the method and results of application of proportional counters for the study of Auger showers were described. To ascertain what fraction of the bursts observed in single chambers are caused by heavy particles we carried out experiments in which the coincidence rate of two proportional counter trays were compared when the trays were arranged in two different positions: (1) in a vertical plane one above the other; (2) in a horizontal plane (Fig. 1).

In the vertical position the trays were separated by a distance of 30 cm so that the solid angle cut out by this telescope equaled 0.6.

The results communicated here were obtained when the sensitivity corresponded to the traversal of each of the chambers of 10, or more, normally ionizing particles (say, mesons of about 3–10^9 ev). The number of coincidences per hour in the horizontal and vertical positions are as follows.

C_h $d=50$ cm	C_h $d=125$ cm	C_v	C_v with 12 cm Pb
7.7 ∓ 1.03	6.3 ∓ 0.87	34.2 ∓ 3.4	15.6 ∓ 1.8

Although, the coincidence rate in the vertical position (C_v) exceeded by almost five times the horizontal counting rate (C_h),* experiments in which a 1.5 g/cm aluminum absorber was interposed between the counter trays showed that only one-third of the difference (C_v-C_h) can be ascribed to single heavily ionizing particles (slow mesons or protons) which is in accord with the results of Veksler, Dobrotin, and Khvoles (to be published soon) who made a careful investigation of these particles by a similar method. The number of coincidences caused by them under our conditions is of the same order as the number of counts caused by Auger showers.**

In the last column of the above table is shown the coincidence rate, after subtraction of accidental coincidences, which was observed when 12 cm of lead was introduced between the counter trays. The observed 15 coincidences per hour (which is just a little less than half the number of coincidences (C_v) recorded when the lead was removed) cannot be ascribed to single heavy particles or to Auger showers because the latter, as was mentioned above, comprise only about 20 percent of the number of vertical coincidences when the Pb was removed.

Clearly, there can be no doubt that coincidences in the presence of a 12-cm lead absorber are caused by penetrating (probably meson) showers which have been observed previously by a large number of other workers, who used the usual counters in coincidence circuits or the cloud-chamber method (Santos, Pompeia, and Wataghin; Jànossy and Rochester; Bostick[1]).

It should be especially noted, however, that in our experiments *atmospheric* showers were observed. The ap-

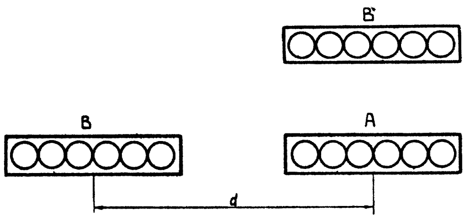

FIG. 1. Different positions of counter trays (vertical and horizontal arrangements).