paratus was located in a canvas tent and there was no dense material above the counter system. It should be especially noted that these penetrating showers which originate in the atmosphere and are composed of more than 10 particles are observed so frequently. According to our data the number of these showers is about twice the number of Auger showers from which at least ten particles pass through each of the recording counter trays. We thus have here a very important component of the atmospheric showers, the significance of which has been underestimated hitherto.

Creation in the atmosphere of showers with the properties mentioned above, irrespective of the mechanism of the phenomenon, required, evidently, the three following conditions: (1) extremely high energy primary shower producing particles (of the order of 10^{11}–10^{12} ev) as it may be expected that the mean angle of divergence of the showers particles is of the order of $\mu c^2/E$; (2) high energy (10^{10}–10^{11} ev) particles in the showers themselves as the scattering must be very small; and finally (3) a large effective cross section (of the order of the geometrical section for collisions with a nucleon) of production of penetrating showers in air; this must be the case because even if the first two conditions were fulfilled the mean free path of the shower in air counting from its point of creation to the recording apparatus cannot be large.

The method applied by us undoubtedly offers new possibilities in the study of these phenomena.

* The accidental counting rate is subtracted in each case.
** The very considerable discrepancy between the number of ionization bursts due to Auger showers and the number of bursts observed in thin-walled ionization chambers (D. Skobeltzyn, Comptes Rendus U.S.S.R. **44**, 203 (1944)) should be ascribed chiefly to very slow particles which are completely absorbed by absorbers of 0.5 g/cm² thickness, this being twice the thickness of the counter walls in our experiments.

[1] W. Bostick, Phys. Rev. **61**, 557 (1942).

Atmospheric Showers and Bursts

D. Skobeltzyn
New York, New York
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LETTERS to the Editor "Investigation of Auger Showers by the Proportional Counter Method" by Lazareva and "Penetrating Atmospheric Showers in Cosmic Rays" by Veksler and Groshev and Lazareva have been published in *The Physical Review* with a considerable delay, because of the impediment by post and other casual circumstances. The experiments they have reported were prolonged. Further information will be published. I have in mind to discuss some points concerning the said letters.

The cascade theory of Auger showers is based on the suggestion that such showers are created by a single particle, electron (or a photon), coming to the earth's atmosphere from cosmic space. Some facts, however, suggest that the electrons creating Auger showers are generated within the atmosphere. If the production of the high energy electrons takes place in a certain amount at the depth of some (5–10) "t"-units also, one may expect very essential anomalies and divergences from the usual conception.

The data now available do indeed show a number of anomalies, though it may be premature to state that the explanation of these anomalies lies in the suggestions above indicated.

I. Atmospheric showers were first discovered and explored by the coincidence method in a system of two, three, or more Geiger-Mueller counters. At the same time, big atmospheric showers can be investigated by another method, observing the bursts (*Hoffmanstosse*) in thin-walled ionization chambers. In connection with the question of anomalies previously mentioned, it is important to know if the number of "bursts" of definite magnitude per hour coincides with the number of "normal" Auger showers of corresponding size per hour.

To answer this question, one could define the expected frequency of bursts, stimulated by Auger showers, using a calculation based on the observed frequency of double or triple coincidences in the Geiger counters registering the extensive showers.

There is, however, the possibility of defining directly (without the calculation) the number of bursts of definite magnitude, stimulated by normal Auger showers, by observations with Geiger counters.

It can be shown, on general grounds, that in a system of *six* Geiger counters placed near enough one to the other, Auger showers will stimulate a number of coinciding impulses equal to the number of coinciding ionization bursts which would be registered by *two* ionization chambers placed side by side, if one could count all the bursts caused by the passage across each of these ionization chambers of *two or a greater number* of normally ionizing particles. It is assumed that the effective cross section of each chamber is equal to the axial cross section of each of the six Geiger counters (the axes of which are in a horizontal plane).

The number C_6 of sixfold coincidences stimulated by Auger showers of definite density can be calculated,[1] assuming

$$C_6 = 2\pi R^2 f \int_0^1 [1-\exp[-(r_0/r)^k]]^6 r dr.$$

On the other hand the number of coinciding impulses in two ionization chambers, under the conditions indicated above, C_2^{II} one may assume to be equal

$$C_2^{\mathrm{II}} = 2\pi R^2 f \times \int_0^1 \left[1-\exp[-(r_0/r)^k] - \left(\frac{r_0}{r}\right)^k \exp[-(r_0/r)^k]\right]^2 r dr.$$

The expressions above are valuable in as much as Poisson's law can be applied to the calculation of space fluctuations of density distribution of particles in the shower. In these equations R is the radius of the shower, f the frequency referred to unit surface of the showers specified by the parameter r_0 (at the given σ), r_0 is a parameter which depends on the cross section σ of counters (or ionization chambers) and on the density or on the energy of the shower (more exactly on the energy of the particle creating it). The parameter r_0 is defined from the condition:

$$\rho(r_0)\sigma = 1,$$

where $\rho(r)$ is the density of particles in the shower, r—the distance from the shower's axis (expressed in the parts of the radius of shower R). The exponent k is a parameter defined by the cascade theory, the magnitude of which depends in some measure on the shower's energy and the height of the observation point above the sea level.

$$\rho(r) \sim 1/r^{k\,2} \quad \text{at} \quad r<R$$
$$\text{and} \quad \rho=0^{*} \quad \text{at} \quad r>R.$$

For normal Auger showers the values of k are in the limits: $0.5<k<1$. Comparing the numerical values of the integrals in (1) and (2), assuming $k=1$ and $k=0.5$, respectively, one may see that C_6 and C_2^{II} coincide within about 25 percent at every r_0 except in the region of small r_0 ($r_0<0.25$) which is unimportant practically.

The observations with a system of six counters forming in a horizontal plane a hexagon with 130-cm radius were made at the height of 3860 m in 1944 by L. Bell (a cross on Fig. 1 of Lazareva's letter). Afterwards, Satzepin made more thorough observations at the same height (unpublished) and investigated the dependence of C_6 on σ (between $\sigma=65$ cm^2 and $\sigma=560$ cm^2). He found that within these limits $C_6 \sim \sigma^{1.5}$ and $C_6 \cong 5$ coincidences per hour at $\sigma=100$ cm^2. These results are in complete agreement with the values which can be calculated from the data by Auger,[3] Hilberry,[4] and others for the number of double and triple coincidences.

At the same time, as the dotted curve on Fig. 1 (Lazareva's letter) shows, there is a tenfold or hundred-fold discrepancy with the data taken with ionization chambers by Young and Montgomery** and with the more recent results of L. Lewis.[5] The discrepancy is much greater in chambers of small dimensions.

The same comparison made at sea level gives entirely different results. We are confronted by the following situation: the number of bursts per hour registered by a thin-walled chamber at sea level corresponds in order of magnitude with the value calculated[2] (there is a possibility still that the coincidence is casual). But at the height of 4000 m there is a hundred-fold divergence.

Thus, observing the bursts in thin-walled chambers at great altitude we have to deal not with Auger showers, but with some other agent stimulating ionization pulses of much higher frequency. Can it be that these are also atmospheric showers, but "narrow" ones? However, there is good reason for the suggestion that these bursts are stimulated by *single* heavily ionizing particles or by the nuclear showers having their origin in the walls of the chamber.[6]

II. Very striking results were obtained in the investigation of the absorption by lead of particles constituting atmospheric showers.

Results reported in the letter by Veksler, Groshev, and Lazareva have been confirmed under improved conditions by V. Veksler and L. Bell. The following improvements have been made.

1. The cylindrical proportional counters were replaced by the flat-walled ones (of rectangular cross section). 2. Instead of double coincidences triple ones were observed (two of the three proportional counters were installed one above the other, and the third one above them or at the side). In the observations of triple coincidences, the influence of chance coincidences and contamination connected with the fluctuations of the ionizing power of mesons traversing two counters one above the other was completely excluded. 3. In the observations with the lead, the counter was carefully screened from the sides.

We shall call "penetrating" a shower observed under the condition that the registering counters are separated by 10–12 cm of lead. The lead may be placed between the two counters installed one over the other, while the third counter is at the side. From the experimental data one may conclude that under certain conditions the *frequency of penetrating showers* of a given density of particles *is equal or even higher than the frequency of normal Auger showers of the same density.* We speak here of the densities of the same order of magnitude that have the "effective" densities of Auger showers, stimulating coincidences in a system of conventional Geiger counters (that is $\rho \simeq 100$ m^{-2}).

Observations on the absorption by lead with conventional Geiger counters (Satzepin) have given results in complete agreement with the results obtained by the proportional counter method. We can speak of a peculiar, very important, penetrating component of atmospheric showers. The data obtained do not, however, exclude the possibility that the penetrating showers are genetically connected with Auger showers. It would be premature also to suggest that from the results of the observations one has to make inevitably the conclusion of the existence of showers of great density consisting of penetrating particles, for instance, of mesons.

Analyzing the results of the experiments on the absorption of atmospheric showers by lead, one must conclude that a very sharp anomaly exists. It is necessary, however, to investigate whether this anomaly is not related to some process involved in the penetration of the shower through the lead. If we were speaking of normal Auger showers we would have to exclude this possibility entirely. But, if ultra-high energy (10^{13}–10^{14} ev) electrons are generated in appreciable amount in the atmosphere, in addition to the normal ones, there could exist a considerable number of "young" showers much richer in high energy (10^{10}–10^{11} ev) particles.

Further investigations must show us whether the anomaly of penetrating power of atmospheric showers is not connected with the presence of unusually large numbers of electrons (or photons) of indicated energies in the soft component. Such a suggestion, presumably, cannot be excluded *a priori*. The number of such electrons could be very insignificant as compared with the total number of particles, and yet they could affect appreciably the intensity of the soft non-equilibrium component at sea level.

* It is certainly permitted to suppose this for the following calculation.
** Here, as in Lazareva's work, we mean simultaneous bursts in two ionization chambers. The difference between the results in such double and in an ordinary chamber may be the result of fluctuations. However, at large registered bursts (more than 10 particles) as in Young and Montgomery's experiments, fluctuations cannot be of importance.

[1] D. V. Skobeltzyn, Comptes Rendus U.S.S.R. 37, 52 (1942) and 41, 57 (1943).
[2] D. V. Skobeltzyn, Comptes Rendus U.S.S.R. 44, 142 (1944).
[3] P. Auger, J. de Physique 6, 17 (1945).
[4] N. Hilberry, Phys. Rev. 60, 1 (1941).
[5] L. Lewis, Phys. Rev. 67, 228 (1945).
[6] D. V. Skobeltzyn, Comptes Rendus U.S.S.R. 44, 186 (1944).