Absorption of Extensive Atmospheric Showers of Cosmic Rays in Air and Lead

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THE intensity and barometric coefficient of the large atmospheric cosmic-ray showers have been measured. These showers, referred to as "*A* showers" in this paper, were defined by double coincidences of two horizontal counters separated by either 3 meters or by 13 meters. Measurements were made at sea level and at 2900 m altitude.

1. BAROMETRIC COEFFICIENT AT SEA LEVEL

Four series of measurements were made at sea level under a thin aluminum roof. The counters were unshielded and had a separation of 3 meters. The duration of the experiment was eight months, and included 35,000 coincidences. Series 1 and 2 were made with counters of different cross sections, and readings were extended over different periods, so that recalculations had to be made in order to facilitate the comparison of these results with those of series 3 and 4. The latter series were made with counters of 200 cm² surface area, and results were recorded every hour.

The mean number of double coincidences per hour for different values of the pressure (the choice of which was made after close examination of the barometer curve) have been plotted on the Fig. 1 against the pressure. The statistical probable error is indicated by a vertical line as usual. The straight lines have been calculated in such a way that the sum of the squares of the distances to the experimental points is minimum, the unit being in each case the probable error. No temperature corrections were made, because the relations between barometric and thermometric variations are opposite in winter and in summer, hence compensation is automatically introduced when measurements cover both of these periods.

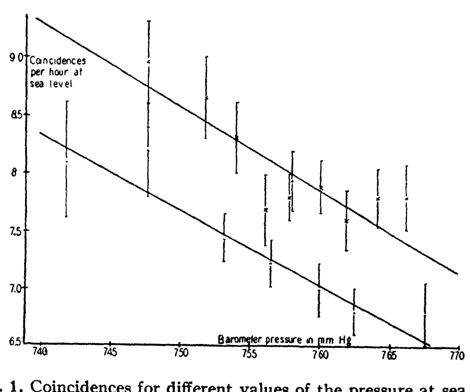

FIG. 1. Coincidences for different values of the pressure at sea level. Counter separations, 3 meters. Counters of two different cross sections were used.

From these data the total barometric coefficient of *A* showers can be deduced: a decrease of 1 cm Hg in the atmospheric pressure gives rise to an increase of 9 percent in the number of showers. The probable error can be estimated at ±1 percent; such a change in the coefficient would bring an increase of 10 percent in the sum of square distances. The mass absorption coefficient μ/ρ for air resulting from these measurements is equal to 0.0068 ± 0.0007 in cm² per gram.

2. INFLUENCE OF THE EXTENSION OF SHOWERS

In another series of measurements a comparison was made between the *A* showers of 3-m and 13-m extension with unshielded counters. The method was exactly the same, and the results are shown in Fig. 2. The straight lines which best represent the experimental points have different slopes. The coefficients are equal to 23 percent±5 percent for the 13-m extension showers, and 11 percent±2 percent for the 3-m

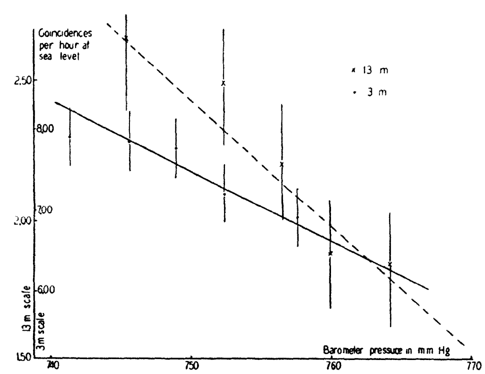

FIG. 2. Coincidences in counters 13 meters and 3 meters apart at sea level.

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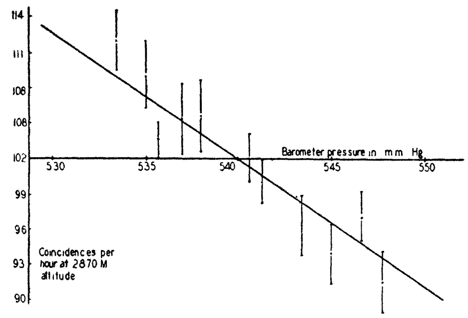

FIG. 3. Coincidences at 2870 meters in counters separated 2 meters.

extension showers (percentage variation per centimeter Hg pressure change.) The striking difference between the two coefficients is in agreement with the results published by Cosyns.[1] It suggests a difference in origin between the narrow local air showers which are mixed with portions of true A showers in the 3-m measurements, and these A showers themselves. The local air showers are probably due to decay electrons and knock-on electrons coming from mesons of high energies.

3. MEASUREMENTS IN HIGH ALTITUDE

Preliminary results of measurements of the barometric effect at 2900-m altitude (Observatoire du Pic du Midi, France) have already been published.[2] These results, were obtained with a set of two unshielded counters at two meters separation. A thorough recalculation of the data has been made in order to permit a comparison with the sea-level measurements. Because of slightly different conditions the data are separated into four series. The two best series give a coefficient equal to 11 percent$\pm$1 percent. The two other series, less reliable, lead to 10 percent and 15 percent, respectively, with probable errors of ± 3 percent. The adopted value, 11 percent, corresponds to a mass absorption coefficient μ/ρ equal to 0.008 ± 0.0008 cm^2 g^{-1}, not noticeably different from the value obtained at sea level (Fig. 3).

Comparison of the absolute number of counts per hour at sea level and at 2900-m altitude gives another value of the absorption coefficient in air. The precision is small, unfortunately, because of the difficulty in obtaining exactly comparable measurements at two distant laboratories. The computed value for A showers of 3-m extension is $\mu/\rho = 0.007$ cm^2 g^{-1} in good agreement with the barometric effects at both stations.

4. ABSORPTION IN LEAD AND IN AIR

It seems difficult to bring the present results into a satisfactory agreement with those obtained in the study of the absorption of the A showers in lead, in terms of the cascade theory only. It has been shown[3] that in high altitude, as well as at sea level, a shield of 10 cm lead on one of the counters of a double coincidence set of 3-m distance causes a decrease of about 85 percent in the number of counts. The protection of the second counter with the same shield brings an additional reduction of the same order. Now this would mean, in the cascade theory, that a considerable fraction of the electrons in an A shower have energies higher than 10^{10} ev. Consequently these showers should be "young," i.e., near their maximum development. This conclusion is again difficult to reconcile with the large absorption and barometric coefficients which are only to be expected from "old" showers, definitely on their decrease, and therefore constituted principally of electrons around the critical energy for air, 10^8 ev.

Another difficulty arises from the fact that in the cascades the tracks of two electrons of high energy are never separated by large distances. Even in air two 10^{11} ev electrons have a very small probability of being found as far apart from one another as one meter, so that the coincidences between two counters shielded by 10 cm lead and separated by 3 m could scarcely be explained by this theory. Also the high counting rate with one counter shielded is difficult to account for, if the cores of the A showers (parts of the showers where the high energy electrons are contained) have a cross section of less than one square meter.

These considerations show that the ordinary cascade theory would have to be modified for particles of very high energy in order to explain the properties of A showers. The modifications would probably involve the production of mesons.

[1] Max Cosyns, Nature **145**, 668 (1940).
[2] Auger, Robley, and Pluvinage, Comptes rendus **209**, 536 (1939).
[3] Auger, Maze, and Grivet-Meyer, Comptes rendus **206**, 1721 (1938).