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Cloud Chamber Photographs of Counter Selected Cosmic-Ray Showers

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A detailed discussion is given of the appearance of cosmic-ray showers from a lead plate 1.3 cm thick in a large cloud chamber controlled by three G–M counters, one above and two below the chamber. Showers of photons were responsible for about half the triple coincident counts, but sprays of electrons from the lead accounted for the tripping of the lower counters in most of the other cases. Three-quarters of the single-centered electron shower sprays were due to electrons which traversed the upper counter and struck the lead from above. The remainder were due to nonionizing rays, presumably photons. Twenty-three photographs out of a total of a hundred seventy-four showed complex phenomena. The distributions of the showers according to size and the shower electrons according to angular spread are given.

WE have described in the form of a letter[1] some preliminary observations on the appearance of cosmic-ray showers obtained with an arrangement of counters and cloud chamber (Fig. 1) particularly selective to electron produced groups. A detailed description of the apparatus will appear in a separate publication. Here we summarize the results of a more extended study of the showers and related effects.

TYPES OF SHOWERS

The average coincidence counting rate with the arrangement of Fig. 1 was 0.162 count per min. making the average wait for a photograph about six minutes. 174 successful photographs were taken. In 94 of these the tripping of the lower counting units could be attributed to shower electrons from the lead. The remaining 80 (46 percent of the total) showed no electron showers below the lead. In 49 (27 percent) of the photographs not more than one straight electron track per picture was visible in the lower

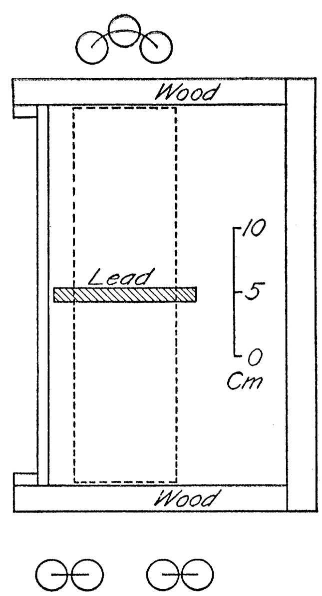

FIG. 1. Geometrical arrangement of counting tubes, cloud chamber and lead scattering block. The lead sheet is 34 cm long and 1.3 cm thick. The counters have a sensitive length of about 19 cm. Above the chamber are three tubes connected in parallel to form one unit, and below are two units, each with two tubes in parallel. A triple coincidence of the three units sets off the expansion.

[1] Stevenson and Street, Phys. Rev. **48**, 464 (1935).

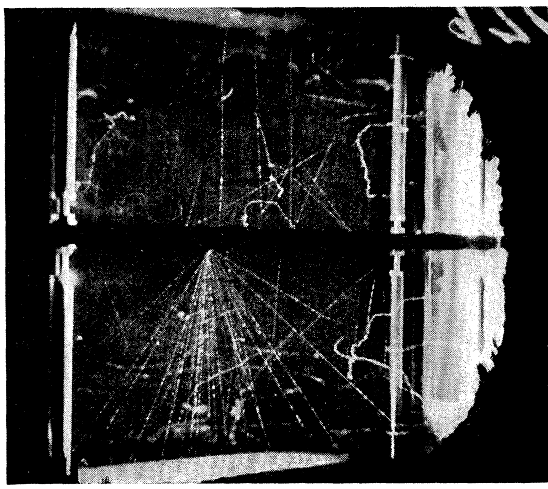

FIG. 2. A shower of 22 rays produced by an electron. The slight displacement of the ray above the lead is due to an irregularity in the expansion, a fact which has been verified by stereoscopic photographs of straight rays.

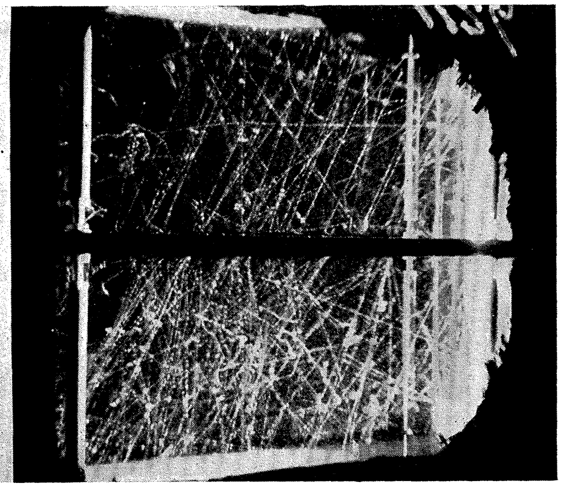

FIG. 3. The most complex shower phenomenon photographed. Several shower centers in the lead are evident.

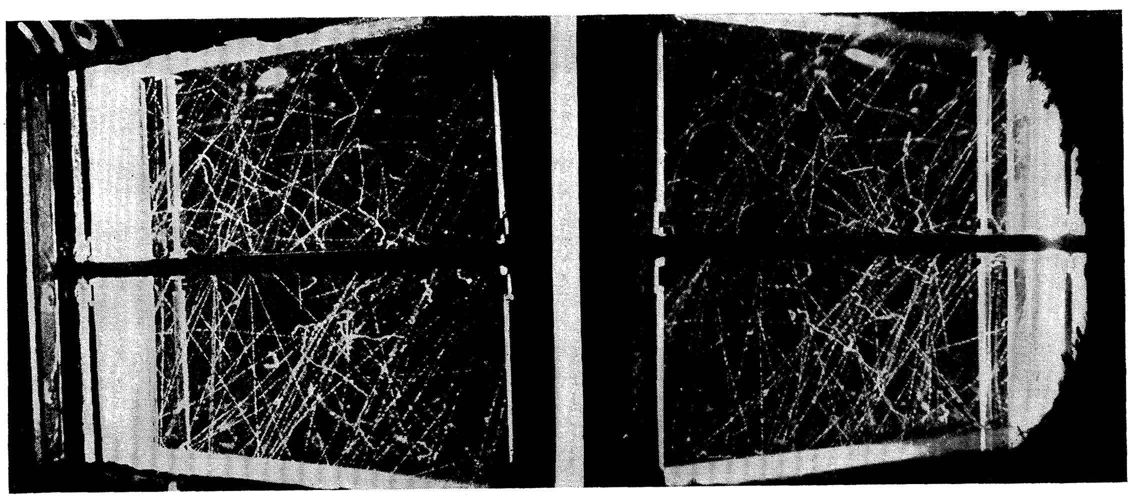

FIG. 4. A stereoscopic pair (each at 30° with the normal) showing another case of many associated rays incident from above.

section of the chamber. The tripping of the lower counters in such cases is probably due to electrons ejected from the walls of the counters by photon showers. In 14 of these cases an electron incident on the lead from above was either stopped or sharply deflected with the possible production of photons.

Of the 94 photographs showing electron sprays from the lead there were 71 with single shower centers, 17 with 2, and 3 with 3 centers. The 3 remaining photographs were of large bursts with many rays entering the chamber from above and an undetermined number of "secondary" showers produced in the lead. Figs. 2, 3, and 4 illustrate certain interesting types. (See earlier letter for other illustrations.) The 71 single showers may be further classified into three groups; 48 produced by electrons, 17 by some nonionizing raidation which is assumed to be of photon character throughout this paper, and 6 whose centers fall outside the lighted area of the lead. The 17 double-center showers consist of 6 due to 2 electrons, 1 due to 2 photons, 7 due to 1 electron and 1 photon, and 3 with one of the

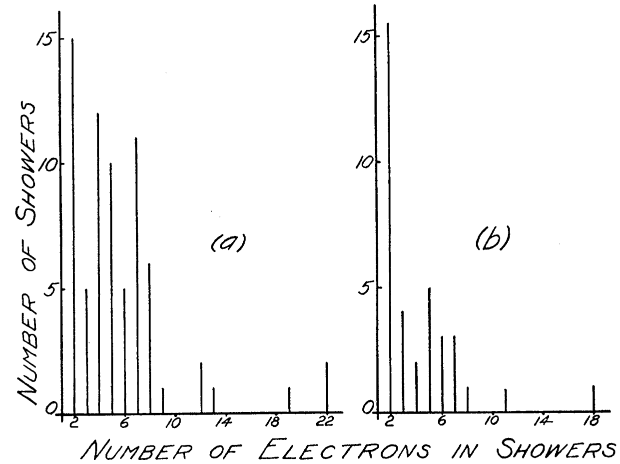

FIG. 5. Frequency distribution of observed showers; (a) electron produced, (b) photon produced.

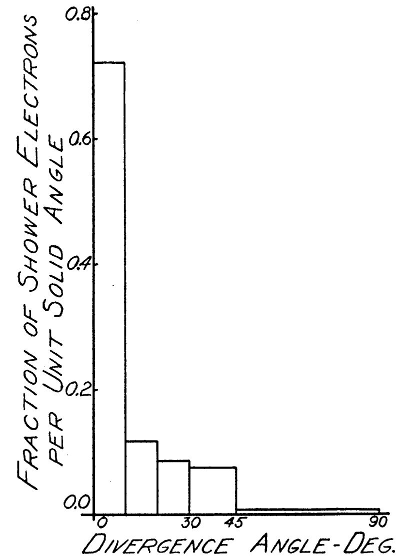

FIG. 6. Distribution of shower electrons about the direction of the incident electron.

centers out of view. The three triple-shower groups are particularly interesting, for in each case two electrons enter on almost parallel paths and each produces a shower in the lead. All show an additional photon produced shower. A photograph of such a triple group was reproduced in the earlier letter.[1]

The mechanism of discharge of the upper counter in those cases where no electron entered the top of the cloud chamber is not evident from our data. There were 22 such cases. Possibly soft secondaries were produced by photons in the walls of the top counter. The latter may have been incident from above or due to back scattering from the lead. The assumption of a soft electron with too low energy to penetrate the top of the chamber is an alternative explanation. Back scattering of electrons was not an appreciable factor, although five pairs were observed traveling up from the lead. Three of these occurred in one photograph (Fig. 2).

Chance of the Production of a Shower by an Electron

A consideration of the multiple showers leads to an estimate of the probability of production of a shower by an electron. On the photographs showing one or more showers we find 72 electron tracks, in addition to one shower producing element per picture, which either traverse or terminate in the lead within the field of view. If the average chance of production of a shower by one of these electrons is P the number of additional showers expected from them would be $72P$. Actually 17 of the 72 electrons in question gave rise to showers. Thus $P \sim 0.24$. In this rough calculation no account has been taken of the enhanced probability of recording a multiple shower. This correction should not reduce P to a value less than 0.08 since in at least one-third of the multiple shower cases any one of the individual showers would have been recorded. Anderson *et al.*,[2] however, found that the total shower phenomena from a thousand single electrons passing through a cm of lead consisted of but two pairs. Thus the electrons we observe which are associated with a shower-producing radiation must have a much greater chance of producing showers than electrons taken at random in the cosmic radiation.

The Shower Electrons

The size distribution plots of the observed showers are given in Fig. 5. The true distribution can be obtained by correcting for the differential selectivity of the counter arrangement for various

[2] Anderson, Millikan, Neddermeyer and Pickering, Phys. Rev. **45**, 352 (1934).

sized showers. This calculation for the present arrangement is extremely difficult and we have found no satisfactory way to obtain it.

The angular distribution of the shower electrons about the directions of the incident particles for the electron produced showers has been determined and is given in Table I. When the data are transformed to express the relative numbers of secondaries per unit solid angle, the plot of Fig. 6 results. A comparison of the angular distributions for large and small showers was made by dividing the showers into two groups, those of more than and those of less than seven particles. This choice placed approximately the same number of shower electrons in each group. Within the expected statistical fluctuations the distributions were the same.

TABLE I. *Number of shower electrons in the angular range.*

0–10°	10–20	20–30	30–45	45–90	> 90
113	56	65	123	64	1

Some Further Consideration of the Processes Involved in Shower Phenomena

The above data show clearly the important role played by photon sprays in the shower phenomena. In more than half of the photographs the explanation of the tripping of one or more of the counters required the assumption of such photon sprays. Since a gamma-ray photon traversing a counter has a chance of about 0.01 of exciting it, large numbers of photons must be involved. This is in agreement with the conclusions of Geiger[3] and his co-workers from counter observations. However, since a considerable fraction of the coincidences observed with the arrangement of Fig. 1 could be explained on the basis of the direct action of electrons alone, the influence of this mechanism should not be overlooked in interpreting counter studies of showers.

From our data nothing can be said concerning the mechanism by which an electron gives rise to shower electrons. The incident electron may actually produce one or more photons which in turn eject the shower particles.

[3] Geiger and Zeiler, Zeits. f. Physik **97**, 300 (1935); Geiger, Erg. exakt. Naturwiss. **14**, 42 (1935).

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Contact Potential Measurements on Tungsten Filaments

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Changes in contact potential of the surface of a tungsten filament have been measured by using a tube containing two filaments. Changes were produced by varying the amount of thorium on the surface, and by varying the temperature. (a) *Changes produced by activation.* When electron emission (i) with very low accelerating fields is compared with the contact potential (V) measured on the same surface and at the same temperature, the theoretical law $dlni/dV=e/KT$ is obeyed. If emission under influence of higher fields, or contact potential at temperatures different from that of emission are used for comparison agreement does not exist. (b) *Changes produced by temperature variations.* Both activated and deactivated thoriated tungsten surfaces showed an increasingly negative contact potential (increasing work function) with rising temperature, the activated surface having the larger rate of change. The difference between the temperature coefficients of the activated and deactivated surfaces observed was 3.3×10^{-4} volt/deg. A relatively large anomalous effect observed at temperatures below the emission range is ascribed to a reversible gas reaction. Pure tungsten seems to show a temperature coefficient of opposite sign, indicating a decreasing work function with rising temperature.

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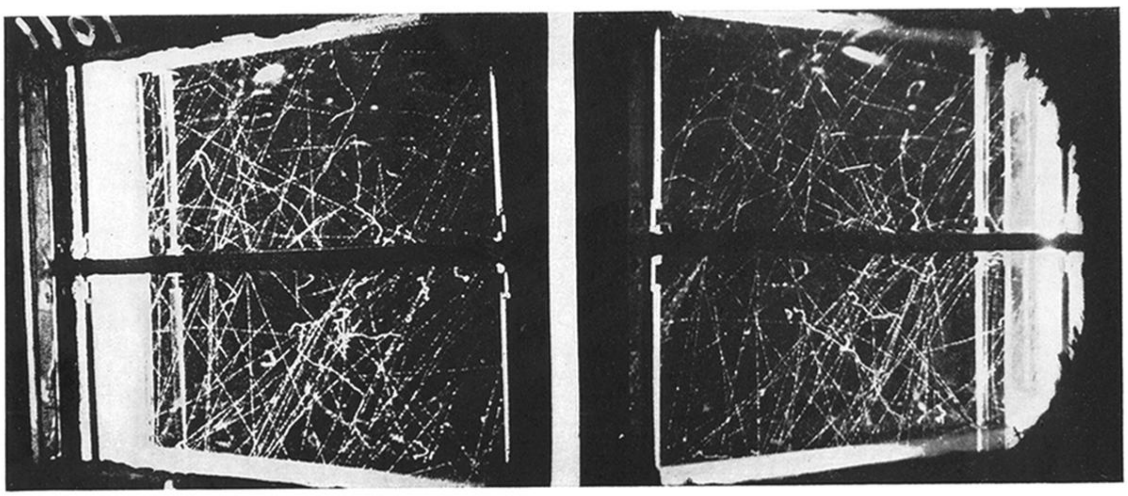

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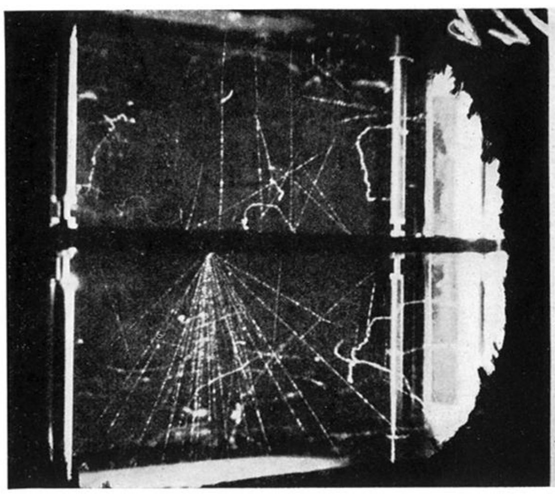

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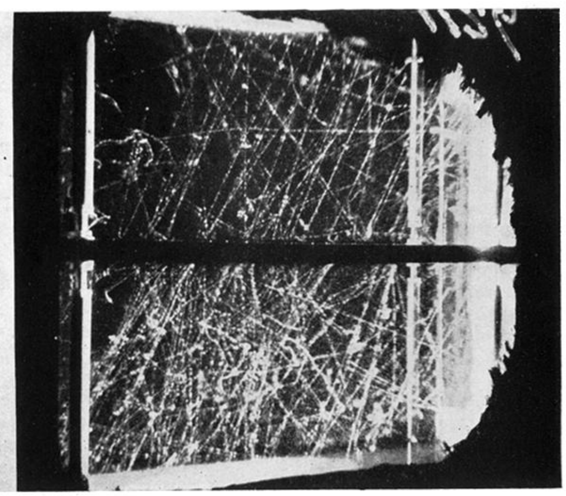

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