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On the Production of Secondary Ionizing Particles by Non-Ionizing Agents in Cosmic Radiation

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Previous experiments have shown that the number of coincidences recorded with a vertical counter arrangement is a few percent larger when some absorber is placed above the counters than with the same absorber between them. The effect is also present when the experimental conditions are such as to exclude the possibility of its being due to shower-production by photons. It had been, therefore, ascribed either to penetrating non-ionizing particles (neutrons, neutrettos) producing ionizing secondary rays, or to ordinary photons producing penetrating secondary particles (mesotrons). The present experiments show that a minor part, if any, of the observed influence of the position of the absorber can be due to the above processes. The major part of it arises from the interference of already known phenomena like scattering, knock-on showers, showers from the air, etc. This conclusion refers only to experiments performed near sea level.

I. INTRODUCTION

SEVERAL authors[1–6] have investigated the production of secondary particles by the non-ionizing component of cosmic rays with counter arrangements, which are, in principle, similar to those represented in Fig. 1. Two or more counters were placed vertically one above the other and the coincidences were recorded with an absorber s either above the whole system of counters (position s_1) or between the counters (position s_2). The counting rate was generally found to be larger in the former than in the latter position. This is what one would expect if ionizing particles were produced in s by non-ionizing agents.

When the absorber s has a comparatively small thickness and no other absorbers are present between the counters, the effect can easily be accounted for by cascade showers produced by photons. When, however, the absorber is thick enough to absorb the soft component of cosmic rays completely, the above interpretation is inadequate and, if the effect is to be accounted for by non-ionizing rays producing ionizing particles in the absorber, one must assume that either (a) the primary ionizing rays are more penetrating than photons (neutrons, "neutrettos,"[7] or (b) the secondary ionizing particles are more penetrating than electrons (mesotrons). If, finally, a difference is found by changing absorber s from s_1 to s_2, with an additional thick absorber S permanently between

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1 B. Rossi, Zeits. f. Physik **68**, 64 (1931).
2 D. S. Hsiung, Phys. Rev. **46**, 653 (1934).
3 H. Maass, Ann. d. Physik **27**, 507 (1936).
4 M. Schein and V. C. Wilson, Phys. Rev. **54**, 304 (1939).
5 F. R. Shonka, Phys. Rev. **55**, 24 (1939).
6 M. Schein, W. P. Jesse and E. O. Wollan, Phys. Rev. **57**, 847 (1940).

7 The possibility that "neutrettos," or neutral mesotrons, may be present in the cosmic radiation was first mentioned by N. Arley and W. Heitler [Nature **142**, 158 (1938)]. See also reference 5.

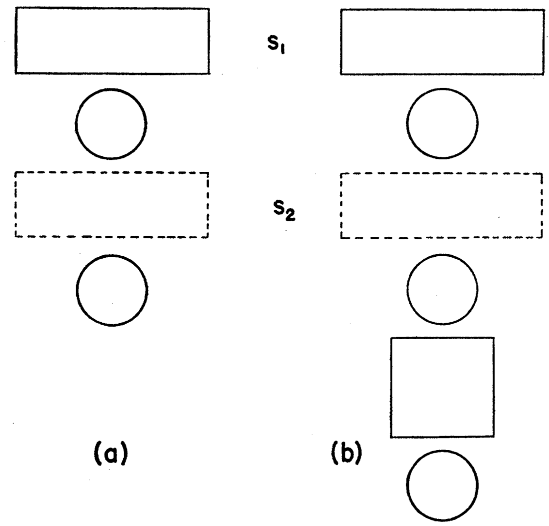

FIG. 1. Schematic arrangement of counters and absorbers for investigating the production of ionizing particles by non-ionizing rays.

the counters (see Fig. 1(b)), only hypothesis (b) is apparently left as a possible explanation.

As a matter of fact, the production of mesotrons by non-ionizing rays is the most likely interpretation of the large effects recently found by Schein and Wilson and by Schein, Jesse and Wollan in the high atmosphere with an arrangement similar to that represented in Fig. 1(b).[4, 6] As for the much smaller differences found near sea level, however, the possibility cannot be ruled out that some spurious effects might have played an important role. We think especially of the following phenomena which have not always been taken adequately into consideration.

(c) *Knock-on showers.*—These contribute a number of extra counts, which is larger when *s* is in the upper than when it is in the lower position. This effect is likely to have influenced, for instance, the results of Rossi's experiments.[1]

(d) *Scattering.*—When the absorber is in the lower position an appreciable number of mesotrons may be removed from the beam by scattering. The scattering is much less effective when the absorber is above the counters for, in this case, the number of particles scattered out of the beam is approximately equal to the number of those scattered in. The effect of scattering depends largely upon the geometrical conditions and may have been quite appreciable, for instance, in the experiments of Maass.[3]

(e) *Side showers.*—Showers coming from the side, i.e., from the air or from whatever dense material may be present near the counters, give rise to coincidences, the number of which is likely to depend upon the position of *s*.

The purpose of the experiments described in the present paper is to determine whether the production of ionizing particles by non-ionizing rays (hypotheses (a) or (b)), or some more obvious effects (hypotheses (c), (d) or (e)) are responsible for the influence of the position of the absorber on the counting rate of a vertical counter arrangement near sea level.

II. EXPERIMENTAL ARRANGEMENTS

Part of the experiments were carried out with a set of nine Geiger-Müller counters, arranged as represented in Fig. 2. The five counters *A* and, similarly, the two counters *D* were connected in parallel. Counters *A* covered the full solid angle subtended by counters *B*, *C*, and *D*. Fourfold coincidences (*ABCD*) and threefold coincidences (*BCD*) were recorded simultaneously. Threefold coincidences (*BCD*) not accompanied by fourfold coincidences (*ABCD*) will be called *anticoincidences* ($BCD-A$). The arrangement is similar to that used by Jánossy and Rossi for investigating the photon component of cosmic rays.[8]

Some experiments were also performed with the arrangement represented in Fig. 3. The six counters *A* were connected in parallel and covered the whole solid angle subtended by counters *B*, *C* and *D*. The lead absorber Σ above the counters was 5.3 cm thick. The cloud chamber *Ch* was operated by anticoincidences ($BCD-A$), i.e., an expansion took place whenever a coinci-

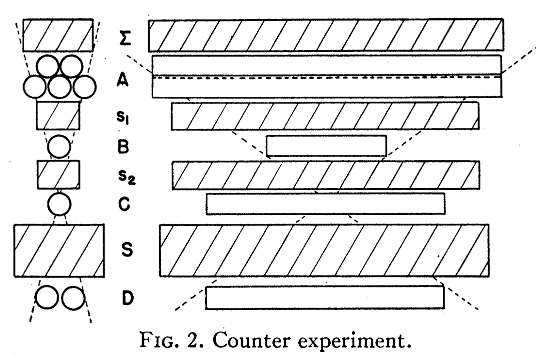

FIG. 2. Counter experiment.

[8] L. Jánossy and B. Rossi, Proc. Roy. Soc. **175**, 88 (1940).

dence (BCD) occurred, which was not accompanied by a discharge in one of the counters A.

The anticoincidences were selected with the circuit represented in Fig. 4. The positive pulses from the output of an ordinary coincidence circuit connected with counters B, C and D set off the discharges of the thyratron T_1, while the pulses from a single stage amplifier connected with the counter battery A set off the discharges of the thyratron T_2. The pulses arising from the discharges of the thyratrons were transformed by the successive stages, as schematically represented in Fig. 5. Since the grid of V_2 was normally kept at a negative potential, a discharge of T_1 not accompanied by a discharge of T_2 gave rise to a positive pulse at the output of the anticoincidence circuit. When, however, T_1 and T_2 were discharged simultaneously, V_2 became conducting *before* the negative pulse from T_1 reached the grid of V_1', and resumed its initial nonconducting condition when this pulse was already over. Thus, the coincidence pulse could not be transmitted to the output.

The efficiency of the counter battery A was shown by control experiments to be greater than 99 percent in both arrangements. The anticoindidence circuit itself had 100 percent efficiency.

III. Search for Penetrating Particles Produced by Non-Ionizing Rays

In order to investigate whether penetrating ionizing particles are produced by non-ionizing

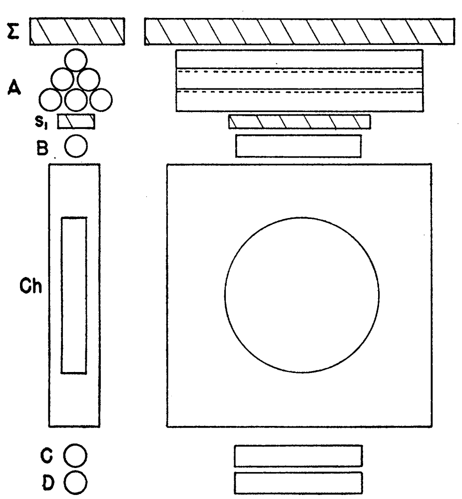

Fig. 3. Cloud-chamber experiment.

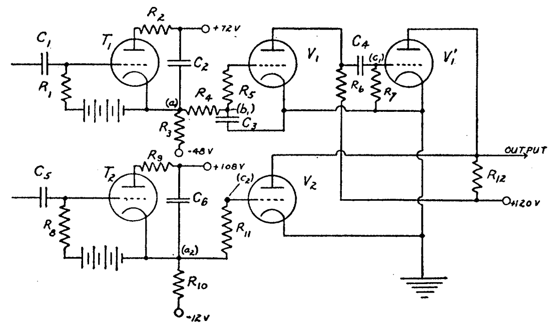

Fig. 4. Anticoincidence circuit. $R_1=R_8=0.2\text{M}\Omega$; $R_2=R_9=200\Omega$; $R_3=R_{10}=0.1\text{M}\Omega$; $R_4=1\text{M}\Omega$; $R_5=R_{11}=2\text{M}\Omega$; $R_6=R_7=2\text{M}\Omega$; $R_{12}=1\text{M}\Omega$; $C_1=C_5=0.0001\mu\text{f}$; $C_2=C_6=0.005\mu\text{f}$; $C_3=0.0005\mu\text{f}$; $C_4=0.01\mu\text{f}$.

rays (hypothesis (b)) measurements were taken with the counter arrangement represented in Fig. 2. A lead absorber 10 cm thick was permanently placed between C and D (position S), while a lead screen s, 5 cm thick, was placed alternately above counter B (position s_1) or between counters B and C (position s_2). No absorber was present above the counter battery A. Since 10 cm of lead are sufficient to stop the electron component of cosmic rays, a threefold coincidence (BCD) could only be produced by a penetrating particle. The experimental results are collected in Table I.

Considering first the threefold coincidences (BCD) alone, it appears that their number is 1.6 ± 0.5 percent larger with the lead in s_1 than with the lead in s_2. This difference is of the same order of magnitude as that found by other authors under similar conditions, and could be interpreted as due to non-ionizing rays, like photons, producing in s penetrating ionizing particles like mesotrons. According to this assumption, however, the same difference which is found for the number of coincidences (BCD) should also be expected for the number of anticoincidences ($BCD-A$). On the contrary, the increase of anticoincidences ($BCD-A$) when the lead is moved from s_2 to s_1 is 8 times smaller than the increase of coincidences (BCD). We conclude that only a minor part, if any, of the 1.6 percent effect for threefold coincidences can be accounted for by the production of penetrating ionizing particles in the absorber s. The major part of it must be due to some disturbing phenomena like those described under (c), (d) and (e). For instance, with the lead in s_1, a

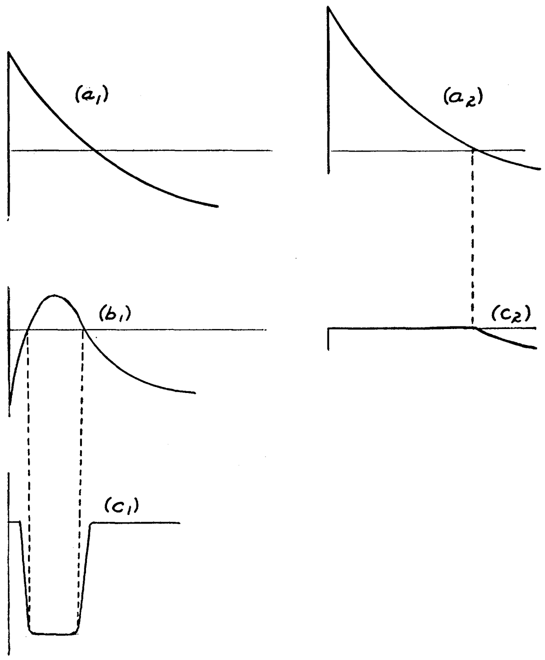

FIG. 5. Shape of the pulses at different points of the anticoincidence circuit Fig. 4.

mesotron traversing C, D and missing B can still give rise to a coincidence (BCD) by producing in s_1 a "knock-on" shower which discharges B. This, of course, cannot happen when the lead is in s_2. The effect of "knock-on" showers does not show when only anticoincidences ($BCD-A$) are recorded, because every particle going through the absorber s_1 and one of the counters D must also traverse one of the anticoincidence counters A.

TABLE I. *Arrangement Fig. 2.* $S=10$ *cm* Pb, $\Sigma=0$ (*s_1 and s_2 are in cm* Pb. *The errors are the standard statistical deviations*).

	TOTAL COUNTS		COUNTS PER HOUR		(a) − (b)	
	(a) $s_1=5$ $s_2=0$	(b) $s_1=0$ $s_2=5$	(a) $s_1=5$ $s_2=0$	(b) $s_1=0$ $s_2=5$	C. PER HOUR	% OF (BCD)
Coincidences (BCD)	87029	79359	328.8 ±1.1	323.5 ±1.2	5.3 ±1.6	1.6 ±0.5
Anticoincidences ($BCD-A$)	963	730	3.64 ±0.12	2.97 ±0.11	0.67 ±0.16	0.20 ±0.05

IV. SEARCH FOR IONIZING PARTICLES PRODUCED BY PENETRATING NON-IONIZING RAYS

The experiments referred to in the foregoing section show that no appreciable number of *penetrating* ionizing particles are generated by non-ionizing rays at sea level. In order to investigate whether *soft* ionizing particles (electrons) are generated by *penetrating* non-ionizing rays (hypothesis (a)), the counter arrangement represented in Fig. 2 was used again, with the only change that the absorber S was removed and a 5-cm thick lead absorber was placed above the counter battery A (position Σ). Under these conditions, photons coming from above cannot produce anticoincidences, since they have a negligibly small probability of traversing Σ without starting a shower which discharges A.[8] A penetrating non-ionizing agent, however, is likely to traverse Σ without encounter, and it can then give rise to an anticoincidence by producing a secondary ionizing particle in s_1.

Measurements were performed (a) with 5 cm of lead in s_1 and nothing in s_2, (b) with 5 cm of lead in s_2 and nothing in s_1, and (c) with no lead either in s_1 or in s_2. The experimental results are given in Table II.

The differences in the number of coincidences (BCD) are not very significant. The anticoincidences ($BCD-A$), however, are distinctly more frequent with the lead in s_1 than with the lead in s_2 or even than with no lead at all. This result is in agreement with hypothesis (a), but

TABLE II. *Arrangement Fig. 2.* $S=0$, $\Sigma=5$ *cm* Pb (*s_1 and s_2 are in cm* Pb. *The errors are the standard statistical deviations*).

	TOTAL COUNTS			COUNTS PER HOUR			(a) − (b)		(a) − (c)	
	(a) $s_1=5$ $s_2=0$	(b) $s_1=0$ $s_2=5$	(c) $s_1=0$ $s_2=0$	(a) $s_1=5$ $s_2=0$	(b) $s_1=0$ $s_2=5$	(c) $s_1=0$ $s_2=0$	C. PER HOUR	% OF (BCD)	C. PER HOUR	% OF (BCD)
Coincidences (BCD)	32110	28049	37681	350 ±2	347 ±2	366 ±2	3 ±2.8	0.86 ±0.80	−16 ±2.8	−4.6 ±0.8
Anticoincidences ($BCD-A$)	620	316	587	6.75 ±0.27	3.90 ±0.22	5.70 ±0.25	2.85 ±0.35	0.8 ±0.1	1.05 ±0.37	0.3 ±0.1

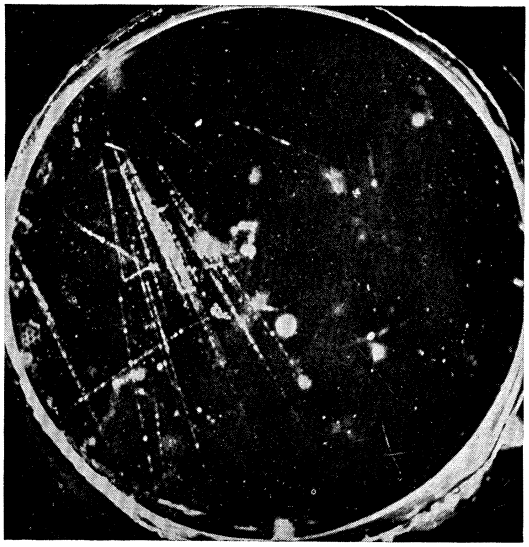

FIG. 6. Shower from the lead.

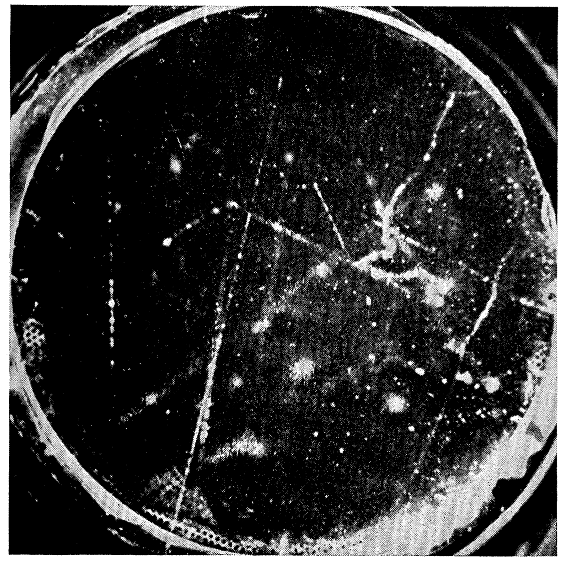

FIG. 7. Single particle accompanied by side shower.

could also be explained by the interference of some spurious effect.

In order to have some more definite information as to the origin of the observed differences, the arrangement represented in Fig. 3 was used. First, as a preliminary experiment, anticoincidences $(BCD-A)$ were recorded with and without a 1.5-cm thick lead absorber above counter B (position s_1). The results are given in Table III. In agreement with the previous results, the presence of the lead absorber between A and B was found to increase the number of anticoincidences. In the main experiment the anticoincidences $(BCD-A)$ were made to operate the cloud chamber *Ch*. A survey of the stereoscopic photographs obtained showed the results summarized in Table IV. The photographs are grouped under three main headings, namely, "blanks," i.e., no tracks due to cosmic-ray particles, "singles," i.e., one particle through B, C and D, and "showers," i.e., several associated particles. The "showers" are further subdivided into "showers from the lead," i.e., showers radiating from s_1, see Fig. 6, and "side showers," i.e., several particles crossing the chamber, presumably due to showers originating in the back of the cloud chamber, in the air, or in the walls of the building. Occasionally "side showers" occur with "singles" as shown in Fig. 7.

The "blanks" are equally frequent with and without the lead screen in s_1, and are mainly to be accounted for by chance coincidences between counters B, C and D. More than half of the remaining pictures exhibit showers coming from the side. All of these pictures and, possibly, some of the "blanks" are due to anticoincidences produced by side showers which discharge counters B, C and D without striking the counter battery A. The probability of such an

TABLE III. *Arrangement Fig. 3.* $\Sigma = 5.3$ *cm* Pb (s_1 *is in cm* Pb; *the errors are the standard statistical deviations*).

	Total counts		Counts per hour		
	(a) $s_1=1.5$	(c) $s_1=0$	(a) $s_1=1.5$	(c) $s_1=0$	(a) − (c)
Anticoincidences $(BCD-A)$	151	82	0.70 ±0.06	0.35 ±0.04	0.35 ±0.07

TABLE IV. *Arrangement Fig. 3.* $\Sigma = 5.3$ *cm* Pb. *Cloud chamber operated by the anticoincidences* $(BCD-A)$. *For easier comparison of the data obtained with* $s_1=0$ *and* $s_1=1.5$ *cm* Pb, *the numbers of the events recorded in the first condition have been reduced to account for the difference in the time of observation (numbers in parenthesis).*

Abs. cm Pb	Time (hr.)	Photographs	Blanks	Singles	Showers Side	Showers Pb	Showers Total
$s_1=0$	136.15	58 (54)	29 (27)	8 (7.5)	21 (20)	0	21 (20)
$s_1=1.5$	127.42	89	29	19	30	11	41

event is apparently increased by the lead in s_1, since anticoincidences accompanied by side showers are more frequent with than without lead. This can be explained by the multiplication of shower particles in the lead.

Most of the "singles" observed without lead are probably due to a small lack of efficiency of the counter battery A. The "singles" obtained with lead in s_1 are more frequent than without lead, so that only part of them may be accounted for by lack of efficiency. The rest of the "singles" under lead and the "showers from the lead" are apparently due to secondary effects produced in the lead either by penetrating non-ionizing rays traversing the absorber Σ without encounter, or by photons missing the absorber Σ, or by electrons missing both the absorber Σ and the counter battery A. There is little doubt that the "singles" accompanied by side showers (see Fig. 7) are the result of secondary effects of electrons or photons. This is likely to be the case also for the remainder of the pictures, so that we do not find in our photographs any conclusive evidence for the existence of penetrating non-ionizing particles in the cosmic radiation. Furthermore these photographs show that most of the anticoincidences are due to spurious effects, especially to showers coming from the side.

The present experiments were initiated in the spring of 1939 in the Physical Laboratory of the University of Manchester, England, and were completed after the departure of the first-named author (B. R.) during the summer of the same year. The publication has been delayed by the recent European events. The writers express their appreciation to Professor P. M. S. Blackett for the facilities made available and for helpful discussions of the problem. One of us (B. R.) acknowledges with thanks the financial support granted to him by the Society for the Protection of Science and Learning.

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The Mean Lifetime of the Mesotron from Electroscope Data

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In order to eliminate some experimental difficulties found in detecting the mesotron decay with Geiger counter apparatus, an experiment which consisted of the measurement of cosmic-ray intensity at various depths in two lakes of widely different altitude but of the same geomagnetic latitude was performed. One of our self-recording electroscopes which has been used in other cosmic-ray work was used. In the higher lake, about 12,000 ft. above the lower, readings were taken at depths of 4.9, 5.9 and 6.9 meters and in the lower lake at 1.3, 2.3 and 3.3 meters, the difference in depth being about equal in mass to the air between the lakes. On the basis of the most recent theory, air and water were assumed to be gram for gram equivalent absorbers for the mesotrons involved. The ratio of intensities at equivalent points in the two lakes was theoretically calculated and by matching this with the observed ratios a mean rest lifetime, τ_0, of 2.8×10^{-6} sec. was found for a rest mass of 160 times that of the electron.

I. Introduction

At the Cosmic-Ray Symposium during the summer of 1939, B. Rossi[1] summarized the then existing evidence for the postulated decay of the mesotron. He pointed out that the temperature effect and the greater absorption of air compared with more dense materials resulted in a mean rest life of the order of 3.0×10^{-6} sec. Other experimental facts gave no evidence for mesotron disintegration although they were not contrary to such a theory. At that time no experiments showed that the mesotron was beta-radioactive. It was concluded that the disintegration evidence was incomplete.

Since the Symposium a number of experiments have been designed specifically to detect the

[1] B. Rossi, Rev. Mod. Phys. 11, 296 (1939).

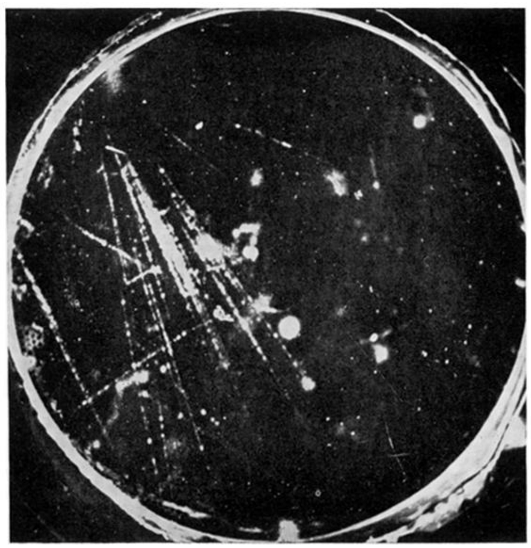

Fig. 6. Shower from the lead.

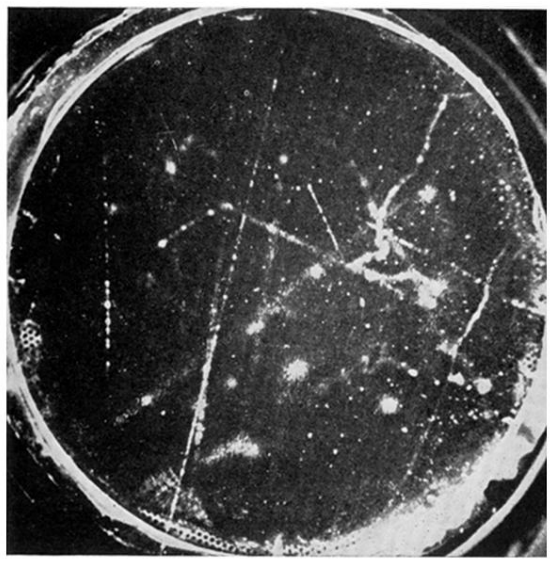

Fig. 7. Single particle accompanied by side shower.